



Development of European Ecolabel and Green Public Procurement Criteria for Imaging Equipment

TECHNICAL BACKGROUND REPORT
KEY ENVIRONMENTAL AREAS – TECHNICAL ANALYSIS
Working Document

for

2nd AHWG MEETING FOR THE
REVISION OF GPP CRITERIA
FOR IMAGING EQUIPMENT

Jiannis Kougoulis, Renata Kaps, Oliver Wolf

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TABLE OF CONTENTS

ABBREVIATIONS	4
LIST OF TABLES	5
LIST OF FIGURES	6
1 Environmental performance of imaging equipment	7
1.1 Environmental performance of imaging equipment with life cycle assessment	7
1.1.1 Findings of the Ecodesign preparatory study on imaging equipment	7
1.1.2 Danish Environmental Agency LCA study on imaging equipment	13
1.1.3 Conclusions of life cycle assessment findings	17
1.2 Environmental performance of imaging equipment with respect to substances of environmental concern in the post consumption lifecycle phase (reuse, recycling, end-of-life management).....	19
1.2.1 Release of hazardous substances from imaging equipment.....	20
1.2.2 Investigation for brominated aromatic additives used in plastics.....	20
1.2.2.1 Background information of brominated aromatic flame retardants	20
1.2.3 Life cycle consideration of brominated aromatic flame retardants	24
1.2.4 Recycling of Brominated Flame Retarded Materials	27
1.2.5 Incineration/thermal treatment of materials containing halogenated flame retardants	28
1.2.6 Deposition and release of halogenated flame retardants from landfills.....	29
1.2.7 Toxicity of brominated dioxins and brominated furans, and mixed halogenated dioxins and furans	30
1.2.8 Contemporary relevance of PBDD, PBDF and brominated-chlorinated PXDD/PXDF	31
1.2.9 Conclusion on assessment of end-of-life treatment of flame retardant containing electronics (and other flame retarded materials)	33
1.2.10 Reference list for brominated flame retardants.....	34
1.2.11 Information on waste streams for imaging equipment ¹³	44
1.2.12 Waste streams within the geographical area of EU-27.....	44
1.2.13 Waste streams outside the geographical area of EU-27	47
1.2.14 Difficulties of plastics recycling from WEEE.....	49
1.2.15 Information regarding the end-of-life considerations of PVC	52
1.2.15.1 Mechanical recycling of PVC and PVC containing materials	52
1.2.15.2 Chemical recycling of PVC and PVC containing materials	55
1.2.15.3 Incineration/thermal treatment of PVC	56
1.2.15.3.1 Negative impact of PVC in cement kilns	56
1.2.15.3.2 Negative impact of PVC in waste incinerators	56
1.2.15.3.3 PVC and PCDD/F formation in thermal processes	57
1.2.15.4 Deposition of PVC in landfills	58
1.2.16 Conclusion on the assessment of end-of-life treatment of PVC	60
1.2.17 Reference list related to the end-of-life environmental consequences of PVC	61
1.2.18 Information regarding the green paper on environmental issues of PVC	62
1.3 Improved environmental performance of imaging equipment due to reuse, recycling and end-of-life management	66
1.3.1 Information on imaging equipment devices considered as best performing products (BAT) regarding reuse.....	67
1.3.2 Information related to resource efficiency of cartridges	68
1.4 Environmental performance of imaging equipment with respect to indoor air emissions	72
1.5 Environmental performance of imaging equipment with respect to noise	78
1.6 Environmental thematic areas addressed in Ecolabel schemes and other relevant schemes	80
1.6.1 Environmental thematic areas addressed by imaging equipment manufacturers	81
1.7 Conclusions on key environmental thematic areas for imaging equipment.....	87
1.8 Reference list	88

ABBREVIATIONS

AHWG	– ad-hoc Working Group
BAT	– Best Available Techniques
BFR	– BFR Brominated flame retardant
BREF	– Reference Document on Best Available Techniques
CEN TC	– European Committee for Standardization Technical Committee
CO ₂	– Carbon dioxide
DT	– Direct Thermal
DS	– Dye Sublimation
EP	– Electrophotography
EMAS	– Eco-Management and Audit Scheme
EPA	– United States Environmental Protection Agency
EU	– European Union
EuP	Energy Using Products
GPP	– Green Public Procurement
IJ	– Ink Jet
ISO	– International Standardisation Organisation
kWh	– Kilowatt hour
LDPE	– Low-density polyethylene
LCA	– Life Cycle Assessment
LCC	– Life Cycle Costing
MFD	– multifunctional devices
MS	– Member State
OM	– Operational mode
OEM	– Original Equipment Manufacturers
PBB	– Polybrominated biphenyls
PBDE	– Polybrominated diphenyl ethers
PVC	– Polyvinyl chloride
s	– Second
SI	– Solid Ink
SVOCs	– semivolatile organic compounds
TT	– Thermal Transfer
UBA	– German Federal Environment Agency
VOC	– Volatile organic compound
UNEP	– United Nations Environment Programme
WEEE	– Waste Electrical and Electronic Equipment

LIST OF TABLES

Table 1 Environmental impact categories and environmental impact aspects investigated in Ecodesign Preparatory studies.....	8
Table 2 A selection of brominated flame retardants commercially used in PC, PC blends, ABS, SAN and PET.....	21
Table 3 Reference list 1 for brominated flame retardants (used in this section).....	23
Table 4: Categories of thermal treatment, related actual processes, prevailing formation pathways ways and potential of PBDD/PBDF formation (Weber and Kuch 2003).....	25
Table 5 Reference list for brominated flame retardants (used in this section).....	34
Table 6 Imaging equipment placed in the EU25 expressed in weight in tonnes ¹³	45
Table 7 Eurostat data for WEEE collected for IT and telecommunications equipment (including imaging equipment) in tonnes.....	45
Table 8 Export from Germany to select countries of destination (reference year 2007) ¹⁴	49
Table 9 Reference list with information regarding PVC.....	61
Table 10 Environmental savings by the remanufacturing of copiers.....	67
Table 11 Review of reported data on indoor air emissions of laser, inkjet printers and MFDs...	73
Table 12 Review of reported data on indoor air emissions of copiers.....	74
Table 13 Recent investigations and findings in indoor air emissions from imaging equipment..	76
Table 14 Thematic areas addressed in the Ecolabel schemes of Member States and in relevant international standards.....	80
Table 15 Manufacturers of imaging equipment (non-exhaustive list).....	81
Table 16 Indicative thematic areas addressed in environmental reports of imaging equipment manufacturers.....	82
Table 17. Reference list used in this chapter (reference list tables found in specific section.....	88

LIST OF FIGURES

Figure 1 Environmental assessment of an MFD-copier life cycle based on the MEEuP Ecodesign methodology.....	11
Figure 2 Environmental impacts for the life cycle of a laser printer for black/white printing per kg printed paper.	14
Figure 3. Environmental impacts for the life cycle of a laser printer for colour printing per kg printed paper.	15
Figure 4 Environmental impacts for the production of a laser printer and contribution of each involved process	16

1 Environmental performance of imaging equipment

1.1 Environmental performance of imaging equipment with life cycle assessment

In this section background information regarding the environmental performance of imaging equipment along the life cycle is presented. The LCA-based environmental assessment of a product covers all the environmental impacts of the processes which are directly or indirectly involved in the product life cycle from cradle to grave. Thus, this includes the phases of raw material extraction, production, distribution, use, recycling/raw material recovery and disposal. As such, not only is the environmental performance of a single product investigated but the environmental performance of the product system or more precisely of product systems which together combined could provide the determined function are also investigated. In the case of imaging equipment, the function investigated is one or more of the following: printing, copying, sending and/or receiving a fax, and creating a digital image via scanning. Furthermore, in the product life cycle the product systems (from cradle to gate) of the imaging equipment device and of the consumed paper, energy and ink or toner in the use are actually investigated.

In this section the findings of the Ecodesign study on imaging equipment [2] in which a life cycle based assessment is made as well as the recent findings of a streamlined LCA on imaging equipment made on behalf of the Danish Environmental Agency [5] will be presented. It is important to highlight is that both studies refer to the environmental performance of the overall European EU-27 stock of imaging equipment which is assessed based on an analysis of representative average products.

1.1.1 Findings of the Ecodesign preparatory study on imaging equipment

The recently finalised preparatory Ecodesign study on imaging equipment [2] provides an overview of the overall environmental impact of imaging equipment throughout Europe. The environmental performance of the product group was assessed using a streamlined life cycle assessment approach. In the environmental assessment, the outcomes are calculated referring to the actual product lifetime in use and the European stock.

In particular, the environmental assessment undertaken by the Ecodesign study follows the methodology of MEEuP [6]. Economic and market data were analysed and information was gathered on the product stock and sales volumes of the product group across the community

market. The gathered information data about user behaviour allows for the identification of use patterns and the determination of the product lifetime. In a later step, representative average products (base cases) were determined. In their totality, the base cases represent the overall product group. A streamlined life cycle inventory of the base case was then conducted followed by an environmental assessment.

In the environmental performance assessment in line with the MEEuP method the environmental impact categories and environmental aspects given in Table 1 were investigated:

Table 1 Environmental impact categories and environmental impact aspects investigated in Ecodesign Preparatory studies.

Environmental Impact Categories	Environmental aspects
Global warming potential Acidification potential Ozone depletion emissions Eutrophication	Energy (gross energy requirement, electricity and feedstock) Water (process and cooling) Waste (hazardous and non-hazardous) Volatile organic compounds (VOC) Persistent organic compounds (POP) Heavy metals (in air and water) Polycyclic aromatic hydrocarbons (PAH) Particulate matter (PM)

The environmental assessment results of each base case refer to the overall environmental impacts throughout the product life cycle (from cradle to grave) for all the respective imaging products which are currently in use in the EU-27 and refer to their lifetime in use.

It should be taken into account that the MEEuP methodology focuses on energy consumption and the product use phase. In the case of imaging equipment, these seem to be the most relevant aspects. However, some aspects were not captured, for instance the ink production (due to data gaps) or advanced material composition because the assessment is made on a representative typical product.

Moreover, the environmental impacts are expressed in both environmental impact categories and in environmental impact aspects. Therefore, in the first case the impacts on equivalent values of the indicator used are calculated, e.g. as CO₂-equivalents for global warming potential and in the second case as mass values of materials and/or hazardous substances, e.g. water volume, PAHs, PM, etc. Therefore the interpretation of the outcomes and especially the comparison between impact categories and impact aspects is not always

straightforward. However, the results give a good general overview of the important thematic areas regarding the environmental performance of the product groups.

In the Ecodesign Preparatory Study six representative imaging equipment products were investigated. The selection and classification of these products were based on functionality (SFDs and MFDs), user pattern (private use or professional use) and performance characteristics (image colour, image creation speed and technology). In particular, the investigated base cases were:

1. Monochrome electro-photographic MFD-copiers for use in working environments (medium speed of 26 ipm)
2. Colour electro-photographic MFD-copier for use in working environments (medium speed of 26 ipm)
3. Monochrome electro photographic printer used in working environments (high speed of 32 ipm)
4. Colour electro-photographic printer used in working environments (high speed of 32 ipm)
5. Colour inkjet MFD-printer used in a personal environment (low speed 20 ipm)
6. Colour inkjet MFD-printer used in a working environment (low speed 20 ipm).

It is important to emphasise at this point that the base cases represent average products found in the Community market and not the best performing products. The technical parameters of the base cases were calculated based on average values of real products. These outcomes could serve as a reference baseline of the performance of average products. However, the performance of Ecolabelled products needs to exceed the performance of the base cases. In any case the results of the Ecodesign base cases can serve for the identification of key environmental thematic areas to which the Ecolabel and GPP criteria shall refer.

Regarding the composition of material for each of the six case studies mentioned the tables indicating the used bill of materials are listed in Annex 1. In general the used chassis (e.g. frame, screws) and most mechanical parts (e.g. rollers, clutches) are considered ferrous metals such as galvanised steel. The electro-mechanics (e.g. stepper motors, wires) are a mix of ferrous and non-ferrous metals with copper as the dominant material mass. The aluminium content varies in the individual products. Plastics are used in the full spectrum of bulk and Tec plastics for housing functionality (e.g. covers, trays, cartridges) and small mechanical parts (e.g. spacers, gear wheels, blends, buttons). Depending on the particular function and technical requirements (e.g. thermal and mechanical stability), manufacturers usually have the option to utilise different bulk and Tec plastics. Bulk plastics PS and ABS,

as well as Tec plastics PC are the most commonly used materials. Glass is mainly found in the scanner lamp and plate. LCDs, ICs and populated electronic boards are listed under various electronics input categories while motors (e.g. small stepper motors) were partly allocated to the database category of 44-big caps & coils. However, a more detailed 'component-material' correlation was limited due to restrictions in the used modelling database [2].

An excerpt from the environmental performance of the investigated MFD-copier as performed in the Ecodesign study using MEEuP is given in Figure 1. Similar outcomes are also available for the other base cases. At this point it is important to highlight the fact that based on the outcomes of the different base cases and despite the fact that the profile of the environmental performance among the different base cases differ, the identified key environmental thematic areas are the same. In Figure 1 the values of the investigated environmental aspects are given in two forms: the first takes into account the paper consumption during the product life cycle, and the second neglects these impacts. This differentiation was made because the very high environmental impact of office paper would hamper a deeper investigation of the impacts of other parameters. The results in Figure 1 are presented as contribution percentage for each product life cycle phase per investigated environmental impact category and aspect. The environmental impact categories and aspects are given in Table 1.

Based on Figure 1 it can be identified that for the majority of the environmental impact categories and aspects, the contribution of the use phase is dominant followed by the manufacturing phase. An important finding from the environmental assessment is that in the life cycle of imaging equipment for the overall environmental performance, paper consumption has the most dominant role followed by energy consumption in the use phase. The high importance of paper consumption is related to the larger demands of energy in the paper production phase.

Indicatively, in the first base case (monochrome MFD-copier in a working environment), the consumption of paper was assumed to be 87 880 pages for each of the six years of the product lifetime. Extrapolating and summing up the results for the overall total energy consumption of the stock of copiers, printers and MFDs as modelled in this study shows that for the reference year 2005, the consumption of paper is responsible for 80 % (or 586 PJ) of the total EU energy consumption related to the life cycle of imaging equipment. This immense contribution to overall energy consumption also affects significantly the other environmental impact categories as significant environmental impacts are related to the energy production phase. This emphasises the need for efficient use of paper towards a final reduction of the total amount of its consumption.

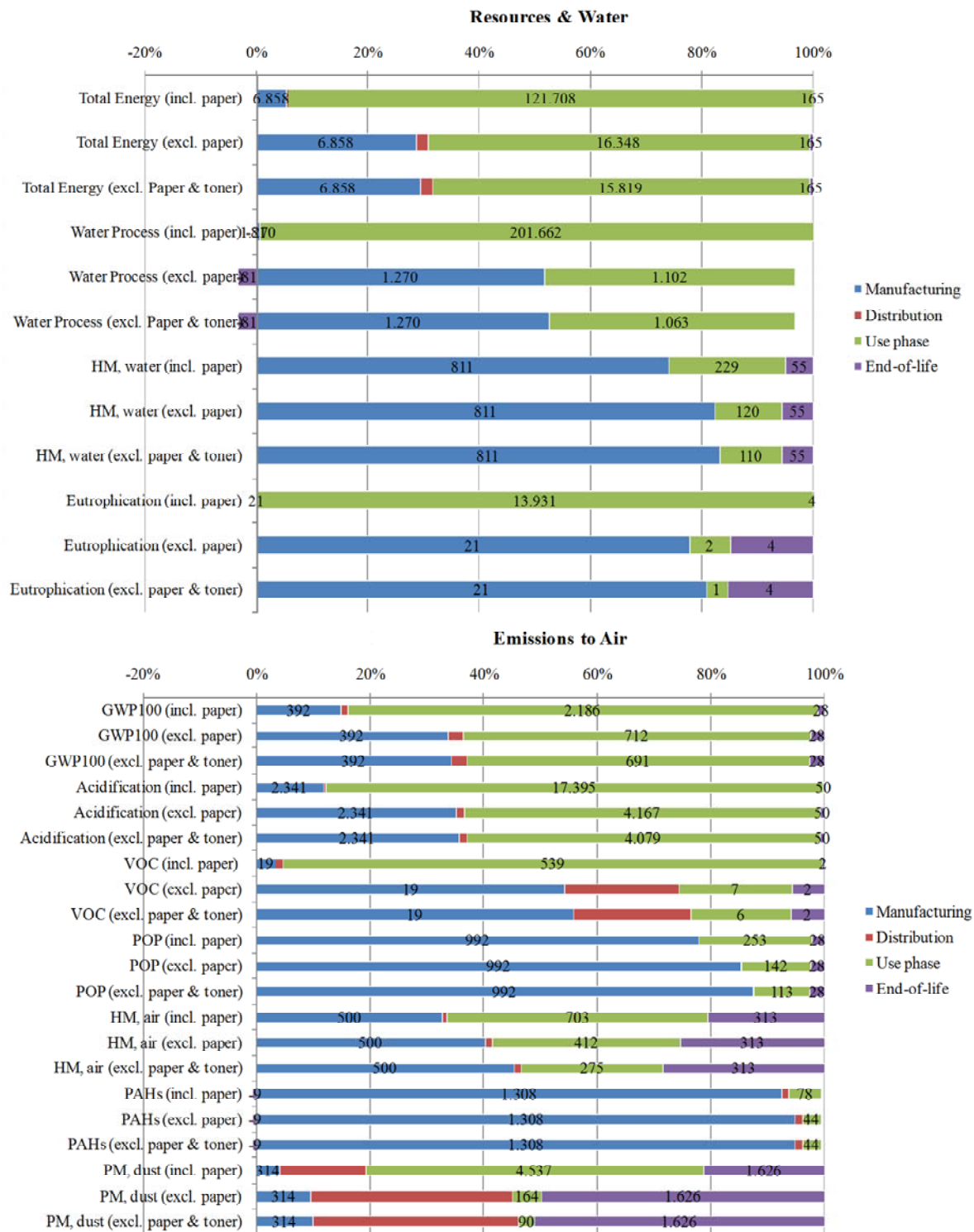


Figure 1 Environmental assessment of an MFD-copier life cycle based on the MEEuP Ecodesign methodology
 Source: Ecodesign Preparatory Study on Imaging Equipment [2]

One choice to reduce paper consumption is when printing and copying is made on both paper sides (duplex image reproduction). This aspect is taken into account in all the Ecolabel schemes by setting one Ecolabel criterion on the basis of the feasibility of duplex printing and/or copying. However, we should emphasise the fact that the consumption of paper is a parameter which depends more on user behaviour and less on the design of a printer or a copier. For instance, despite the automated duplex printing and copying capability of a imaging equipment, it is eventually up to the user to apply this function or not.

The next most important aspect regarding the life cycle environmental performance of imaging equipment as found in the preparatory Ecodesign study is energy consumption in the use phase. It was assessed that energy consumption in the use phase accounts for approximately 2/3 of the total energy consumption of imaging equipment during product lifetime (energy consumption related to paper use is not considered). Thus, a better environmental performance can be achieved by energy efficient products. The consumption of less energy is also beneficial with respect to the other investigated environmental aspects, due to the lower pollutant emissions in the energy production phase. An additionally important aspect on this is that most of this energy is not consumed during image reproduction but during the inactive mode (standby losses). Among the different types of imaging equipment, especially high standby losses are found from fax machines as they reach up to 90 % of the total electricity consumption during their lifetime [7, 8].

The electricity consumption in the use phase is an aspect which is dependent on the product design (different from the aforementioned strong user dependent paper consumption aspect). Therefore for all currently available imaging equipment, Ecolabel criteria of Member States (e.g. Blue Angel and Nordic Swan) and of third countries (e.g. EcoMark, etc.) as well the GPP criteria have a special focus on the energy efficiency requirements of the product. As mentioned before in Task 1, Section 9, the majority of the different Ecolabel schemes require compliance with the energy efficiency requirements of the Energy Star label.

In addition, it is important to identify which materials or processes used in the manufacturing process contribute the most to the environmental impacts of the imaging equipment life cycle. Based on the findings for the example of the MFD-copier, significant contributions are found for galvanised steel (the modelling input in the MEEuP method is '21-St sheet') and polystyrene (5-PS).

In this case study, galvanised steel amounts to almost 36 kg and 56 % of the total product weight. Steel is used for frame structures, rollers and other mechanical parts.

According to the MEEuP methodology, this 'non-hazardous waste' category reflects the waste generation during ore extraction and metal processing. Ferrous metals on the other

hand have a high recycling potential, which partly compensates for their overall environmental impacts. In particular, galvanised steel shows considerable emissions to air. The concentration of steel in the product dominates the POP (94 %), GWP (33 %), and VOC (33 %) impact categories.

Polystyrene (PS) (in which both PPE and PPS are included) is the second largest material fraction by weight. PS amounts to 7.5 kg or roughly 12 % of the total product mass. The environmental impact of PS is strongly related to the high PAH (polycyclic aromatic hydrocarbons) concentration, which is an indicator for toxicity, measured in Ni equivalents. In this case study, polystyrene amounts to 70 % of the total PAHs.

1.1.2 Danish Environmental Agency LCA study on imaging equipment

A study of the Danish Environmental Agency [5] conducted by environmental and LCA experts was undertaken in 2009 in which environmental screening LCAs for different product groups with available preparatory Ecodesign studies were made. Among these studies was also the Ecodesign Preparatory Study on Imaging Equipment.

In this case, a streamlined LCA was performed using the LCA software tool SimaPro, referring to process data from the LCI Ecoinvent database and investigating a number of environmental impact categories (the LCIA "stepwise 2006" method covering 15 environmental impact categories was applied). In general this LCA study was conducted based on the same main assumptions made in the respective Ecodesign study. Thus, the analysis is again based on average imaging devices and not on the best performing products.

Regarding the environmental screening of the imaging equipment product group this study concludes that the environmental impact of imaging equipment comes from the consumption of paper, the consumption of toner and the electricity consumption during use. The environmental impacts associated with the consumption of toner differ based on whether the toner is for black/white printing or for colour.

Moreover, another outcome highlighted in this report is that although the energy efficiency of office imaging equipment is generally at a good level, under real life conditions, the energy efficiency potential of imaging equipment is not necessarily fully exploited due to a potentially suboptimal use by the consumer. Furthermore, it is suggested that the focus should be put on designing toners with fewer overall environmental impacts.

In Figure 2 and Figure 3 the overall environmental impacts for several environmental impact categories during the life cycle of a laser printer for black/white and respectively colour printing are indicatively presented. In general the overall outcomes referring to the environmental performance of printers are also considered to be applicable for copiers and MFDs. These findings are presented referring to the use of the printer per kg of printed paper and not referring to the total consumption of paper in the imaging equipment life cycle. This is because the overall environmental impacts associated with paper consumption are immense compared with the impacts associated with other factors. Nevertheless, expressing the outcomes per kg of consumed paper makes an investigation of other contributing parameters feasible.

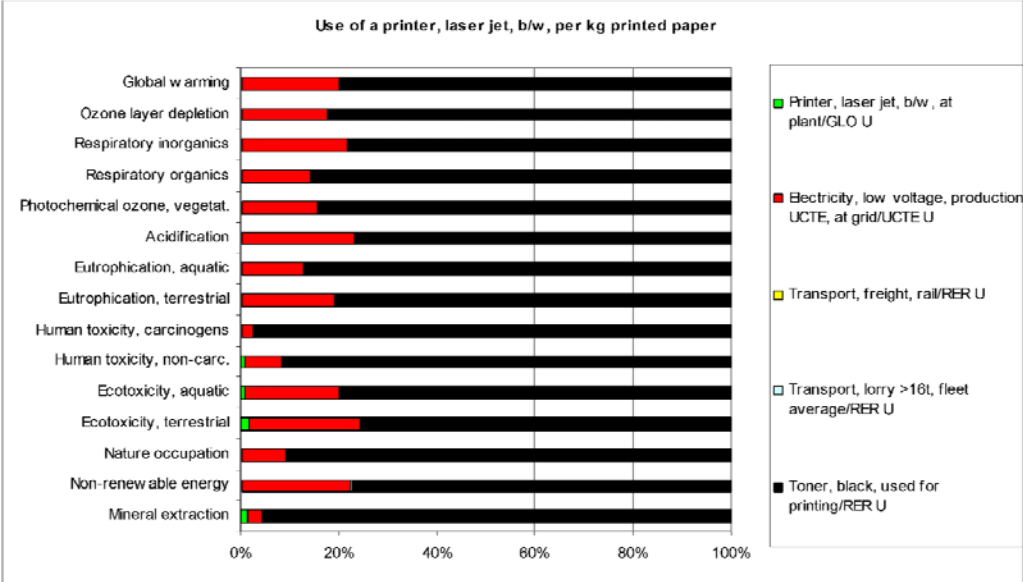


Figure 2 Environmental impacts for the life cycle of a laser printer for black/white printing per kg printed paper.
Source: [5]

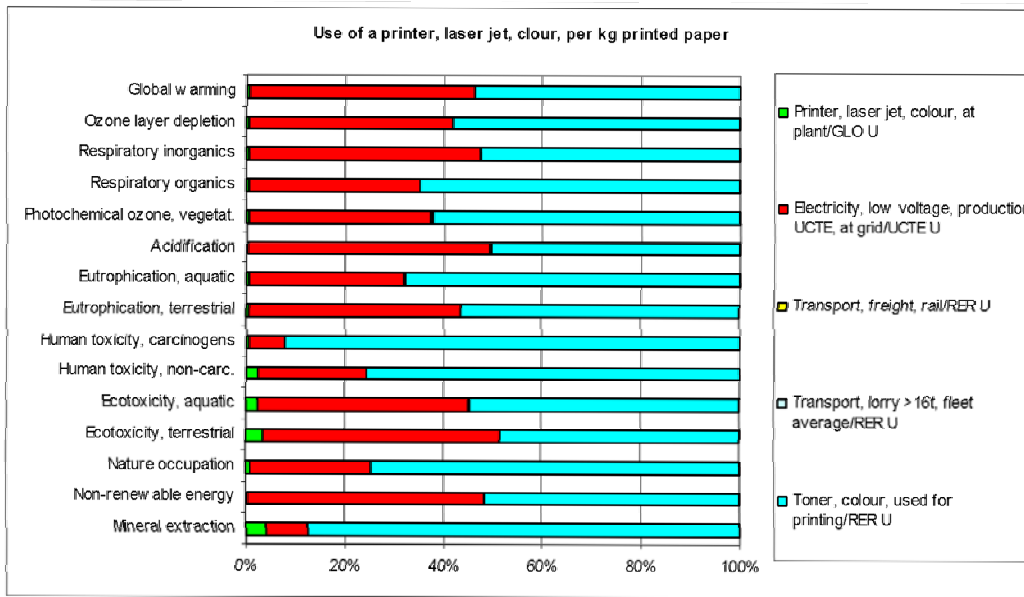


Figure 3. Environmental impacts for the life cycle of a laser printer for colour printing per kg printed paper.
Source: [5]

Based on Figure 2 and Figure 3 it can be concluded that when using a printer, the electricity consumption is significant for most of the environmental impacts (exclusion: mineral extraction). The significance of the production of the printer itself is considered relatively low. On the contrary the environmental impacts associated with the toner are relatively high. The environmental impacts from the production of toner mainly come from the production of the toner module, the toner (powder), the production of aluminium and the electricity for manufacturing the toner.

In Figure 4 the environmental impacts associated with the production of a laser printer for black/white printing are presented. In Figure 4 the contribution per environmental impact category of each process involved is also given.

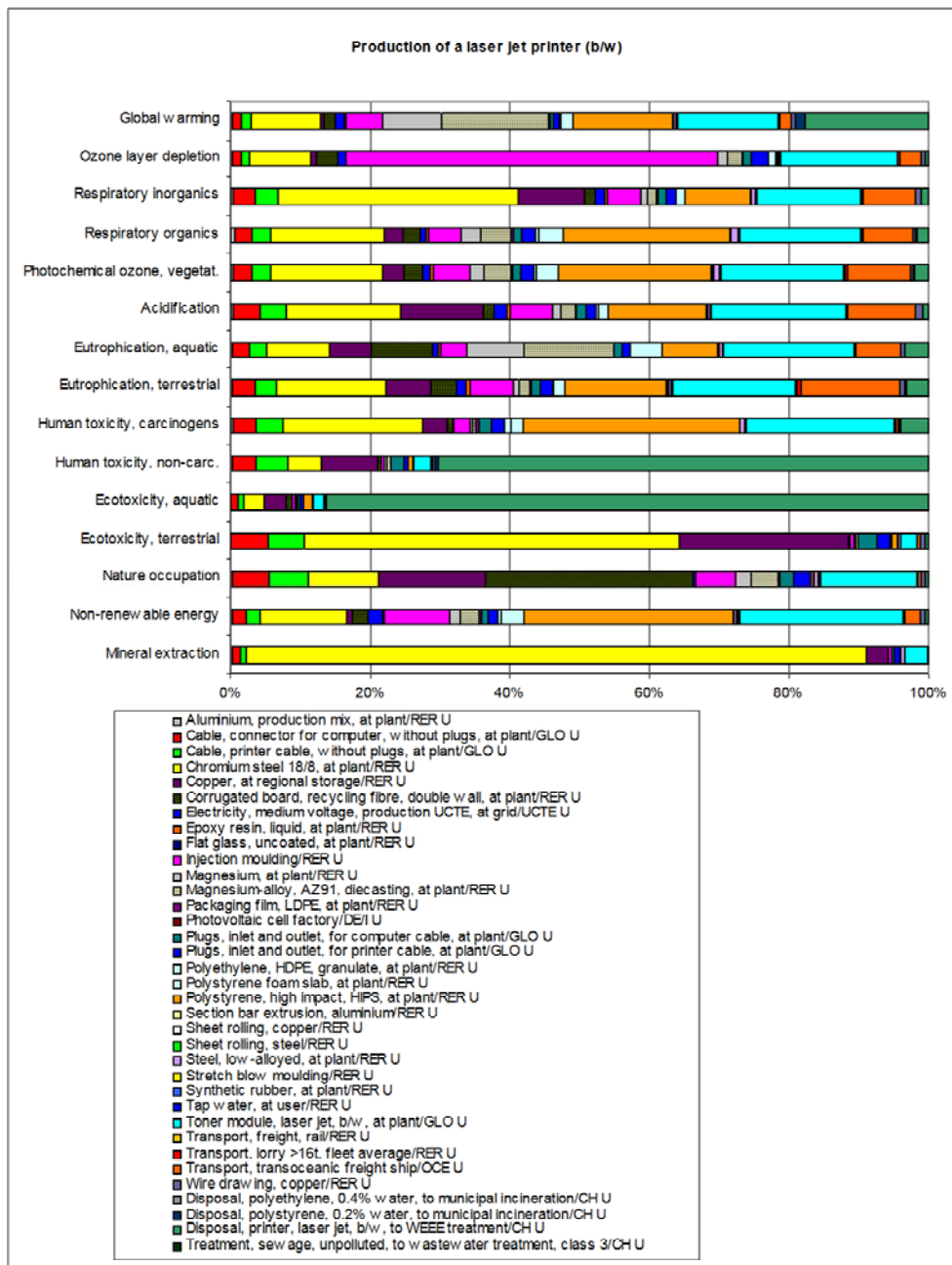


Figure 4 Environmental impacts for the production of a laser printer and contribution of each involved process
Source: [5]

This study concludes that the environmental impacts from the production of a printer mainly come from the production of chromium steel (18/8), polystyrene and the toner module. As presented in Figure 4, chromium steel marked with yellow is a major contributor to the impact categories of mineral extractions, to terrestrial ecotoxicity and to respiratory organics. Polystyrene which is marked in Figure 4 with orange contributes significantly to the impact category of human toxicity/carcinogens, to photochemical ozone and to non-renewable

energy. Moreover, the impacts associated with the toner module (marked with green colour in Figure 4) dominate the categories of aquatic, human toxicity/non-carcinogens. In addition injection moulding contributes significantly to ozone layer depletion. The final disposal of the printer contributes significantly to human toxicity (non-carcinogen) and ecotoxicity (aquatic). These contributions are mainly due to emissions of antimony, dioxins, arsenic and copper.

It can be concluded that based on the findings of the Danish Environmental Protection Agency, the environmental performance of imaging devices along the life cycle is strongly related to the paper consumption, the energy efficiency of the device and the consumption of toner or ink (which was a factor not covered in the Ecodesign study).

At this point it should be mentioned that apart from substituting hazardous materials used in the toner or ink, another well established strategy to reduce the overall environmental impacts associated with these consumables is refilling and/or remanufacturing toner and ink cartridges. In this case, the design of the cartridges has a significant role. Both aspects are addressed in the Ecolabel criteria as described in Task 1 and would also be an area of focus in the development of EU Ecolabel and GPP criteria.

1.1.3 Conclusions of life cycle assessment findings

LCA is a decision support tool in which alternative options can be compared in a system approach which covers the whole product life cycle. The main advantage of determining the environmental performance with an LCA approach is that it avoids shifting environmental problems between product life cycle stages (e.g. better performance in the production phase but worse in the use or recycling phase, etc.) as well as between environmental impact categories.

In the aforementioned studies of Ecodesign and of the Danish Environmental Protection Agency the performance of imaging equipment was assessed, and the areas of significant environmental concern and the environmental hot-spots were identified.

The areas of significant environmental concern can be summarised as:

- paper consumption,

- energy efficiency in the use phase
- consumption of toner and ink.

The most significant factor is paper consumption followed by the energy efficiency during operation and the impacts associated with toner and ink consumables.

These two LCA studies also identify the materials and the processes which have a major contribution to the overall environmental impact of the life cycle product system. In particular these are the production of chromium steel (18/8), polystyrene and the toner module. In addition, injection moulding which contributes to ozone layer depletion and the disposal of the product contributes significantly to human toxicity (non-carcinogen) and ecotoxicity (aquatic). The contributions to these are mainly due to emissions of antimony, dioxins, arsenic and copper. In addition, based on the Ecodesign Study, the galvanised steel and polystyrene (as modelled in MEEuP 21-St steel and 5-PS, in the latter are PPE and PPS included) as well as electronics are the materials with considerable overall contribution. Polystyrene has a significant impact in the category of polycyclic aromatic hydrocarbons (PAHs) emissions while galvanised steel in persistent organic compounds (POP), in global warming potential (GWP) and volatile organic compounds (VOC). Electronics despite their very low weight in the final imaging device their environmental impacts in the manufacturing phase dominate in 9 out of the 16 investigated environmental categories in the Ecodesign LCA analysis.

It is important to emphasise that LCA can also be used in comparative assertions. In this case the overall life cycle environmental performance of one or more imaging equipment devices against alternative options is analysed. In such a type of LCA analysis, it is feasible to compare several alternative scenarios like the substitution of materials or components, different user behaviour (e.g. double-sided printing, more users per printer, etc.), different energy efficiency levels of the devices, different recycling and reuse scenarios, different end-of-life scenarios and other managerial options (e.g. longer product durability, better logistics, less packaging, etc.). Such kinds of LCAs are often conducted by imaging equipment manufacturers and are used to assess the undertaken environmental improvement measurements.

However, in the comparative LCA analyses assumptions are made which are dependent on the purpose of the study (as these are explicitly defined in the goal and scope phase of LCA

in line with the ISO 14040 standard). LCA results are strongly based on these assumptions. Thus, in comparative LCAs the interpretation of outcomes needs to take into account that the validity of the assumptions is not always ensured.

1.2 Environmental performance of imaging equipment with respect to substances of environmental concern in the post consumption lifecycle phase (reuse, recycling, end-of-life management)

One important point in the technical analysis and later in the criteria development regarding the environmental performance of products and the identification of better performing products along the life cycle is the investigation of minimized use (or avoidance of use) of hazardous substances. In this process it is important to identify first the substances of concern (either due to the associated environmental impacts or due to their health risks related to their hazardous properties) and then investigate if substitutes on the level of substances or materials are available. The investigation of alternative technologies in which the substances are not more necessary to be used shall also be covered. For example the use of Mercury in backlight displays of imaging equipment can be avoided if the LED lights are applied.

Ecolabel Regulation 66/2010 stipulates that in the determination of the Ecolabel criteria the substitution of hazardous substances by safer substances shall be considered. This substitution can be as such or via the use of alternative materials or designs, wherever it is technically feasible and this together with the potential to reduce environmental impacts due to durability and reusability of products.

The relevance of these aspects for the product group of imaging equipment is evident, e.g. from the discussion on the similar product group-personal computers and laptops. Background information is available from researchers working on behalf of governments, manufacturers of imaging equipment, producers of ink and toners and independent experts in research institutes and universities.

Scientific evidence on the aspects of imaging equipment reuse, recycling, end-of-life management as well identification of hazardous substances is presented in the following

Section. It needs to be taken into account that generalisations and an extrapolation of the findings is not always straightforward because of the case-specific validity of the assumptions made and the potential restrictions in quantifying the calculated environmental benefits. Nevertheless, this background information, which identifies the relevant actions regarding the environmental management of imaging equipment devices, is considered sufficient to support the ecological criteria development in line with the requirements of Ecolabel Regulation 66/2010 and the Communication from the Commission for Public procurement for a better environment, COM (2008) 400.

1.2.1 Release of hazardous substances from imaging equipment

Discarded electrical and electronic products (often called e-waste), is recognised as one of the fastest growing waste streams. Based on estimations these items already constitute 8 % of municipal waste. The imaging equipment product category together with its consumables is also subsumed in e-waste. The increasing volumes of e-waste, in combination with the complex composition of these items and the resulting difficulties in treating them properly, are causes of concern. The hazardousness of e-waste is well recognised and the knowledge on these hazards and the resulting risks associated with different treatment options is expanding.

Components and hazardous substances in e-waste can contain a large number of hazardous substances, including heavy metals (e.g. mercury, cadmium, lead), substances used as flame retardants (e.g. pentabromophenol, polybrominated diphenyl ethers (PBDEs), tetrabromobiphenol-A (TBBPA) etc.), and others.

1.2.2 Investigation for brominated aromatic additives used in plastics

1.2.2.1 Background information of brominated aromatic flame retardants

In this section, an overview of the field of the most commonly found brominated aromatic flame retardants is presented. Information with regard the different types of FRs and in which

* This section was jointly developed and elaborated with the external technical experts: Stefan Posner, Swerea IVF AB, Besöksadress: Argongatan 30, 431 53 Mölndal, Sweden
Roland Weber, POPs Environmental Consulting, D-73035 Göppingen, Germany

plastic parts they are used is given. The relevant reference list for this section is given in Table 3:

Flame retardants are commercially used in PC, PC-blends, ABS, SAN and PET. The average loads are between 10 – 20% w/w and depend on the specific requirements and properties needed for the end product as presented in more detail in Table 2.

A selection of brominated flame retardants commercially used in PC, PC blends, ABS, SAN and PET is presented in Table 2.

Table 2 A selection of brominated flame retardants commercially used in PC, PC blends, ABS, SAN and PET[†]

Additive used for the flame retardant properties		Material					
		CAS RN	Poly carbonate (PC)	Poly carbonate blends (PC/ABS)	Acrylonitrile butadiene styrene terpolymer (ABS)	Styrene acrylonitrile copolymer (SAN)	Poly ester (PET)
BROMINATED FLAME RETARDANTS (BFR)	Brominated polystyrene/ATO [‡]	88497-56-7					X
	DecaBDE/ATO	1163-19-5	X	X		X	
	Decabromodiphenyl Ethane/ATO	84852-53-9	X	X		X	
	Ethylene bistetrabromo phthalimide	32588-76-4	X	X			X
	Pentabromobenzyl acrylate	85-22-3					X
	Poly(pentabromobenzyl acrylate) / as polymer	59447-55-1	As polymer	X	As monomer		As monomer
	Pentabromobenzyl acrylate / as reactive monomer						
	Pentabromotoluene	87-83-2			X		X
	TBBP-A	79-94-7	X	X			
	TBBPA carbonate oligomer				X		
Tris(tribromoneopentyl) phosphate	19186-97-1				X		

[†] Norwegian EPA (KLIF), "EMERGING "NEW" BROMINATED FLAME RETARDANTS IN FLAME RETARDED PRODUCTS AND THE ENVIRONMENT" (2009)

[‡] ATO: Antimony trioxide, CAS Nr: 1309-64-4, a common synergist together with brominated flame retardants

	1,2-Bis(2,4,6-tribromophenoxy)ethane	37853-59-1			X		
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Polybrominated diphenylethers (PBDEs) are a group of additive flame retardants. The term PBDE includes commercial pentabromodiphenylether (C-PentaBDE), commercial octabromodiphenylether (C-OctaBDE) and commercial decabromodiphenylether (C-DecaBDE), which are commercial mixtures of homologues of brominated diphenylethers with various substitution levels of bromine substituted to the aromatic rings.

Since C-PentaBDE and C-OctaBDE, due to their hazardous properties, have been phased out in several regions and countries worldwide, C-DecaBDE is the PBDE still produced and used in large quantities worldwide.

DecaBDE is applied in the range between 10%-30% of the polymer weight to various polymers such as styrenics and polyolefins, but may also be applied in textile back coatings. The vast majority of the decaBDE currently produced is used in the outer casing of electric equipment.

In order to reduce the overall amount of brominated-FR use in a polymer, the synergist antimony[§] is often added in the form of antimony trioxide. DecaBDE has an optimum applied ratio with antimony trioxide of *1 part antimony: 3 parts bromine*, which has shown to be the most effective ratio concerning flame retardant synergetic effects in a wide range of polymers in order to achieve optimum fire retardant properties.

TBBPA is an aromatic brominated organic compound and, as previously described, is primarily used as a reactive intermediate in the manufacture of flame retarded epoxy and polycarbonate resins. Therefore, it is an integral part of the polymer.

[§] The term synergistic effect is used in the connection with the development of flame retardants. This term means that the desired effect of two or more components working together is greater than the effect of each component separately. Perhaps one of the most important effects historically in flame retardant chemistry is the one between halogen and antimony, where antimony reacts in the form of antimony trioxide with the formation of radicals, finally forming antimony tribromide and antimony oxibromide and their chlorinated equivalents. These flame retardants react in gaseous phase and usually contain halogens of the bromine and chlorine type.

Further, TBBPA may also be used as an additive flame retardant physically mixed into the polymer, for example in the manufacture of acrylonitrile-butadiene-styrene resins (ABS) and phenolic resins. When TBBPA is used as an additive flame retardant it is usually with antimony trioxide which is not the case when it is used as a reactive flame retardant.

TBBPA is also used for the manufacture of derivatives to TBBPA-dimethylether, TBBPA-dibromopropylether, TBBPA-bis(allylether), TBBPA-bis (2-hydroxyethyl ether), TBBPA-brominated epoxy oligomers and TBBPA-carbonate oligomers.

Besides the PBDEs and TBBPA and its oligomers, there are several other aromatic brominated flame retardants that may be applied in imaging equipment.

Table 3 Reference list 1 for brominated flame retardants (used in this section)

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1.2.3 Life cycle consideration of brominated aromatic flame retardants

Environmental concerns about the use of Brominated flame retardants are raised due to their role in the formation of Br-dioxins (PBDD), Br-furans (PBDF) as well as Br/Cl-dioxins (PXDD) and Br/Cl-furans (PXDF) when chlorine is present.

In general the degree of Bromine containing dioxins and furans formation depends on the precursor quality and on the type of treatment. In Table 4 the potential of dioxin formation in relation to the thermal treatment undertaken is given. All brominated aromatic compounds can act as PBDD/PBDF precursors in thermal processes of:

a) pyrolysis /gasification as in this case 350 – 800 °C is often reached with low oxygen content (category 2 of Table 4) and;

b) in thermal processes with insufficient combustion conditions i.e. incinerators operating in non-BAT conditions, secondary metal plants, uncontrolled burning (3 of Table 4).

The relevance of incinerators operating in non-BAT conditions is higher as a large share of e-waste (including exported European electronics and e-waste) or plastic from e-waste is finally treated in developing countries and countries in transition economies under such conditions.

Table 4: Categories of thermal treatment, related actual processes, prevailing formation pathways ways and potential of PBDD/PBDF formation (Weber and Kuch 2003)

Category	Processes	Conditions	Prevailing formation pathways	PXDD/PXDF formation potential
1) Thermal stress	Production, recycling (include shredding, molding and extrusion)	100 – 300 °C, mechanical stress	Selected precursors (e.g. PBDEs)	Low -> moderate
2) Pyrolysis/gasification	Pyrolysis/gasification facilities (pyrolysis of plastics, shredder fractions or sludges). Accidental fires; uncontrolled burning	350 – 800 °C, low oxygen content	Precursors + formation of aromatic compounds and halogenation.	High
3) Insufficient combustion conditions	Accidental fires, uncontrolled burning, non-BAT incinerators. Secondary metal plants	Uncontrolled parameters: temperature, residence time, oxygen content, turbulence.	Precursors	High
4) Controlled combustion conditions	BAT incinerators, cement plants	Optimised combustion control	Formation of aromatic compounds and halogenation	Low

With regard to brominated dioxins and furans, the precursor pathway for their formation can be identified more easily than in the case of Cl-dioxins and Cl-furans (PCDD/PCDF) in which the precursor pathway for their formation cannot be identified precisely. Bromine is primarily present in specific plastics.

Bromine is found in plastics in the form of BFRs. Brominated aromatic compounds can act as precursors for PBDD/PBDF formation (e.g. brominated diphenylethers (PBDEs) or brominated phenols (PBP)). Hence, the precursor pathway is of higher relevance for the formation of polybrominated dibenzodioxins (PBDDs) and polybrominated dibenzofurans (PBDFs) during thermal processes compared to their chlorinated analogues.

PBDD/PBDF and brominated-chlorinated PXDD/PXDF have similar toxicity as PCDD/PCDF and sometimes even exceed the toxicity of their chlorinated counterparts (see Annex 6.11.6). PBDD/PBDF and PXDD/PXDF are relevant contributors to dioxin-like exposure to humans.

The total amounts of brominated dioxins/furans generated from the polybrominated diphenyl ethers alone are estimated in the tonnes scale and are comparable in magnitude to the total global release of chlorinated dioxins and furans from all thermal sources combined (Zennegg et al. 2009).

During the entire life cycle of BFR-containing materials, PBDD/PBDF, and in the presence of a chlorine source also brominated-chlorinated PXDD/PXDF, can be formed and released into the environment (Ebert and Bahadir 2003, Kajiwara et al.2008; Kajiwara & Takigami 2010; Weber and Kuch 2003; WHO 1998).

Hence, a key concern regarding brominated flame retardants (this is applicable also for halogenated FRs in general) is at their end-of-life management. The three main options for materials treated with aromatic brominated flame retardants and other halogenated flame retardants are:

- (1) recycling,
- (2) incineration/thermal,
- (3) land filling.

Management of end-of-life waste flows can vary widely based on the type of waste management schemes used in various countries and the different materials involved (e.g. flame-retarded plastic in e-waste). The relevant environmental concerns raised for each option of waste management will further be analysed in more detail.

As there are numerous studies in which the environmental considerations along the product life cycle of products containing brominated flame retardants, which are related to the formation of Br-dioxin (PBDD) and Br-Furans (PBDF), are highlighted. A list of references used is given in section in the end of this section.

1.2.4 Recycling of Brominated Flame Retarded Materials

The advantage of mechanical recycling as a method for end-of-life treatment of flame retarded materials is that it contributes to the overall reduction of the energy-intensive production of new materials.

Brominated aromatic flame retardants are precursors of brominated dioxins and brominated dibenzofurans. Some brominated aromatic BFRs (in particular PBDE) can form brominated dibenzofurans, even during necessary recycling operations like extrusion and molding of new plastic products requiring elevated temperatures (Meyer et al 1993, Mc Alister 1990, Weber and Kuch 2003).

Further, significant material flows containing halogenated flame retardants and other toxic materials are often exported to developing/transition countries and recycled there with cheap labour and primitive methods** (see also Annex 6.12). As documented for global e-waste flow or shipment, these recycling practices have resulted in large-scale environmental and human contamination (Basel Action Network 2002, Greenpeace 2008, Wong et al 2007, Bi et al 2007, Leung et al 2007, Luo et al 2008).

Recycled PBDE-containing plastics are frequently contaminated with PBDDs/PBDFs, and it has been reported that it can exceed legislative limits (Mayer et al 1993, Schlummer et al 2007). Moreover, workers in industrial countries can be exposed to high levels of brominated flame retardants and other toxic chemicals during the recycling of e-waste (including the

** Siddharth Prakash, Andreas Manhart, Yaw Amoyaw-Osei, Obed Opoku Agyekum "Socio-economic assessment and feasibility study on sustainable e-waste management in Ghana for Inspectorate of the Ministry of Housing, Spatial Planning and the Environment of the Netherlands (VROM-Inspectorate) and the Dutch Association for the Disposal of Metal, and Electrical Products (NVMP), Oeko Institute 2010, <http://www.oeko.de/oekodoc/1057/2010-105-en.pdf>

plastic fraction) or during production of i.e. polyurethane foam (Sjödin et al 2001, Stapelton et al. 2008). In industry reports it has been also concluded that mechanical recycling of such plastic waste is not recommended (Mayer et al 1993, Mark 2006).

However, it is common practise that mixed plastic fractions from electronic waste are normally not reused in electronics but are mostly “downcycled” into less demanding applications. Recent studies showing that brominated flame retardants are present in plastic household goods (Chen et al 2010), video tape casings (Hirai and Sakai 2007) and plastic children's toys. Chen et al. 2009 have revealed that such downcycling takes place in an uncontrolled manner for BFR-containing plastics. These practices dilute BFRs and chlorinated flame retardants in plastic streams, leading to unnecessary human exposure to plastic products from recycled materials. This shifting of environmental burdens from one product life cycle to another highlights the importance of focusing on environmental strategies in which prevention of environmental impacts shall be the first priority.

1.2.5 Incineration/thermal treatment of materials containing halogenated flame retardants

It should be highlighted that BFRs can be destroyed with high efficiency if BFR/HFR-containing wastes are destroyed in incinerators constructed according to best available technology (BAT) and operated according to best environmental practice (BEP) (Sakai et al 2001, Vehlow et al 2000, Weber and Kuch 2003). However, for BAT incineration, costs per tonne of incinerated material are high (in the order of \$100/t) and such facilities are too costly for treating municipal waste in developing/transition countries (Brunner and Fellner 2007).

Nonetheless, even in BAT grate incinerators (the technology applied in most municipal waste incinerators), elevated PBDD/PBDF levels were found in the bottom ashes (Wang et al 2010b), most probably due to grate shifting (particle matter falling through the grate not subjected to a complete burnout).

A large proportion of brominated flame retarded materials are combusted. Depending on the quality of combustion, high levels of brominated dioxins and furans can be formed and released as a result of the dioxin precursor properties of aromatic brominated flame retardants (Weber and Kuch 2003). In particular, open burning of e-waste is estimated to

globally generate PBDDs/PBDFs and PXDDs/PXDFs on a scale of tonnes (Zennegg et al 2009) and for many geographical areas can be considered as common practice. Areas in which such open e-waste burning has been practised for years have been transformed into PCDD/PCDF, PBDD/PBDF and PXDD/PXDF contamination sites (Li et al 2007, Yu et al 2008, Zennegg et al 2009). With regard to chlorinated PCDD/PCDF its source for the release is the presence of PVC as reported by Zennegg et al 2009.

PBDD/PBDFs are also emitted from open waste burning in industrial countries (Gullett et al 2010), other open burning practices, and other sources (Ebert and Bahadir 2003). Large amounts of brominated flame retardants in e-waste (together with car interiors) are treated in the metal industry for recovery of precious metals from e-waste (or iron and aluminium from cars and other goods). These operations can be regarded as an incomplete combustion process resulting in the emission of PBDD/PBDFs and halogenated flame retardants (Wang et al 2010a, Odabasi et al 2009).

1.2.6 Deposition and release of halogenated flame retardants from landfills

A large portion of HFR-treated products end up in landfills. This is particularly true for end-of-life treatment in developing and transition countries having no thermal waste treatment options other than open burning or other limited incineration methods not meeting BAT requirements. Even in industrialized countries, a large share of flame retarded wastes is landfilled, as was recently documented in California (Petreas and Oros 2009). It is worth highlighting that in many countries there are very few or even no waste incineration capacities at all (i.e. Australia which is an industrialised country).

There is growing evidence and concern that brominated flame retardants including POPs/PBDEs are leaching from landfills and contaminating the environment (Danon-Schaffer 2010, Odusanya et al 2009, Oliaei et al 2002, Osako et al 2004, Weber et al 2010). Significant PBDE emissions in leachates are detected from landfills in industrial countries (Danon-Schaffer 2010, Oliaei et al 2002, Osako et al 2004). Substantial concentrations of PBDEs were present in the soil adjacent to all landfills and dumpsites in various regions of Canada (Danon-Schaffer, 2010), revealing significant POP/PBDE releases from landfills in an industrial country.

Recently, PBDE-contaminated groundwater from South African landfills has been reported (Odusanya et al 2009), indicating that new POPs/ PBDEs are present in significant amounts in the end-of-life stage in developing/transition countries and are adding to the environmental contamination generated by primitive e-waste recycling.

However, with engineered landfills with bottom liners, leachates that escape to the environment can be collected and treated to reduce the flow of contaminants to ground and surface water for some time (Osako et al 2004). Nevertheless, such treatments are expensive, and the resulting solids from adsorption of pollutants need further treatment or deposition. Because of their persistence, POPs/PBDEs will remain in landfills for many decades – and probably centuries. Over these extended time frames, landfill engineering systems, including basal and capping liners, gas and leachate collection systems, will inevitably degrade and lose their ability to contain the contaminants (Buss, Butler et al. 1995; Allen 2001, Danon-Schaffer, 2010). Therefore, land filling does not appear to be a sustainable solution for long-term containment of brominated FR-treated materials and other persistent organic pollutant-containing waste.

1.2.7 Toxicity of brominated dioxins and brominated furans, and mixed halogenated dioxins and furans

Brominated dioxins and furans have been shown to have toxicities similar to, and in some cases greater than, their chlorinated counterparts in human cell lines and mammalian species (World Health Organisation 1998; Birnbaum et al. 2003; Weber & Greim 1997; Behnisch et al. 2003; Samara et al. 2010; Olsman et al. 2007; Matsuda et al. 2010; D'Silva et al. 2004). Thymic atrophy, wasting of body mass, lethality, teratogenesis, reproductive effects, chloracne, immunotoxicity, enzyme induction, decreases in T₄ and vitamin A, and increased hepatic porphyrins have been observed in animal studies of both brominated and chlorinated dioxins and furans (WHO, 1998, Birnbaum et al 2003, Weber and Greim 1997). *In vitro* responses of brominated PBDD/DF are similar to chlorinated PCDD/PCDF, including enzyme induction, anti-oestrogen activity in human breast cancer cells, and transformation of mouse macrophages into tumour cells and standard bio assays for dioxin-like toxicity testing (World Health Organisation 1998; Behnisch et al. 2003; Samara et al. 2010; Samara et al. 2009; Olsman et al. 2007; Matsuda et al. 2010).

In particular it should be emphasised that 2,3,7,8-Tetrabromodibenzofuran (2,3,7,8-TBDF) has a dioxin-like toxicity close to 2,3,7,8-TCDD (Matsuda et al. 2010; Behnisch et al. 2003; Samara et al. 2009; Samara et al. 2010) and is therefore far more toxic than the 2,3,7,8-TCDF. This is of particular concern because 2,3,7,8-TBDF is one of the most prevalent PBDD/PBDF congeners in human tissue (Ericson Jogsten et al. 2010) and human milk samples (Kotz et al. 2005) but can also be rather high in flame retarded plastics from WEEE (Riess et al. 2000).

Recent studies indicate that some brominated-chlorinated (PXDD/DF) dioxins/furans also have similar, and for some mixed congeners possibly greater, toxicity compared to their chlorinated homologues (Behnisch et al.2003; Mennear and Lee 1994; Birnbaum et al. 2003; Olsman et al. 2007; Matsuda et al. 2010). It is particularly notable that 2,3-Dibromo-7,8-dichlorodibenzodioxin and 2,3,7,8-T4BDD are shown to elicit up to 2.5 times the toxic response of 2,3,7,8-T4CDD, often thought to be the most toxic anthropogenic chemical. With regard to the contemporary relevance of PBDD, PBDF and brominated-chlorinated PXDD/PXDF more information is given below.

In conclusion, PBDD/PBDF and brominated-chlorinated PXDD/PXDF are of high concern similar to PCDD/PCDF and the prevention of their formation is of particular importance.

1.2.8 Contemporary relevance of PBDD, PBDF and brominated-chlorinated PXDD/PXDF

Today brominated dioxins and furans are relevant dioxin contributors in daily life as can be derived from their high contribution (about 30%) of the dioxin-like toxicity in food in the UK^{††} (Rose et al 2010) It is notable that the EU country with the most stringent flame retardant standards (UK) report on this consistently high PBDD/PBDF and PXDD/PXDF levels in food. A direct link between these PBDD/PBDF levels and the BFR use have not been established yet.

Furthermore PBDD/PBDF were found as the major dioxin-like compounds in the first comprehensive assessment of dioxin-like compounds in house dust. The dioxin-like PBDF levels considerable exceeded the dioxin-like contribution of polychlorinated dioxins, furans

^{††} Rose, M.D. Fernandes, A.R. (2010). Are BFRs responsible for brominated dioxins and furans (PBDD/Fs) in food? BFR2010. Kyoto

and dioxin-like PCBs^{‡‡} (Suzuki et al 2010). While for PCDD/PCDF food exposure is for the average population the most relevant exposure pathway for the PBDD/PBDF the indoor contamination of house dust from flame retarded material can have a significant contribution or is probably the most relevant exposure pathway.

PBDD/PBDF have globally been detected in house dust^{§§ *** †† ‡‡ ††}(Franzblau et al. 2009; Takigami et al. 2008; Suzuki et al. 2006; Ma et al. 2009; Suzuki et al. 2010). Japan is the first country to have performed a more systematic screening of total dioxin-like compounds in house and office dust^{‡‡} (Suzuki et al. 2010). It was found that PBDF are the major contributors to dioxin-like toxicity in this particularly relevant exposure matrix. Suzuki showed that dioxin-like PBDF toxicity considerably exceeded the combined amount from chlorinated PCDD, PCDF and dioxin-like PCBs in the samples from 19 households and 14 offices/laboratories^{‡‡} (Suzuki et al. 2010).

The bio-TEQ levels in these dusts were up to 1,400 ng (median 160 ng) CALUX-TEQ/kg. These levels are three to five orders of magnitude higher than those in food samples. As there was a difference of approximately three orders of magnitude for dioxin-like PCBs and PBDD/DF concentrations in these indoor dusts Suzuki concluded that this indicated the specific source of PBDD/PBDF as the indoor environment^{‡‡} (Suzuki et al. 2010).

An assessment of daily intake of dioxin-like compounds for children (1-5 years) revealed a significant contribution to daily intake from dust even for a moderate intake scenario of 50 mg dust/day. A simple calculation for the highest concentration shows that a child could be ingesting 280 pg TEQ/day. Child specific exposure factors from United States Environmental

^{‡‡} Suzuki, G.,Someya, M. Takahashi, S, Tanabe, S. Sakai, S., Takigami, H. (2010). Dioxin-like Activity in Japanese Indoor Dusts Evaluated by Means of in Vitro Bioassay and Instrumental Analysis: Brominated Dibenzofurans Are an Important Contributor Environ. Sci. Technol.44 (21), 8330–8336

^{§§} Franzblau, A.,Demond, A.,Towey, T.,Adriaens, P.,Chang, S.C.,Luksemburg, W.,Maier, M.,Garabrant, D.,Gillespie, B.,Lepkowski, J.,Chang, C.W.,Chen, Q. Hong, B., (2009). Residences with anomalous soil concentrations of dioxinlikecompounds in two communities in Michigan, USA: a case study. Chemosphere 74(3): 395-403

^{***} Takigami, H.,Suzuki, G.,Hirai, Y. Sakai, S.-i., (2008). Transfer of brominated flame retardants from components into dust inside television cabinets. Chemosphere 73(2): 161-169

^{†††} Suzuki, G.,Nose, K.,Takigami, H.,Takahashi, S. Sakai, S.-I., (2006). PBDE and PBDD/Fs in house and office dust from Japan. Organohalogen Compounds 68

^{‡‡‡} Ma, J.,Addink, R.,Yun, S.,Cheng, J.,Wang, W. Kannan, K., (2009). Polybrominated Dibenzo-p-dioxins/Dibenzofurans and Polybrominated Diphenyl Ethers in Soil, Vegetation, Workshop-Floor Dust, and Electronic Shredder Residue from an Electronic Waste Recycling Facility and in Soils from a Chemical Industrial Complex in Eastern China. Environ Sci Technol 43(19): 7350-7356;

Protection Agency (US-EPA)^{§§§} show that the mean bodyweight over this age range is between approximately 11 kg at 1 year to 19.5 kg at 5 years. Consequently the daily intake can range from about 14 to over 25 pg/kg bw/day from dust alone. These exposures far exceed of the WHO and European Tolerable Daily Intakes for chlorinated dioxins. For a high dust exposure scenario of 200 mg dust/day and median dust concentrations levels the daily intake of dioxin-like compounds of children via dust exceeded the daily intake of TEQ from PCDD/PCDF via food^{****} (Suzuki et al. 2007):

1.2.9 Conclusion on assessment of end-of-life treatment of flame retardant containing electronics (and other flame retarded materials)

In conclusion, the end-of-life management of imaging equipment, in which brominated aromatic substances are used in plastics, entails health and environmental risks.

Plastic containing brominated aromatic substances has a negative influence on the recycling of imaging equipment as the plastic fraction containing BFR needs to be removed from any separately collected WEEE and disposed of or recovered with specific requirements based on the provisions of Directive 2002/96/EC on waste electrical and electronic equipment (WEEE). Difficulties on WEEE are presented in more detail in Annex 6.12.3.

A large proportion of brominated flame retarded materials are combusted. Depending on the quality of combustion, high levels of brominated dioxins and furans can be formed and released as a result of the dioxin precursor properties of aromatic brominated flame retardants. In particular, open burning of e-waste is estimated to globally generate PBDD/PBDFs and PXDD/PXDFs on a scale of tons and for many geographical areas can be considered as common practice (see also section 1.2.5). The toxicity and environmental concerns related to dioxins and furans are high (see section 1.2.7). Brominated flame retardants in plastics can be destroyed with high efficiency only if the plastics are treated in incinerators constructed and operating according to best available technology (BAT) and best environmental practices (BEP). However, in this case costs per ton of incinerated material are considered high (in the order of \$100/t).

^{§§§} Environmental Protection Agency (US), Child-Specific Exposure Factors 2002, <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=199243#Download>

^{****} Suzuki, G., Takigami, H., Nose, K., Takahashi, S., Asari, M., Sakai, S.i., (2007). Dioxin-Like and Transthyretin-Binding Compounds in Indoor Dusts Collected from Japan: Average Daily Dose and Possible Implications for Children. Environ. Sci. Technol. 41(4): 1487-1493

Additionally, a large portion of Brominated FR-treated products end up in landfills and there is growing evidence and concern that brominated flame retardants including POPs/PBDEs are leaching from landfills and contaminating the environment in industrial countries as well as in developing/transition countries. Only in engineered landfills with bottom liners, leachates that escape to the environment can be collected and treated to reduce the flow of contaminants to ground and surface water for some time but such treatments are expensive and not state-of-the art. Because of their persistence, POPs/PBDEs will remain in landfills for many decades – and probably centuries and are expected to be eventually released to the environment as the landfill engineering systems (including basal and capping liners, gas and leachate collection systems) will inevitably degrade and lose their ability to contain the contaminants. Therefore, land filling does not appear to be a sustainable solution for long-term containment of brominated FR-treated materials (as presented in section 1.2.6).

The praxis showed that these substances can be avoided and resulting to avoidance of their associated environmental impacts.

1.2.10 Reference list for brominated flame retardants

The references used in Annex 6.11 regarding brominated flame retardants are presented in Table 5.

Table 5 Reference list for brominated flame retardants (used in this section)

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Wyrzykowska, B., Gullett, B.K., Tabor, D. Touati, A. (2008). Levels of brominated diphenylether, dibenzo-p-dioxin, and dibenzofuran in flue gases of a municipal waste combustor. *Organohalogen Compounds* 70.

Wyrzykowska, B., Tabor, D. Gullett, B.K., (2009). Same-sample determination of ultratrace levels of polybromodiphenylethers, polybromodibenzo-p-dioxins/furans, and polychlorodibenzo-p-dioxins/furans from combustion flue gas. *Analytical Chemistry* 81(11): 4334-4342

Yosuke, T., Miho, O., Muneaki, M., Masahide, K., Yasuhiro, K. Morita, M., (2008). Determination of pbdd/fs in dust sample inside television sets in the recycling factory. *Organohalogen Compounds* 70: 2272-2275

Yu, X., Zennegg, M., Engwall, M., Rotander, A., Larsson, M., Ming Hung, W. Weber, R., (2008). E-waste recycling heavily contaminates a Chinese city with chlorinated, brominated and mixed halogenated dioxins. *Organohalogen Compounds* 70: 813-816

Zennegg, M., Yu, X., Wong, M.H. Weber, R., (2009). Fingerprints of chlorinated, brominated and mixed halogenated dioxins at two e-waste recycling sites in Guiyu/China. *Organohalogen Compounds* 71, 2263-2267.

1.2.11 Information on waste streams for imaging equipment¹⁴

Information and data regarding the waste stream of imaging equipment follows.

Imaging equipment originating from households in EU-27 shall be collected following the provisions of WEEE Directive. In this frame imaging equipment waste streams are reported and statistics are kept in Eurostat. In these statistics imaging equipment are documented together with other IT equipment i.e. computers and laptops. A significant amount of electronic equipment which is primarily sold and used in EU-27 is exported as second hand products from EU-27 to third countries mainly from Africa and Asia. From a life cycle perspective the investigation of the environmental impacts of end-of-life phase of these products shall also be captured. In life cycle assessments the boundaries of the product life cycle system has no restrictions based on the geographical origin in which the environmental impacts may occur. Further, numerous environmental considerations are associated with the end-of-life management of the imaging equipment whose are shipped out from EU-27 as in the destination countries the recycling facilities, the thermal treatment (i.e. uncontrolled burning) or the land filing does not meet the European health and environmental standards.

1.2.12 Waste streams within the geographical area of EU-27

The WEEE Directive currently sets a minimum collection target of 4 kg per year per inhabitant for WEEE from private households. This target was originally based on estimates made by the EU Priority Waste Stream project group that future quantities of WEEE are expected to be over 20 kg per person per year, of which the consumer sector accounts for 12 kg, the industrial sector for 5 kg, and the cables sector for 3 kg. No collection target was set for non-household WEEE.

Based on the study on WEEE of 2008 for DG ENV¹⁴, currently in Western Europe the amount of WEEE produced per person is estimated to be higher than in the new Member States in which the amounts are substantially lower, but expected to rise in the future. A general characteristic of current collection rates is that these are, in the majority of Member

¹⁴ Huisman, Jaco, Delgado Clara, Magalini Federico, Kuehr Ruediger, Maurer, Claudia Artim, Eniko Szlezak, Josef Ogilvie, Poll Jim, Steve Abs, final Report for DG ENV, 2008 Review of Directive 2002/96 on Waste Electrical and Electronic Equipment (WEEE), United Nations University, 2008

States, far below 100% of the goods sold many years ago. Increasing collection is therefore one of the key issues to enhance the effectiveness of WEEE and to achieve the original intent of the Directive.

The new estimate¹⁴ of the expected waste of electric and electronic equipment (WEEE) arising across the EU27 is between 8.3 and 9.1 million tonnes per year for 2005. This increase is due to expansion of the EU, growth in the number of households and inclusion of items that may have been excluded previously (B2B). Forecasts models predict that by 2020, total WEEE arisings will grow annually between 2.5% and 2.7% reaching about 12.3 million tonnes. Out of them 8.0% is allocated to the category of IT and Telecom excl. CRT's, in which imaging equipment are classified together with computers which makes 664 to 828 thousand tonnes for 2005 and 984 thousand tonnes in 2020. The estimate for imaging equipment is 268 thousand tonnes for 2008 as given in Table 6. These values are higher than the collected volumes reported in Eurostat (given here in

Table 7-Annex 6.10.) which reach just in 2008 the 539,833 tonnes.

Table 6 Imaging equipment placed in the EU25 expressed in weight in tonnes¹⁴

Weight (tonnes)	2004	2005	2006	2007	2008
B&W laser printers	56,310	55,230	55,710	55,425	55,635
Colour laser printers	20,070	25,020	26,190	29,310	30,570
B&W copiers	50,950	54,000	52,000	50,500	47,500
Colour copiers	13,700	14,300	16,300	17,200	17,900
Inkjet printers & MFDs	109,010	112,185	113,575	115,435	116,780
Total	250,040	260,735	263,775	267,870	268,385

Table 7 Eurostat data for WEEE collected for IT and telecommunications equipment (including imaging equipment) in tonnes

IT and telecommunications equipment (including imaging equipment) waste collected (in tonnes per year

GEO/TIME	2005	2006	2007	2008
Belgium	10,673.94	12,155.19	14,372.85	16,284.71
Bulgaria	:	:	3,835.72	4,553.71
Czech Republic	:	:	7,270.9	9,784.1
Denmark	:	11,380	17,043	16,507
Germany (including former GDR from 1991)	:	102,336	117,749	155,007
Estonia	:	687.04	870.71	970.7
Ireland	:	:	11,163	9,599
Greece	449	1,001	2,981.53	5,941.94

Spain	:	:	14,406	17,019
France	:	8,540	28,574	47,766
Italy	:	:	:	:
Cyprus	263.6	856.9	127.62	290.11
Latvia	:	:	800.78	853.48
Lithuania	288	1,072	1,575	1,415
Luxembourg	:	570.18	852.94	827.51
Hungary	1,242	2,377.8	3,472.5	5,719.1
Netherlands	16,838	18,440	21,049	23,069
Austria	3,148.2	11,365.5	13,212	15,342.8
Poland	:	3,067.3	8,714.74	14,948.73
Portugal	:	1,175.65	3,238.15	11,937
Romania	:	274.24	1,164.32	6,252.69
Slovenia	:	:	:	:
Slovakia	285.65	857.9	2,101.01	2,532
Finland	2,841	7,012	10,375	11,647
Sweden	9,440	25,174	29,782	29,556
United Kingdom	:	:	55,831.34	132,009.89
Malta	:	:	:	:
EU-27 Total	45,469	208,343	370,563	539,833
: not available				

The EU15 Member States' average collection performance is roughly half that of Switzerland and Norway. This is mainly due to lower performance in the collection of categories other than the category referring to large household appliances. Although the WEEE Directive collection target can be easily met by EU15 Member States, it remains a very challenging target for the New Member States¹⁴.

The estimated amount of WEEE currently collected and treated as a percentage of the amounts of WEEE arising for the EU27 in 2005 for the category in which imaging equipment are covered is 27.8%. There is no information available on differences between imaging equipment and computers as these are not differentiated in Eurostat categories but it is suggested that there shall be no large differences.

This means that for computers and imaging equipment there is substantial room for improvement (up to 70 %) of the waste stream covered by WEEE Directive. Further, it is important to highlight that there were identified large differences in performance by different Member States per sub-category which indicates that there is much room for improvement in collection performance¹⁴.

Regarding impacts of WEEE for metals there appear to be no major difficulties concerning the recovery and recycling for metals. On the contrary for plastics data from literature seems to confirm that at present plastic output streams from WEEE recycling operations are mostly not recovered, but are landfilled together with other residue streams, as opposed to the apparent preference for the recycling option.

Annex II of WEEE Directive requires that plastics containing brominated flame retardants are removed from any separately collected WEEE and are disposed of or recovered in compliance with Article 4 of Council Directive 75/442/EEC on Waste.

It is suggested that the removal obligation reduces the amount of plastics available for recycling and hinders the meeting of recycling targets in some plastic dominated WEEE categories. Further, recycling of BFR plastics into non electronic and electric applications (houseware, automotive, building...) can cause dispersion of additives into other diverse streams, which could be interpreted as against the principle that recovery should ensure that pollutants are not transferred into products and minimises the formation, transfer and dispersion of hazardous substances in the process.

1.2.13 Waste streams outside the geographical area of EU-27

It is considered that a high number of EEE including imaging equipment is exported from EU27 as reused products. This way the waste of these products is not handled and treated in EU27 (in which WEEE Directive is applicable) but in the destination countries in which often lower health and environmental standards are applied along the end-of-life phase of the products. Trade statistics to non EU Members embrace a part of the actual exports. However, statistics do not differentiate between used and new goods. Thus, capturing the actual volume of these products is difficult. In Eurostat exports outside EU27 of WEEE are reported to be either zero or in marginal amounts compared with the overall arising of waste of EEE.

As this issue has gained awareness a study for the German Federal Environmental Agency regarding the trans-boundary shipment of waste electrical and electronic equipment /

electronic scrap was conducted in 2010¹⁵. This report describes approaches, measures and regulation structures for the export of used electrical/electronic equipment and waste electrical/electronic equipment to non-EU countries with aim to optimise the protection of the environment and resource flows. Volumes on used imaging equipment shipped in 2008 from the port of Hamburg to Ghana, Nigeria, South Africa, Vietnam, Philippines and India.

The export of the equipment types investigated in non-EU countries took place exclusively as used equipment. However, the value of these products which are exported for reuse lies significantly below the value compared with the respective items exported to Member States. Notified waste exports of such equipment is not known. In general the equipment originates from a multiplicity of sources (in all >4,000 sources), in part from private end users, in part from commercial sources and partially from the waste regime.

Private collection and reloading points represent one of the most important pivotal points for the export of low-value equipment. In the countries of destination, the equipment encounters recovery and disposal structures, which are not suitable to ensure the protection of human health and the environment as well as the extensive recovery of resources. Through this, several hundred of kilos of precious metals and rare earths are lost from the economic cycle.

The total quantity of the exports extrapolated within the framework of the investigation from German Federal Agency in 2008 lay between 93,000 t and 216,000 t. In the countries of destination, the equipment encounters recovery and disposal structures, which are not suitable to ensure the protection of human health and the environment as well as the extensive recovery of resources.

As found in Table 8 for imaging equipment the largest amount 5.154 tonnes was shipped from Hamburg to South Africa while 2.875 tonnes to India, 754 tonnes to Vietnam 722 tonnes to Nigeria and lower amounts to Philippines and Ghana 178 tonnes and 106 tonnes respectively. In total the amount of imaging equipment shipped as reused items towards

¹⁵ Knut Sander, Stephanie Schilling for the Federal Environment Agency (Germany), "Transboundary shipment of waste electrical and electronic equipment / electronic scrap – Optimization of material flows and control", Ökopol GmbH, 2010
http://www.umweltbundesamt.de/uba-info-medien/mysql_medien.php?anfrage=Kennummer&Suchwort=3933

countries in which the end-of-life facilities are not meeting the health and environmental standards of EU in one year and only from the port of Hamburg was 9,789 tonnes.

Table 8 Export from Germany to select countries of destination (reference year 2007)¹⁵

Goods code	Plaintext	Ghana	Nigeria	South Africa	Vietnam	Philippines	India
		Weight in t					
WA8415	Air conditioning units	33	32	778	83	46	525
WA8418	Refrigerators, freezers, heat pumps	64	312	791	169	24	517
WA8443	Printing machines and accessories for printing machines	106	722	5.154	754	178	2.875
WA8450	Machines for washing or drying clothes	22	19	358	19	27	49
WA8469	Typewriters, word processing machines	1	-	-	0	1	1
WA8471	Automatic data processing machines	56	152	782	170	24	108
WA8510	Razors, shears with electric motor	0	-	25	-	0	1
WA8516	Electric hot water heaters and immersion heaters	20	56	1.106	3	85	68
WA8517	Telephone sets, telecommunication equipment	10	478	1.234	116	34	1.737
WA8521	Audio/video recording equipment	1	60	6	0	0	0
WA8525	Transmission equipment for broadcast etc., television cameras	1	56	64	24	3	25
WA8527	Receiving equipment for radiotelephone traffic or broadcast	1	4	149	0	0	10
WA8528	Television sets, video monitors	153	787	145	802	1	129
Total		468	2.678	10.592	2.140	423	6.045

1.2.14 Difficulties of plastics recycling from WEEE

Number of facilities which can separate plastics in the EU including separation of BFR plastic

Whilst there are several WEEE recycling plants in Europe using 'state-of-the-art' technologies for the separation of plastics, there are still only a handful of facilities for comprehensive treatment integrating plastic separation and recycling, and only a very few plants separate BFR-containing plastic¹⁶. Most WEEE recycling companies dismantle and sort equipment into various streams and then pass the plastic rich fraction to other specialised operators. Some aim for the recovery of residual metals in these polymer-rich fractions, others recycle parts of the plastic fraction, a third group recovers energy and a

¹⁶ UNEP (2010) Technical review of the implications of recycling commercial penta and octabromodiphenyl ethers. Stockholm Convention document for 6th POP Reviewing Committee meeting (UNEP/POPS/POPRC.6/INF/6) Geneva 11-15. October 2010.

proportion of WEEE plastics are sold as mixed plastic for export - mainly to China¹⁶. Only about 8 % of plastic from WEEE is recycled^{17,18}.

Reasons for the limited recycling of WEEE plastic

The four main reasons for the limited number of approaches for recycling plastics from WEEE are included below¹⁶:

a) Industry using secondary plastic materials has tight specifications in relation to polymer quality, both chemically (RoHS compliance) and with respect to material properties. This is also used as an argument to depress the prices of recyclate thus increasing the economic challenges.

b) WEEE plastics contain at least 15 different plastic types (Dimitrakakis et al. 2009, UNEP 2011). The efficient sorting of this mixture presents difficult technical challenges and a degree of cross-contamination is inevitable in practice. According to Dimitrakakis¹⁸ three polymers (ABS, PS, PP) account for between 70 % and 85 % of total while other studies estimate that this fraction is a bit lower at 50-70%.

c) WEEE plastics contain RoHS listed BFRs (PentaBDE, OctaBDE, DecaBDE; but normally no PBB which is also listed). Potential customers are therefore risk adverse to contaminated recyclate.

d) Production of larger volumes with identical properties and performance, as required by many major manufacturers, requires consistent quality and composition of inputs.

Japan has already established a Japanese Industrial Standard (JIS) for plastics for use in electric home appliances, "*marking for identification of plastic parts for electrical and electronic equipment (C9912)*." This standard requires the marking of plastic parts such as flame retardants (FR), recycled plastics and dismantling assistance. In particular, the marking system includes plastics already recycled by 'closed-loop recycling' (i.e. recycling within the same product group). Target recycling rates for different electronic categories have also been set¹⁹ (Aizawa et al. 2010).

¹⁷ UNEP (2011). Guidance on the Best Available Techniques (BAT) and Best Environmental Practice (BEP) for recycling and waste disposal of articles containing POP-PBDEs. Draft 10/2011.

¹⁸ Dimitrakakis E., Janz A., Bilitewski B. Gidakos E. (2009) Small WEEE: Determining recyclables and hazardous substances in plastics. *Journal of Hazardous Materials* 161(2-3): 913-919

¹⁹ Aizawa H., Hirai Y., Sakai S.-I. (2010) Development of Japanese Recycling Policy for Electric Home Appliances by the Addition of Plastics Recycling. BFR2010: 5th International Symposium on Brominated Flame Retardants. 7.-9. April 2010, Kyoto/Japan

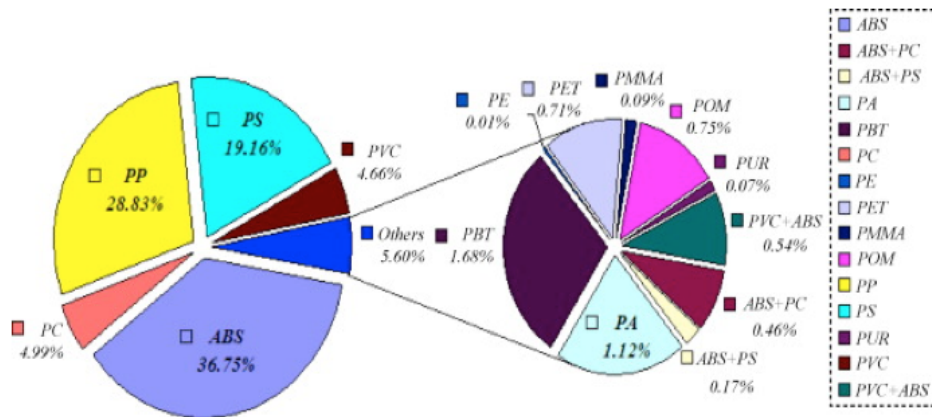


Figure 1: Polymer types identified in WEEE plastic samples (% w/w)¹⁸

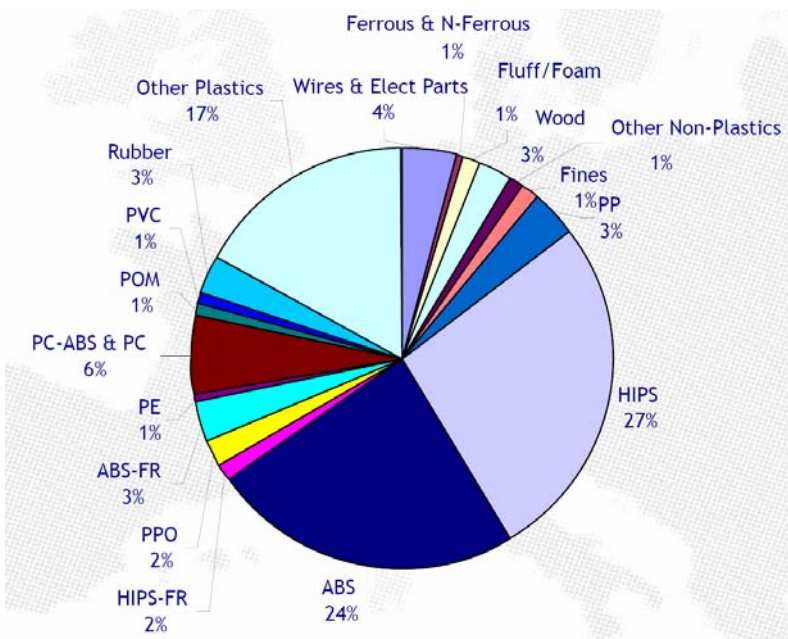


Figure 2: Polymer types and other materials identified in WEEE plastic samples (% w/w)¹⁷

1.2.15 Information regarding the end-of-life considerations of PVC

A key concern regarding PVC is at end-of-life management. The management of PVC waste should be assessed in the context of the European waste management policy. The Communication from the Commission on the review of the Community strategy for waste management⁴⁵ has confirmed *“the hierarchy of principles that prevention of waste shall remain the first priority, followed by recovery and finally by the safe disposal of waste.”* It is further stated that *“preference should be given, where environmentally sound, to the recovery of material over energy recovery operations. This general rule is based on the fact that material recovery has a greater effect on waste prevention than energy recovery. It will nevertheless be necessary to take into account the environmental, economic, and scientific effects of either option. The evaluation of these effects could lead, in certain cases, to preference being given to the energy recovery option.”* In its Resolution⁴⁶ of 24 February 1997, the Council endorsed this hierarchy of principles.

The three main options for end of life management of materials containing PVC are: (1) reuse/recycling (2) incineration/thermal treatment (3) deposition. Management of end-of-life waste flows can vary widely based on the type of waste management schemes used in various countries and the different materials involved (PVC in mixed plastic fraction; PVC as; PVC in hospital wastes).

1.2.15.1 Mechanical recycling of PVC and PVC containing materials

Mechanical recycling refers to recycling processes where PVC waste is treated only mechanically, mainly through shredding, sieving, and grinding. From a life cycle perspective, the preferred method for end-of-life treatment of PVC and PVC containing wastes would be mechanical recycling because it reduces the energy-intensive production of new materials.

A number of life cycle assessments⁴⁹ on some specific PVC products have shown that mechanical recycling provides an environmental advantage for production waste, cut-offs and post-consumer PVC waste, which can be separated. The environmental advantages of the down-cycling of mixed plastics for the production of products which substitute concrete, wood or other non-plastic applications are less certain.

However, the presence of additives classified as hazardous, such as lead, cadmium and PCB, in large PVC waste streams, raises specific issues during their potential recycling. The recycling of PVC waste containing heavy metals results in a dilution of these substances in a greater quantity of PVC, since it is necessary to add virgin material. The heavy metals are not directly released into the environment during the recycling process and the renewed service life. The recycling of PVC material containing these heavy metals postpones the final disposal to a later stage. Due to the product-specific additives formulations, recyclers would prefer recycling into similar applications.

A prohibition of the recycling of PVC waste containing heavy metals would eliminate the mechanical recycling of post-consumer PVC wastes from building applications - the waste stream with the highest potential for high-quality recycling - as they virtually all contain lead or cadmium. It should be noted that, except for Denmark, Member States, which have banned the use of cadmium as stabilisers, allow the recycling of PVC waste containing cadmium.

The problem of PCBs in PVC cable waste has been addressed in Directive EC/96/59 on the disposal of PCB and PCT, which states that cables containing more than 50 ppm of PCBs are considered PCBs and therefore have to be decontaminated or disposed of in accordance with the provisions established under this Directive.

The resulting recyclates (in powder form) can be processed into new products. Depending on the degree of contamination and the composition of the collected material, the quality of the PVC recyclates can vary to a large degree. The quality of the recyclates determines the degree to which virgin material can be substituted by recyclates: "high-quality" recyclates can be reused in the same types of PVC applications, whereas "low-quality" recyclates from mixed waste fractions can only be "down-cycled" into products usually made from other material (EC 2000).

In the baseline scenario presented in the PVC green paper about 9 % of the total PVC waste could be mechanically recycled in 2010 and 2020, representing about 400 000 tonnes of PVC waste in 2010 and 550 000 tonnes in 2020 (EC 2000, Prognos 2000). Compared to this baseline scenario, maximum recycling potentials, which represent the PVC quantities which can be recycled (taking into account the technical and economic limits of PVC) recycling

have been estimated by Prognos in 2000 (EC 2000). According to this scenario, the potential for post-consumer waste was estimated to about 800 000 tonnes in 2010.

However the recycling quota of PVC today demonstrates that PVC recycling is still a major challenge. According to the estimates of the Vinyl Institute *"it is anticipated that the total recycled will reach up to 200 000 tons of PVC waste in 2010"*²⁰ only 4 % of thr PVC waste amount for 2010 will be recycled.

The largest part of the remaining 96 % of the PVC wastes goes to landfills and some of the waste into incineration. The suggested recycled amount would therefore be only 50 % of the baseline scenario and only 25 % of the estimated maximum recycling potential projection from the Commission in the 'Green Paper – Environmental Issues of PVC' (EC 2000). The Vinyl Institute states that this small recycling quota would only be reached with governmental support *'For this recycling volume to be reached there is a need for support from public authorities to create and organise appropriate waste collection schemes'* (Vinyl 2010). This means that governmental support in collection (which is the most expensive part of recycling) is a precondition even for a 4 % recycling quota.

According to the EC Green Paper, the recycling of PVC is also limited by the overall recycling costs (EU 2000) which is probably the main driving force for the low recycling quota. Economic profitability is reached when the net recycling costs (i.e. the overall costs for collection, separation and processing minus the revenues from sale of the recyclates) are lower than the prices for alternative waste management routes for related PVC wastes. The EC further states that *'If economic profitability cannot be reached, the recycling of PVC waste will not take place under free market conditions, unless there are legal obligations or voluntary measures enforcing or promoting the recycling of PVC. Collection represents the major bottleneck regarding the availability of waste and costs.'*

For PVC in electronics like imaging equipment, the sorting cost would add to these expenses. Cable insulation is the only post-consumer waste which can be recycled at competitive costs, due to the presence of valuable metals, such as copper (EC 2010). High-quality mechanical recycling of PVC for post-consumer wastes is considered to be in a

²⁰ Vinyl 2010, Reporting of the activities of the year 2010 and summarising the key milestones of the past 10 years, The European PVC Industry's Sustainable Development Programme, http://www.vinyl2010.org/images/progress_report/2011/vinyl2010_progress_report_2011_final.pdf

preliminary stage and in 2000 existed only for few product groups and with low quantities (about 3.600 tonnes of rigid profiles, 5,500 tonnes of PVC pipes and 550 tonnes of flooring) (EC 2000).

In respect of the use of PVC in articles which finally generate a mixed plastic fraction (like electronics including imaging equipment), the EC paper concludes that PVC can have a negative influence on the recycling of other plastics in mixed plastic waste (EC 2010): '*When PVC is processed with other plastics, such as in the packaging waste stream, the processing temperature is limited to the range of PVC-processing, which is a relatively low range compared to other plastics. Due to similar densities, polyethylene terephthalate (PET) and PVC waste are difficult to separate and the presence of PVC puts additional costs on some PET recycling schemes such as the PET bottles.*' (EC 2010). This is an important consideration for restriction of PVC in electronics such as imaging equipment.

1.2.15.2 Chemical recycling of PVC and PVC containing materials

Chemical recycling denotes a number of processes, by which the polymer molecules that constitute plastic materials are broken up into smaller molecules. These can either be monomers that can be used directly to produce new polymers or other substances that can be used elsewhere as starting materials in processes of the basic chemical industry.

In the case of PVC, in addition to the breaking up of the backbone of the polymer molecules, the chlorine attached to the chains is set free in the form of hydrogen chloride (HCl). Depending on process technology, HCl can be reused after purification or has to be neutralised to form various products that can be used or have to be disposed of (EC 2000).

For 2010, the total PVC waste quantities which could be chemically recycled in the baseline scenario, were estimated to about 80 000 tonnes as a fraction in mixed plastics waste with low chlorine content (mostly from packaging) and about 160 000 tonnes in mixed plastic fractions with higher PVC content, mostly from automotive and electric and electronic waste (EC 2000).

1.2.15.3 Incineration/thermal treatment of PVC

1.2.15.3.1 Negative impact of PVC in cement kilns

PVC has a crucial negative impact on the incineration and thermal recovery of polymer waste in cement kilns. PVC (and other halogenated material) limits or even restricts the use of thermal recycling in cement plants which normally accept polymer waste as secondary fuel up to a chlorine content of 0.5 %. In the best available techniques reference documents on cement, lime and magnesium oxide manufacturing industries²¹ is reported in the BAT chapter that in order to reduce HCl emission the producer has to use a) raw materials and fuels containing a low chlorine content, b) limit the amount of chlorine content for any waste that is to be used as raw material and/or fuel in a cement kiln. Moreover, cement quality composition specification included limitation of chlorine content due to corrosion problems that may occur in the concrete reinforcement.

1.2.15.3.2 Negative impact of PVC in waste incinerators

An assessment of the quantities of flue gas cleaning residues resulting from the incineration of PVC waste concluded that the incineration of 1 kg of PVC generates on average⁵⁹ between 1 and 1.4 kg of residues for the dry process with lime, semi-dry and semi-wet wet processes (Bertin technology 2000). With the use of sodium hydrogen-carbonate as a neutralisation agent in semi-dry process, 1 kg of PVC generates about 0.8 kg of residue. In case of wet processes, between 0.4 and 0.9 kg of liquid effluent is generated²².

These flue gas cleaning residues are classified as hazardous waste (EC 1994). The residues are generated separately (in particular in semi-wet and wet systems) or mixed with fly ash. The residues contain the neutralisation salts, the excess neutralisation agent as well as pollutants such as heavy metals and dioxins that were not destroyed. Landfilling of the residues is, with some exceptions, the only option used within the Member States. Several processes have been devised to recover calcium chloride and sodium chloride from the residues of the dry and semi-dry processes, but few of them are currently used commercially. The EC highlighted that these technologies are “end of the pipe” solutions, less preferable

²¹ European Commission, Best available techniques reference documents on cement, lime and magnesium oxide manufacturing industries, Joint Research Centre, Institute for Prospective Technological Studies, IPPC bureau, 2010

²² . There is a difference between the amounts of neutralisation agent required and residues produced between soft and rigid PVC. Flexible PVC contains less chlorine than rigid PVC. The amounts of neutralisation agents required and of residues generated are therefore lower for flexible PVC than for rigid PVC (1 kg of soft PVC generates between 0.5 and 0.78 kg of residues) (Bertin Technology 2000).

than a preventive measure aimed at reducing at source the quantity of residues generated (EC 2000).

Therefore - for the treatment in BAT incineration, the minimization of PVC input should be considered.

In summary, PVC at in the municipal solid waste stream has the following effect on the flue gas cleaning residues in comparison to incineration of municipal solid waste without PVC⁶³:

- PVC incineration contributes to an increase in the quantity of flue gas cleaning residues (about 37 % for the dry systems, 34 % for semi-dry systems and 42 % for semi-wet wet 64);
- PVC incineration contributes to an increase in the content of leachable salts in the residues by a factor of two. These are primarily chlorides of calcium, sodium, and potassium;
- The incineration of PVC increases the amount of leachates from the residues put into landfill (about 19 % for dry systems, 18 % for semi-dry systems, 15 % for the semi-wet wet systems and 4 % for wet systems). The leachates need to be treated prior to any discharge.

Furthermore PVC waste incineration increases the operating costs of the incinerators due to the use of neutralisation agents to neutralise the acid flue gas, and adds additional costs for the waste management of the resulting residues. Up to EUR 300 per tonne for dry systems (Bertini et al 2000). These additional costs are not borne specifically by new PVC products or by PVC waste, but are included in the overall incineration cost of waste. A reduction of PVC waste would have a positive effect on this.

1.2.15.3.3 PVC and PCDD/F formation in thermal processes

The question on the role of PVC in the formation and release of PCDD/PCDF in combustion raised awareness since many years now (many references go back to 1999). A similar situation exists for combustion of PVC-containing materials as described for brominated flame retardants in Table 7.

State of the art municipal waste incinerators can treat PVC containing waste (up to 1 % chlorine) and hazardous waste incinerators (wastes above 1 % chlorine) without a significant

increase in PCDD/PCDF formation, since the limiting parameter for PCDD/PCDF de novo synthesis in the cooling zone is not chlorine (which in fly ashes is about 10%), but carbon (which in BAT incineration ash is at levels well below 1 % or even 0.1 %).

However for small scale incinerators and non-BAT incinerators with lower combustion efficiency, carbon levels (products of incomplete combustion) are high, and the chlorine content (with PVC as main contributor) is the determining factor for PCDD/PCDF formation and release. PCDD/PCDF formation and release has a strong correlation to the PVC content, which is the major driver for high PCDD/PCDF emission levels (Ibashi 2011).

PVC products disposed of in landfills contribute to the formation of dioxins and furans during accidental landfill fires (EC 2000). The release of PCDD/PCDF from landfill fires and open burning is one of major PCDD/PCDF sources in the national inventories established under the Stockholm Convention. Of particular interest in respect to EEE (including imaging equipment) is the high release of PCDD/PCDF in primitive WEEE recycling in developing countries: it has been shown for e-waste recycling sites in China that PVC was the main source of PCDD/PCDF environmental contamination, while the brominated flame retardants were the main source for the brominated and chlorinated-brominated PXDD/PXDF (Zennegg et al 2009). Since the EU is party to the Stockholm Convention, unintentional POP releases need to be minimised, and the substitution approach applied. Similar considerations were made in the development of the criteria establishment by the Nordic Swan²³.

1.2.15.4 Deposition of PVC in landfills

Deposition in landfills is the most common waste management route for PVC waste. It can be estimated that several tens of million tonnes of PVC waste have already been sent to landfills during the past 30 years.

All materials in landfills including PVC are subject to different reactive conditions, which are determined by parameters such as temperature, moisture, presence of oxygen, activity of

²³ Nordic Swan (2007): "The Nordic countries are bound by the Stockholm Convention on Persistent Organic Pollutants (POPs) to omit waste containing POPs at source so that POPs are destroyed or pacified without impacting the environment (www.pops.int). The convention considers the incineration of PVC, for example, to be a source of POPs, in particular dioxins". (Nordic Swan 2007) "Furthermore, there is always a risk of POP emissions (dioxins) from uncontrolled fires that involve PVC and other materials containing chlorine, e.g. houses, hotels and hospitals". (Nordic Swan 2007).

micro-organisms and the interactions between parameters at different stages of the ageing process of landfills²⁴.

Investigations have been carried out on both rigid and soft PVC samples mainly through laboratory equipment studies, examination of the effects of biological treatment, and of microbiological tests (Argus 1999).

The PVC polymer is generally regarded as being resistant under soil-buried and landfill conditions (Mersiovski et al 1999). However, an attack on the PVC polymer of a thin packaging foil has been detected (Argus 1999). This remains an isolated result and the attack was observed under aerobic conditions and at 80°C, conditions which, if they occur in landfills, are transient.

Losses of plasticisers, especially phthalates, from flexible PVC are widely recognised in the literature (EC 2000). Results from studies on the degradability of phthalates under landfill conditions show that degradation of phthalates occurs, but may not be complete depending on conditions and type of phthalate. Both phthalates and their degradation substances can be detected in landfill leachates (EC 2000). In addition, long-chain phthalates, such as DEHPs, are only partly degraded in usual leachate and sewage treatment plants and accumulate on suspended solids. Losses of phthalates could also contribute to gaseous emissions from landfills. As for other emissions from landfills, emissions resulting from the presence of PVC in landfills can last longer than the guarantee of the technical barrier, and there is no evidence that the release of phthalates will end after a given period of time.

A study into the long-term behaviour of PVC waste under landfill conditions showed a release of lead stabiliser from flexible PVC waste (Mersiowski et al 1999). Stabilisers in rigid PVC waste are more encapsulated in the matrix. Hence, migration is expected to be lower in rigid PVC and would mainly affect the surface of the PVC. The effect on the bulk of the material is uncertain.

²⁴ Four main phases can be distinguished: short initial aerobic phase, anaerobic acidogenic phase (variable duration, longer than aerobic phase), anaerobic methanogenic phase (up to several centuries), final aerobic phase.

As mentioned above, PVC products disposed of in landfills contribute to the formation of dioxins and furans during accidental landfill fires (EC 2000). The release of PCDD/PCDF from landfill fires and open burning is one of major PCDD/PCDF sources in the national inventories established under the Stockholm Convention.

1.2.16 Conclusion on the assessment of end-of-life treatment of PVC

The PVC recycling quota is very low. Based on the prediction of vinyl2010²⁵ the recycling quota of PVC would be only 4% of the total PVC waste amount for 2010. This recycled amount would be only 50 % of the baseline scenario estimated from the Commission in the “Green Paper – Environmental Issues of PVC”. Even for this small recycling quota, governmental support in collection (which is the most expensive part of recycling) is a precondition.

PVC has a negative influence on the recycling of other plastics such as the recycling of mixed plastic waste (i.e. imaging equipment). As stated in the Green Paper for PVC, the processing temperature is limited to the range of PVC processing, which is a relatively low range compared to other plastics.

PVC (together with other chlorine containing polymers) has crucial negative impact on the incineration and thermal recovery of polymer waste in cement kilns. The presence of PVCs in mixed plastic waste fractions restrict the use of PVC containing waste as fuel in cement plants which normally accept polymer waste up to a chlorine content of 0.5%.

PVC has a negative impact in incineration plants which operate under BAT conditions, due to the high costs of the treatment of flue gas cleaning residues which are produced in increased volumes when PVC is present. Flue gas cleaning residues are classified as hazardous waste and their treatment is associated with high costs which are directly linked to the operational

²⁵ Vinyl 2010 is the voluntary programme on Sustainable Development by the PVC industry. Vinyl 2010 represents the whole PVC industry chain. Its four founding members are: ECVN (the European Council of Vinyl Manufacturers), representing the 13 European PVC resin producing companies which account for almost 100% of the current total EU-27 PVC resin production, ESPA (the European Stabilisers Producers Association), representing 11 companies which produce more than 98% of the stabilisers sold in Europe, ECPI (the European Council for Plasticisers and Intermediates), representing the seven major European plasticiser and intermediate producers, EuPC (the European Plastics Converters) represents close to 50,000 companies in Europe, producing over 45 million tonnes of plastic products of various types every year.

costs of the incinerator. As highlighted in the EC Green Paper for PVC, a preventive measure aimed at reducing the quantity of residues generated at source is more preferable than the treatments of them afterwards.

PVC-containing waste is associated with the formation of dioxins and furans in thermal processes with insufficient combustion conditions i.e. incinerators operating on non-BAT conditions, uncontrolled burning, accidental fires etc.

Deposition in landfills is the most common waste management route for PVC. Degradation of plasticisers used in PVC occurs in landfills, resulting to emissions both to leachates and to air. Environmental impacts are related to the release of these substances. Emissions from PVC can last longer than the guarantee of the technical barrier used in landfills.

1.2.17 Reference list related to the end-of-life environmental consequences of PVC²⁶

Table 9 Reference list with information regarding PVC

<p>AEA Technology, Economic evaluation of PVC waste management, a report produced for the European Commission Environment Directorate-General, June 2000.</p> <p>Argus in association with University Rostock (1999) ,The Behaviour of PVC in Landfill, Study for DG ENV,</p> <p>Bertin Technologies, The influence of PVC on quantity and hazardousness of flue gas residues from incineration, Study for DG XI, April 2000</p> <p>European Commission (2000) GREEN PAPER Environmental issues of PVC; COM (2000) 469 final; Brussels, 26.7.2000.</p> <p>Mersiowski et al. 1999, Behaviour of PVC in landfills, ECVM, Technical University Hamburg-Harburg Prognos, Mechanical recycling of PVC wastes, Study for DG XI, January 2000</p> <p>Vinyl (2010) REPORTING ON THE ACTIVITIES OF THE YEAR 2010 and summarising the key milestones of the past 10 years.</p> <p>Zennegg, M.,Yu, X.,Wong, M.H. Weber, R., (2009). Fingerprints of chlorinated, brominated and mixed halogenated dioxins at two e-waste recycling sites in Guiyu/China. Organohalogen Compounds 71, 2263-2267</p>

²⁶ With regard to the formation of dioxin and furans see also references presented in section 6.11.9

1.2.18 Information regarding the green paper on environmental issues of PVC

The following questions and answers as published in the official website of the EU²⁷ related to the publication of the Green Paper on environmental issues of PVC²⁸ are presented as follows:

Green Paper on environmental issues of PVC

Reference: MEMO/00/46 Date: 26/07/2000

Brussels, 26 July 2000

Green Paper on environmental issues of PVC QUESTIONS & ANSWERS

1. Why is the Commission taking an initiative on PVC?

The Green Paper follows the commitment of the Commission, made in its Proposal for a Directive on end of life vehicles²⁹.

The whole life cycle of PVC raises a number of environmental issues, in particular due to the use of certain additives (lead, cadmium and phthalates) and during the management of PVC waste. Some Member States have recommended or adopted measures related to specific aspects of the PVC life cycle. These measures are not identical and some may have consequences for the functioning of the internal market.

PVC is one of the most widespread plastics used today with a production of about 5.5 million tonnes in Europe in 1998 (21 million tonnes world-wide, about 20 % of all plastics production). Overall production of PVC compounds (PVC resin and all additives) was at about 7.2 million tonnes in 1998. The economic weight of the industrial sector is important: the total PVC producing and transforming industry in Western Europe represents about 21,000 companies, 530 000 jobs and a turnover of more than 72 billion €.

2. What is PVC used for?

The main applications of PVC in Europe today are in the building sector (windows, profiles, pipes, flooring), which accounts for 57% of all uses. The other largest uses are in the fields of packaging (9%), household (18%) and automotive appliances (7%).

3. The main distinction between the numerous applications is between « rigid PVC » (accounting for about two thirds of total use) and « flexible PVC » (accounting for about one third). The main uses of rigid PVC are pipes, window frames, other profiles, and parts of household appliances. Flexible PVC is mainly used in cables, flooring, as packaging material (flexible films), car under-floor protection and instrument panels for cars. What are the key figures for additive use and Waste quantities?

About 1 million tonnes of phthalates are used annually as plasticisers to manufacture flexible PVC products. About 112,000 tonnes of lead stabilisers (containing about 51,000 tonnes of lead metal) were used in 1998 (overall consumption of lead for use in all kinds of products was 1.6 mill. Tonnes in Europe in 1997), 50 t of cadmium metal were used in 1170 tonnes of stabiliser formulations.

About 3.6 million tonnes of post-consumer PVC waste are generated annually in Europe. An increase of PVC waste quantities of about 80% is expected in the coming 20 years. About 0.5 million pre-

²⁷ Press release European Commission

<http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/00/46&format=HTML&aged=0&language=EN&guiLanguage=en>

²⁸ European Commission, COM(2000) 469 GREEN PAPER Environmental issues of PVC

<http://ec.europa.eu/environment/waste/pvc/pdf/en.pdf>

²⁹ Available online at:

http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/00/46&format=HTML&aged=0&language=EN&guiLanguage=en#file.tmp_Foot_1#file.tmp_Foot_1.

consumer waste (production and installation waste) is generated, 85% of which is recycled.

4. Why is the Commission only adopting a Green Paper and not a strategy with proposals for specific measures?

The Green Paper is the first step towards the adoption of a Community strategy on PVC to be adopted in early 2001.

The Commission wants to open a transparent consultation process to stimulate a debate on PVC. The European Parliament, the Member States, the NGOs, the Consumers, the industry have to be involved in this important issue.

It is essential to launch a Europe-wide public debate on the basis of the fair and balanced analysis made in the Green Paper. Similar debates have already taken place in some Member States, but not in all of them.

5. Is it better to recycle, incinerate or landfill PVC?

Currently about 3% of PVC waste is recycled (100,000 t), about 17% incinerated (about 600,000 t) and the rest landfilled (about 2.9 million t).

The Green Paper gives a detailed analysis on the advantages and disadvantages of each of these options. On the basis of this analysis and given the present low recycling rate, the Commission considers that recycling of PVC should be increased. However, it is expected that recycling of PVC waste could contribute only to the management of about one fifth of PVC post-consumer waste. Other waste management routes will therefore remain important.

The Green Paper presents the problems linked with the incineration of PVC and in particular the generation of residues from flue gas cleaning (classified as hazardous) due to the presence of chlorine in PVC.

Concerning landfilling, the Green Paper discusses the stability of PVC under landfill conditions and the losses of phthalates from soft PVC, which are widely recognised in a number of published studies, but the quantities and the associated risks need to be assessed further.

The Green Paper presents a number of potential measures to improve, in accordance with the general Community Waste Management Strategy, the management of PVC waste present in various waste streams and analyses the economic consequences of deviating PVC from incineration to recycling or landfill.

It is too early to define a clear preference between incineration and landfilling for all types of PVC under all conditions. It is one of the purposes of the Green Paper to collect further information and the various opinions about this question.

6. What does the Commission think about the voluntary commitment of the PVC industry?

The European PVC industry has signed a voluntary commitment on the sustainable development of PVC, which, *inter alia*, addresses the reduction of the use of certain heavy metal stabilisers, the mechanical recycling of certain post-consumer wastes, and the development of further recycling technologies.

The Green Paper describes the content of this voluntary commitment and presents this initiative of the industry as one of the potential future options for the Community strategy on PVC.

The signing and entry into force of this commitment (the implementation will start in 2001), which involves the complete industrial chain from producers to transformers, represents an important step which needs to be assessed in function of the effectiveness criteria mentioned in the Communication of the Commission concerning agreements in the area of the environment (COM(96)561 final).

The success of this approach will require a constant progression in the efforts realised in the specific areas covered by the agreement and, in particular, reduction in the production and use of certain additives, more ambitious target quantities for recycling, industry's contribution to added costs of incineration, and a fully operational funding mechanism.

While this can be seen as a first step there is still work to be done to ensure an effective participation by industry in achieving Community goals in this area. It should be underlined that the services of the Commission are currently preparing a Proposal for a framework Regulation concerning Community environmental agreements to be adopted by Council and Parliament.

7. Is the Commission going to propose legislative instruments on PVC?

There is a whole range of instruments available to address the environmental impacts of PVC, among them legislative measures, such as a Proposal for a Directive on PVC, or proposals for adaptation of various existing legal instruments. All possible options are mentioned in the Green Paper, together with questions regarding their effectiveness as well as their environmental and economic implications.

The Commission expects that the contributions provided by the stakeholders during the public consultation process will give further indications on which strategy is the most appropriate. On the basis of the analyses developed in the Green Paper and the outcome of this consultation process, the Commission will present at the beginning of 2001 a Communication setting out a comprehensive Community strategy on the environmental issues of PVC. The strategy will set out all necessary measures, including, if appropriate, the development of proposals for legislative measures.

8. Is the Commission going to adopt measures concerning phthalates, lead and cadmium in PVC? Are there going to be risk assessments on these hazardous substances?

In line with its general policy, the Commission will, in the light of a scientific and economic evaluation, propose and adopt all appropriate measures to address the use of these substances in PVC. Five phthalates have been included on the first three priority lists for risk assessment in accordance with Council Regulation 793/93 on the evaluation and control of existing substances. The risk assessments on these five substances are carried out by Member State rapporteurs (France, Sweden and The Netherlands respectively). The risk assessments on DEHP, DIDP, DINP, DBP have been or are expected to be completed in 2000 and in 2001 for BBP.

It should also be noted that the specific risks due to the use of phthalates in certain soft PVC toys and childcare articles have been assessed by the Scientific Committee on Toxicity, Ecotoxicity and the Environment (CSTEE). On the basis of these opinions, the Commission has adopted on 10 November 1999 a Proposal for a Directive and on 7 December 1999 a Decision under the emergency procedure of Directive 92/59/EEC in order to ban of the use of phthalates in certain toys and childcare articles intended to be put in the mouth.

Although at present no comprehensive risk assessments have been completed on the use of cadmium and lead compounds as stabilisers in PVC products, important work is already ongoing: a risk assessment is being finalised on cadmium and cadmium oxide under Regulation 793/93. For lead, the CSTEE has recently adopted an opinion regarding a draft ban on the use of lead in products in Denmark.

The CSTEE is currently working on the issue of risks from the use of lead in general and an opinion, building *inter alia* on a study to be commissioned by the services of the Commission, should be adopted by mid-2001 on both the environmental and human health risks of lead.

9. What will happen after the Green Paper?

In addition to the publication, the Green Paper will be transmitted to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions. It will be published in the Official Journal and on the internet.

A public hearing will be organised in October 2000. The targeted stakeholders are the general public as well as environmental and consumer NGOs, the producers and transformers of PVC, the users of PVC (automobile, electronic, construction, distribution and packaging industries), as well as the public administrations of the Member States. The consultation period is scheduled to continue until the end of November 2000.

On the basis of the analyses developed in the Green Paper and the outcome of this consultation process, the Commission will present, at the beginning of 2001, a Communication setting out a comprehensive Community strategy on the environmental issues of PVC to be implemented through various initiatives and measures.

10. Why is the Green Paper not focussing more explicitly on prevention and the substitution of PVC?

Prevention is explicitly addressed on several occasions, in particular concerning the use of certain hazardous additives and recycling.

The question of substitution is also explicitly addressed in the context of promoting more sustainable products as part of an Integrated Product Policy. Such a substitution policy could be considered for specific applications, which can not be easily separated from the general waste stream and therefore are difficult to recycle such as in packaging, motor vehicles, electric and electronic equipment.

At present, PVC is competing with alternative materials for a number of applications. Given the large range of applications, often requiring a very specific technical performance, PVC cannot be replaced by one single material in all its applications. For each product type, potential substitute materials are different. These can either be other plastics such as polypropylene (PP) or polyethylene terephthalate (PET) in packaging, polyethylene (PE) and PP for construction applications, or other types of materials such as wood (e.g. for window frames) or concrete, cast iron for pipes

It is stressed in the Green Paper that a potential substitution policy would need to be underpinned by a comprehensive and objective assessment of the main environmental impacts both of PVC and of

potential substitutes during their whole life cycle. As the information on the environmental impacts of potential substitutes is generally scarce, the Green Paper at this stage cannot draw firm conclusions.

11. Why is the Green Paper only addressing environmental issues? Why not also human health concern?

Firstly, the Commitment accepted by the Commission in 1997 and restated in 1999 concerned exclusively environmental aspects of PVC.

Nevertheless, all related issues regarding human health that are known today have been addressed in the paper. In addition, as human health is mostly concerned indirectly through environmental impacts, the issue is (implicitly) taken into account.

12. What is the link between the PVC initiative and the integrated product policy approach which the Commission is developing?

The PVC Initiative 'integrates' the basic principles of this approach, i.e. the examination of all issues from cradle to grave, as for other waste initiatives on packaging, end-of-life vehicles, WEEE and others have also already anticipated.

The Commission has the intention to adopt a Green Paper on the Integrated Product Policy in 2000.

13. What About the Incineration of PVC and dioxin formation?

The potential influence of the incineration of PVC waste on the emissions of dioxins has been at the centre of a major scientific debate since PVC is currently the largest contributor of chlorine into incinerators. The contribution of incinerators to the total emissions of dioxins in the Community was about 40% between 1993 and 1995.

It has been suggested that the reduction of the chlorine content in the waste can contribute to the reduction of dioxin formation, even though the actual mechanism is not fully understood. It is most likely that the main incineration parameters, such as the temperature and the oxygen concentration, have a major influence on the dioxin formation and much more so than the content of chlorine.

Whilst at the current levels of chlorine in municipal waste there does not seem to be a direct quantitative relationship between chlorine content and dioxin formation, it is possible that an increase of chlorine content in the waste stream above a certain threshold could contribute to an increase of the dioxin formation in incinerators. The threshold of 1% of chlorine has been suggested but uncertainties remain on the level of this threshold.

The Proposal for a Directive on the incineration of waste⁽²⁾ foresees an emission limit value of 0,1 ng/m³. This shall decrease the emissions of dioxins from incinerators, esp. from those that at present are not yet operating with the state-of-the art technology.

⁽¹⁾COM(97) 358 final

⁽²⁾COM(1998) 558 final

1.3 Improved environmental performance of imaging equipment due to reuse, recycling and end-of-life management

One of the most successful resource efficiency strategies is to reuse a product as a whole or a part of it. In the overall category of reuse, remanufacturing is often included. Remanufactured products and product components, in principle, serve the same function and are of the same quality as new products.

By utilising recovered product parts after the consumption product life cycle phase, remanufacturing is able to reduce the environmental and economic costs of manufacturing and disposing of products and components. With remanufacturing, a much smaller fraction of the end-of-life resources goes to disposal and/or to material recycling. In addition, intelligent remanufacturing systems provide the opportunity for product upgrades. Therefore, apart from resource conservation, remanufacturing also has a positive effect on extending product life (durability of the product).

However, often it is the case that the level of reduction in resource intensity that could be achieved by efficient and intelligent remanufacturing systems is not quantified taking into account the product life cycle. Furthermore, remanufacturing also has additional system requirements that are not always taken into account. For example, additional packaging and transport are necessary to return products for remanufacturing. Energy, water and materials are also required during the remanufacturing process. Therefore it is essential to consider the entire product life cycle system when assessing and quantifying the environmental benefits of remanufacturing.

In a study of Xerox Corporation's remanufacturing system in the example of a photocopier, the overall life cycle environmental benefits of remanufacturing are investigated and analysed as presented by Wendy Kerr et. al. [18]. In this case it is reported that remanufacturing can reduce resource consumption and waste generation over the life cycle of a photocopier by up to a factor of 3, with the greatest reductions if a product is designed for disassembly and remanufacturing.

In particular, in this study, four remanufactured and non-remanufactured Xerox photocopiers were compared throughout their life cycle. The investigation covered both a copier with a modular design for disassembly and remanufacturing (copier modules); and a copier model which was not explicitly designed for remanufacturing.

The environmental impacts results are delivered on a life cycle inventory level (e.g. waste going to landfill, water consumption, energy consumption, etc.) without applying LCIA methods in which the inventory results are linked to environmental impact categories (e.g. human toxicity, eutrophication).

The results of the remanufacturing case study of Wendy Kerr et. al. [18] are summarised in Table 10 in which it can be seen that for the modular designed copier, the environmental savings range from 38 to 68 % among the different environmental impact aspects investigated whereas for the other photocopier model, savings are in the range of 19 to 35 %. The success of applying the modular remanufacturing strategy on imaging equipment by Xerox was the reason for its further development and wider scale implementation, which is reported in the 2009 Environmental, Health & Safety Report of Xerox.

Table 10 Environmental savings by the remanufacturing of copiers

Environmental impact aspect	Photocopier non-modular design		Photocopier modular design	
	Product life cycle with remanufacturing compared to product life cycle without remanufacturing		Product life cycle with remanufacturing compared to product life cycle without remanufacturing	
	Environmental savings %	Reduced by a factor of	Environmental savings %	Reduced by a factor of
Materials consumption (kg)	25	1.3	49	1.9
Energy consumption (MJ)	27	1.4	68	3.1
Water consumption (L)	19	1.2	38	1.6
Landfilled waste (kg)	35	1.5	47	1.9
CO ₂ equivalents (kg)	23	1.3	65	2.9

Source: [18]

1.3.1 Information on imaging equipment devices considered as best performing products (BAT) regarding reuse

Regarding reuse in the product group of imaging equipment BAT-products have been identified. These BAT-products are specially designed for reuse and are marked business to business (B2B). The overall reuse rate for these products

reaches 82%³⁰. Nonetheless, these examples are currently limited either to pilot programs or to geographical regions outside EU-27 i.e. Japan and Hong Kong. Further, reuse is not a common practise among manufacturers despite the fact that reuse (according to the waste management hierarchy) is preferred over recycling.

1.3.2 Information related to resource efficiency of cartridges

Within the development of EU Ecolabel and GPP criteria for imaging equipment stakeholders for the area of reuse and recycling of cartridges, both OEM cartridge producers and cartridge remanufacturer were consulted and provided information by answering a respective questionnaire. The response to this was mainly from cartridge remanufacturer stakeholders as many imaging equipment manufacturers consider that a proper recycling of the cartridges could achieve sufficient environmental benefits (see also information regarding a footprint LCA study and which follows). The main outcomes of this consultation (questionnaire feedback) are given below:

1. with regard to cartridge waste volumes and reuse rates of cartridges, stakeholders suggest that:
 - a. 300-500 million ink cartridges and 10-20 million toner cartridges are annually sold in the EU-27;
 - b. an estimated 20 % (at least) of these cartridges are reused.
 - c. A few OEM producers are involved in remanufacture activities whereas many are involved in recycling activities;
 - d. It is estimated that in total volume per year the 40 -70 % of the cartridges end up in landfills and/or incinerators.
2. with regard to the cartridge reuse circles stakeholders suggest that:
 - a. It is estimated that ink and toner cartridges can be reused at least once but on average two-three times, and printing quality remains sufficient at this level of reuse;
 - b. Toner cartridges can be remanufactured more easily than ink cartridges and there are extreme examples of up to 25 reuse circles;
 - c. Some parts have to be changed in the remanufacturing process;

³⁰ http://www.rioh.com/environment/product/resource/02_01.html

-
- d. The number of reuse circles depends on the model and the condition of the collection of the cartridge.
3. with regard to parameters affecting the cartridge reuse circles stakeholders suggest that:
 - a. This is a very complex area and there several parameters affecting the reuse of the cartridge which vary based on the type and model of the cartridge. In cases of remanufacturing of OEM cartridges via cartridge return programs obviously there are no problems. However, for cartridge remanufacturing by third parties the identified technical parameters can be summarised in:
 - i. clever/killer/smart chips;
 - ii. design features that hamper remanufacturing i.e. welding, glue, blind screws or conjoined parts to fit cartridge-parts together;
 - iii. Weaker print heads.
 - b. Legal barriers because of patents

In conclusion, the potential for achieving environmental savings and resource conservation via reusing cartridges is high as the majority of them are disposed after the first use. Reuse has either better or coequal environmental benefits as recycling, thus it shall be prioritised as an option. This is in line with the waste management hierarchy and with priorities set in the MS Ecolabel criteria for imaging equipment and for remanufactured cartridges. **Error! Reference source not found.** also includes that the design of the cartridges shall also facilitate recycling.

The cartridge reuse circles depend on the type, model and the collection system, however, based on the stakeholders, a cartridge can be reused at least one time but the average is three times with a high improvement potential as there are examples of cartridges which were reused up to 25 times. As the number of reuse circles is not definite for each cartridge it is suggested that no threshold values on the cartridge reuse circles shall be given in this phase but instead allow manufacturers to determine thresholds based on the case specific parameters.

The technical parameters which can affect the reuse are numerous and vary based on the type of cartridge and the model. However, practice shows that when a cartridge is designed for reuse these barriers are not present. Hence, in **Error! Reference source not found.** it is proposed to design the cartridges for reuse.

Freedom given to the designer on how to achieve this goal is considered of importance as no eco-innovation shall be hampered. For verification a demonstration, if requested by the competent bodies, on how a cartridge can be reused is considered to be sufficient.

Footprint life cycle assessment of cartridges

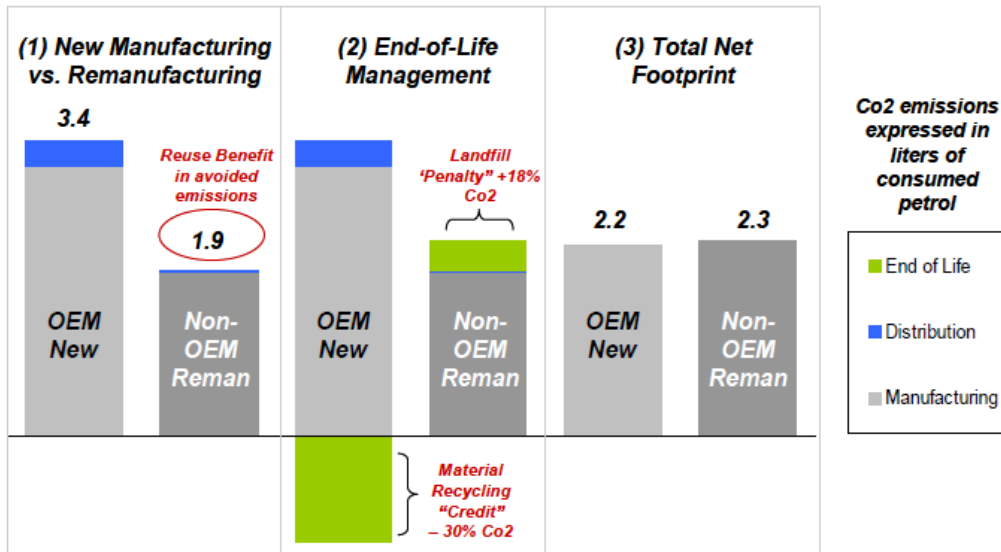
Industry data shows 80 % of aftermarket remanufactured toner cartridges are discarded after use due to non-OEM remanufacturers preference for virgin empties. [InfoTrends 2007 Supplies Recycling Report, pg 16].

Reuse and Remanufacturing can, under certain conditions offer the greatest carbon avoidance potential. In contrast to material recycling, however, the reuse of a toner cartridge does not end the product's life cycle. Quality and reliability during use of the remanufactured cartridge and its ultimate end-of-life management are crucial factors that shape the full life cycle footprint of the cartridge. Poor quality or irresponsible end-of-life handling can quickly offset the benefits of materials reuse. The following sections illustrate these factors using carbon footprint measurements of new and remanufactured cartridges.

To demonstrate the significant impact of proper end-of-life management, the chart below compares the carbon footprint of a new OEM cartridge (with material recycling after use) and a remanufactured cartridge without an end-of-life recycling program³¹ (i.e. assuming the cartridge ends up in a landfill³²):

³¹ Examples based on a toner cartridge Life Cycle Assessment by WSP Environment and Energy for Lexmark, 7/2009, represents a T64X 21,000 page toner cartridge. Conducted in accordance with ISO 14044 guidelines for Life Cycle Assessment. Expressed in liters of petrol consumed from EPA Greenhouse Gas Equivalencies Calculator <http://www.epa.gov/RDEE/energy-resources/calculator.html>. Converted from gallons.

³² "InfoTrends" research found that the chance of a remanufactured cartridge ending up in a landfill after the first remanufacturing cycle is high. In the U.S. and Europe, 80% of remanufactured toner cartridges and 86% of remanufactured inkjet cartridges are thrown away. This is because remanufacturers have such a strong preference for virgin empties" (InfoTrends 2007 Supplies Recycling Report, pg 16)



1. It can be identified that the initial benefit of remanufacturing vs. new manufacturing: Reuse of the cartridge materials through remanufacturing has a carbon footprint equivalent to burning 1.9 liters of petrol vs. 3.4 liters petrol equivalent for manufacturing a new cartridge.

2. Impact of End-of Life management: Assuming the empty new cartridge is collected and fully recycled (providing a 30% 'credit' to the footprint for returning those materials back to the materials stream), the remanufactured cartridge by weight (75 %) goes to landfill³³. This gives the remanufactured cartridge an incremental +15 % footprint 'penalty'.

3. The net footprints of both the new cartridge (with material recycling at end-of-life) and the remanufactured cartridge (in landfill) are about equal, with the remanufactured version having a slightly larger environmental impact overall.

Without end-of-life material recycling, the reuse on an empty toner cartridge does not deliver an overall environmental benefit versus a new OEM cartridge material recycled at end-of-life.

³³ Of the unusable cartridges collected by U.S. and European remanufacturers, we estimate that about 25% of the material is recycled." (2007 Supplies Recycling in US and Europe. InfoTrends. May, 2007. Page 10).

Ultimately, the vendor of a remanufactured cartridge must collect and material recycle the product at its ultimate end-of-life in order to avoid offsetting the benefits of reuse. This is also the case for cartridges the vendor collects but does not reuse.

1.4 Environmental performance of imaging equipment with respect to indoor air emissions

As previously mentioned, using LCA for the environmental performance avoids shifting environmental problems between product life cycle stages as well as between environmental impact categories and therefore supports sound decisions in product environmental management. However, the current lack of knowledge and data especially regarding some specific environmental impact categories does not allow a LCA to capture all environmental impacts. LCAs investigate the major environmental impact categories in a generic way for all the processes involved in the product system life cycle.

In the case of the environmental performance of imaging equipment, one relevant environmental impact category not covered through a common LCA based approach are indoor air emissions. LCA researchers recognised the importance of indoor air exposure concluding that the indoor exposure should be routinely addressed within the LCA. Thus, there are currently ongoing activities on establishing the methodological framework for integrating the environmental impact category of indoor air quality in an LCA [9].

It has been known for many years that imaging equipment is a source of indoor air pollutants. There are several reports and investigations worldwide on indoor emissions related to imaging equipment. Office equipment has been found to be a source of ozone, particulate matter, volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) [10].

In a review study of Destailats et.al. [11] laser and inkjet printers, MFDs, and photocopiers were investigated with respect to their emitted indoor pollutants. In this study volatile organic chemicals (VOCs), ozone, particulate matter and semi-volatile organic compound (SVOCs) emission data are reported and are reproduced here in

Table 11 and Table 12. Emissions are reported for both idle and operation mode of the imaging device.

Table 11 Review of reported data on indoor air emissions of laser, inkjet printers and MFDs

Chemical	Laser printers ^(a,b)		Ink-jet printers ^(a)		All-in-one office machines ^(a)	
	Chamber concentration (ppbv)		Chamber concentration (ppbv)		Chamber concentration (ppbv)	
	Idle	In operation	Idle	In operation	Idle	In operation
VOCs						
Freon 12	0.48— 0.52	0.61— 0.66	0.36	0.43	0.3	0.45
Methyl chloride	0.53— 0.60	0.71— 0.82	0.48	0.55	0.52	0.62
Freon 11	0.24— 0.29	0.25— 0.28	0.23	0.24	nd.	0.27
Methylene chloride	0.38— 0.42	0.46— 0.58	0.57	0.61	0.69	0.74
Chloroform	0.96— 1.07	1.17— 1.31	0.81	0.94	0.74	0.96
Benzene	0.52— 0.57	0.77— 0.84	0.42	0.41	0.52	0.52
Toluene	14—15	15—16	6.22	6.43	7.9	8.2
Tetrachloroethene			0.23	0.21	0.52	0.43
Ethylbenzene	1.4—2.1	2.0—3.0	1.2	1.26	1.5	1.6
m,p-Xylene	1.2	1.6—1.7	0.86	0.92	0.9	0.9
Styrene	2.7—4.0	3.2—5.3	1.14	1.43	1.2	1.9
o-Xylene	0.9—1.0	2.0—2.3	0.69	0.68	0.58	0.58
1,4-Dichlorobenzene			0.34	0.32	0.34	0.35
1,3-Dichlorobenzene			0.34	0.32	0.34	0.35
1,2-Dichlorobenzene			0.21	0.21	0.26	0.22
1,2,4-Trichlorobenzene			0.86	0.63	0.23	0.2
Hexachlorobutadiene			0.37	0.36	0.88	0.64
ΣVOC		300— 1400				

		(20—60m)				
Ozone						
Ozone		9—10 1—13 (20m)		5—6		6
Aerosol particles						
PM ₁₀		65		20—38		41
When available, the duration of operation (min) is indicated in parenthesis. (^a) Lee, S.C., Lam, S., Fai, H.K., 2001. Characterization of VOCs, ozone, and PM ₁₀ emissions from office equipment in an environmental chamber. Building and Environment 36, 2001 (^b) Smola, T., Georg, H., Hohensee, H., Health hazards from laser printers? Gefahrstoffe Reinhaltung der Luft 62, 2002						

Source: Destailats et.al. [11]

Table 12 Review of reported data on indoor air emissions of copiers

Chemical	Emission rate ($\mu\text{g h}^{-1} \text{unit}^{-1}$)	Chamber concentration ($\mu\text{g m}^{-3}$)		Reference
		Idle	In operation	
VOCs				
Toluene	110—760			(^a)
	540—2000			(^b)
Ethylbenzene	<50—28000			(^a)
	23000—29000			(^b)
		4.1	552—608	(^c)
m, p-Xylene	100—29000			(^a)
	22000—29000			(^b)
		4.5	467—515	(^c)
o-Xylene	<50—17000			(^a)
	12000—15000			(^b)
Styrene	300—12000			(^a)
	6300—8400			(^b)
Styrene+o-Xylene		3.1	354—390	(^c)
Isopropylbenzene	150—160			(^b)
n-Propylbenzene	<50—2100			(^a)
	360—460			(^b)
		<0.4	7.8	(^c)
Benzaldehyde	<100—3800			(^a)
	980—1500			(^b)
		1.3	25—26	(^c)
	<50—330			(^a)

	500—730			(^b)
		1.3	16—18	(^c)
1,2,4-Trimethylbenzene		0.6	3.6—4.2	(^c)
Butylbenzene		<0.4	14—15	(^c)
Acetophenone		1.6	11—13	(^c)
Methoxyethylbenzene		0.9	6.6	(^c)
C9-ester		<0.5	23	(^c)
Butenylbenzene		1.1	28—37	(^c)
n-Decane	<50—450			(^a)
2-Ethyl-1-hexanol	130—14000			(^a)
Limonene	<50—1100			(^a)
n-Nonanal	1100—3900			(^a)
n-Undecane	62—2000			(^a)
n-Dodecane	75—960			(^a)
Formaldehyde	<500—2600			(^a)
	1900—3200			(^b)
Acetaldehyde	<500—1200			(^a)
	510—1300			(^b)
Acetone	<100—2800			(^a)
Propionaldehyde	<100—260			(^a)
2-Butanone	<100—380			(^a)
	n.d.—600			
Butyraldehyde	<100—840			(^a)
	n.d.—410			(^b)
Valeraldehyde	<100—540			(^a)
n-Hexanal	100—1200			(^a)
	n.d.—950			(^b)
ΣVOC		49	1630—1900	(^c)
Ozone				
Ozone	1300—7900			(^a)
	1700—3000			(^b)
Aerosol particles				
PM (respirable fraction)	1420—2950	6—11	19—22	(^c)
<p>(^a) Leovic, K.W., Sheldon, L.S., Whitaker, D.A., Hetes, R.G., Calcagni, J.A., Baskir, J.N., Measurement of indoor air emissions from dry-process photocopier machines. <i>Journal of Air and Waste Management Association</i> 46, 1996</p> <p>(^b) Leovic, K., Whitaker, D., Norheim, C., Sheldon, L., Evaluation of a test method for measuring indoor air emissions from dry-process photocopiers. <i>Journal of Air and Waste Management Association</i> 48, 1998</p>				

(^c) Brown, S.K., Assessment of pollutant emissions from dry process photocopiers. *Indoor Air* 9, 1999

Source: Destailats et.al. [11]

Laser printers and photocopiers have been found to generate ozone in varying amounts while toner and paper dust from printing devices may become airborne, generating respirable particles that include ultrafine aerosols. Printers and photocopiers have also been reported as sources of VOCs, which are derived, at least in part, from the toner that is heated during printing. Among all emissions presented in Table 2, reported levels of VOCs have been highest from laser printers and, although the difference is generally small, the levels were higher during operation than in idle mode. Toxicological effects or potentially significant consequences due to these emission have been described in the literature e.g. ozone and particulate matter have been associated with occupational symptoms such as eye, nose or throat irritation, headache and fatigue [12].

Similar results were also reported from other researchers. In Table 13 recent findings from investigations in indoor air emissions from imaging equipment are summarized. These results complement the previously shown information and go into more detail in investigating the different parameters which affect the indoor emissions from imaging devices.

Table 13 Recent investigations and findings in indoor air emissions from imaging equipment

Summary	Reference
<p><i>Lee et al</i> investigated different types of imaging equipment including fax machines, laser printers, inkjet printers, scanners and photocopiers. Several pollutants were analysed covering volatile organic compounds (VOCs), total VOCs, ozone and respirable particles (PM₁₀). The VOCs were further analysed and separated in fractions of toluene, ethylbenzene, m,p-xylene and styrene. The emissions varied from 0.2 to 7.0 µg/print.</p>	<p>S.C. Lee, Sanches Lam, Ho Kin Fai, "Characterization of VOCs, ozone, and PM10 emissions from office equipment in an environmental chamber", <i>Building and Environment</i>, 36, 2001</p>
<p><i>Naoki Kagi et al.</i> in their study on laser and inkjet printers confirmed the emissions of VOCs, ozone and</p>	<p>Naoki Kagi, Shuji Fujii, Youhei Horiba, Norikazu</p>

<p>ultrafine particles. The results in this research confirmed an increase in the concentration of ozone from 1.5 to 1.6 ppb and ultrafine particle during printing. Especially for the case of around 50nm particles, particulate concentration increased greatly during printing. Styrene and ozone were detected from the laser printer and alcohols were detected from the inkjet printer. The concentrations on styrene and xylenes slightly increased to 200 – 3000 mg/m³ in the printing process for the laser printer. The source of styrene from the laser printer was the toner and the source of pentanol from the ink-jet printer was the ink.</p>	<p>Namiki, Yoshio Ohtani, Hitoshi Emi, Hajime Tamura, Yong Shik Kim, "Indoor air quality for chemical and ultrafine particle contaminants from printers", <i>Building and Environment</i>, 42, 2007</p>
<p><i>Antti J. Koivisto et al.</i> in a recent study on ultrafine particle emissions from printing by simulating the indoor air conditions suggested that a print job increases ultrafine particle concentrations to a maximum of $2.6 \times 10^5 \text{ cm}^{-3}$.</p>	<p>Antti J. Koivisto, Tareq Hussein, Raimo Niemelä, Timo Tuomi, Kaarle Hämeri, "Impact of particle emissions of new laser printers on modeled office room", <i>Atmospheric Environment</i>, 44, 2010</p>
<p>In the research of <i>Congron He et al</i> a positive correlation between the laser printer emissions of PM_{2.5} and the temperature of the printer's roller was confirmed. Based on the results of this study which was carried out on 30 laser printers almost all printers were shown to be high particle number emitters (e.g. over 1.01×10^{10} particle/min) and ozone while colour printing generated more PM_{2.5} than monochrome printing.</p>	<p>Congrong He, Lidia Morawska, Hao Wang, Rohan Jayaratne, Peter McGarry, Graham Richard Johnson, Thor Bostrom, Julien Gonthier, Stephane Authemayou, Godwin Ayoko, "Quantification of the relationship between fuser roller temperature and laser printer emissions" <i>Journal of Aerosol Science</i>, 41, 2010</p>

1.5 Environmental performance of imaging equipment with respect to noise

Noise pollution is an environmental impact category which, similar to the case of indoor air pollution, can not be captured by a product environmental assessment based on a life cycle assessment. The sources of noise as well as the modelling of noise pollution when this is investigated for complex large product systems is currently not sufficient enough and therefore is considered non-operational in the context of LCA methodology.

Nevertheless, in the frame of developing ecological criteria for Ecolabel and GPP noise pollution is considered relevant for the product group of imaging equipment. In this case noise pollution is restricted to the noise produced during the operation of an imaging device. Acoustics of a product is recognised as an important parameter for both end-users and product designers and is related to sound and vibration. Quiet operation of imaging equipment should not be considered only as a single advantage of the product. Noise is often an underestimated threat that can cause a number of short and long term health problems.

In common use, the word noise means any unwanted sound [20]. Noise pollution can affect health, yet the effects are very difficult to quantify. Some of the potential adverse effects can be summarised as:

- Annoyance. It creates annoyance to the receptors due to sound level fluctuations.
- Physiological effects. The physiological features like breathing amplitude, blood pressure, heart-beat rate, pulse rate, blood cholesterol are effected.
- Loss of productivity. Noise has negative impacts on cognitive performance. For attention and memory, a 5 dB(A) reduction in average noise level results in approximately a 2 – 3 % improvement in performance.
- Nervous system. It causes pain, ringing in the ears, feeling of tiredness, thereby effecting the functioning of human system.
- Sleeplessness. It affects sleepiness by inducing people to become restless and lose concentration during their activities.

Annoyance is the most widespread problem caused by environmental noise. Annoyance reflects the way that noise affects daily activities. It has been estimated by the WHO that 20 % of the population is exposed to levels exceeding 65 dB(A) during the daytime which is a value close to the noise levels caused by operating

printers and/or copiers. Some groups are more vulnerable to noise. Chronically ill and elderly people are more sensitive to disturbance. The noise exposure time is also a significant parameter which becomes even more important if we consider working environments with many imaging devices operating at the same time, e.g. copy/print centres as then the overall effective sound level is higher.

The effects of noise on humans indoors and in low levels similar to the ones produced by imaging devices are not easily quantifiable but are possible to be detected. In a study of Gary W. Evans, et. al [21] low-level noise in open-style offices was investigated. The findings indicate higher levels of stress and lower task motivation of the participants exposed to noise. However, the participants did not perceive their stress.

Noise levels for office environments recommended by the WHO or similar organisations are not available at present. However, the WHO guidelines for community noise recommend less than 30 A-weighted decibels (dB(A)) in bedrooms during the night for a sleep of good quality and less than 35 dB(A) in classrooms to allow good teaching and learning conditions. In addition, for night noise the WHO recommends less than 40 dB(A) of annual average outside of bedrooms to prevent adverse health effects from night noise. In the past several years, epidemiological evidence was accumulated supporting the hypothesis that persistent noise stress increases the risk of cardiovascular disorders including hypertension and ischaemic heart disease [22].

Although noise impacts are very difficult to quantify, in many Ecolabel schemes, one of the environmental impact categories addressed is noise. For instance in the EU Ecolabel criteria for the product group of personal computers one criterion refers to noise requirements during operation. Blue Angel and Nordic Swan Ecolabel criteria for imaging equipment also include noise as an environmental impact category area.

Moreover, imaging equipment manufacturers have focused on reducing unwanted noise, e.g. by introducing a feature that allows users to adjust the sound level of the printer. Some printers have the option of quiet mode in which the operating noise level of printers can be additionally lowered by three decibels. Other alternatives are to avoid beep sounds while typing hard-on buttons.

1.6 Environmental thematic areas addressed in Ecolabel schemes and other relevant schemes

Based on the analysis regarding the Ecolabel schemes at the Member State level, the key actors are Blue Angel from Germany and Nordic Swan from the Nordic countries. These two schemes together with the Japanese Eco Mark are also considered among the most important ones globally. Moreover, it was found that in many other Ecolabel schemes, criteria originating from these two schemes are used by cross-referencing. Ecolabel criteria of Blue Angel, Nordic Swan and Eco Mark are harmonised.

Furthermore another relevant activity undertaken in the US is the development of the IEEE 1680.2 [23]. This standard defines environmental performance standards for imaging equipment and is currently under development. Similar to the Ecolabel scheme this standard intends to provide a clear and consistent set of performance criteria for the design of imaging equipment, and to provide an opportunity to secure market recognition for efforts to reduce the environmental impact of these electronic products. The US Environmental Protection Agency (EPA) manages this activity. This label is based on self-declaration, but after the product enters into the market a third party verification system is foreseen.

In Table 14 the thematic areas addressed by the Blue Angel and Nordic Swan Ecolabel Schemes with the thematic areas addressed in the IEEE 1680.2 on imaging equipment are listed.

Table 14 Thematic areas addressed in the Ecolabel schemes of Member States and in relevant international standards

Blue Angel and Nordic Swan Ecolabel	US IEEE 1680.2 Standard
Energy in use phase	Energy conservation
Substance emissions	<ul style="list-style-type: none"> • Energy Star and others
<ul style="list-style-type: none"> • Electrophotographic devices • Inkjet devices • User information on substance • Products of identical design 	Environmentally sensitive material
Noise	<ul style="list-style-type: none"> • Compliance with RoHs and others
General requirements	Material selection
<ul style="list-style-type: none"> • Recyclable design • Material requirements • Marking of plastics 	<ul style="list-style-type: none"> • Recycled content
	Design for end-of-life
	<ul style="list-style-type: none"> • Easy for recycling
	Product longevity/lifecycle extension
	<ul style="list-style-type: none"> • Warranties, spare parts
	Packaging

<ul style="list-style-type: none"> • Batteries • Printing paper • Double-sided printing and copying • Photoconductor drums • Guarantee of repairs • Maintenance of equipment • Product take-back • Packaging <p>Requirements for toners and inks as well as for modules and containers for toner and ink</p> <ul style="list-style-type: none"> • Modules and containers for toner and ink • Material-related requirements for toners for use in electrophotographic devices and inks for use in inkjet devices 	<ul style="list-style-type: none"> • Recyclable and recycled content <p>End-of-life management</p> <ul style="list-style-type: none"> • Take-back and recycling <p>Corporate performance</p> <ul style="list-style-type: none"> • EMS, environmental policy report
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A comparison of the two columns in the table shows large overlaps. For example the common overall thematic area of energy conservation is addressed in both schemes. Checking the subcategories of IEEE 1680.2 standard we can find that almost all the areas are also included in the Member states' Ecolabels. One exception is the category of the corporate performance criteria which are not considered relevant for an Ecolabel ISO type II declaration. Acoustic performance as well indoor air emissions from imaging equipment are found to be considered relevant in the Ecolabel schemes, contrary to the current form of the IEEE 1680.2 criteria considerations.

1.6.1 Environmental thematic areas addressed by imaging equipment manufacturers

There are numerous producers of imaging equipment. An indicative list of important manufacturers and the country of origin is presented in Table 15; the list is non-exhaustive.

Table 15 Manufacturers of imaging equipment (non-exhaustive list)

Manufacturers of imaging equipment			
Brother JPN	Fuji Xerox USA/JPN	NEC JPN	Samsung Korea

cab GmbH Germany	Fujifilm JPN	Nikon JPN	Sanyo JPN
Canon JPN	Fujitsu JPN	NRG (Ricoh) UK (JPN)	Sharp JPN
Copystar USA	Hewlett-Packard USA	Océ NL	Tally Genicom USA
CPG International Italy	Hitachi JPN	Oki JPN	TA Triumph-Adler DE
Datamax USA	IBM USA	Olivetti Italy	Toshiba JPN
Dell USA	Konica Minolta JPN	Panasonic JPN	Toshiba TEC JPN
AMT Datasouth USA	Kyocera Mita JPN	Philips NL	Utax Germany
Eastman Kodak USA	Lanier Ricoh USA/JPN	Pitney Bowers USA	Xerox USA
Epson JPN	Lexmark USA	Printronix USA	
Olympus JP	Polaroid US	Ricoh JPN	

The European market is dominated by companies from the US as well from the Far East, mainly Japan. However, of special importance is that despite the numerous companies operating, the market is dominated by only a few manufacturers. In particular, a market analysis report for Europe showed that in 2006 in the case of printers just five companies, namely Hewlett-Packard, Canon, Epson, Lexmark and Brother covered 86 % of the overall market.

Table 16 presents the environmental thematic areas related to the performance of imaging equipment as addressed by some manufacturers.

Table 16 Indicative thematic areas addressed in environmental reports of imaging equipment manufacturers

Manufacturer	Environmental thematic areas addressed	Efforts, innovation and achievements
Ricoh	New material design	Development of biomass resins Since 2002 began developing biomass plastic components as materials for copiers. In 2005 was used plastic with 50% biomass content in the main component of a multifunctional digital copier. In 2008 released a model which employs a newly developed plastic component with roughly 70% biomass content In 2009 released a model, equipped with a biomass toner (25% biomass content)

	Easy to recycle design	Material design easy-for-recycling Marking of plastics. Requirements of surface cover. Promotion of recycled copier business. Recycling information system
	Material design, reuse and recycling	Reduction in size/weight of products and a longer product lifecycle, enhancement of reuse and recyclability, promotion of closed loop material recycling, increasing production and sales of recycled copiers and the reduction of packaging materials. Increased quantity of reused parts, resources collected from used products and re-circulated. Commercialise biomass toners. Inner loop recycling. Recycling rate in 2009 for copiers 98 % and toner cartridges 99 % (data is not restricted to Europe)
	Energy efficiency	"Quick start up technology".The recovery time from the energy-saving mode is reduced to less than 10 seconds For monochrome multifunctional copiers,
	Paper consumption	PO BOX printing
	Reduce the use of environmentally sensitive substances	Achieved Blue Angel Ecolabel indoor air emissions criterion requirements for 17 copiers released in 2009
Canon	New material design	Use of biomass plastics with high flame retardance level
	Material design, reuse and recycling	Introduction of returnable packaging material Closed-loop packaging recycling. Packaging is collected and reused after unpacking. Use recycled plastics for internal parts.
	Energy efficiency	Canon on demand fixing technology
	Reduced package size	Example inkjet printers packaging 11 %reduced
	Promotion of toner cartridge collection and recycling	
Lexmark	Energy efficiency	Use of "Instant Warm-Up Fusing" technology into the color laser products. New products use 28 to 50 % less energy Eco-Mode, optimizes energy efficiency Energy efficient galvo printhead.
	Paper consumption	
	Toner cartridge efficient use	High-yield and extra high-yield cartridges
	Product recyclability and chemicals in product components	Complies with international legislation that restricts the use of substances such as lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ether (PBDE) flame retardants as outlined (RoHS). Since 2006 all Lexmark products, including the ink and toner

		<p>cartridges (which are not included in the scope of the RoHS), have been fully compliant with the RoHS directive.</p> <p>Efforts to substitute 98 % of PVC packaging of inkjet cartridges</p> <p>To date, Lexmark has safely eliminated the use of brominated flame retardants in the covers and chassis of our laser and inkjet printers</p> <p>A minimal concentration of solvents is used in inks. Methyl alcohol or ethylene glycol are not used in inks.</p>
	Product acoustics	<p>All of Lexmark's laser printing products meet the noise requirement in the Blue Angel Ecolabel specification.</p> <p>All laser products announced in the fall of 2008 were designed with a Quiet Mode feature that allows users to adjust the sound level of their printer to meet their personal preferences</p>
	Product packaging	
	End of life	<p>Product durability and upgradeability Product take-back and collection strategies. Cartridge collection program and reuse and material recovery</p>
brother	Energy efficiency	Improve energy conservation during use
	Reuse and Recycle	<p>Collection and recycling</p> <p>Easy to recycle at the end of life</p>
	Packaging and distribution	<p>Reducing product packaging and waste.</p> <p>Reducing CO₂ emissions in distribution and transport</p>
	Hazardous materials	<p>Products do not contain hazardous materials as defined under the European RoHS directive and in accordance to the Brother Group hazardous chemical listing in the Green Procurement Standard.</p> <p>Products are made via eco-friendly processes.</p>
	End of life management	<p>Areas of focus:</p> <p>size and weight, parts reuse/recyclability, disassembly/dismantling, avoidance of difficult-to-disassemble structures, integration of resin materials, packaging materials' size, weight and recyclability.</p> <p>Material labelling</p>

epson	Commitment to Recycling	Benefits of reusing the main unit. Inclusion of all products in the resource reuse and recycling loop
	Energy-saving design	The power consumed during use accounts for a large portion of a product's total environmental impact across its life cycle. With this in mind, we set energy-saving performance goals for each product and work to ensure steady progress
	Resource saving	Environmental goals are set for: recyclable rates (the ratio of total product weight calculated as recyclable based on a product's design drawings), reducing the cost of disassembly and sorting and finding ways to reduce impacts by making products smaller and lighter.
	Elimination of harmful substances	Epson standards specify substances that are prohibited from inclusion in products and substances whose inclusion must be controlled. Information on these substances is gathered in a database to help ensure safety in all processes, from design and procurement to mass production. REACH Compliance.
	Reducing transport CO ₂ emissions	Green Purchasing of Production Materials
	Product design	The PX-W8000 large-format printer uses nearly odourless water-based ink, meaning it can be used in any office without a special ventilation system and is compliant with the Energy Star programme
		The TM-T88V thermal receipt printer consumes approximately 15% less total power per year*1 than the TM-T88IV (2006) Paper-saving features*2 reduce paper use by up to 30%
	Paper consumption	Save paper by not printing Scans images directly to a memory card and transfers them to a PC. Creates a double-sided print from two source sheets. Prints up to four pages on a single sheet with double-sided, and multi-page printing Reduces paper waste. Fits web pages to the width of the paper. Save energy. Prints directly from a memory card, no PC required
Collection and Recycling	Epson's applies a toner and ink cartridge collection system, and "used ink cartridge pick-up"	

Xerox	Energy efficiency	80% of eligible new products launched met the 2007 Energy Star (version 1.0) standard.
	Reducing hazardous materials	Worldwide hazardous waste volumes were decreased 10 % from 2007 and 96 % was beneficially managed. Reduced the use of PBTs in Xerox supply chain through adherence to Xerox's chemical use standards for all suppliers and Electronic Industry Citizenship Coalition's Code of Conduct requirements for xerox's 50 key global suppliers, representing 90% of cost, by 2012. In 2009, developing systems and processes to provide a complete accounting of materials throughout the value chain that will support progress toward zero PBT
	Ink/toner cartridge design	Investing in "cartridge-free" solid ink technology that produces up to 90 % less waste from supplies and packaging than conventional office color printers
	Reuse and recycling	Maintaining over 90 % reuse or recycling of recovered Xerox equipment and supplies offerings. Xerox achieved >90% reuse or recycle rate for 106 million pounds of postconsumer equipment and supplies waste, bringing the total landfill avoidance to 2.2 billion pounds since 1991

Note. The list is indicative and not exhaustive

Source: [24], [25], [26], [27], [19]

Comparing the findings in Table 16 between manufacturers we can conclude that all of them pay special attention to:

- Energy efficiency,
- Prevention and/or restriction of hazardous substances,
- Develop recycling and reuse of materials and components, end of life management,
- Ink and/or toner design and packaging.

In the majority of the cases the thematic areas of noise and paper consumption are also addressed.

1.7 Conclusions on key environmental thematic areas for imaging equipment

Based on the outcomes of the previous findings, we can identify from the LCA based studies that key environmental areas are:

- Paper consumption
- Energy efficiency during operation
- Ink and toner consumables

Furthermore, based on product oriented environmental investigations we can identify the following key environmental thematic areas:

- Indoor air emissions
- Noise emissions during operation

Moreover, we can identify that regarding the product design developments in all the Ecolabel criteria for imaging equipment, in similar schemes (e.g. EPEAT program in US) and in the environmental management programs undertaken by the imaging equipment manufactures additional key environmental areas are:

- Substitution of hazardous substances and materials, and substances which raise environmental concerns in the post consumption phase
- Promotion of reuse, recycling and sound end of life management

Therefore, the proposed key environmental thematic areas for which the development of the Ecolabel and GPP criteria shall focus on are:

1. Energy efficiency during operation
2. Paper consumption
3. Indoor air emissions
4. Noise emissions during operation
5. Design of product: Preventing the use of hazardous substances and materials
6. Design of product: Promotion of reuse, recycling and sound end-of-life management
7. Ink and toner consumables.

1.8 Reference list

Table 17. Reference list used in this chapter (separate reference list tables are also presented in specific sections i.e. table 3, table 5, table 9).

1. Official Journal of the European Union, EU Ecolabel, Regulation (EC) No66/2010
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