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Integration of resource efficiency and waste management criteria in the implementing measures under the Ecodesign Directive

Contribution to Impact Assessment

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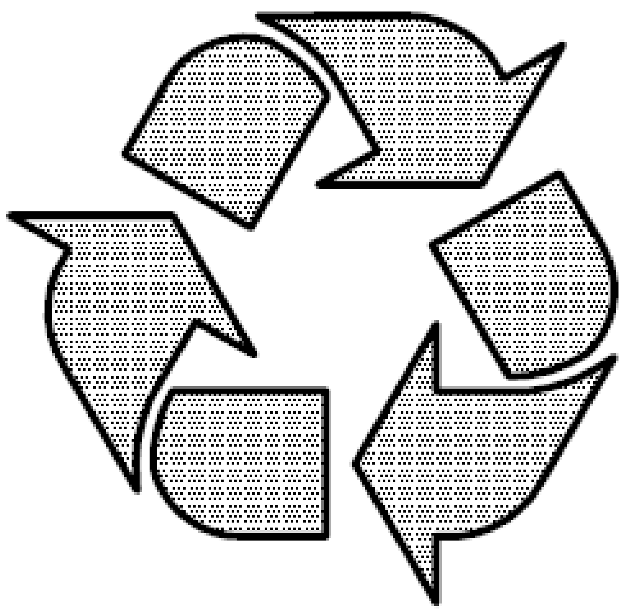

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Executive Summary

The scope of the present deliverable is the discussion of the potential requirements introduced in Deliverable 2 and the assessment of their relevance for the HDD case-study.

As foreseen in the present Administrative Arrangement, the deliverable has been structured as a 'preliminary' environmental impact assessment of the considered case-study product and the related potential requirements. Outcomes of the deliverable could support any subsequent full impact assessment. Note that the analysis is not a complete impact assessment (i.e. it does not take into account, among others, the technical feasibility, the related costs and the technology implications), but it mainly serve to illustrate the application of the proposed methodologies and the potential benefits.

The first part of the deliverable presents the Life Cycle Assessment (LCA) of the Hard Disk Drive (HDD) case-study. The scope of the LCA is to provide a general overview of the impacts of the product, to estimate the contribution of each life cycle stage and to identify the potential key components (those responsible of the largest impacts).

The analysis concluded that the use phase is very relevant for the majority impact categories. However, manufacturing dominates the Abiotic Depletion Potential (element) and contributes relevantly to all the other impact categories. The end-of-life phase can bring substantial environmental benefits for various impact categories.

A further step of the analysis shows that printed circuit board is a key component of the HDD. In particular it is noted that some materials (e.g. gold in the circuit board), even if negligible in term of mass, are relevant in terms of environmental impacts. A selective separation of the product's key components can therefore help to optimize the End-of-Life treatment and to grant relevant environmental benefits. This conclusion is also in line with the methodological discussion in Deliverable 2 concerning the need of a prioritisation of resource for the assessment of Reusability/ Recyclability/ Recoverability (RRR).

The outcomes of the LCA analysis have been used successively to assess the relevance of the potential Ecodesign requirements. In particular, the improvement of the disassemblability of the printed circuit board has been identified as a relevant issue for the End-of-Life of the HDD and the improvement of the overall product's life cycle environmental performance. In particular, the improved selective recycling of the circuit board could produce relevant environmental benefits in terms of reductions of the Abiotic Depletion Potential (elements), Freshwater Aquatic Ecotoxicity and Terrestric Ecotoxicity.

Other potential requirements concerning the RRR have been found irrelevant for the HDD case-study, and in particular:

- Requirements on the indices based on the mass fraction are irrelevant because these do not address the recycling to the recycling of the key materials;
- Requirements on the Reusability could interfere with the product's energy consumption or the technological development of the product (e.g. the miniaturisation of the components);

- Requirements on the thresholds of the ‘Recyclability Benefit Ratio’ need a more robust calculation methodology and more comprehensive data set on the environmental impacts of products;
- Requirements on the energy recoverability are not relevant because the low content of energy recoverable parts.

Requirements on the ‘recycled content’ could be addressed to plastics used in the products. However, due to the low content of plastics in the HDD, recycled content requirements were found not relevant for this product category. However, this might not be the case for other EuP and ErP products.

Analogously the low content of hazardous substances in the HDD does not justify the potential introduction of specific requirements.

Abbreviations

ABS: Acrylonitrile Butadiene Styrene
BOM: Bill of Materials
EoL: End of Life
EuP: Energy Using Products
FU: Functional Unit
GWP: Global Warming Potential
HDD: Hard Disk Drive
LCA: Life Cycle Assessment
LCI: Life Cycle Inventory
LCIA: Life Cycle Impact Assessment
PE-LD: Polyethylene low density
PS-E: Polystyrene expandable
RRR: Reusability/Recyclability/Recoverability
SVHC - Substance of Very High Concern (as defined by REACH Regulation EC 1907/2006)
TBBP-A: Tetrabromobisphenol A.

Introduction

The Deliverable 2 - "In-depth analysis of the measurement and verification approaches, identification of the possible gaps and recommendations" has developed new methodologies for the assessment and the verification of the following parameters:

- Recyclability/Reusability/Recoverability (RRR),
- Recycled content,
- Use of priority resources and
- Use of hazardous substances.

The Deliverable 2 has also identified some potential requirements for the Ecodesign of Energy Using Products (EUP), with the focus on the case-study of an internal Hard Disk Drive (HDD) for desktop computers.

As foreseen in the present Administrative Arrangement, the deliverable has been structured as a 'preliminary' environmental impact assessment of the proposed methodologies and potential requirements. Outcomes of the deliverable could support any subsequent full impact assessment.

In particular, the present deliverable testes the developed methodologies, discusses the potential requirements and assesses their relevance for the HDD case-study.

The first part of the report will concern the Life Cycle Assessment (LCA) of the HDD. The scope of the LCA is to provide a general overview of the impacts of the product, to estimate the contribution of each life cycle stage and to identify the potential key components (those responsible of the largest impacts).

Successively the report will discuss the potential Ecodesign requirements that have been introduced in the Deliverable 2. The relevance of the requirements will be assessed qualitatively and, when possible, quantitatively.

1 Life Cycle Assessment of the Hard-Disk Drive

1.1 Introduction

The present chapter illustrates the Life Cycle Assessment (LCA) of the internal Hard-Disk Drive (HDD) described in the Deliverable 2 – Chapter 5.

The case-study product represents a typical component of a desktop computer (Figure 1). Table 1 synthesizes the Bill of Materials (data adapted from [Mohite, 2005]).

Figure 1 Hard Disk Drive

Table 1 Bill of Material of the Hard Disk Drive

Component	*Material description*	*Mass [kg]*	*Component*	*Material description*	*Mass [kg]*
Printed Circuit Board	Glass	1.2E-02	Top Cover	Aluminium	0.12
	Copper	1.2E-02		Steel	1.3E-03
	Epoxy Resin	7.6E-03	Hard Disk	Aluminium	0.022
	Ceramics	4.2E-03		Steel	4.8E-04
	TBBP-A	3.5E-03	Upper circular plate	Aluminium	0.006
	Iron	1.4E-03	Circular plate that holds the hard disk	Aluminium	0.002
	Aluminium	8.5E-04		Steel	3.2E-04
	Lead	6.4E-04	Pointer assembly	Aluminium	0.008
	Nickel	2.4E-04	Pointer Holding Frame	Steel	0.076
	Barium	1.8E-04		Steel	0.001
	Zinc	3.0E-05	Bottom circular Plate	Aluminium	0.052
	Gold	2.0E-05		Steel	4.8E-04
	Silver	2.0E-05	Plastic assembly	Acrylonitrile butadiene styrene (ABS)	0.001
	Antimony	1.0E-05		Steel	1.6E-04
	Chromium	1.4E-06	Main Frame	Aluminium	0.242
	Cadmium	1.1E-07	Packaging	Corrugated Cardboard	0.03
	Beryllium	4.7E-08		PE-LD	0.001
	Mercury	1.4E-09		PS-E	0.02
	Steel	4.8E-04	Manual	Paper	0.01

1.2 Life Cycle Assessment (LCA)

1.2.1 Goal definition

The goal of the present LCA is to analyze a case-study Hard Disk Drive (HDD) in order to provide a general overview of the impacts of the product, to estimate the contribution of each life cycle stage and to identify the potential key components (those responsible of the largest impacts)[2]. The outcomes of the LCA will be successively used, in the next chapter, to estimate the potential benefits related to the potential Ecodesign Requirements and their related environmental benefits.

Note that the present LCA is for illustrative purposes, aiming at supporting the illustration/explanation of the methodologies and Ecodesign requirements previously discussed in Deliverable 2. The presented results are therefore not suitable for general judgments upon the investigated product category

1.2.2 Scope definition

1.2.2.1 Functional Unit

The selected Functional Unit (FU) is: *an internal Hard Disk Drive for a desktop computer operating for 5 years into an office*. A different 'home use' scenario will be successively investigated in the sensitivity analysis.

The case-study HDD is a device with the Integrated Drive Electronics (IDE) interface produced in 2005. The maximum data storage amounts to 10 GB.

Note that the data storage capacity of the HDDs greatly increased in the last years. However, the growth of the capacity is not related to a similar grow of the masses of the use materials. In various cases, it has been observed instead a miniaturization of the devices. Generally new generations of HDDs are also characterised by lower power consumption compared to older devices. It can be assumed that material breakdown of the case-study HDD is still representative of product-category.

Furthermore, it is assumed that the average lifetime of HDD is 5 years[3]. Different values of the lifetime will be discussed in the sensitivity analysis.

1.2.2.2 System Boundaries

The following sections describe the system boundaries of the study and the related assumptions.

[2] Considering the 'Goal Situations' of the International Reference Life Cycle Data System (ILCD) Handbook [ILCD, 2010], the present case-study configures as 'Identification of Key Environmental Performance Indicators (KEPI) of a product group for Ecodesign - Goal situation A".

[3] Some studies estimate that the average lifetime of desktop computers is 6 years [IVF, 2007]. However this value refers to the whole computer, while it is observed that some computer components can have a shorter lifetime. This, for example, happens to the HDDs, which can be substituted beforehand to improve the performance of the computer.

1.2.2.2.1 Manufacture and assembly

It is assumed that the case-study HDD is manufactured and assembled in Malaysia. Primary data about the manufacture and assembly of the HDD were not available for the present study. Missing information has been derived form the scientific literature, as follows:

- Data about the HDD's composition refers to [Mohite, 2005];
- No primary data have been used concerning the manufacturing of HDD's components. Impacts of the manufacturing have been estimated on the basis of the Bill of Material of the HDD;
- The production of materials refers to average European data;
- The energy consumption for the assembly of Printed Circuit Board is estimated from data about the assembly of generic circuit boards[4].
- The energy consumption for the assembly of other HDD's components is estimated from data about the assembly of a desktop computer[5].

1.2.2.2.2 Use stage

The energy consumption during the use stage is estimated on the basis of the following use assumptions.

The HDD is embodied into a desktop computer for office uses. The operating time of the computer is estimated on the basis of a generic employee working time (220 days per year and 9 hours per day[6]).

The energy consumption of the HDD is related to the different use modes:

- Read/Write/Idle: it involves the main activities of the HDD, reading and writing, and also the 'Idle' time or the time during which the HDD is running without working. The 'Idle' time also includes the period of inactivity before the standby mode.
- Standby: it represents a 'low consumption' mode when the disks are stopped, but the device is ready to start again. The 'standby' mode is influenced by the user's setting of the HDD.

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[4] Williams, 2004 estimates that the assembly of Printed Circuit Boards consumes 34 kWh/m^2 of electricity and 116 MJ/m^2 of thermal energy from fossil fuels (average data, per unit of surface, for the production of circuit boards in different countries in 2000 [Williams, 2004]).
Considering that the case-study HDD has a circuit board with a surface of 0.0149 m^2, it results that the assembly of he circuit board consumes 1.73 MJ of fossil fuels and 0.51 kWh of electricity. In the study of Williams it is not specified what fossil energy is used. In the present study it is assumed to use natural gas (lower heating value: 46 MJ/kg).

[5] Williams, 2004 estimates that the assembly of a desktop computer consumes 28 kWh of electricity and 65 MJ of thermal energy from fossil fuels (data refer to the overall production of personal computers in USA in 2000 [Williams, 2004].
It is assumed that the energy demand for the assembly is proportional to the mass of the components. Assuming that the overall mass of the desktop computer amounts to 9.7 kg (from [IVF, 2007]) and considering that the overall mass of the HDD is 0.53 kg (excluding packaging, manuals and printed circuit board), it is estimated that the assembly of the HDD consumes 1.5 kWh of electricity and 3.5 MJ of fossil fuels. In the study of Williams it is not specified what fossil energy is used. In the present study it is assumed to use natural gas (lower heating value: 46 MJ/kg).

[6] The overall number of working days considers 52 weeks per year, 5 working days per week and 40 days of annual leaves. Concerning the number of operating hours, eight working hours per days are assumed plus 1 hour for the breaks.

- Sleep: this is the lowest energy consumption mode of the HDD, when all the functions are deactivated. The sleep mode is associated to the long working pauses, and it is influenced by the user's setting of the HDD.
- Seek: this is the mode during which the HDD is running to search the location of the selected files/folders.
- Spin-up: this is the mode when the HDD starts or when it passes from the Standby/Sleep mode to the operative modes. It is involves a cycle of about 5-6 seconds during which the disks reach the rotating speed, causing higher power consumption.

Use modes of the HDD are largely dependant on the user's behaviour and, in particular, on the frequency of the accesses to the disk. It is very difficult to estimate an average user profile, but some considerations follow:

- The spin-up cycles are the most energy consuming phases. However, the number of these cycles is generally limited during a working day (the switch on, the restarts, and the passing from the Standby/sleep modes to the operative mode). The number of spin-up cycles is estimated in the range of 10÷20 times per day (corresponding to few minutes, and less than 0.5% of the daily operating time).
- The time spent on the standby mode is influenced by the typology of use of the computer and by computer's settings (e.g. the time of inactivity before the standby)[7]. It can be assumed that the standby mode is activated during the working time for 5 ÷ 15 minutes per hour (7.5% ÷ 22% of the operating time). Note that the estimations about standby are affected by large uncertainty.
- The sleep mode follows the standby mode. It is generally activated after 15 ÷ 20 minutes of inactivity. The sleep mode is generally reached after long working breaks. It can be assumed that the sleep mode is activated during the working time for 30 ÷ 90 minutes per day (5.5% ÷ 17% of the operating time). Also estimations about the sleep mode are largely uncertain.
- The remaining percentage of the operating time (60% ÷ 87%) is spent in the Read/Write/Idle mode and, to a smaller rate, in the Seek mode. This last is assumed to vary from 5% to 10% of the time for the Read/Write/Idle mode.

According to the previous assumptions and consideration, some use rate ranges have been defined for each use mode. Table 2 presents the use rate ranges and the power consumption[8]. Two consumption scenarios have been defined:

- the 'low consumption' scenario: the HDD consumes 53.6 kWh of electricity during the operating time;

[7] Modern computers have generally by default some standby settings for energy-saving, including the activation of the standby mode of the HDDs after 10 ÷ 15 minutes of inactivity.
[8] The values of the power consumption during each mode have been derived from the technical specifications of the HDD.

- the ‘high consumption’ scenario: the HDD consumes 68.8 kWh of electricity during the operating time.

Successively an ‘average’ scenario is defined, assuming an average consumption between the previous two scenarios. This average consumption will be assumed as reference value for the ‘*base-case*’ office use scenario. Note that an additional scenario about a different use profile (‘home use’ scenarios) will be successively discussed in the sensitivity analysis.

Table 2 Office use scenarios of the Hard Disk Drive

Power consumption						
Day per year	220					
Hours per day	9					
Years of working	5					
Total working time (hours)	*9900*					
Operating mode	*Power [W]*	Use rate ranges [%]		Consumption scenarios [kWh]		
				Low	Average	High
Read/Write/Idle	7.5	54.45%	82.51%	40.4		61.3
Seek	13.7	6.05%	4.34%	8.2		5.9
Standby	1.3	22%	7.5%	2.8		1.0
Sleep	0.7	17%	5.5%	1.2		0.4
Spinup	18.4	0.50%	0.15%	0.9		0.3
Total consumption during the use phase [kWh]				**53.6**	***61.2***	**68.8**

1.2.2.2.3 End of Life

The WEEE Directive establishes that “*Member States shall ensure that producers or third parties acting on their behalf set up systems either on an individual or on a collective basis […] to provide for the recovery of WEEE collected separately*”. In particular, an HDD belongs to the category of “IT and telecommunications equipment” for which the following minimum thresholds are set [EU, 2002]:

- “*the rate of recovery shall be increased to a minimum of 75 % by an average weight per appliance, and*
- *component, material and substance reuse and recycling shall be increased to a minimum of 65 % by an average weight per appliance*”.

However, the European Commission observed that: “*Despite such rules on collection and recycling only one third of electrical and electronic waste in the European Union is reported as separately collected and appropriately treated. A part of the other two thirds is potentially still going to landfills and to sub-standard treatment sites in or outside the European Union*.” [EC, 2011].

In the LCA, it is considered a ‘base’ EoL scenario of the HDD, with the rates based on the WEEE thresholds:

- The hard disk is dismantled and it is assumed that 0.45 kg of aluminium is recycled (65% of the mass of the HDD).

- Packaging and plastic components are incinerated with energy recovery;
- The Printed Circuit Board and the remaining metal components are landfilled.

This scenario allows assessing how of the EoL of the HDD waste can affect the eco-profile of the product. The modelling of the EoL and in particular of the recycling processes is in accordance with the ILCD recommendations[9].

A different EoL scenario of the HDD will be discussed in the next Chapter, supposing to increase the recycling/recovery rates due to the adoption of Ecodesign requirements.

1.2.2.2.4 Transport

Data concerning the transportations during the product's life cycle stages have been estimated. In particular, transportations have been sub-divided into (Table 3):

- Transport for the manufacture: it includes the transport of subassembly, components and packaging to the manufacturing company. It is assumed that components are produced in the South-East of Asia, and that transport includes lorry (distance 600 km) and ship (distance 2500 km).
- Transport to the user: it is assumed that the HDD is shipped from Malaysia to the Europe by transoceanic ship (distance 7,000 km) and successively distributed to the user with an average lorry (distance 1000 km);
- Transport for the EoL: it is assumed that the HDD components and packaging are transported to local treatment plants by an average lorry (distance 300 km). It is assumed that the different EoL assumptions do not affect the transport for the EoL.

Note that the assumptions concerning the transportations are affected by a large variability. However, as successively discussed in the life cycle impact assessment phase, the incidence of the transportations to the impact categories is not relevant.

[9] It is assumed that primary aluminum is used for the manufacturing of the HDD. Successively, environmental impacts are credited to the EoL phase due to the aluminum recycling. In particular, it is assumed that the recycled aluminum will substitute primary aluminum in the market; burden due to the recycling process are accounted as well as the impacts due to landfilling of the residual components. Further methodological details are provided in [ILCD, 2010]

Table 3 Transport during the life cycle of the Hard Disk Drive

Transport to manufacture		
Transport mean	Distance [km]	Overall transportation [tkm]
Lorry	600	0.38
Ship	2500	1.59
Trasport to user		
Transport mean	Distance [km]	Overall transportation [tkm]
Ship	7000	4.46
Lorry	1000	0.64
Trasport to disposal		
Transport mean	Distance [km]	Overall transportation [tkm]
Lorry	300	0.19

1.2.2.2.5 Base-case scenario and alternative scenarios

It is defined a 'base-case' HDD scenario with the following assumptions:

- Manufactured/assembled according to the assumptions of Chapter 1.2.2.2.1
- The average energy consumption during the operating time is 61.2 kWh (Table 2)
- The 'base' EoL scenario in line with the WEEE thresholds.

Successively, the base-case scenario has been compared with other two consumption scenarios ('low' and 'high' consumption scenarios) related to different consumptions during the use stage.

Other alternative scenarios will be discussed during the life cycle interpretation phase (sensitivity analysis).

1.2.2.3 Environmental impact categories

The Life Cycle Impact Assessment will be based on the impact categories listed in Table 4.

The optional phases of 'normalisation' and 'weighting' of the impacts have been not applied.

Table 4 List of the selected impact categories 'I' for the Life Cycle Impact Assessment[10]

Impact category	Characterization factor	Unit of measure
Resource depletion	Abiotic Depletion Potential -ADP (elements)	kg $Sb_{eq.}$
Resource depletion	Abiotic Depletion Potential – ADP (fossil fuels)	MJ
Acidification	Acidification potential - AP	kg $SO2_{eq.}$
Eutrophication	Eutrophication Potential - EP	kg $Phosphate_{eq.}$
Freshwater Aquatic Ecotoxicity	Freshwater Aquatic Ecotoxicity Pot. - FAETP	kg $DCB_{eq.}$
Climate change	Global warming Potential - GWP	kg $CO2_{eq.}$
Human Toxicity Potential	Human Toxicity Potential - HTP	kg $DCB_{eq.}$
Ozone depletion	Ozone Layer Depletion Potential - ODP	kg $R11_{eq.}$
Photochemical Ozone Creation	Photochemical Ozone Creation Potential - POCP	kg $Ethene_{eq.}$
Terrestric ecotoxicity	Terrestric ecotoxicity potential - TETP	kg $DCB_{eq.}$

1.2.2.4 Data quality and data sources

The present LCA is exclusively based on secondary data from the scientific references.

Concerning the production of materials, data have been referred to average European production. The inventory data of energy sources are from the ELCD database and, in particular, the electricity refers to the average production in the EU-27 [ELCD, 2010].

Note that the present LCA is only illustrative to support the assessment of the potential Ecodesign requirements. Therefore, the use of data in this study does not reflect any endorsement of the data, nor the associated databases. A list of potential exemplary life cycle inventory data sources suitable for the present case-study is provided in Table 5.

Table 5 Exemplary data source of Life Cycle Inventory data

Material	Reference
Aluminium, Copper, Glass fibres , Lead	[GaBi 4]
Zinc, ABS, PE-LD, PS-E	[ELCD, 2010]
Gold, Silver, Cadmium, Mercury, Barium, Chromium, Nickel, Bisphenol A, Paper	[ecoinvent]
Epoxy resins	[PlasticsEurope]
Steel, cardboard	[BUWAL, 1996]
Energy	**Reference**
Electricity, Natural gas	[ELCD, 2010]
Transports	**Reference**
Lorry	[ELCD, 2010; GaBi 4]
Ship	[ELCD, 2010]
EoL	**Reference**
Landfill	[ELCD, 2010]
Incineration (plastics, cardboard)	[ELCD, 2010]

[10] Note that some potentially relevant impact categories have not been considered in this methodological illustrative study. Their exclusion does not imply that they would have been identified as not relevant.

No life cycle inventory data have been available about some components of the Circuit Board (beryllium, antimony and ceramic): their contribution to the product's ecoprofile has been not considered. Furthermore, inventory data of "*bisphenol A*" are used in place of "*tetrabromobisphenol A*" (TBBA)[11].

The life cycle inventory data of transport by lorry refer to average data for different lorries[12]; inventory data about shipping refer to average container ship[13].Inventory data concerning the landfill or incineration refer to the ELCD database [ELCD, 2010].

1.2.2.5 Main assumptions and limits of the study

As previously described, the present LCA is based on secondary data from references. Manufacturing process has been modelled considering average inventory data that are representative for the European production context.

The use stage has been modelled with assumptions concerning the working time and the different operative modes of the HDD.

Assumptions about the EoL have been based of a feasible scenario of treatment of the product after its useful life.

The results of the LCA should therefore be considered as an approximation/estimation of the environmental impacts of the studied HDD. This is, however, in line with the goals of the study: to provide a general overview of the impacts of the product, to estimate the contribution of each life cycle stage and to identify the potential key components of the product. Table 6 synthesizes the main assumption of the study.

Table 6 Main assumptions of the study

Manufacturing	▪ Material breakdown from reference ▪ The energy consumption during the assembly has been estimated from references, assuming that impacts were proportional to the surface of the Printed circuit board and to the mass of the other components of the HDD
Transport	▪ Rough estimation, considering the production in the south-east of Asia and the delivery to Europe ▪ Rough estimations concerning the EoL transport
Inventory data	▪ Inventory data for materials and components from LCA databases concerning the European or global production context ▪ Impacts of beryllium, Antimony and ceramic have been neglected. ▪ Inventory data of 'bisphenol A' are used instead of TBBP-A
Impact categories	▪ Multi-criteria approach (see Chapter 1.2.2.3)
Use stage	▪ Estimation of the usage profile based on different scenario assumptions ▪ Operating time of the HDD: 5 years
End of Life	▪ EoL base-case scenario in line with the WEEE thresholds

[11] TBBPA is produced by the bromination of bisphenol A with various solvents. Bromine content amounts to about 20% in mass.

[12] Lorry with 22t total weight according to a mix of the Euro 0, 1, 2, 3 and 4 emission limits (data from [ELCD, 2010] as presented/elaborated in [GaBi 4]).

[13] Container ship ocean with 27,500 dead weight tons pay load capacity [ELCD, 2010].

1.2.3 Life Cycle Inventory of the HDD

A summary of inventory data of the ‘base-case’ HDD is presented in Annex 1.

References and details of inventory data of materials, energy sources and processes have been previously described in Chapter 1.2.2.4.

1.2.4 Life Cycle Impact Assessment of the HDD

1.2.4.1 Impact Assessment of the ‘base-case’ HDD

The Life Cycle Impact Assessment (LCIA) of the ‘base-case’ HDD has been performed with the impact categories introduced in Chapter 1.2.2.3.

Table 7 presents the environmental impacts due to the manufacture and use and EoL stages. It is underlined that negative values of the EoL correspond to the potential benefits (credits) that can be achieved for each impact category by the recycling at the EoL. The EoL assumptions have been detailed in Chapter 1.2.2.2.3 and 1.2.2.4.

Table 8 presents how relevant are the life cycle stages. The use is responsible of the largest environmental impacts concerning six impact categories. The manufacture is instead dominating the Abiotic Depletion Potential (element) and it is very relevant concerning the Freshwater Ecotoxicity, Human Toxicity and the Terrestric Ecotoxicity.

The EoL is relevant for seven impact categories and, in particular for the Human Toxicity Potential.

Table 7 Life Cycle Impact Assessment of the HDD ‘base-case’ office use scenario[14]

		Abiotic Depletion Pot. (elements)	**Abiotic Depletion Pot. (fossil fuels)**	**Acidification Potential**	**Eutrophication Potential**	**Freshwater Aquatic Ecotoxicity Pot.**	**Global Warming Potential**	**Human Toxicity Potential**	**Ozone Depletion Potential**	**Photochem. Ozone Creation Pot.**	**Terrestric Ecotoxicity Potential**
		[kg $Sb_{eq.}$]	[MJ]	[kg SO2 $_{eq.}$]	[kg $Phosphate_{eq.}$]	[kg DCB $_{eq.}$]	[kg $CO2_{eq.}$]	[kg $DCB_{eq.}$]	[kg R11 $_{eq.}$]	[kg $Ethene_{eq.}$]	[kg $DCB_{eq.}$]
HDD 'Base-case' scenario: office use	Manufacture	1.3E-03	8.6E+01	5.6E-02	2.5E-03	1.4E-01	8.3E+00	1.9E+00	9.4E-07	4.4E-03	3.3E-02
	Use	2.4E-06	3.7E+02	2.8E-01	9.3E-03	1.0E-01	3.6E+01	3.1E+00	8.8E-06	1.4E-02	4.9E-02
	Manufacture + Use	**1.3E-03**	**4.6E+02**	**3.4E-01**	**1.2E-02**	**2.4E-01**	**4.4E+01**	**5.0E+00**	**9.7E-06**	**1.8E-02**	**8.2E-02**
	End-of-life	-1.6E-06	-4.8E+01	-3.5E-02	-1.1E-03	-2.7E-02	-5.1E+00	-1.2E+00	-4.7E-07	-2.8E-03	-1.0E-02
	Total	***1.3E-03***	***4.1E+02***	***3.0E-01***	***1.1E-02***	***2.1E-01***	***3.9E+01***	***3.8E+00***	***9.2E-06***	***1.5E-02***	***7.1E-02***

[14] Note that the presented results are only illustrative of the case-study and not suitable for general judgments upon the investigated product category.

Table 8 Relevance of the life cycle stages in the 'base-case' scenario[15]

		Abiotic Depletion Pot. (elements)	Abiotic Depletion Pot. (fossil fuels)	Acidification Potential	Eutrophication Potential	Freshwater Aquatic Ecotoxicity Pot.	Global Warming Potential	Human Toxicity Potential	Ozone Depletion Potential	Photochem. Ozone Creation Pot.	Terrestric Ecotoxicity Potential
HDD 'Base-case' scenario: office use	Manufacture	99.8%	18.8%	16.7%	21.3%	58.0%	18.6%	37.4%	9.7%	24.0%	40.1%
	Use	0.2%	81.2%	83.3%	78.7%	42.0%	81.4%	62.6%	90.3%	76.0%	59.9%
	End-of-life	-0.1%	-10.5%	-10.5%	-8.9%	-11.1%	-11.4%	-24.0%	-4.9%	-15.3%	-12.6%

Legend

Relevance	
Not relevant	[0; 10%]
Relevant	[10; 30%]
Very relevant	[30; 70%]
Dominant	> 70 %

1.2.4.2 Impact Assessment of the 'low' and 'high' consumption scenarios

This paragraph discusses how the different assumptions on the use stage influence the final HDD's ecoprofile. In particular, it has been estimated that the consumption during the use can vary within the range of 53.6 kWh (low consumption scenario) and 68.8 kWh (high consumption scenario). Two new scenarios have been then built upon the 'base-case' assuming to modify only the energy consumption during the operating time

Table 9 presents the impacts for the two new scenarios. It is possible to note that the different assumptions about the use stage generally affect each impact category of about ±10%. Much lower variations have been observed for the Abiotic Depletion Potential (element).

It can be concluded that that different assumptions about the use stage are generally relevant for various impact categories and these assumptions can affect final results.

Table 9 Life Cycle Impact Assessment of the consumption scenarios compared to the base-case

		Variation ranges of the impacts due to different use scenarios		
		Low consumption scenario	Base-case scenario	High consumption scenario
Abiotic Depletion Pot. (elements)	[kg $Sb_{eq.}$]	1.3E-03	1.3E-03	1.3E-03
Abiotic Depletion Pot. (fossil fuels)	[MJ]	3.6E+02	4.1E+02	4.5E+02
Acidification Pot.	[kg $SO2_{eq.}$]	2.7E-01	3.0E-01	3.4E-01
Eutrophication Pot.	[kg $Phosphate_{eq.}$]	9.7E-03	1.1E-02	1.2E-02
Freshwater Aquatic Ecotoxicity Pot.	[kg $DCB_{eq.}$]	2.0E-01	2.1E-01	2.3E-01
Gloal Warming Pot.	[kg $CO2_{eq.}$]	3.5E+01	3.9E+01	4.4E+01
Human Toxicity Pot.	[kg $DCB_{eq.}$]	3.4E+00	3.8E+00	4.2E+00
Ozone Depletion Pot.	[kg $R11_{eq.}$]	8.2E-06	9.2E-06	1.0E-05
Photochem. Ozone Creation Pot.	[kg $Ethene_{eq.}$]	1.4E-02	1.5E-02	1.7E-02
Terrestric Ecotoxicity Pot.	[kg $DCB_{eq.}$]	6.5E-02	7.1E-02	7.7E-02

[15] Percentages are calculated with respect to the sum of impacts due to manufacture and use.

1.2.4.3 Impact Assessment: detail of the manufacturing stage

As previously noted, manufacturing contributes in a relevant way to various impact categories (see Table 8). The present chapter presents a detail of the impact of the manufacturing in the 'base-case' scenario.

Table 10 presents the impacts due to each component, while Table 11 provides the relevance of each component (estimated as percentage of the overall impact due to the manufacturing). The majority of the impacts are related to the production of the aluminium components (mainly the main frame and the top cover) and to the production of the Printed Circuit Board. For some impact categories (as Global Warming Potential, Ozone Depletion and Acidification) also the energy consumption for the assembly contributes relevantly.

Successively, a further detail has been provided concerning the manufacturing of the Printed Circuit Board (Table 12 and Table 13).

It is worth of note that the manufacturing of the gold is responsible of the largest share of impacts of the circuit board. Note that gold, despite its negligible mass (about 0.003% of the mass of the HDD), contributes in a relevant way to the overall ecoprofile of the product. For example, the manufacturing of the gold dominates (over 90%) the overall Abiotic Depletion Potential (element) and contributes to almost 40% of the overall Freshwater Ecotoxicity Potential and 25% of Terrestric Ecotoxicity Potential of the whole HDD.

This result supports the conclusions of Deliverable 2: product's components can be negligible in terms of mass fraction but being relevant in terms of contribute to the product's overall environmental impacts. Measures for the recovery of such 'key components' can contribute in a relevant way to the improvement of the product's environmental performance.

Table 10 Life Cycle Impact Assessment of the HDD 'base case': detail of the manufacturing stage[16]

		Abiotic Depletion Pot. (elements)	Abiotic Depletion Pot. (fossil fuels)	Acidification Potential	Eutrophication Potential	Freshwater Aquatic Ecotoxicity Pot.	Global Warming Potential	Human Toxicity Potential	Ozone Depletion Potential	Photochem. Ozone Creation Pot.	Terrestric Ecotoxicity Potential
		[kg $Sb_{eq.}$]	[MJ]	[kg $SO2_{eq.}$]	[kg $Phosphate_{eq.}$]	[kg $DCB_{eq.}$]	[kg $CO2_{eq.}$]	[kg $DCB_{eq.}$]	[kg $R11_{eq.}$]	[kg $Ethene_{eq.}$]	[kg $DCB_{eq.}$]
Manufacturing of the HDD	Aluminium components	1.8E-06	5.7E+01	4.0E-02	1.3E-03	3.1E-02	6.0E+00	1.3E+00	5.7E-07	3.2E-03	1.3E-02
	Printed Circuit Board	1.3E-03	1.3E+01	7.1E-03	7.9E-04	9.9E-02	8.9E-01	4.3E-01	1.2E-07	6.4E-04	1.8E-02
	Packaging/manual	9.2E-08	2.0E+00	4.6E-04	5.8E-05	4.0E-04	1.0E-01	8.8E-03	1.0E-08	5.8E-05	3.1E-04
	Pointer	5.5E-09	2.8E-01	7.5E-04	6.0E-05	6.5E-03	2.5E-01	1.9E-02	1.9E-08	1.0E-04	9.2E-05
	Plastic Assembly	1.5E-09	8.8E-02	1.4E-05	1.4E-06	1.6E-05	4.3E-03	1.6E-04	4.0E-11	1.7E-06	4.1E-06
	Assembly of HDD	7.3E-08	1.3E+01	7.1E-03	2.4E-04	2.6E-03	9.5E-01	7.9E-02	2.2E-07	3.7E-04	1.3E-03
	Transportation	9.3E-10	6.1E-01	8.1E-04	9.2E-05	5.1E-05	4.6E-02	1.7E-03	8.5E-11	5.2E-05	2.2E-05
Total		**1.3E-03**	**8.6E+01**	**5.6E-02**	**2.5E-03**	**1.4E-01**	**8.3E+00**	**1.9E+00**	**9.4E-07**	**4.4E-03**	**3.3E-02**

[16] Note that the presented results are only illustrative of the case-study and not suitable for general judgments upon the investigated product category.

Table 11 Detail of the Impact assessment of the manufacturing stage: relevance of each component[17]

		Abiotic Depletion Pot. (elements)	Abiotic Depletion Pot. (fossil fuels)	Acidification Potential	Eutrophication Potential	Freshwater Aquatic Ecotoxicity Pot.	Global Warming Potential	Human Toxicity Potential	Ozone Depletion Potential	Photochem. Ozone Creation Pot.	Terrestric Ecotoxicity Potential
Manufacturing of the HDD	Aluminium components	0.1%	66.1%	71.2%	51.1%	22.1%	72.9%	71.2%	61.0%	72.0%	38.6%
	Printed Circuit Board	99.8%	14.9%	12.6%	31.1%	71.0%	10.7%	22.9%	12.3%	14.7%	56.2%
	Packaging/manual	<0.1%	2.4%	0.8%	2.3%	0.3%	1.3%	0.5%	1.1%	1.3%	1.0%
	Pointer	<0.1%	0.3%	1.3%	2.4%	4.7%	3.0%	1.0%	2.0%	2.4%	0.3%
	Plastic Assembly	<0.1%	0.1%	<0.1%	0.1%	<0.1%	0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	Assembly of HDD	<0.1%	15.5%	12.6%	9.5%	1.9%	11.5%	4.2%	23.5%	8.3%	3.9%
	Transportation	<0.1%	0.7%	1.4%	3.6%	<0.1%	0.6%	0.1%	0.0%	1.2%	0.1%

Legend

Not relevant	**[0; 10%]**
Relevant	**[10; 30%]**
Very relevant	**[30; 70%]**
Dominant	**> 70 %**

Table 12 Impact Assessment of the HDD 'base case': Printed Circuit Board manufacturing [18]

		Energy for assembly	Epoxy/glass fibre support	Aluminium	Copper	Nickel	Gold	Silver	Other components	**Total**
Abiotic Depletion Pot. (elements)	[kg $Sb_{eq.}$]	2.6E-08	2.2E-06	3.5E-09	8.5E-05	2.5E-08	1.2E-03	2.7E-05	2.1E-06	**1.3E-03**
Abiotic Depletion Pot. (fossil fuels)	[MJ]	5.0E+00	1.3E+00	1.1E-01	6.1E-01	3.1E-02	5.2E+00	1.1E-01	1.4E-02	**1.2E+01**
Acidification Potential	[kg $SO2_{eq.}$]	2.4E-03	3.6E-04	7.7E-05	2.6E-04	4.1E-04	3.4E-03	1.2E-04	3.2E-05	**7.0E-03**
Eutrophication Potential	[kg $Phosphate_{eq.}$]	8.1E-05	5.7E-05	2.5E-06	1.5E-05	4.3E-06	5.9E-04	1.7E-05	3.9E-07	**7.6E-04**
Freshwater Aquatic Ecotoxicity Pot.	[kg $DCB_{eq.}$]	8.7E-04	7.5E-05	5.8E-05	1.7E-03	3.0E-04	8.5E-02	2.7E-03	1.1E-05	**9.1E-02**
Global Warming Potential	[kg $CO2_{eq.}$]	3.2E-01	1.0E-01	1.2E-02	4.9E-02	2.7E-03	3.8E-01	8.7E-03	1.4E-03	**8.7E-01**
Human Toxicity Potential	[kg $DCB_{eq.}$]	2.6E-02	1.3E-03	2.5E-03	3.5E-02	9.6E-03	3.1E-01	3.3E-03	6.1E-04	**3.9E-01**
Ozone Depletion Potential	[kg $R11_{eq.}$]	7.3E-08	2.2E-09	1.1E-09	2.4E-09	2.1E-10	3.5E-08	7.1E-10	1.1E-10	**1.1E-07**
Photochem. Ozone Creation Pot.	[kg $Ethene_{eq.}$]	1.2E-04	8.3E-05	6.0E-06	1.6E-05	1.8E-05	3.7E-04	1.1E-05	1.5E-06	**6.3E-04**
Terrestric Ecotoxicity Potential	[kg $DCB_{eq.}$]	4.3E-04	1.0E-04	2.4E-05	1.8E-04	6.5E-05	1.7E-02	1.0E-04	1.4E-05	**1.8E-02**

Table 13 Impact Assessment of Printed Circuit Board manufacturing: relevance of components[19]

	Energy for assembly	Epoxy/glass fibre support	Aluminium	Copper	Nickel	Gold	Silver	Other components
Abiotic Depletion Pot. (elements)	<0.1%	0.2%	<0.1%	6.7%	<0.1%	90.9%	2.1%	0.2%
Abiotic Depletion Pot. (fossil fuels)	40.3%	10.3%	0.9%	4.9%	0.2%	42.4%	0.9%	0.1%
Acidification Potential	33.8%	5.1%	1.1%	3.7%	5.8%	48.3%	1.8%	0.4%
Eutrophication Potential	10.6%	7.4%	0.3%	2.0%	0.6%	76.8%	2.2%	0.1%
Freshwater Aquatic Ecotoxicity Pot.	1.0%	0.1%	0.1%	1.9%	0.3%	93.7%	3.0%	<0.1%
Global Warming Potential	36.6%	11.9%	1.3%	5.6%	0.3%	43.1%	1.0%	0.2%
Human Toxicity Potential	6.8%	0.3%	0.7%	9.1%	2.5%	79.6%	0.8%	0.2%
Ozone Depletion Potential	63.6%	1.9%	1.0%	2.1%	0.2%	30.5%	0.6%	0.1%
Photochem. Ozone Creation Pot.	19.8%	13.2%	1.0%	2.6%	2.8%	58.6%	1.8%	0.2%
Terrestric Ecotoxicity Potential	2.4%	0.5%	0.1%	1.0%	0.4%	94.9%	0.6%	0.1%

Legend

Not relevant	**[0; 10%]**
Relevant	**[10; 30%]**
Very relevant	**[30; 70%]**
Dominant	**> 70 %**

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[17] Percentages are calculated with respect to total impacts due to the manufacturing.
[18] Note that the presented results are only illustrative of the case-study and not suitable for general judgments upon the investigated product category.
[19] Percentages are calculated with respect to the total impacts due to the manufacturing of the circuit board

1.2.5 Life Cycle Interpretation

The last part of the LCA includes the interpretation phase in which the findings of the inventory analysis and the impact assessment are considered and assessed together.

First of all, it has been observed that assumptions about the use stage are relevant. Furthermore, all the previous results have been referred to an average 'office use' scenario.

Different figures could be obtained assuming a 'home use' profile. Therefore, different scenarios about the use stage will be discussed (Chapter 1.2.5.1).

Furthermore, it has been observed that:

- Impacts due to manufacturing have been estimated on the basis of the BOM and of data from the literature. Inventory data for the manufacturing have been referred to average European data. Unfortunately, no data have been available concerning the area of production of the HDD (south-east Asia). However available data concerning the manufacturing are assumed to be suitable for the goals of the study[20].
- Lifetime of HDD has been estimated in 5 years. However this assumption could affect the results. Different lifetime alternatives will be discussed in Chapter 1.2.5.2.
- Transport has been roughly estimated. In the base-case scenario, impacts due to the transport are generally lower than 1% for all the impact categories (except 3% for the Eutrophication Potential). It is possible to assume that the contribution of transport has generally a low relevance and, therefore, further analysis/assumptions are not necessary;
- Assumptions concerning the EoL stage have been discussed in Chapter 1.2.2.2.3. It was also observed that the recycling could contribute relevantly to the reduction of some impact categories. Therefore a further investigation concerning the EoL is necessary.

The following chapters will discuss the additional scenarios concerning the use stage and the product's lifetime. Chapter 2.2.1.2 will instead discuss the additional scenario about the EoL of the product, in relation with a potential Ecodesign requirement.

1.2.5.1 Sensitivity Analysis of the use stage: 'home use' scenarios

The previous chapters underlined the role of the use stage in the life cycle impact assessment of the HDD. In particular, the use stage of the HDD has been based on estimations of the operating modes and time of use. These estimations can vary due to the user's behaviour and the frequency of access to the HDD.

For this purpose, two energy use scenarios have been analyzed (Chapter 1.2.2.2.2). These scenarios have been based on the general assumption that the HDD is installed into a desktop computer for office use. However, the energy consumption during the use could largely differ if, for example, the HDD is installed into desktop computers for the domestic use. .

[20] Note that the goal of the study is to provide a general overview of the impacts of the product, to estimate the relevancy and contribution of each life cycle stage and to identify the components responsible of the largest impacts.

For such purpose the present Chapter will analyze new scenarios concerning the ‘home use’. The uncertainty of the new scenario is larger that that observed for the ‘office use’ scenarios, because the typologies and behaviours of private users largely differ.

First of all the total number of operating hours is very variable (more variable than in the ‘office use’ in which the operating time has been estimated in line with the average working time). In the domestic use, the total number of operating hours of the HDD can vary from few to several hours per day.

Furthermore, the use of the HDD is largely dependant on the typology of software and the frequency of the access to the device. In some case, the user has only occasional access to the HDD (to save/load files when necessary), while other users make a massive access to the HDD (e.g. by playing music and videos, or by running special software).

Due to the difficulties to generalize an average ‘home use’ profile, two different scenarios have been introduced:

- ‘*Home use - moderate’ scenario*:
  - Operating time: it is assumed that the HDD is used for 2 hours per day during the week (from Monday to Friday) and for 4 hours per day during the week-ends. The HDD lifetime is 5 year;
  - Spin-up mode: it is assumed that few spin-up cycles take place during a day due to few changes from the standby to the operative modes and few restarts. On average, five spin-up cycles per day of 5 seconds each one are assumed (equivalent to about 0.25% of the overall operating time);
  - Stand-by mode: due to few accesses to the HDD, it is assumed that 10 minutes per hours is spent in the stand-by mode (equivalent to about 17% of the overall operating time);
  - Sleep mode: it is assumed that the sleep mode is reached after long breaks, for an average of five minutes per hours (equivalent to about 8% of the overall operating time)
  - Read/Write/Idle and Seek modes: the remaining time (about 75%) is assumed to be spent in the ‘Read/Write/Idle’ and the Seek mode. This last is assumed to be 10% of the ‘Read/Write/Idle’ mode.
- *‘Home use – intensive’ scenario*:
  - Operating time: it is assumed that the HDD is used for 4 hours per day during the week (from Monday to Friday) and for 8 hours per day during the week-ends and. The HDD is used for 5 year;
  - Spin-up mode: compared to the previous scenario, it is assumed that more spin-up cycles take place, mostly due to more restarts and more passage from the standby to the operative modes. On average, 15 spin-up cycles per day of 5 seconds each one are assumed (equivalent to about 0.37% of the overall operating time);

- Stand-by mode: due to frequent accesses to the HDD, it is assumed that 5 minutes per hours is spent in the stand-by mode (equivalent to about 8% of the overall operating time)
- Sleep mode: in this scenario it is assumed that the sleep mode it is never reached because of the frequent accesses to the HDD.
- Read/Write/Idle and Seek modes: the remaining time (about 91%) is assumed to be spent in the 'Read/Write/Idle' and the Seek modes. This last is assumed to be 10% of the 'Read/Write/Idle' mode.

The estimated consumptions during the 'home use' scenarios are summarized in Table 14.

Table 14 Estimation of the consumption during the 'home use' scenarios

"Home use - moderate" scenario				"Home use- intensive" scenario			
		Days per year	Hours per day			Day per year	Hours per day
Use during working days		220	2	Use during working days		220	4
Use during weekend & holidays		145	4	Use during weekend & holidays		145	10
Years of operation	5			Years of operation	5		
Total working time (hours)	*5100*			*Total working time (hours)*	*11650*		
Operating mode	*Power [W]*	*Use rate [%]*	*Consumption [kWh]*	*Operating mode*	*Power [W]*	*Use rate [%]*	*Consumption [kWh]*
Read/Write/Idle	7.5	67.3%	25.7	Read/Write/Idle	7.5	82.2%	71.8
Seek	13.7	7.5%	5.2	Seek	13.7	9.1%	14.6
Standby	1.3	16.7%	1.1	Standby	1.3	8.3%	1.3
Sleep	0.7	8.3%	0.3	Sleep	0.7	0%	0.0
Spinup	18.4	0.25%	0.2	Spinup	18.4	0.33%	0.7
Total consumption during the use [kWh]			**32.6**	**Total consumption during the use [kWh]**			**88.4**

The two 'home use' scenarios have been built upon the base-case scenario by changing only the consumption during the use stage. Table 15 presents the life cycle impact indices for the two new scenarios compared to the base case, while Table 16 presents the relevance of each life cycle stage.It is possible to note that the new assumptions concerning the use stage changes sensibly the ecoprofile of the HDD.

For example, in the 'home use - intensive' scenario the relevance of the use phase is very high for some environmental impact categories as GWP, Acidification and ODP. The manufacturing always dominates the impact category of the Abiotic Depletion Potential (element) and it is very relevant for Freshwater Aquatic Ecotoxicity and Terrestric Ecotoxicity potentials. EoL is only relevant for two impact categories.

On the other side, in the 'home use - moderate' scenario the lower consumption during the use stage generally increases the relevance of the manufacturing and EoL. Manufacture would be relevant or very relevant for all the considered impact categories; EoL would be relevant for 7 categories and very relevant for the Human Toxicity.

It can be concluded that the assumptions concerning the use stage are very relevant and they sensibly affect the ecoprofile of the HDD. These assumptions also affect the considerations concerning the relevance of the manufacture and EoL.

Table 15 Life Cycle Impact Assessment of the 'home use' scenarios[21]

		Abiotic Depletion Pot. (elements)	Abiotic Depletion Pot. (fossil fuels)	Acidification Potential	Eutrophication Potential	Freshwater Aquatic Ecotoxicity Pot.	Global Warming Potential	Human Toxicity Potential	Ozone Depletion Potential	Photochem. Ozone Creation Pot.	Terrestric Ecotoxicity Potential
		[kg Sb_{eq}]	[MJ]	[kg $SO2_{eq}$]	[kg $Phosphate_{eq}$]	[kg DCB_{eq}]	[kg $CO2_{eq}$]	[kg DCB_{eq}]	[kg $R11_{eq}$]	[kg $Ethene_{eq}$]	[kg DCB_{eq}]
HDD Base case scenario	Manufacture	1.3E-03	8.6E+01	5.6E-02	2.5E-03	1.4E-01	8.3E+00	1.9E+00	9.4E-07	4.4E-03	3.3E-02
	Use	2.4E-06	3.7E+02	2.8E-01	9.3E-03	1.0E-01	3.6E+01	3.1E+00	8.8E-06	1.4E-02	4.9E-02
	Mmanufacture + Use	**1.3E-03**	**4.6E+02**	**3.4E-01**	**1.2E-02**	**2.4E-01**	**4.4E+01**	**5.0E+00**	**9.7E-06**	**1.8E-02**	**8.2E-02**
	End-of-life	-1.6E-06	-4.8E+01	-3.5E-02	-1.1E-03	-2.7E-02	-5.1E+00	-1.2E+00	-4.7E-07	-2.8E-03	-1.0E-02
	Total	***1.3E-03***	***4.1E+02***	***3.0E-01***	***1.1E-02***	***2.1E-01***	***3.9E+01***	***3.8E+00***	***9.2E-06***	***1.5E-02***	***7.1E-02***
Home use - moderate scenario	Manufacture	1.3E-03	8.6E+01	5.6E-02	2.5E-03	1.4E-01	8.3E+00	1.9E+00	9.4E-07	4.4E-03	3.3E-02
	Use	1.3E-06	2.0E+02	1.5E-01	5.1E-03	5.4E-02	1.9E+01	1.7E+00	4.7E-06	7.4E-03	2.6E-02
	Mmanufacture + Use	**1.3E-03**	**2.8E+02**	**2.1E-01**	**7.6E-03**	**1.9E-01**	**2.8E+01**	**3.5E+00**	**5.6E-06**	**1.2E-02**	**5.9E-02**
	End-of-life	-1.6E-06	-4.8E+01	-3.5E-02	-1.1E-03	-2.7E-02	-5.1E+00	-1.2E+00	-4.7E-07	-2.8E-03	-1.0E-02
	Total	***1.3E-03***	***2.4E+02***	***1.7E-01***	***6.6E-03***	***1.7E-01***	***2.3E+01***	***2.3E+00***	***5.1E-06***	***9.0E-03***	***4.9E-02***
Home use - intensive scenario	Manufacture	1.3E-03	8.6E+01	5.6E-02	2.5E-03	1.4E-01	8.3E+00	1.9E+00	9.4E-07	4.4E-03	3.3E-02
	Use	3.5E-06	5.3E+02	4.0E-01	1.3E-02	1.5E-01	5.2E+01	4.5E+00	1.3E-05	2.0E-02	7.1E-02
	Mmanufacture + Use	**1.3E-03**	**6.2E+02**	**4.6E-01**	**1.6E-02**	**2.8E-01**	**6.1E+01**	**6.4E+00**	**1.4E-05**	**2.4E-02**	**1.0E-01**
	End-of-life	-1.6E-06	-4.8E+01	-3.5E-02	-1.1E-03	-2.7E-02	-5.1E+00	-1.2E+00	-4.7E-07	-2.8E-03	-1.0E-02
	Total	***1.3E-03***	***5.7E+02***	***4.2E-01***	***1.5E-02***	***2.6E-01***	***5.5E+01***	***5.2E+00***	***1.3E-05***	***2.2E-02***	***9.3E-02***

Table 16 Life Cycle Impact Assessment of 'home use' scenarios: relevance of the life cycle stages[22]

		Abiotic Depletion Pot. (elements)	Abiotic Depletion Pot. (fossil fuels)	Acidification Potential	Eutrophication Potential	Freshwater Aquatic Ecotoxicity Pot.	Global Warming Potential	Human Toxicity Potential	Ozone Depletion Potential	Photochem. Ozone Creation Pot.	Terrestric Ecotoxicity Potential
HDD Base case scenario	Manufacture	99.8%	18.8%	16.7%	21.3%	58.0%	18.6%	37.4%	9.7%	24.0%	40.1%
	Use	0.2%	81.2%	83.3%	78.7%	42.0%	81.4%	62.6%	90.3%	76.0%	59.9%
	End-of-life	-0.1%	-10.5%	-10.5%	-8.9%	-11.1%	-11.4%	-24.0%	-4.9%	-15.3%	-12.6%
Home use - moderate scenario	Manufacture	99.9%	30.2%	27.3%	33.2%	72.1%	29.9%	52.8%	16.7%	37.0%	55.7%
	Use	0.1%	69.8%	72.7%	66.8%	27.9%	70.1%	47.2%	83.3%	63.0%	44.3%
	End-of-life	-0.1%	-16.9%	-17.1%	-13.9%	-13.8%	-18.5%	-33.9%	-8.4%	-23.7%	-17.5%
Home use - intensive scenario	Manufacture	99.7%	13.8%	12.3%	15.9%	48.9%	13.6%	29.3%	6.9%	18.0%	31.7%
	Use	0.3%	86.2%	87.7%	84.1%	51.1%	86.4%	70.7%	93.1%	82.0%	68.3%
	End-of-life	-0.1%	-7.7%	-7.7%	-6.6%	-9.4%	-8.4%	-18.8%	-3.5%	-11.5%	-9.9%

Legend		
	Not relevant	**[0; 10%]**
	Relevant	**[10; 30%]**
	Very relevant	**[30; 70%]**
	Dominant	**> 70 %**

1.2.5.2 Sensitivity Analysis of the HDD lifetime

The length of the useful life is another important variable of the HDD's life cycle. The previous scenarios supposed an average duration of 5 years. However, longer or shorter lengths can be assumed, in relation also to the user's behaviour. Potentially, the HDD can last longer than 5 years, but the device is sometimes substituted in advance to upgrade the performance of the computer or to avoid the risks of breakage and data loss. On the other side, a low use of the HDD can grant longer lifetimes.

The present chapter discusses the effect on 'base case' scenario due to changes of the estimated lifetime. Two 'lifetime' scenarios are introduced:

- 'Short lifetime' scenario: assuming that the lifetime of the HDD is 4 years;
- 'Long lifetime' scenario: assuming that the lifetime of the HDD is 6 years.

These two scenarios have been built on the 'base case' scenario, assuming that:

[21] Note that the presented results are only illustrative of the case-study and not suitable for general judgments upon the investigated product category.
[22] Percentages are calculated with respect to the sum of impacts due to manufacture and use.

- In the ‘short lifetime’ scenario it is supposed that the HDD will be substituted after 4 years with another device with the same lifetime of the previous device. For simplicity, it is assumed that new HDD would have the same BOM and the same manufacturing and transport of the base HDD. In order to compare the results with the FU of the ‘base case’ scenario[23], it is here assumed to compare the data on a time length of 5 years. It is therefore supposed that impacts due to manufacturing, transportation and EoL are scaled by factor “*5/4*”.
- In the ‘long lifetime’ scenario the lifetime of the HDD is assumed to be 6 years, lasting more than the FU’s time frame. Analogously to the previous scenario it is supposed that impacts due to manufacturing, transportation and EoL are scaled by factor “*5/6*”.
- For both the new scenarios it is assumed that, during the considered 5 years of operating time, the energy consumption during use stage are the same of the base case scenario (based on the assumptions on Chapter 1.2.2.2.2).

The ecoprofile of the new scenarios are presented in Table 17. It is possible to observe that the majority of the impact categories have small variations, except the Abiotic Depletion Potential (elements), which varies of about ±20%. The ‘Abiotic Depletion Potential (elements)’ impact category is, in fact, dominated by the manufacturing stage. Variations of the manufacturing affect therefore this category relevantly.

Table 17 Impact assessment of the ‘lifetime’ scenarios[24]

		Abiotic Depletion Pot. (elements)	Abiotic Depletion Pot. (fossil fuels)	Acidification Potential	Eutrophication Potential	Freshwater Aquatic Ecotoxicity Pot.	Global Warming Potential	Human Toxicity Potential	Ozone Depletion Potential	Photochem. Ozone Creation Pot.	Terrestric Ecotoxicity Potential
		[kg $Sb_{eq.}$]	[MJ]	[kg $SO2_{eq.}$]	[kg $Phosphate_{eq.}$]	[kg $DCB_{eq.}$]	[kg $CO2_{eq.}$]	[kg $DCB_{eq.}$]	[kg $R11_{eq.}$]	[kg $Ethene_{eq.}$]	[kg $DCB_{eq.}$]
Base case - 'office use' scenario	Manufacture	1.3E-03	8.6E+01	5.6E-02	2.5E-03	1.4E-01	8.3E+00	1.9E+00	9.4E-07	4.4E-03	3.3E-02
	Use	2.4E-06	3.7E+02	2.8E-01	9.3E-03	1.0E-01	3.6E+01	3.1E+00	8.8E-06	1.4E-02	4.9E-02
	Mmanufacture + Use	***1.3E-03***	***4.6E+02***	***3.4E-01***	***1.2E-02***	***2.4E-01***	***4.4E+01***	***5.0E+00***	***9.7E-06***	***1.8E-02***	***8.2E-02***
	End-of-life	-1.6E-06	-4.8E+01	-3.5E-02	-1.1E-03	-2.7E-02	-5.1E+00	-1.2E+00	-4.7E-07	-2.8E-03	-1.0E-02
	Total	**1.3E-03**	**4.1E+02**	**3.0E-01**	**1.1E-02**	**2.1E-01**	**3.9E+01**	**3.8E+00**	**9.2E-06**	**1.5E-02**	**7.1E-02**
Long Lifetime scenario (office use)	Manufacture	1.1E-03	7.1E+01	4.7E-02	2.1E-03	1.2E-01	6.9E+00	1.6E+00	7.8E-07	3.7E-03	2.7E-02
	Use	2.4E-06	3.7E+02	2.8E-01	9.3E-03	1.0E-01	3.6E+01	3.1E+00	8.8E-06	1.4E-02	4.9E-02
	Mmanufacture + Use	***1.1E-03***	***4.4E+02***	***3.3E-01***	***1.1E-02***	***2.2E-01***	***4.3E+01***	***4.7E+00***	***9.6E-06***	***1.8E-02***	***7.6E-02***
	End-of-life	-1.3E-06	-4.0E+01	-2.9E-02	-8.8E-04	-2.2E-02	-4.2E+00	-1.0E+00	-3.9E-07	-2.3E-03	-8.6E-03
	Total	**1.1E-03**	**4.0E+02**	**3.0E-01**	**1.1E-02**	**1.9E-01**	**3.9E+01**	**3.7E+00**	**9.2E-06**	**1.5E-02**	**6.8E-02**
Short Lifetime scenario (office use)	Manufacture	1.6E-03	1.1E+02	7.0E-02	3.1E-03	1.7E-01	1.0E+01	2.3E+00	1.2E-06	5.4E-03	4.1E-02
	Use	2.4E-06	3.7E+02	2.8E-01	9.4E-03	1.0E-01	3.6E+01	3.1E+00	8.8E-06	1.4E-02	4.9E-02
	Mmanufacture + Use	***1.6E-03***	***4.8E+02***	***3.5E-01***	***1.2E-02***	***2.8E-01***	***4.7E+01***	***5.5E+00***	***9.9E-06***	***1.9E-02***	***9.0E-02***
	End-of-life	-2.0E-06	-6.0E+01	-4.4E-02	-1.3E-03	-3.3E-02	-6.4E+00	-1.5E+00	-5.9E-07	-3.5E-03	-1.3E-02
	Total	**1.6E-03**	**4.2E+02**	**3.1E-01**	**1.1E-02**	**2.4E-01**	**4.0E+01**	**4.0E+00**	**9.4E-06**	**1.6E-02**	**7.7E-02**

[23] The Functional Unit (FU) has been defined in Chapter 1.2 as: *an internal Hard Disk Drive for a desktop computer operating for 5 years into an office*

[24] Note that the presented results are only illustrative of the case-study and not suitable for general judgments upon the investigated product category.

1.3 Hard Disk Drive in the EU-27 scenario

The next step of the analysis is the calculation of the environmental impacts due to HDDs in the European scenario. This calculation is useful to assess the potential significance of the product category and of related potential Ecodesign requirements.

It is underlined that the investigated HDD case-study is only representative of the product category of internal HDDs for desktop computer[25].

The overall number of HDDs has been indirectly estimated from available data about the sales of personal computers in Europe. The preparatory study for computer estimates the figures of Table 18 [IVF, 2007]. The study also assumes that 30% of the desktops are in office use and 70% in home use.

Table 18 Estimation of used desktops in the EU-25 [IVF, 2007]

	Desktops (million)	
	Office	Home
2009	50	123
2010	51	130

The previous values refer only to the EU-25 area. A correction of these figures has been made proportionally to the ratio among the population of the EU-27 and the EU-25[26]. Successively it has been estimated that the number of HDDs varies from 1 to 1.5 devices per computer[27].

It is estimated that the number of HDDs *currently used in the EU-27 ranges from 192 to 288 millions of devices.* It is still assumed the percentage distribution of 30% office desktops and 70% home desktops. Two new scenarios have been defined:

- 'EU - lower number HDDs' scenario: it has been considered the lower estimated number of HDD in the EU-27 (192 millions). Office devices (30%) are assimilated to the previous 'base case' scenario; home devices (70%) are assimilated to the 'home use – moderate' scenario.
- 'EU - higher number HDDs' scenario: it has been considered the higher estimated number of HDD in the EU-27 (288 millions). Office devices (30%) are assimilated to

[25] Note that the category of HDD is very large, including several other devices than the case-study here analyzed (including e.g. external HDDs and laptop HDD). Furthermore the HDDs, as other technological devices, are affected by fast changes in relatively short time span,. It is therefore important to underline that the present assessment provides only an approximate figure of the environmental impacts of the studied product category.

[26] Values of the population refer to [Eurostat, 2010]. The correction factor for the calculation of the HDDs in the EU-27 amounts to 1.06.

[27] As minimum, one HDD is generally installed in a desktop computer. Some computers (especially those that are upgraded during the time) are provided with additional HDDs. It is assumed that the number of additional internal HDDs is generally not too large because external HDDs are generally used to file extra data. Note that external HDDs and laptop HDDs are not included in the present analysis.

the previous ‘base case’ scenario; home devices (70%) are assimilated to the ‘home use – intensive’ scenario.

Table 19 presents the estimated impacts for the two new EU scenarios (higher and lower number of HDD). Values refer to yearly impacts[28]. It can be observed that the variation ranges are large and this is due to the large uncertainties of the study’s assumptions, including:

- The total number of the HDDs in the EU has been indirectly estimated from references in the scientific literature;
- The ‘base-case’ and the ‘home–use’ scenarios are assumed as representative of the product category of the internal HDD for desktop computers. However, the technological progress produces very fast changes of the characteristics of HDDs, with potential relevant variations of the life cycle impacts;
- The LCIA is based on the previous assumptions about the life cycle of the product (Chapter 1.2.2.5). Different assumptions could relevantly affect the results.

Table 19 Estimated environmental life cycle impacts due to HDD for desktop computer in the EU[29]

Impacts of Desktop HDDs in the EU-27 ('lower' and 'higher' number of HDD scenarios)	**Abiotic Depletion Pot. (elements)**		**Abiotic Depletion Pot. (fossil fuels)**		**Acidification Potential**		**Eutrophication Potential**		**Freshwater Aquatic Ecotoxicity Pot.**	
	lower	*higher*	*lower*	*higher*	*lower*	*higher*	*lower*	*higher*	*lower*	*higher*
	[kton Sb_{eq}/year]		[10^3 TJ]		[kton $SO_{2\ eq}$/year]		[kton $Phosphate_{eq}$/year]		[kton DCB_{eq} /year]	
	0.05	0.1	10.9	30	8.0	22.3	0.30	0.79	6.9	14.1
	Global Warming Potential		**Human Toxicity Potential**		**Ozone Depletion Potential**		**Photochem. Ozone Creation Pot.**		**Terrestric Ecotoxicity Pot.**	
	lower	*higher*	*lower*	*higher*	*lower*	*higher*	*lower*	*higher*	*lower*	*higher*
	[Mton $CO_{2\ eq}$ /year]		[kton DCB_{eq} /year]		[ton $R11_{eq}$ /year]		[kton $Ethene_{eq}$ /year]		[kton DCB_{eq} /year]	
	1.05	2.9	105.3	274.1	0.24	0.69	0.42	1.1	2.1	5.0

[28] The LCIA of the previous chapters has been referred to 5 years of useful life of the HDD. The yearly impacts have been obtained dividing by 5 the overall figures.

[29] Note that the results here presented are only illustrative for the purposes of the study and they are not suitable for general judgments upon the investigated product category.

1.4 Summary

The present chapter describes a Life Cycle Assessment (LCA) of the case-study product: an internal Hard Disk Drive (HDD) for desktop computer.

The LCA is based on the Bill of Materials reported in Deliverable 2 – Chapter 5. Impacts due to manufacturing have been based on data from the scientific literature; impacts due to transport and to the End of Life have been based on estimations and general assumptions; inventory data of materials refer to average European production processes. The Life Cycle Impact Assessment has been based on various environmental impacts categories.

All the main assumptions of the study have been synthesized in Chapter 1.2.2.5. It is possible to observe that, concerning the base life cycle scenario:

- The use stage is the most relevant stage for the majority of the considered impact categories.
- The manufacture is dominating the Abiotic Depletion Potential (elements); it is very relevant for the Terrestric Ecotoxicity, Human Toxicity and Freshwater Aquatic Ecotoxicity potentials. Furthermore manufacture is relevant for all the other impact categories.
- The EoL is relevant (from 10% to 25%) for various impact categories.

Successively, different initial assumptions concerning the use stage and the product's lifetime of the HDD have been introduced. It is possible to observe that different assumptions about the use profile can largely modify product's ecoprofile. Furthermore, different scenarios about the product's lifetime can have a relevant incidence on some impact categories.

In line with the goal of the study it has been also analyzed more in detail the manufacturing to identify components that are responsible of relevant impacts. It has been estimated that the majority of the manufacturing impacts are related to the aluminium components and to the printed circuit board.

It has been also noted that the small quantity of gold is responsible of the majority of the environmental impacts in printed circuit board. In particular the gold manufacturing dominates the value of the Abiotic Depletion Potential (element) of the whole HDD. This result supports the conclusions of Deliverable 2: product's components can be negligible in terms of mass fraction but being relevant in terms of contributes to the product's overall environmental impacts.

It is therefore noted that different EoL assumptions and, in particular, the selective recycling of some product's components could grant relevant environmental benefits for some impacts categories. This topic will be investigated in detail in the next chapters.

2 Assessment of the potential requirements

2.1 Introduction

The Deliverable 2 has introduced and discussed the methodologies for the calculation and the verification (at the design stage) of some parameters (Reusability / Recyclability / Recoverability - RRR, recycled content, Use of priority resources and Use of hazardous substances). In particular:

- the measurement of the RRR is based on the analysis of the BOM of the product and on the analysis of the dismantling process;
- the measurement of the recycled content is based on the material breakdown and on declarations from manufacturers concerning the use of post-recycled materials in the production process;
- the prioritisation of the resources has been based on the potential benefits that can be achieved by reusing/recycling/recovering the materials;
- the assessment of the use of hazardous substances is based on the LCA methodology and the use of various environmental impact indicators.

These methodologies have been illustrated upon the case-study of an internal HDD for desktop computer. Deliverable 2 has also identified and discussed a list of potential illustrative Ecodesign requirements (Table 20). The present chapter will further discuss such requirements to estimate their relevance.

Note that the current analysis is not a complete impact assessment (i.e. it does not take into account, among others, the technical feasibility, the related costs and the technology implications), but it mainly serves as preliminary screening of the identified requirements on the basis of qualitative and, when possible, quantitative judgments.

Note also that the potential requirements here discussed are based on only one case-study product. However, the setting of requirements for a product category needs a more comprehensive analysis with the selection of various products.

Table 20 Potential Ecodesign requirements

n°	Requirements	Description	n°	Requirements	Description
1	Declaration of the Reusability Ratio (or teh Reusability Benefit Ratio)	The manufacturer has to declare the value of the Reusability Benefit Ratio of the product.	10	Manual disassembly of components containing hazardous substances	Components containing hazardous substances shall be easily and safely removable
2	Declaration of the Recyclability Ratio (or the Recyclability Benefit Ratio)	The manufacturer has to declare the value of the Recyclability Benefit Ratio of the product.	11	Content of hazardous substances into key components	Manufacturer has to declare the content of hazardous substances (regulated and unregulated) contained in the component.
3	Declaration of the Energy Recoverability Ratio (or the Energy Recoverability Benefit Ratio)	The manufacturer has to declare the value of the Energy Recoverability Benefit Ratio of the product.	12	Limit of hazardous substances	Target components heavier than X [g] shall not contain more than Y% by mass of substances that are classified with the following risk phrases: R45, R46, R60, R61, R50/53, R51/53 as defined in Council Directive 67/548/EEC
4	Threshold of the Reusability Ratio (or teh Reusability Benefit Ratio)	The product shall have a minimum Reusability Benefit Ratio of X%.	13	BOM	Manufacturers have to compile the BOM of the product and to make it available on request to surveillance authority
5	Threshold of the Recyclability Ratio (or the Recyclability Benefit Ratio)	The product shall have a minimum Recyclability Benefit Ratio of X%.	14	Identification of plastic components	Plastic components with a mass higher than X [g] shall be marked with a material code in accordance with the identification and marking requirements of ISO 11469:2000.
6	Threshold of the Energy Recoverability Ratio (or the Energy Recoverability Benefit Ratio)	The product shall have a minimum Energy Recoverability Benefit Ratio of X%.	15	Contamination of Plastics	Plastic enclosures shall not contain moulded-in or glued-on metal inserts unless these are easy to remove by one person alone with commonly available tools
7	Manual disassembly of the key components	Key components of the product shall be easily accessible to professionally trained recyclers in order to facilitate their removal.	16	'Mono-material'	Only one plastic material type shall be used in each plastic enclosure part with a mass higher than X [g]
8	Declaration of the recycled content of plastics.	Manufacturers have to declare the 'post-consumer' recycled content of plastic components.	17	Compatibility of labels with recycling.	Labels, inks, glues, adhesives and paints with a mass higher that X% of the component shall be compatible with the recycling, or they shall be easily removable without leaving residues that could interfere with the reuse/recycle/recovery
9	Threshold of the recycled content of plastics.	The product shall have at least X% of post-consumer recycled plastic content (measured as percentage of the overall mass of plastics components).			

2.2 Requirements concerning the Reusability, Recyclability and Recoverability

The first set of discussed requirements regards the indices related to the 'RRR Ratio' and to the 'RRR Benefits Ratio', as defined in the Deliverable 2 - Chapter 7. These requirements can be divided into three groups:

- the first group (req. n° 1, 2 and 3) requests that the manufacturers would declare the value of the *RRR* Ratio (or the *RRR* Benefit Ratio) indices of their product;
- the second group (req. n° 4, 5 and 6) fixes minimum thresholds of the *RRR* Ratio (or the *RRR* Benefit Ratio) indices that the manufacturers have to achieve;
- the third group (req. n° 7) requests that identified 'key components' should be easy to disassembly.

The first group of requirements aims to characterize the product. The declared values represent additional information provided to the stakeholders, without requiring any particular engagements from the manufacturer.

The second group of requirements, instead, sets minimum performance that the products have to achieve to be suitable for the commercialisation.

The third group instead focuses on the Reuse/Recycling/Recovery of some specific components that have been identified as critical for some reasons e.g. for the content of materials that can grants relevant benefits if reused/recycled/recovered.

The requirements about the *RRR* aim at improving the potential reuse/recycle/recovery of the products by, for example:

- the improvement of the 'disassemblability' of the components (especially 'key components' responsible of the highest environmental impacts);
- the reduction of the source of contamination among materials (e.g. adhesives, glues, paints, solders, etc.) that could interfere with the reuse/recycle/recovery of the materials;
- the substitution of initial materials with other materials that, for example, have a higher recyclability or recoverability.

It is important to highlight that some of the discussed Ecodesign requirements could lead to design measures that worsen the product's overall environmental life cycle performance. For example, the reuse of some EuP's components could cause higher energy consumption during the use phase.

In order to avoid potential 'shifting of burden' it is recommended the adoption of a life cycle check for some requirements as, for example, those fixing minimum thresholds concerning the 'RRR Ratio' and the 'RRR Benefit Ratio'[30].

Note that requirements about the 'RRR Ratio' and the 'RRR Benefits Ratio' can coexist. In fact, they aim at different targets: requirements on the RRR Ratio focus on the minimisation of the flow of waste (in mass), while requirements on the RRR Benefits Ratio focus on the maximisation of the potential benefits due to the reuse/recycling/recovery.

A further consideration regards the combined use of declarative and threshold requirements. The threshold requirements set the minimum values of the indices that have to be achieved. Manufacturers could go forward and reach, for example, higher values of the *RRR* Ratio indices. By declaring the values of the indices, manufacturers can better communicate to the users the effective achievement. Furthermore, the setting of declarative requirements could be preliminary / preparatory to the setting threshold requirements.

On the other side, the communication of the 'RRR Ratio' or of the 'RRR Benefit Ratio' indices alone could lead to incomplete/misleading information to the consumers. The reporting of the indices has, therefore, to be assessed case-by-case and additional information /explanations could also be required in order to communicate correctly the overall performance of the product (e.g. by jointly reporting life cycle based indices).

[30] For further details, see Deliverable 2 – Chapter 7.

2.2.1 Application of the *RRR* indices to the HDD case-study

The calculation of the RRR Ratios and the RRR Benefits Ratios to the HDD case-study resulted in the following figures:

- Reusability Ratio = 28.5%;
- Recyclability Ratio = 57.5%;
- Energy Recoverability Ratio = 63.9%;
- Reusability Benefit Ratio = 33.5%;
- Recyclability Benefit Ratio = 61.3;
- Energy Recoverability Benefit Ratio = 89.5%.

The RRR Ratio values are based on the mass fraction index of Deliverable 2- Chapter 2. As discussed, this mass based approach does not distinguish among different material but just focuses on the components with larger mass. Components with a small mass are, instead negligible, independent of the materials contained.

Requirement of the masse based RRR Ratio indices can be useful for the minimisation of the amount of waste flows but they not focus on the life cycle impacts of the materials. From the results of Chapter 1 it can be concluded that the recycling of general components is not relevant for the majority of the considered impact categories.

On the other side, Deliverable 2 points out that the attention shall be focused on the potential reuse/recycling/recovery of some ‘priority’ resources, meaning those resources that can grant the largest benefits when reused/recycled/recovered.

The following sections will focus the attention on the relevance of potential requirements about the RRR Benefits Ratio indices. The procedure illustrated in Deliverable 2 – Figure 18 has been applied to identify potential relevant Ecodesign requirements.

2.2.1.1 Requirements on the Reusability Benefits Ratio for the HDD case-study

The requirement n° 1 states that the manufacturer has to declare the value of the Reusability Benefit Ratio of the product. Similarly the requirement n° 4 states that “*the product shall have a minimum Reusability Benefit Ratio of X%*”. The percentage ’X’ should be set in function of the selected product category.

The scope of these requirements is to induce the manufacturers to design reusable parts that could be successively re-inserted into the manufacturing process of new product. Reusable components substitute primary materials in the production process causing lower environmental impacts.

The setting of thresholds for the reusability index has to derive from a detailed analysis of the products and production processes available in the market. However, the present analysis focuses only on an illustrative case-study and not on the whole product category. Information available on the products are, therefore, not sufficient to extract general considerations for the product categories. Furthermore the value of the reusability index has been calculated under some assumptions about the product reuse that, however, have been not confirmed by manufacturers[31]. Therefore requirements concerning the reusability are here assumed as not relevant for the considered case-study.

We also underline the criticality of requirements for the Reusability. Reusable components have, in fact, to be collected, tested and reinserted into the manufacturing chain for the production of new products. In some case (as for the product category of the HDD) the setting of reusability threshold could represent a constraint to the technological changes of the devices and the progressive miniaturisation of components.

Therefore the setting of requirements concerning the reusability has to be carefully investigated and discussed, involving manufacturers and designers.

2.2.1.2 Requirements on the Recyclability Benefits Ratio for the HDD case-study

The requirement n° 1 stated that the manufacturer has to declare the value of the Recyclability Benefit Ratio of the product. Similarly the requirement n° 5 states that "*the product shall have a minimum Recyclability Benefit Ratio of X%*".

The scope of such requirement is to induce the manufacturers to improve the recyclability of the products. The higher recyclability can support/facilitate the recycling of potential valuable materials that, otherwise, would have been differently treated (e.g. landfilled, etc).

The results of the HDD in Chapter 1 showed that the recycling of some components at the product's EoL can be relevant for some impact categories as the Abiotic Depletion Potential (elements). In particular this impact category is dominated by the manufacturing of the printed circuit board, due to the content of some relevant resources (the precious).

Requirements on the Recyclability Benefits Ratio could improve the recyclability of the product's key components. However, Chapter 3.5.2 of Deliverable 2 illustrated the methodology for the assessment of the Recyclability Benefit Ratio only upon the GWP impact category. Therefore, the setting of requirements on the Recyclability Benefits Ratio it is not relevant for the considered product category. Different results could be achieved by considering different impact categories.

[31] Assumptions about the reuse of HDD's components have been introduced in order to illustrate the methodology for the calculation of the reusability indices.

The attention has been therefore focused on potential requirements that could improve the manual disassembly and successively the recycling of ‘key components’ meaning those components that contain resources that can grant high benefits if recycled. For example, requirement n 7 states that: “*key components of the product shall be easily accessible to professionally trained recyclers (using the tools usually available to them) in order to facilitate their removal*”.

‘Disassemblability’[32] represents one of the most important factors that influence the RRR of a product. Often a component is not reused/recycled/recovered because of the difficulties for its disassembly. Even the costs related to the disassembly are one the constraints to identify components that can be separated or be disposed.

Mechanical dismantling by shredding is nowadays in Europe and other developed economies one of the most common technique for the dismantling of the products, because simpler and cheaper in comparison with the manual disassembly. On the other side, not all the materials can be separated during and after shredding. Furthermore, mechanical dismantling causes a large contamination among the materials with a sensible reduction of the materials potential for recycling/recovering. The shredding is also not compatible with the reuse of the components.

The manual disassembly grants, instead, a higher ‘quality’ of the separated components that can be reused or better recycled/recovered. On the other side, manual disassembly is not always viable due to the large required efforts/costs. The improvement of the manual disassembly of some components of the products is a key issue to improve the *RRR*.

On the basis of these considerations a further specific requirement for the Printed Circuit Board of the HDD has been introduced, based on the illustrative requirement n°7.

Requirement: Design for Disassembly of the Printed Circuit Board

The manufacturer shall demonstrate that the Printed Circuit Board can be easily dismantled by professionally trained personnel using the tools usually available to them, for the purpose of recycling of environmental relevant materials.

Verification:

The manufacturer shall provide to the market surveillance authority a declaration to this effect, together with appropriate supporting documentation, as follows:

- BOM
- Disassembly report (including the schemes of the printed circuit board within the HDD, details of the component fastening system, disassembly procedure, tools needed for disassembly).

[32] Disassemblability can be defined as the aptitude of a product to be manually decomposed in its constituting components.

Note that this requirement is also in line with the prescription of the WEEE Directive, which stated that "*as a minimum the following substances, preparations and components have to be removed from any separately collected WEEE: […] printed circuit boards of mobile phones generally, and of other devices if the surface of the printed circuit board is greater than 10 square centimeters*" [EU, 2002]. The above introduced requirement could contribute to simplify/facilitate the separation of the component for its recovery.

In the presented HDD case-study it has been observed that the circuit board is easy to identify and remove. This is in fact assembled at the bottom of the HDD by means of three screws. An overall, the manual disassembly of the HDD can be done in 56 seconds (Table 23).

Table 21 Detail of the manual disassembly of the Printed Circuit Board of the HDD

Component number	Name	Mass [g]	Note	Disassembly Procedure	Disassembly time [s]
1	Printed Circuit Board	43	Content of resources with high benefits if recycled: gold (0.02 g); silver (0.02 g)	Unscrew 3 torx screws	56

In order to assess the relevance of this requirement, an additional EoL scenario has been considered for the LCA of the HDD. This will be analyzed in the following chapter.

2.2.1.2.1 Improved EoL scenario for the LCA of the HDD case-study

The present chapter analyzes the 'improved EoL scenario' of the HDD. The scenario is analogous to the 'base-case' except for some new assumptions concerning the EoL of the HDD. It is assumed that an improved 'disassemblability' of the product can simplify the manual separation and the recycling of the product's components.

The new EoL scenario of the HDD considers that:

- the printed circuit board is removed from the HDD and addressed to a selective recycling of some metals (especially gold, silver);
- the ABS plastic of the circuit board is incinerated with energy recovery. Other residuals materials from the circuit board are landfilled;
- the other components of the HDD are made by aluminium (except some minor parts in made by steel and a very small plastic component). Therefore metals can be separated by shredding and successively recycled;
- Packaging is incinerated with energy recovery.

In particular, it is assumed that the following recycling figures are achieved:

- Recycling of precious metals in the circuit board (gold and silver): 95%
- Recycling of aluminium: 90%.

Other assumptions are in line with the base-case described in Chapter 1.2.2.2.5.

Table 22 and 23 and figure 2 illustrate the results. It is possible to observe that the improved EoL scenario[33] can grant relevant contribution, in terms of credit of impacts, for the following impact categories:

- Abiotic Depletion Potential (elements);
- Freshwater Aquatic Ecotoxicity potential;
- Terrestric Ecotoxicity.

In particular the new scenario influences in a dominant way the Abiotic Depletion Potential-ADP (elements). It means that the selective recycling of the circuit board can grant a saving up to about 90% of the impacts due to manufacturing[34].

It is therefore concluded that the requirement suggested in Chapter 2.2.1.2 can contribute relevantly to the reduction of the impacts of the case-study product.

Table 22 Life Cycle Impact Assessment of the HDD 'improved EoL scenario'[35]

		Abiotic Depletion Pot. (elements)	Abiotic Depletion Pot. (fossil fuels)	Acidification Potential	Eutrophication Potential	Freshwater Aquatic Ecotoxicity Pot.	Global Warming Potential	Human Toxicity Potential	Ozone Depletion Potential	Photochem. Ozone Creation Pot.	Terrestric Ecotoxicity Potential
		[kg Sb_{eq}]	[MJ]	[kg $SO2_{eq}$]	[kg $Phosphate_{eq}$]	[kg DCB_{eq}]	[kg $CO2_{eq}$]	[kg DCB_{eq}]	[kg $R11_{eq}$]	[kg $Ethene_{eq}$]	[kg DCB_{eq}]
HDD 'improved EoL' scenario	Manufacture	1.3E-03	8.6E+01	5.6E-02	2.5E-03	1.4E-01	8.3E+00	1.9E+00	9.4E-07	4.4E-03	3.3E-02
	Use	2.4E-06	3.7E+02	2.8E-01	9.3E-03	1.0E-01	3.6E+01	3.1E+00	8.8E-06	1.4E-02	4.9E-02
	Manufacture + Use	**1.3E-03**	**4.6E+02**	**3.4E-01**	**1.2E-02**	**2.4E-01**	**4.4E+01**	**5.0E+00**	**9.7E-06**	**1.8E-02**	**8.2E-02**
	End-of-life	-1.1E-03	-5.3E+01	-3.8E-02	-1.6E-03	-1.1E-01	-5.4E+00	-1.5E+00	-5.0E-07	-3.1E-03	-2.8E-02
	Total	***1.5E-04***	***4.0E+02***	***3.0E-01***	***1.0E-02***	***1.3E-01***	***3.9E+01***	***3.5E+00***	***9.2E-06***	***1.5E-02***	***5.4E-02***

Table 23 Relevance of the life cycle stages in 'improved EoL' scenario[36]

		Abiotic Depletion Pot. (elements)	Abiotic Depletion Pot. (fossil fuels)	Acidification Potential	Eutrophication Potential	Freshwater Aquatic Ecotoxicity Pot.	Global Warming Potential	Human Toxicity Potential	Ozone Depletion Potential	Photochem. Ozone Creation Pot.	Terrestric Ecotoxicity Potential
HDD 'improved EoL' scenario	Manufacture	99.8%	18.8%	16.7%	21.3%	58.0%	18.6%	37.4%	9.7%	24.0%	40.1%
	Use	0.2%	81.2%	83.3%	78.7%	42.0%	81.4%	62.6%	90.3%	76.0%	59.9%
	End-of-life	-88.2%	-11.5%	-11.4%	-13.9%	-46.1%	-12.1%	-29.7%	-5.2%	-17.1%	-33.9%

Legend

Relevance	
Not relevant	**[0; 10%]**
Relevant	**[10; 30%]**
Very relevant	**[30; 70%]**
Dominant	**> 70 %**

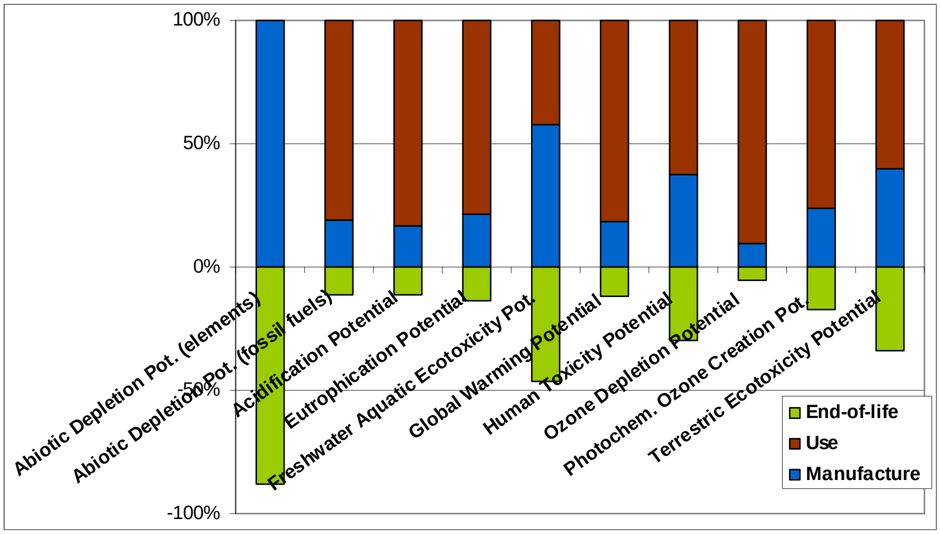
[33] It is reminded that the negative values of the EoL correspond to the potential environmental benefits (credits) that can be achieved for each impact category by the recycling. The impacts due to EoL refer to assumptions in Chapter 1.2.2.4.

[34] The contribution of the use stage to the ADP elemental is negligible.

[35] Note that the results here presented are only illustrative and they are not suitable for general judgments upon the investigated product category.

[36] Percentages are calculated with respect to the sum of impacts due to manufacture and use.

Figure 2 Improved EoL scenario in the LCA of the HDD: percentage contribution to each impact categories[37]



2.2.1.3 Requirements on the Energy Recoverability Benefits Ratio for the HDD case-study

The requirement n° 3 stated that the manufacturer has to declare the value of the Energy Recoverability Benefit Ratio of the product. Analogously, the requirement n° 6 states that "*the product shall have a minimum Energy Recoverability Benefit Ratio of X%*".

The scope of such requirement is to improve the recoverability of the product. It means that the potential recoverable components are not mixed / contaminated with other materials and they can be easily separated for incineration or other recovery alternatives.

The feedstock energy contained into materials could be incinerated with heat recovery to use, for example, for the production of electricity. However the analysis of chapter 1 has demonstrated that the use stage of the product largely dominated the energy balance throughout the product's life cycle.

The potential environmental benefits achievable thought recoverability requirements are therefore not relevant for the considered case-study of HDD. The product is, in fact, mostly constituted by metals parts.

Therefore, requirements on the recoverability are assessed as not relevant for the HDD case-study. However this conclusion cannot be generalized. Other product categories could have larger amount of potential recoverable components, and the energy recovery of components could be potentially relevant.

[37] Percentages are calculated with respect to the sum of impacts due to manufacture and use.

2.3 Requirements concerning the Recycled content

The requirements n° 8 and 9 refer to the recycled content of the product. The scope of these requirements is to push manufacturers to use secondary materials that otherwise would have been differently treated (e.g. landfilled) because they are not 'attractive' for the recycling due to their low market value or the low market demand. The increase of the recycling content of the product aims at reducing the impacts during the manufacturing stage.

Analogously to the *RRR*, the requirements on recycled content can be subdivided into two groups: the first relates to declarations provided by the manufacturer about the recycled content of product's components, while the second group refers to minimum thresholds of recycled content that have to be achieved.

According to the procedure described in Deliverable 2, manufacturer has to acquire information from the suppliers in order to assess the percentage of recycled content of the product's materials. If the minimum threshold is not achieved, manufacturer has to change suppliers or/and to purchase materials/assemblies with a higher recycled content. Alternatively, the manufacturer could change the design of the product to select different materials or assemblies.

2.3.1 General considerations about 'Recycled content' requirements

The Deliverable 2 illustrated the methodology for the assessment and verification of the recycled content. The Deliverable also discussed about the opportunity to avoid requirement concerning the recycled content of the whole product, setting instead requirements concerning specific components or materials. The scope is to promote the recycling of materials that generally, for economic or technical reasons, are not recycled but incinerated or disposed to landfills.

Some potential target materials for 'recycled content' requirements are for example:

- Materials that have been identified as 'priority' for some specific problems (e.g. supply-risks);
- Materials generally not recycled because of some barriers (e.g. costs or limited consumer acceptance). In particular, requirements about the recycled content should mainly regard materials that have a very low market value after the recycling compared to the primary material and where hence landfilled / incinerated. The setting of recycled content requirements could contribute to increase the demand of recycled material.

A further note concerns the potential adoption of declarative requirements on Recycled content (as requirement n° 8). These requirements can be complementary to the threshold requirements because they allow communicating to the user the precise level of achieved recycled content of the components. Furthermore, the setting of declarative requirements could be preliminary / preparatory to the setting threshold requirements.

However the communication of the 'recycled content' index alone could lead to incomplete/misleading information to the users. The adoption of declarative requirements has to be assessed case-by-case and additional information about the product life cycle could be requested in order to correctly communicate the effective performance of the product.

2.3.2 Requirements concerning the recycled content for the HDD case-study

Following the considerations in the previous chapter, plastics are potential target materials for recycled content requirements in the HDD case study.

The analysis of the HDD, however, showed that plastic components are negligible in terms of mass and in terms of contribution to the product's ecoprofile. For that reason the setting of requirements on the recycled content for the HDD case-study (without packaging) is not relevant.

However this conclusion cannot be generalized. The requirement could be potentially relevant for other product categories with a larger amount of plastics components.

Note also that other potential target materials for recycled content requirement can be indentified for other product categories as, for example, technical glass.

2.4 Requirement concerning the use of hazardous substances

Deliverable 1 and 2 have discussed the relevance of the content of hazardous substances in a product and their relation to other product's characteristic including the influence to the *RRR*.

The RoHS directive regulated the content of: lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE). The RoHS Directive, however, introduced some exemptions: some products can contain limited quantities of these hazardous. Products and components contaminated by these substances should be carefully handled and managed at their EoL. The presence of such hazardous substance can reduce, and in some case reset, the potential *RRR* of the components.

Furthermore, several other potentially toxic substances[38], although not restricted by the European legislation, are currently used for the manufacturing of products. These substances could be included in the future to the list of regulated/restricted substances.

The requirements about the use of hazardous substances can be therefore grouped in three categories:

- Requirements concerning the disassembly of key components (those containing the hazardous substances
- Requirements concerning the declaration of the content of hazardous substances (including, for example, a detailed BOM of the product or of some components);
- Requirements concerning the maximum quantity of hazardous substances in use in a product (or its components).

The first two categories include illustrative/declarative requirements.

The last category, instead, is based on thresholds requirements, similar for example to those set by the RoHS Directive. The main difference is that such requirements could be targeted to the limitation of other potential substances that have been not regulated yet.

For example, the survey of the scientific literature points out that flame retardants[39] represent a 'critical' category of substances for Energy Using Product and, in particular, for electric and electronic products. Flame retardants are largely employed to reduce the risk of combustion of the plastic components. However, various flame retardants currently adopted are classified with several risk phrases[40], including:

- R45: May cause cancer.
- R46: May cause heritable genetic damage
- R50/53; Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.

[38] For example the Substances of Very High Concern (SVHC) on the basis of the REACH Regulation EC 1907/2006

[39] A list of toxic substances not regulated by the RoHS Directive is presented by [Öko-Institut, 2008].

[40] Risk phrases have been regulated by the Council Directive 67/548/EEC and successively modified by the Commission Directive 2001/59/EC.

- R51/53: Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.
- R60: May impair fertility.
- R61: May cause harm to the unborn child.

Therefore, an exemplary and illustrative requirement concerning the reduction of the use of hazardous substances can be structured as follows (Requirement n° 12):

> "Target components *heavier than X [g] shall not contain more than Y% in mass of substances that are classified with the following risk phrases: R45, R46, R50/53, R51/53, R60, R61, as defined in the Directive 2006/121/EC*".

Thresholds 'X' and 'Y' of the previous requirement should be set case-by-case, depending on the considered product category. For example they could be referred to 'plastic parts' as target components, and to flame retardant as target substances. Similar requirements have been set in the EU-Ecolabel criteria for some product categories.

The Ecolabel criteria generally set a threshold 'X=20 grams' and the threshold 'Y=0.1%'. however, it is underlined that the Ecolabel criteria identifies the environmental "excellence" while Ecodesign requirements aim at setting the minimum environmental performance that products should achieve. For that reason, for some the Ecodesign requirements the 'Y' thresholds should fix higher thresholds (e.g. Y= 1%).

It is important to remind that the use of some substance can have some specific function in the product. For example the use of flame retardants into product is necessary to accomplish to safety requirements. Another example is represented by the use of mercury into CFL that allow lower energy consumptions during the use phase.

Therefore, requirements on the threshold of hazardous substances have to be preliminarily assessed with a 'life cycle' approach, comparing different alternative technologies and/or assessing the use of other replaceable substances.

Declarative/descriptive requirements on the use of hazardous substances can be useful to identify potential key components (those containing relevant quantities of hazardous substances). This additional information can be useful for the handling of the component at the product's EoL. An exemplary of requirement is:

> *"Manufacturer has to declare the content of hazardous substances contained in the component. The listed substances should include substances regulated by European Directives and Regulation (e.g. RoHs or REACH) and substances classified with the following risk phrases: R45, R46, R60, R61, R50/53, R51/53 as defined in Council Directive 67/548/EEC"*.

Finally some requirements about the manual disassembly of key components could be defined, in order to improve the recovery of the components:

> *"Components containing hazardous substances shall be easily and safely removable"*.

The requirement is conceptually similar to the declarative requirements discussed in the previous chapter 2.2.1.2 about components containing priority materials for recycling. Even in this case it is required a description of the manual disassembly of the component, with annexed technical documentation including, for example:

- details of the component and of the fastening systems;
- procedures for the manual disassembly (with particular care to potential risk for the disassemblers);
- list of the required tools for the manual disassembly.

2.4.1 Requirements concerning the use of hazardous substances for the HDD case-study

The BOM of case-study HDD revealed the presence of some regulated and not regulated substances. In particular:

- The use of mercury (1.4 10^{-6} [g]) and cadmium (1.1 10^{-4} [g]) in the printed circuit board.
- The Tetrabromobisphenol A (TBBP-A), used as flame retardant for the printed circuit board. According to the scientific studies TBBP-A is classified as R50/53 [Öko-Institut, 2008]. Although the TBBP-A is not a regulated substance and it does not fulfil the criteria for Substances of Very High Concern (SVHC), there are indications of potential effects on the endocrine system in some in vitro tests with aquatic organisms. Furthermore, TBBP-A is considered to be 'persistent' or potentially 'very persistent'.

It is however noted that the content of regulated substances in the HDD is largely under the thresholds in weight for homogeneous materials as fixed in the EU legislation [EC, 2005].

Concerning the potential hazardous substances not regulated, the TBBP-A used in epoxy resin for printed circuit board can be potentially substituted by other non-toxic flame retardants as DOPO (Dihydrooxaphosphaphenantrene) or Poly(1,3-phenylene methylphosphonate) [Öko-Institut, 2008]. However the data here discussed are not enough to support the establishment of some Ecodesign requirement about the limitation of this substance.

Requirements concerning the manual disassembly of printed circuit board could be set analogously to the requirement for the recycling of the priority resources (note that in the present case study, the printed circuit board is a key component for both the priority resources and use of hazardous substances). Therefore the same requirement could aim to different targets.

Analogously, the content of potential hazardous substances in the product is not relevant also for the introduction of other declarative/descriptive requirements.

2.5 Additional requirements

The following section analyzes the additional requirements described in Deliverable 2 – chapter 7.3. These requirements are targeted to various project's parameters simultaneously, and in particular, to RRR, to the use of priority resources and to use of hazardous substances.

The requirements are based on similar criteria introduced in some environmental labelling schemes (as the EU Ecolabel or the IEEE standard n° 1680.1 [IEEE, 2009]).

Note that these additional requirements are only illustrative and they have been introduced as potential prototypes of requirements for the improvement of the resource efficiency and waste management. The assessment of the requirements requires also the analysis of the technical/technological feasibility, which is however out of the scope of the present deliverable.

2.5.1 Requirements concerning the characterisation of the product

The Deliverable 2 discussed the key issues related the *RRR* of a product. In particular, the characterization of the product and its components has been recognised as one on the most important prerequisite for the improvement of the *RRR* of the product. A component that can be easy identified and separated is the first step for its diverting from the waste flow and separately treated. Furthermore, a detail of the product composition can be useful to identify the content of priority resources or hazardous substances.

Some requirements have been introduced aiming at improving the characterisation of the product.

For example, requirement n° 13 assumes that *manufacturers have to compile the BOM of the product and make it available on request to the stakeholders*[41].

Target stakeholders could include the surveillance authorities but, also, the general disclosure of the information to the public. In this case the BOM could be also available as part of the product's manuals or as additional file in the company's website. A BOM available to the public could be particular useful for recyclers to know the product composition and to identify product's components suitable for reuse/recycle/recovery.

Requirements n° 14 states that "*plastic components with a mass higher than X [g] shall be marked with a material code in accordance with the identification and marking requirements of ISO 11469:2000*".

This typology of requirement characterises the product's components by marking instead than by additional paper. Compared to the previous requirement n° 13, the use of a coded marking (as that introduced by the ISO 11469 for plastics) is easier to apply and it has been also introduced by some schemes for the environmental certification of electronic products[42].

[41] Details about information to be provided is Deliverable 2 - Chapter 7.3.
[42] For example, the IEEE standard n° 1680.1 [IEEE, 2009].

It is assumed that the marking could contribute to the separation of the plastics and their recovery.

Similar requirements could be potentially set for the marking of other materials potentially worth for the recovery (e.g. components containing priority resource or hazardous substances).

2.5.2 Requirements concerning the contamination of the materials

Contamination is one of the causes of the material degradation and the loss of the potentials for reuse/recycle/recovery. The previous chapters 2.4 already discussed the issue of the contamination by hazardous substances. The present chapter considers, instead, other potential sources of contamination.

The scientific literature on the Ecodesign suggests the use of 'mono-material' components as one of the feasible strategies to improve the recyclability of the products.

It has been observed in Deliverables 1 and 2 that plastic components are those generally most depreciated by contamination. Multi-plastics components cannot be generally separated mechanically while plastic residues from shredding are generally largely contaminated by other materials, including other polymers, being in some cases not suitable for the recycling[43].

Furthermore, labels, glues, paints and adhesives are other examples of common sources of contamination. These contaminants can interfere with the manual disassembly of the components and their treatment at the EoL.

Examples of requirements about contamination have been included in the EU Ecolabel criteria, as the follows:

- (*for Personal Computers*) "plastic parts shall be of one polymer or compatible polymers, except for the cover, which shall consist of no more than two types of polymers which are separable and uncoated with, for example, paint";
- (*for televisions*): "plastic parts shall be of one polymer or be of compatible polymers for recycling";
- (*for Personal Computers and Vacuum cleaners*): "plastic parts shall contain no metal inlays that cannot be separated by a single person using simple tools".

The following paragraphs illustrate some potential Ecodesign requirements for the reduction of contamination:

- Requirement 15: "*Plastic enclosures shall not contain moulded-in or glued-on metal inserts unless these are easy to remove by one person alone with commonly available tools*",

[43] Examples of plastic mixes not compatible with the recycling have been provided in Deliverable 2 - Table 9.

- Requirement 16 states that "*Only one plastic material type shall be used in each plastic enclosure part with a mass higher than X [g]* [44]", and
- Requirement 17 states that "*Labels, inks, glues, adhesives and paints with a mass higher that X%*[45] *of the component shall be compatible with the recycling, or they shall be easily removable without leaving residues that could interfere with the reuse/recycle/recovery*".

It is important to note that the Ecolabel criteria apply to all the plastic components while, for example, the illustrative requirement n° 16 applies only to plastics over a minimum threshold mass. This threshold should be set 'case-by-case' on the basis of the considered product category.

Requirement n° 15 is an example of requirement for the prevention of contamination. The requirement is based on a similar criteria introduced by the IEEE standard 1680.1 for the "Environmental Assessment of Personal Computer Products".

Finally requirement n° 17 identifies labels or adhesives as one of the most common sources of contamination. Several labels fully compatible with the recycling of plastics and paper are nowadays produced[46]. Ecodesign requirements could be therefore introduced to foster manufacturers and designer to the choice of compatible materials, in order to improve Reusability and Recyclability of the products.

[44] The threshold mass should be defined case-by-case
[45] The threshold mass should be defined case-by-case
[46] For example, see a detailed discussion in [Onusseit, 2006].

2.6 Summary

The present chapter describes and analyzes the Ecodesign requirements introduced in Deliverable 2 – Chapter 7. In particular, the scope of the analysis is the discussion of the characteristics of the requirements and the assessment of their potential relevance for the HDD case-study.

Requirements concerning the mass-based RRR Ratios have been assessed as not relevant for the HDD case-study.

Instead, potential relevant requirements concern the RRR Benefits Ratio (focusing on the recycling of key components that could grant the largest environmental benefits). In particular, the improvement of the manual 'disassemblability' of the printed circuit board has been identified relevant for the HDD. Following a life-cycle approach, the analysis has demonstrated that an improved and selective recycling of the circuit board could produce very large environmental benefits of the Abiotic Depletion Potential (elements), and relevant benefits related to other impact categories (Freshwater Aquatic Ecotoxicity and Terrestric Ecotoxicity).

Other potential requirements concerning the RRR have been considered not relevant in the HDD case-study, and in particular:

- Requirements on the reusability could interfere with the product's energy consumption or the technological development (e.g. the miniaturisation of the components)
- Requirements on the energy recoverability are not relevant because the low content of energy recoverable parts.
- Requirements on the recycled content are not relevant for the almost null content of plastics into components;
- Requirements on the use of hazardous substances are not relevant for the low content of hazardous substances (both regulated and not regulated).

The chapter also describes the potential benefits that could be achieved by improving the description/characterisation of the product composition, by the identification and marking of recyclable part (e.g. plastics), and by reduction of the contamination among different materials.

Final Conclusions and Recommendations

The deliverable discusses the potential Ecodesign requirements introduce in Deliverable 2, in relation with the life cycle impacts of the considered case-study product: an internal Hard Disk Drive (HDD) for desktop computer. The assessment has been based on qualitative and, when possible, quantitative estimations.

Life Cycle Assessment (LCA) of the HDD

The first part of the Deliverable illustrates the LCA of the HDD, assessing the main environmental impact categories and the contribution of each life cycle stage. Successively the assessment has been also extended to the estimated number of HDD in use in the EU-27.

The main outcomes of the LCA are:

- the 'use stage' is very relevant for the majority of the impacting categories; manufacturing dominates the Abiotic Depletion Potential (element) and contributes relevantly to all other impact categories. The EoL has is relevant (from 10% to 25%) for various impact categories;
- the sensitivity analysis has been performed to assess the incidence of some initial assumptions including: the user profile ('office use' and 'home use' scenarios), the energy consumption, and the useful life of the HDD. The analysis points out that the results of the use stage are largely influenced by the initial assumptions;
- alternative scenarios that affect the manufacturing stage can influence in a relevant way some impacts categories and, in particular, the Abiotic Depletion Potential (element).

The LCA has also identified the following 'key components' of the HDD:

- The manufacturing of the Printed Circuit Board is the main contributor to several impacts categories as Abiotic Depletion Potential (elements), Freshwater Ecotoxicity, Terrestric Ecotoxicity;
- The aluminium components are responsible of the largest impacts during manufacturing for the following impact categories: Global Warming, Acidification, Photochemical Ozone Creation and Human Toxicity potentials.

The Life Cycle Impact Assessment also illustrates that the gold into the circuit board, although negligible in term of mass, largely affects the environmental impacts of the printed circuit board and of the whole product. This result confirms the considerations already presented and discussed in Deliverable 2: some components could be not relevant in terms of mass but relevant in terms of environmental impacts.

Analogously, the recovery of some specific materials (as gold in the circuit board) could grant relevant benefits for some considered impact categories. This conclusion has been applied successively for the assessment on a new 'improved EoL' scenario, in relation with a potential Ecodesign requirement on the improvement of the manual disassembly of the circuit board.

Requirements about Reusability, Recyclability, Recoverability

Requirements concerning the RRR can focus on the RRR mass-based Ratio or the RRR Benefits Ratios as defined in Deliverable 2. The structure of the requirements can be as follows:

- Declarative requirements of the value of the RRR Ratios (or the RRR Benefit Ratios) for the considered product;
- Thresholds on the values of the of the RRR Ratios (or the RRR Benefit Ratios) for the considered product;
- improvement of the 'disassemblability' of key components (those containing materials that can grant relevant benefits if reused/recycled/recovered).

It is noted that requirements about the RRR Ratios and the RRR Benefits Ratios can coexist. In fact, they aim at different targets: requirements on the RRR Ratios focus on the minimisation of the waste masses while requirements on the RRR Benefits Ratios focus on the maximisation of the potential benefits due to the reuse/recycling/recovery.

It is possible the combined use of declarative and threshold requirements concerning the RRR. The threshold requirements set the minimum values of the indices that have to be achieved. Manufacturers could go forward and reach higher values of the RRR indices. By declaring these indices, manufacturers can better communicate to the users the effective achievement. Furthermore, the setting of declarative requirements could be preliminary / preparatory to the setting threshold requirements.

On the other side, the communication of the '*RRR* indices' alone (or of the '*RRR* Benefit Ratio indices' alone) could lead to misleading information to the consumers. The reporting of the *RRR* indices has to be assessed case-by-case and additional information could also be required in order to communicate correctly the overall performance of the product.

Requirements concerning the mass-based RRR Ratios have been assessed as not relevant for the HDD case-study.

Instead, potential relevant requirements concern the RRR Benefits Ratio (focusing on the recycling of key components that could grant the largest environmental benefits). In particular, the improvement of the manual 'disassemblability' of the printed circuit board has been identified relevant for the HDD. Following a life-cycle approach, the analysis has demonstrated that an improved and selective recycling of the circuit board could produce very large environmental benefits for the Abiotic Depletion Potential (elements), and relevant benefits related to other impact categories (Freshwater Aquatic Ecotoxicity and Terrestric Ecotoxicity).

Other potential requirements concerning the RRR have been considered not relevant in the HDD case-study, and in particular:

- Requirements on the reusability could interfere with the product's energy consumption or the technological development (e.g. the miniaturisation of the components)
- Requirements on the energy recoverability are not relevant because the low content of energy recoverable parts.

Requirements on the Recycled content

Concerning the Recycled content, potential target materials for Ecodesign requirements are:

- Materials identified as "priority" for some specific problems (e.g. supply-risk);
- Materials generally not recycled because of some barriers (e.g. costs or limited consumer acceptance). In particular, requirements about the recycled content should mainly regard materials that have a very low market value after the recycling compared to the primary materials. The setting of recycled content requirements could contribute to increase the demand of the recycled material.

Concerning the HDD case-study, potential target materials for 'recycled content requirements' are the plastics used into some components and packaging. However, due to the low content of plastics in the product, recycled content requirements are not relevant.

Requirements on hazardous substances

Requirements concerning the use hazardous substances can be based on:

- declaration/detail of the content of hazardous substance in the product (or some specific components)
- improvement of the manual 'disassemblability' of components containing the hazardous substances
- limitation of the sue of the hazardous substance in the product (or some specific components)

However, threshold requirements on the use of hazardous substances should consider in detail the technical feasibility, the specific function of the substance in the product (e.g. the use of flame retardants in the product to reduce the fire risks) and the availability of replaceable substances not hazardous.

Some illustrative requirements have been therefore discussed. However, due to the low content of hazardous substances (both regulated and not regulated) in the HDD, no relevant threshold Ecodesign requirements have been identified. A declarative/illustrative requirement could be set about the disassembly of the circuit board, in analogy to that previously illustrated for the improvement of the recyclability.

Additional requirements on the characterisation of the product (or some components) and the reduction of the contamination sources

The last part of the deliverable discusses some potential requirements concerning the characterisation of the product (or the identification of key components) or the reduction of contamination sources. The detailing of product's component and the reduction of contaminations are some feasible strategies to improve the RRR, to identify key components (for their content of priority resources or hazardous substances) and to better manage potential harmful components during the product's EoL.

The additional requirements are, however, not relevant for the HDD case-study. The requirements have only illustrative purposes and they have been introduced as potential 'prototypes' for the improvement of the resource efficiency and waste management (also in line with similar requirements introduced by some international environmental labelling schemes).

Finally it is important to remind that the present deliverable has mainly an illustrative purpose, discussing how the proposed methodologies and the potential Ecodesign requirements could affect the life cycle performance of the case-study product. Further developments are, however, needed especially to identify other sectors in which the improvement potentials could be significant.

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Annex 1: Life Cycle Inventory of the HDD (summary)

Table A1.1 Life Cycle Inventory of HDD (base case-study): Inputs - Main Energy resources

INPUT - Energy resources (not renewable)	[kg]
Crude oil (resource)	1.3E+00
Hard coal (resource)	5.4E+00
Lignite (resource)	9.7E+00
Natural gas (resource)	2.9E+00
Uranium (resource)	5.7E-04

Table A1.2 Life Cycle Inventory of HDD (base case-study): Inputs - Main non renewable resource

INPUT - Material resources (non renewable elements)	[kg]
Aluminum	3.7E-04
Cadmium	2.9E-06
Cerium	-1.4E-19
Chromium	2.9E-04
Cobalt	1.1E-09
Copper	8.2E-05
Fluorine	8.0E-07
Gallium	2.0E-13
Gold	2.2E-05
Indium	8.4E-10
Iron	5.4E-03
Lanthanides	8.8E-20
Lead	3.2E-06
Magnesium	1.2E-06
Manganese	1.0E-05
Mercury	3.0E-08
Molybdenum	1.2E-05
Neodymium	-2.0E-19
Nickel	1.0E-03
Palladium	2.6E-10
Phosphorus	8.9E-06
Platinum	1.4E-11
Praseodymium	-6.6E-21
Rhenium	2.1E-12
Rhodium	6.1E-12
Samarium	-1.2E-20
Silicon	3.7E-12
Silver	2.3E-05
Sulphur	8.2E-05
Tantalum	1.4E-09
Tellurium	1.9E-10
Tin	1.3E-07
Zinc	8.8E-05
Zirconium	1.9E-09

Table A1.3 Life Cycle Inventory of HDD (base case-study): Outputs – Main emissions to air (heavy metals)

OUTPUTS - Emissions to air (heavy metals)	[kg]
Antimony	1.8E-06
Arsenic (+V)	3.3E-06
Arsenic trioxide	8.1E-13
Cadmium (+II)	2.5E-07
Chromium (+III)	1.1E-09
Chromium (+VI)	2.5E-08
Chromium (unspecified)	2.7E-06
Cobalt	7.4E-07
Copper (+II)	4.4E-06
Heavy metals to air (unspecified)	7.9E-09
Hydrogen arsenic (arsine)	6.7E-11
Iron	5.0E-07
Lanthanides	3.0E-12
Lead (+II)	8.5E-06
Manganese (+II)	5.8E-06
Mercury (+II)	1.3E-06
Molybdenum	1.7E-08
Nickel (+II)	8.9E-06
Palladium	1.1E-14
Platinum	2.2E-14
Rhodium	1.1E-14
Selenium	9.9E-06
Silver	5.5E-11
Tellurium	1.5E-10
Thallium	4.4E-09
Tin (+IV)	3.1E-06
Titanium	2.1E-08
Vanadium (+III)	2.1E-05
Zinc (+II)	1.8E-05

Table A1.4 Life Cycle Inventory of HDD (base case-study): Outputs – main inorganic emissions to air

OUTPUTS - Emissions to air (inorganic)	[kg]	OUTPUTS - Emissions to air (inorganic)	[kg]
Ammonia	4.0E-04	Hydrogen phosphorous	4.3E-09
Ammonium	4.9E-10	Hydrogen sulphide	6.0E-04
Ammonium carbonate	7.6E-11	Iodine	1.1E-07
Ammonium nitrate	3.1E-11	Isocyanide acid	1.6E-09
Argon	2.5E-14	Lead dioxide	1.8E-11
Barium	2.2E-05	Magnesium	8.4E-11
Beryllium	1.0E-07	Nitrate	2.7E-08
Boron	1.8E-06	Nitrogen (atmospheric nitrogen)	3.0E-03
Boron compounds (unspecified)	9.9E-05	Nitrogen dioxide	2.1E-04
Boron trifluoride	1.9E-18	Nitrogen monoxide	6.4E-10
Bromine	4.2E-05	Nitrogen oxides	7.5E-02
Carbon dioxide	3.7E+01	Nitrous oxide (laughing gas)	9.2E-04
Carbon dioxide (biotic)	1.4E-02	Oxygen	2.1E-02
Carbon dioxide (biotic)	4.2E-02	Ozone	1.3E-06
Carbon dioxide, land transformation	6.3E-04	Phosphorus	3.8E-08
Carbon disulphide	2.6E-06	Scandium	8.5E-11
Carbon monoxide	2.1E-02	Silicium tetrafluoride	8.9E-12
Carbon monoxide (biotic)	1.0E-04	Sodium chlorate	2.5E-10
Chloride (unspecified)	7.4E-06	Sodium dichromate	6.5E-10
Chlorine	5.1E-06	Sodium formate	9.5E-09
Cyanide (unspecified)	3.2E-06	Sodium hydro	2.2E-10
Fluoride	4.2E-05	Steam	1.1E+02
Fluorine	1.6E-08	Strontium	3.2E-08
Helium	3.4E-07	Sulphate	1.5E-10
Hexaflourosilicates	9.6E-09	Sulphur dioxide	2.2E-01
Hydrogen	5.4E-04	Sulphur hexafluoride	2.0E-08
Hydrogen bromine (hydrobromic acid)	9.7E-08	Sulphur trioxid	-2.1E-10
Hydrogen chloride	4.3E-03	Sulphuric acid	1.8E-07
Hydrogen cyanide (prussic acid)	8.5E-09	Tin oxide	1.6E-12
Hydrogen fluoride	3.7E-04	Zinc oxide	3.2E-12
Hydrogen iodide	1.1E-10	Zinc sulphate	1.6E-09

Table A1.5 Life Cycle Inventory of HDD (base case-study): Outputs – Main emissions to air (VOC)

OUTPUTS - Emissions to air (organic VOC)	[kg]
Hydrocarbons (unspecified)	1.3E-04
Methane	7.4E-02
Methane (biotic)	3.5E-05
Organic chlorine compounds	1.0E-07
Polycyclic hydrocarbons	4.6E-26
VOC (unspecified)	1.3E-05

Table A1.6 Life Cycle Inventory of HDD (base case-study): Outputs – Main emissions to air (particles)

OUTPUTS - Emissions to air (particles)	[kg]
Aluminum	6.1E-04
Dust (> PM10)	1.5E-04
Dust (PM10)	9.6E-04
Dust (PM2,5 - PM10)	5.2E-05
Dust (PM2.5)	6.3E-03
Dust (unspecified)	4.2E-03
Ethyl cellulose	8.0E-11
Metals (unspecified)	2.4E-06
Wood (dust)	5.9E-10

Table A1.7 Life Cycle Inventory of HDD (base case-study): Outputs – Main emissions to air (other)

OUTPUTS - Emissions to air (other)	[kg]	OUTPUTS - Emissions to air (other)	[kg]
1-Butanol	1.4E-15	Fluoranthene	8.5E-10
Acentaphthene	1.5E-12	Fluorene	2.7E-09
Acetaldehyde (Ethanal)	7.0E-06	Formaldehyde (methanal)	1.3E-04
Acetic acid	3.8E-05	Formic acid (methane acid)	8.7E-09
Acetone (dimethylcetone)	8.7E-06	Furan	2.4E-09
Acetonitrile	1.3E-09	Heptane (isomers)	3.9E-06
Acrolein	2.7E-09	Hexamethylene diamine (HMDA)	2.8E-11
Acrylic acid	2.2E-11	Hexane (isomers)	7.7E-06
Aldehyde (unspecified)	2.5E-06	Hydrocarbons, aromatic	6.9E-07
Alkane (unspecified)	1.4E-04	Isoprene	1.1E-10
Alkene (unspecified)	1.1E-04	Mercaptan (unspecified)	3.0E-07
Aromatic hydrocarbons (unspecified)	4.7E-06	Methacrylate	2.5E-11
Benzaldehyde	9.4E-12	Methanol	1.3E-05
Benzene	4.2E-05	Methyl amine	4.7E-14
Butadiene	4.8E-10	Methyl borate	8.4E-18
Butane	2.6E-04	Methyl formate	9.6E-14
Butane (n-butane)	9.7E-05	Methyl tert-butylether	1.2E-09
Butanone (methyl ethyl ketone)	3.9E-08	Monoethanolamine	4.6E-09
Butene	6.6E-08	NMVOC (unspecified)	2.1E-03
Butylene glycol (butane diol)	4.5E-13	Octane	1.8E-06
butyrolactone	1.3E-13	Pentane (n-pentane)	3.1E-04
Chlorosilane, trimethyl-	3.9E-13	Phenol (hydroxy benzene)	6.4E-06
Cumene (isopropylbenzene)	8.6E-06	Propane	1.1E-03
Cycloalkanes (unspec.)	2.1E-08	Propanol (iso-propanol; isopropanol)	8.5E-09
Cyclohexane (hexahydro benzene)	1.5E-08	Propene (propylene)	1.3E-05
Diethylamine	1.2E-14	Propionaldehyde	9.9E-12
Ethane	1.0E-03	Propionic acid (propane acid)	3.2E-08
Ethanol	1.6E-05	Propylene oxide	2.4E-09
Ethene (ethylene)	1.5E-06	Styrene	7.3E-07
Ethine (acetylene)	4.2E-08	Terpenes	1.1E-09
Ethyl benzene	1.1E-04	Toluene (methyl benzene)	5.0E-05
Ethylene acetate (ethyl acetate)	3.9E-08	Trimethylbenzene	1.6E-11
Ethylene oxide	3.9E-10	Xylene (dimethyl benzene)	4.5E-04
Ethylenediamine	5.7E-09	Xylene (meta-Xylene; 1,3-Dimethylbenzene)	1.4E-08

Table A1.8 Life Cycle Inventory of HDD (base case-study): Outputs – Main emissions to fresh water (heavy metals)

OUTPUTS - Emissions to fresh water (heavy metals)	[kg]
Antimony	7.4E-08
Arsenic (+V)	1.9E-06
Cadmium (+II)	2.1E-06
Cesium	2.1E-09
Chromium (+III)	1.1E-06
Chromium (+VI)	3.4E-07
Chromium (unspecified)	3.8E-06
Cobalt	7.3E-09
Copper (+II)	2.6E-05
Heavy metals to water (unspecified)	2.2E-08
Iron	1.6E-02
Lead (+II)	1.9E-05
Manganese (+II)	4.6E-05
Mercury (+II)	1.7E-07
Molybdenum	1.1E-05
Nickel (+II)	1.2E-05
Selenium	2.0E-06
Silver	2.2E-08
Strontium	3.3E-05
Thallium	2.5E-10
Tin (+IV)	1.8E-09
Titanium	1.3E-06
Tungsten	1.6E-08
Vanadium (+III)	3.7E-06
Zinc (+II)	2.5E-04

Table A1.9 Life Cycle Inventory of HDD (base case-study): Outputs – Main emissions to fresh water (inorganic)

OUTPUTS - Emissions to fresh water (inorganic)	[kg]
Acid (calculated as H+)	3.9E-05
Aluminum (+III)	5.3E-04
Aluminum ion (+III)	1.2E-11
Ammonia	8.7E-08
Ammonium (total N)	5.4E-11
Ammonium / ammonia	2.2E-04
Barium	2.0E-05
Beryllium	1.5E-08
Boron	3.6E-05
Bromate	4.5E-07
Bromine	2.6E-06
Calcium (+II)	6.8E-03
Carbonate	2.5E-04
Chlorate	8.8E-06
Chloride	1.4E-01
Chlorine (dissolved)	5.3E-04
Cyanide	4.5E-05
Dichromate	1.5E-09
Fluoride	1.6E-02
Fluorine	5.1E-08
Hexaflourosilicates	1.7E-08
Hydrogen chloride	1.3E-09
Hydrogen fluoride (hydrofluoric acid)	3.7E-09
Hydrogen peroxide	6.2E-08
Hydrogen sulphide	5.2E-09
Hydroxide	1.1E-04
Hypochlorite	1.9E-08
Inorganic salts and acids (unspecified)	8.9E-04
Iodide	2.2E-07
Lithium	4.4E-06
Magnesium (+III)	3.9E-05
Magnesium chloride	3.0E-09
Magnesium ion (+II)	2.3E-09
Metal ions (unspecific)	1.6E-13
Metals (unspecified)	4.1E-30
Neutral salts	4.5E-09
Nitrate	6.8E-04
Nitrite	2.5E-08
Nitrogen	5.5E-06
Nitrogen dioxide	1.4E-12
Nitrogen organic bounded	1.5E-05
Phosphate	1.7E-05
Phosphorus	4.9E-06
Potassium	2.8E-05
Rubidium	3.2E-08
Scandium	1.4E-08
Silicate particles	1.3E-10
Sodium (+I)	2.2E-02
Sodium chloride (rock salt)	7.9E-09
Sodium hypochlorite	4.1E-09
Sulphate	6.8E-02
Sulphide	2.1E-05
Sulphite	1.1E-05
Sulphur	5.9E-07
Sulphuric acid	2.1E-07

Table A1.10 Life Cycle Inventory of HDD (base case-study): Outputs – Main emissions to fresh water (organic - hydrocarbons)

OUTPUTS - Emissions to fresh water (organic - hydrocarbons)	[kg]
Acenaphthene	4.5E-10
Acenaphthylene	1.6E-10
Acetic acid	2.3E-07
Acrylonitrile	1.7E-09
Alkane (unspecified)	2.7E-07
Alkene (unspecified)	2.5E-08
Anthracene	8.4E-10
Aromatic hydrocarbons (unspecified)	1.8E-06
Benzene	1.5E-05
Benzo{a}anthracene	3.7E-11
Benzofluoranthene	6.6E-12
Butene	9.0E-11
Butylene glycol (butane diol)	1.8E-13
butyrolactone	3.2E-13
Chrysene	1.3E-10
Cresol (methyl phenol)	5.1E-11
Ethanol	3.3E-10
Ethene (ethylene)	2.7E-08
Ethyl benzene	9.8E-08
Ethylene acetate (ethyl acetate)	2.2E-14
Ethylene oxide	3.0E-11
Fatty acids (calculated as total carbon)	7.8E-06
Fluoranthene	1.4E-10
Formaldehyde (methanal)	3.2E-08
Hexane (isomers)	6.8E-12
Hydrocarbons (unspecified)	6.1E-06
Methanol	2.6E-05
Methyl tert-butylether	2.3E-11
Oil (unspecified)	1.9E-04
Phenol (hydroxy benzene)	3.3E-05
Polycyclic aromatic hydrocarbons (PAH, unspec.)	5.1E-06
Propene	7.6E-06
Propylene oxide	5.7E-09
Sodium formate	2.3E-08
Toluene (methyl benzene)	7.8E-07
VOC (unspecified)	7.5E-07
Xylene (isomers; dimethyl benzene)	7.5E-07
Xylene (meta-Xylene; 1,3-Dimethylbenzene)	1.2E-10
Xylene (ortho-Xylene; 1,2-Dimethylbenzene)	9.0E-11

Table A1.11 Life Cycle Inventory of HDD (base case-study): Outputs – Main emissions to fresh water (organic - other)

OUTPUTS - Emissions to fresh water (organic - other)	[kg]
1-Butanol	1.4E-10
Acetaldehyde (Ethanal)	2.6E-10
Acetone (dimethylcetone)	9.7E-06
Acrylic acid	5.2E-11
Carbon, organically bound	1.6E-05
Cumene (isopropylbenzene)	2.1E-05
Ethylenediamine	1.4E-08
Methyl acrylate	4.9E-10
Methyl amine	1.1E-13
Methyl isobutyl ketone	1.7E-11
Methylformat	3.8E-14
Naphthalene	2.1E-08
n-Butyl acetate	1.9E-10
Organic chlorine compounds (unspecified)	5.7E-07
Organic compounds (dissolved)	2.6E-06
Organic compounds (unspecified)	4.0E-05

European Commission

Joint Research Centre – Institute for Environment and Sustainability
Title: *Contribution to impact assessment*
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Abstract
The scope of the present report is the discussion of the potential requirements introduced in Deliverable 2 and the assessment of their relevance for the HDD case-study.

As foreseen in the present Administrative Arrangement, the deliverable has been structured as a 'preliminary' environmental impact assessment of the considered case-study product and the related potential requirements. Outcomes of the deliverable could support any subsequent full impact assessment. Note that the analysis is not a complete impact assessment (i.e. it does not take into account, among others, the technical feasibility, the related costs and the technology implications), but it mainly serve to illustrate the application of the proposed methodologies and the potential benefits.

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