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

Review of resource efficiency and end-of-life requirements

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¹ Administrative Arrangement n° 070307/2009/546207/G2
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Glossary and abbreviations

AD – Anaerobic Digestion
ASTM - American Society for Testing Materials
CEN - European Committee for Standardization
CFL – Compact Fluorescent Lamp
CRT – Cathode Ray tube
EEE – Electrical and Electronic Equipment
EoL – End of Life
ELV – End-of Life of Vehicles
ERP – Energy Related Product
EuP – Energy Using Products
GWP - Global Warming Potential
HID - High Intensity Discharge
IEEE - The Institute of Electrical and Electronics Engineers
IM – Implementing Measures
IMDS - International Material Data System
ISO - International Organization of Standardization
JRC - Joint Research Centre
LCA – Life Cycle Assessment
LCD - Liquid Cristal Display
PBT - Persistent, Bioaccumulative and Toxic
REACH - Registration, Evaluation, Authorisation and Restriction of Chemicals
RRR - Recyclability/Recoverability/Reusability
RoHS - Restriction of Hazardous Substances
SVHC - Substance of Very High Concern
US EPA – Environmental Protection Agency of USA
vPvB - very Persistent and very Bioaccumulative
WEEE - Waste Electrical and Electronic Equipment
Executive Summary

Overview

The present Deliverable 1 reports the scientific survey on the implementation of resource efficiency and waste management criteria into product’s design. In particular, the survey aims at identifying the ‘key issues’ concerning the following parameters:

- Recyclability/Recoverability/Reusability (RRR);
- use of recycled materials/recycled content;
- limitation of the use of priority resources;
- restriction of the use of hazardous substances.

The first part of the deliverable concerns the analysis of the European legislation that already implemented the concepts of ‘resource efficiency’ and ‘waste management’. The second part focuses on the international standards and the scientific literature.

The main findings of the survey will be the basis for the development of the methodologies for the measurement and verification of the above mentioned parameters.

The survey of the legislation (Chapter 1) shows that some requirements about RRR have been included in the Directive 2005/64 on type-approval of motor vehicles. This Directive implements the principles and the calculation methods of the ISO 22628 “Road vehicles-Recyclability and recoverability”. It is noted that the methodological steps and the reference data format and factsheets of the ISO 22628 have been modelled on the vehicle case study. Adaptation on other designed products is however feasible, based on the specific material breakdown and composition of products. A competent body is responsible to verify the truthfulness of the manufacturer’s assertions and to validate the provided information and the calculation of the RRR rates.

The survey has also shown that various requirements concerning the RRR, the recycled content and the use hazardous substances have been introduced by Ecolabel criteria for some product categories. The compliance to the requirements is based on by “self declared” statements supported by a sufficient technical documentation.

The last part of the survey of the legislation has analyzed the RoHS, the REACH and the WEEE Directive and their potential relations with the Ecodesign policies.

The survey of the scientific literature (Chapter 2) shows that several methodologies have been developed to measure the RRR of the products at the design stage. However, such methodologies are generally complex (including several different variables) and mainly designed to support the ‘decision making’ process by manufacturers during the design of the product (i.e. for the assessment of different design alternatives). From the survey, some
methodological ‘key issues’ have been identified: the design for the disassembly of the product, the intrinsic chemical-physical properties of the materials, and the content of contaminants. These issues have been discussed in detail and they will further analyzed in the following steps of the project. Chapter 2 has also identified the key role of the material breakdown of the products (Bill of Materials – BOM) and the disassembly plans.

The survey in Chapter 3 has shown that there are no reliable technologies for the physical measurement of the recycled content of materials. The recycled content has, therefore, to be indirectly measured, on the basis of data from the manufacturing and the suppliers. Some requirements on the recycled content have been already included in some Ecolabel criteria. Other requirements have been adopted by other international labelling schemes (e.g. the IEEE 1680.1). The verification of the requirements is always based on self-declared statements, supported by technical documentation. Requirements of self-declared environmental claims have been underlined by standard ISO 14021.

Concerning the use of priority resources (Chapter 4), the survey discusses some recent studies on ‘resource depletion’ and ‘resource prioritisations’. Some preliminary results of other on-going studies have been presented, with particular attention to the recycling of priority resources. This option, in fact, can potentially allow to reduce supply problems and to ease the pressure on natural reserves. Prioritisation of resources can help to introduce different ‘weights’ (i.e. relevance determined e.g. as avoided environmental burdens per kg of recycled resource) of materials into a product’s BOM for the calculation and of RRR. This topic will be further discussed in the next deliverables.

Concerning hazardous substances (Chapter 5), the report focuses on substances that are potentially toxic for humans and ecosystems. The chapter is divided in two parts: the first relates to the procedures for the compliance to requirements about the use of regulated; the second part of the Chapter analyses some potentially harmful substances that are not regulated. It has been observed that the procedures for verification are mainly based on a self-declared statement supported by tests and other sufficient technical documentation.

It is concluded that potential requirements on hazardous substances have to be based on a lifecycle perspective, evaluating environmental impacts and benefits throughout the product lifecycle. The use of hazardous substances is often related to some specific technologies that have, for example, better overall performance (due e.g. to a lower energy consumption during the use phase). For this reason, several exemptions to the RoHS restrictions have been introduced for some specific product categories.

The use of the life cycle assessment methodology for the evaluation of the use of hazardous substances into products will be discussed in the next deliverables of the project.
Introduction and Background

The improvement of the resource efficiency represents one of the most important targets of the European environmental policies. The Sixth Community Environment Action Programme, among the others, aims at:

“better resource efficiency and resource and waste management to bring about more sustainable production and consumption patterns, thereby decoupling the use of resources and the generation of waste from the rate of economic growth and aiming to ensure that the consumption of renewable and non-renewable resources does not exceed the carrying capacity of the environment” [EU, 2002c].

The Action Programme identifies as a potential objective:

“encouraging re-use and for wastes that are still generated: the level of their hazardousness should be reduced and they should present as little risk as possible; preference should be given to recovery and especially to recycling; the quantity of waste for disposal should be minimised and should be safely disposed of[…].” [EU, 2002c].

Furthermore, Action Programme identifies priority actions for the resource efficiency including, among the others:

- “[…] encourage ecologically sound and sustainable product design;
- raising awareness of the public's potential contribution on waste reduction;
- the formulation of operational measures to encourage waste prevention, e.g. stimulating re-use and recovery, the phasing out of certain substances and materials through product-related measures […]” [EU, 2002].

The Ecodesign principles have been fully implemented in the Directive 2005/32 [EU, 2005] and the following recast Directive 2009/125/EC [EU, 2009] establishing a ‘framework for the setting of Ecodesign requirements for energy-related products’ (generally cited as the ‘Ecodesign Directive’).

The scope of the Ecodesign Directive is to provide “requirements which the energy-related products covered by implementing measures must fulfil in order to be placed on the market and/or put into service”.

The ‘Implementing Measures’ (IMs) are documents specifically conceived for a product category and including a series of ‘Ecodesign requirements’ in relation to a product, or the design of a product, and “intended to improve its environmental performance, or any requirement for the supply of information with regard to the environmental aspects of a product”.

Before placing a product covered by implementing measures on the market and/or putting such a product into service, the manufacturer (or the importer) “shall ensure that an
assessment of the product’s conformity with all the relevant requirements of the applicable implementing measure is carried out”.

A product should be regulated by implementing measures when the following criteria are met (art. 15) [EU, 2009]:

(a) “the product shall represent a significant volume of sales and trade, [...]”;

(b) the product shall, considering the quantities placed on the market and/or put into service, have a significant environmental impact within the Community, [...] and

(c) the product shall present significant potential for improvement in terms of its environmental impact without entailing excessive costs, taking into account in particular:

(i) the absence of other relevant Community legislation or failure of market forces to address the issue properly and

(ii) a wide disparity in the environmental performance of products available on the market with equivalent functionality”.

Furthermore, Article 15 of the Directive states that IMs shall meet all the following criteria [EU, 2009]:

(a) “there shall be no significant negative impact on the functionality of the product, from the perspective of the user;

(b) health, safety and the environment shall not be adversely affected;

(c) there shall be no significant negative impact on consumers in particular as regards the affordability and the life cycle cost of the product;

(d) there shall be no significant negative impact on industry’s competitiveness;

(e) in principle, the setting of an Ecodesign requirement shall not have the consequence of imposing proprietary technology on manufacturers; and

(f) no excessive administrative burden shall be imposed on manufacturers”.

In accordance with Article 16 of the Directive, the Commission has established a working plan setting out an indicative list of product groups which will be considered as priorities for the adoption of implementing measures between 2009 and 2011 [EC, 2008f]. A second working plan setting a priority list of products to be considered for implementing measures for the period 2012-2014 is currently being developed2.

IMs are built upon the outcomes of ‘preparatory studies’ that analyze in detail a product category and aim at determining whether and which Ecodesign requirements should be set. Currently, seventeen preparatory studies have been completed and others are under

2 http://www.ecodesign-wp2.eu/
development\(^3\). Finally, IMs have been already adopted for eleven product categories\(^4\). The selected requirements of adopted IMs will be described in detail in the following Chapters.

The present Report is the first Deliverable of the project “Integration of resource efficiency and waste management criteria in the implementing measures under the Ecodesign Directive”\(^5\). The project analyzes the feasibility and opportunity of developing resource-efficiency requirements for Ecodesign implementing measures and Ecodesign policies in general.

In particular the scope of project is the development of some methodologies and procedures for the assessment and verification of the following parameters:

- recyclability/recoverability/reusability;
- use of recycled materials/recycled content;
- limitation of the use of priority resources;
- restriction of the use of hazardous substances.

The present report summarizes the outcomes of the first phase of the Project, focusing on a scientific survey of the above mentioned parameters. In particular, the report is divided in two parts:

- The first part describes the survey of the current EU legislation to identify procedures, definitions, methodologies, requirements, and other key issues that can relate to the scope of the project.

- The second part describes the survey of the scientific literature and the technical standards concerning approaches and methodologies for the assessment of the above mentioned parameters. In particular, it has been realized one chapter for each studied parameter.

The aim of the present report is to identify those ‘key issues’ that can influence the studied parameters and the related measurement and verification methods. The second phase of the project will be then built on the outcomes of the presented survey.

\(^3\) Information refer to the website (http://ec.europa.eu/energy/efficiency/studies/ecodesign_en.htm) updated to January 2011.

\(^4\) http://ec.europa.eu/energy/efficiency/ecodesign/legislation_en.htm

\(^5\) Administrative Arrangement n° n° 070307/2009/546207/G2 between DG Environment and Joint Research Centre.
Chapter 1. Survey of the current legislation

1.1 The Directive on the End-of Life Vehicles (ELV) and the related legislation


The Directive introduced some requirements about the End-of Life (EoL) of the vehicles, including targets about reuse and recovery, and promoting the recyclability and recoverability of the vehicles, the provision of information to stakeholders, the promotion of waste prevention and the restriction of hazardous substances. The main requirements are following synthesized:

- **Company should provide users and other stakeholder with key environmental information about their vehicles.** In order to facilitate the disassembly, the recovery and the recycling of end-of life vehicles, manufacturers should provide treatment facilities with all the available dismantling information, with particular attention to the content of hazardous substances. Furthermore, vehicles can be stored and treated only by authorized treatment facilities, which must meet minimum technical environmental requirements;

- **Target about reuse and recovery of vehicles are set.** For all end-of life vehicles produced after 1 January 2006:
  - the reuse and recovery shall be increased to a minimum of 85 % by an average weight per vehicle and year;
  - the reuse and recycling shall be increased to a minimum of 80 % by an average weight per vehicle and year.

Starting from January 2015 the above thresholds are increased to 95% and 85% respectively;

- **Restrictions of the use of heavy metals have been introduced.** Companies shall grant that materials and components of vehicles put on the market after 1 July 2003 do not contain lead, mercury, cadmium or hexavalent chromium other than in cases listed in the Directive Annex II.

- **Waste prevention is encouraged.** In particular Member States shall encourage:
  - The integration of increasing quantities of recycled material in vehicles, in order to develop the markets for recycled materials;
Companies to take into full account and facilitate the dismantling, reuse and recovery during the design and production of new vehicles.

1.1.1 Key issues concerning reusability, recyclability and recoverability

Concerning reuse, recycle and recovery, the ELV Directive gave a large relevance to the provision of information by manufacturers. Key information includes:

- dismantling information, meaning “all information required for the correct and environmentally sound treatment of end-of-life vehicles. It shall be made available to authorized treatment facilities by vehicle manufacturers and component producers in the form of manuals or by means of electronic media” [EU, 2000];
- identification and labelling of materials and components of vehicles that can be stripped before further treatment;
- the design of vehicles and their components with a view to their recoverability and recyclability;
- the environmentally sound treatment of end-of-life vehicles, in particular the removal of all fluids and dismantling;
- the development and optimisation of ways to reuse, recycle and recover end-of-life vehicles and their components;
- the progress achieved with regard to recovery and recycling to reduce the waste to be disposed of and to increase the recovery and recycling rates.

Such information becomes the basis:

- to identify material and components potentially recyclable/recoverable;
- to identify and characterize hazardous wastes;
- to identify recycling technologies and facilities for the dismantling and treatment of vehicles;
- to demonstrate and quantify the efforts of companies towards a more ecological design of vehicles.

An important aspect of the Directive is about the promotion of methods for the assessment and verification of recyclability/recoverability targets. Article 7.4 states that “the Commission shall promote the preparation of European standards relating to the dismantlability, recoverability and recyclability of vehicles” [EU, 2000]. This has been specified and put into practise in the following European Directive 2005/64/EC [EU, 2005b] and in the Decisions of 27th February 2003 [EC, 2003] and 1st April 2005 [EC, 2005], as following described.
1.1.2 Ecodesign requirements about vehicles: the Directive 2005/64

The Directive 2005/64 “on the type-approval of motor vehicles with regard to their reusability, recyclability and recoverability and amending Council Directive 70/156/EEC” established that vehicle manufacturers and their suppliers should include reusability, recyclability and recoverability of component parts “at the earliest stages of the development of new vehicles, in order to facilitate the treatment of vehicles at the time when they reach the end of their life” [EU, 2005b].

This Directive represents one of the first examples of implementation of the Ecodesign principles into the European legislation. In particular, the focus is here shifted to the recyclability and recoverability of the vehicles before being produced and commercialised. Annex I established that:

“Vehicles [...] shall be so constructed as to be:

- reusable and/or recyclable to a minimum of 85 % by mass, and
- reusable and/or recoverable to a minimum of 95 % by mass”

These targets are slightly higher compared to those of the ELV Directive, considering also the time lag between the two Directives; furthermore, the ELV refers to recycle/recovery targets while the Directive 2005/64 to recyclability and recoverability. Requirements about vehicle recovery/recycle are then set lower than the potentials of vehicles for recycling and recovering.

The Directive 2005/64 also established that, when submitting an application for EC vehicle type approval, producers shall also submit an “information document” where a minimum set of information is provided, as [EU, 2005b]:

- Mass of the reference vehicle⁶ with bodywork;
- Masses of materials of the reference vehicle;
- Mass of material taken into account at the pre-treatment step;
- Mass of material taken into account at the dismantling step;
- Mass of material taken into account at the non-metallic residue treatment step, considered as recyclable;
- Mass of material taken into account at the non-metallic residue treatment step, considered as energy recoverable;
- Materials breakdown;
- Total mass of materials, which are reusable and/or recyclable;
- Total mass of materials, which are reusable and/or recoverable.

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⁶ “Reference vehicle” means the version within a type of vehicle, which is identified by the approval authority, in consultation with the manufacturer and in accordance with the criteria laid down in the Directive, as being the most problematic in terms of reusability, recyclability and recoverability [EU, 2005b].
The information document includes also an assessment of the two key indexes “Recyclability rate” and “Recoverability rate”, defines as:

- **Recyclability rate (R_{cyc})** of a vehicle means the percentage by mass of a new vehicle, potentially able to be reused and recycled;
- **Recoverability rate (R_{cov})** of a vehicle means the percentage by mass of a new vehicle, potentially able to be reused and recovered.

These shall be calculated in compliance with *ANNEX B of standard ISO 22628* [ISO 22628, 2002] (see chapter 1.1.3 for the details).

### 1.1.3 Calculation method for recoverability and reusability (ISO 22628)

The ISO standard 226328 [ISO 22628, 2002] underlines the need for indicators to evaluate the ability and potential of new vehicles to be recovered/recycled.

The calculation of the recyclability and recoverability rates is carried out through the following *four steps* on a new vehicle, for which component parts, materials or both can be taken into account at each step:

- a) pre-treatment;
- b) dismantling;
- c) metals separation;
- d) non-metallic residue treatment.

Preliminary to the calculation, a **material breakdown** of the analyzed vehicle is necessary. All the materials composing the vehicle have to be divided into the following categories:

1. metals;
2. polymers, excluding elastomers;
3. elastomers;
4. glass;
5. fluids;
6. modified organic natural materials (MONM), such as leather, wood, cardboard and cotton fleece;
7. others (components, materials or both, for which a detailed material breakdown cannot be established such as compounds, electronics, electrics).

Successively, parameters shown in Table 1.1 shall be calculated. All the masses have to be expressed in kilograms.
The recyclability and recoverability rates are then calculated as following (for the symbols, see Table 1.1):

1) Recyclability rate \( R_{\text{cyc}} \) = \( \frac{m_p + m_D + m_M + m_{Fe}}{m_y} \cdot 100 \)

2) Recoverability rate \( R_{\text{cov}} \) = \( \frac{m_p + m_D + m_M + m_{Fe} + m_{C}}{m_y} \cdot 100 \)

In order to support the calculation of the previous rates, the ISO standard reports two summary factsheets (shown in Figures 1.1 and 1.2) that drive the companies in the collection and compiling of key data and information.

Figure 1.1 shows the four methodological steps for the calculation, where all the different types of components are catalogued. Concerning “Dismantling” company has to assess their recyclability based on the key parameters for disassembly as accessibility and fastening (see Table 1.1 - \( m_0 \)). Concerning “Non-metallic residues” their recyclability/recoverability is also assessed and declared by the company on the basis of the component’s materials and the availability of practicable recycling technologies. The manufacturer should therefore recommend a strategy for the treatment of end-of-life vehicles. This should be based on proven technologies, which are available or in development at the time of the vehicle design.

The scheme in Figure 1.2 drives companies through the material breakdown. Compilers have to report the name of components, their composition and mass, and the suggested recycling technology.
Table 1.1. Parameters needed for the calculation of recyclability and recoverability rates.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( m_V )</td>
<td><strong>Vehicle mass</strong>&lt;br&gt;It represents the complete vehicle shipping mass, plus the mass of lubricants, coolant, washer fluid, fuel (tank filled to at least 90% of the capacity specified by the manufacturer), spare wheel(s), fire extinguisher(s), standard spare parts, chocks, standard tool-kit.</td>
</tr>
<tr>
<td>( m_p )</td>
<td><strong>Mass of materials taken into account at the pre-treatment step</strong>&lt;br&gt;This parameter represents the sum of all the materials that have to be separated before any further treatment. These component parts and materials are considered reusable / recyclable for the purpose of the calculation. These include:&lt;br&gt;- all fluids (fuel, engine oil, transmission/gearbox oil, power steering oil, coolant, brake fluid, shock absorber fluid, air conditioning refrigerant, windscreen washer fluid, engine mounting oil and hydraulic suspension fluid);&lt;br&gt;- batteries;&lt;br&gt;- oil filters;&lt;br&gt;- liquefied petroleum gas (LPG) tanks;&lt;br&gt;- compressed natural gas (CNG) tanks;&lt;br&gt;- tyres;&lt;br&gt;- catalytic converters.</td>
</tr>
<tr>
<td>( m_D )</td>
<td><strong>Mass of materials taken into account at the dismantling step</strong>&lt;br&gt;It includes certain other of the vehicle's reusable or recyclable component parts that may be taken into account. A component part shall be considered as reusable, recyclable or both based on its dismantlability, assessed by:&lt;br&gt;- accessibility,&lt;br&gt;- fastening technology, and&lt;br&gt;- proven dismantling technologies.&lt;br&gt;As a specific requirement, a component part shall be considered as recyclable, based on:&lt;br&gt;- its material composition, and&lt;br&gt;- proven recycling technologies.</td>
</tr>
<tr>
<td>( m_M )</td>
<td><strong>Mass of metals taken into account at the metal separation step</strong>&lt;br&gt;All metals, ferrous and non-ferrous, which have not already been accounted for in the previous steps shall be taken into account. Both ferrous and non-ferrous metals are considered as recyclable.</td>
</tr>
<tr>
<td>( m_{Tr} )</td>
<td><strong>Mass of materials taken into account at the non-metallic residue treatment step and which can be considered as recyclable</strong>&lt;br&gt;The remaining other materials constitute the non-metallic residue. At this step, the recyclable materials are the sum of masses of non-metallic residue considered as recyclable on the basis of proven recycling technologies.</td>
</tr>
<tr>
<td>( m_{Te} )</td>
<td><strong>Mass of materials taken into account at the non-metallic residue treatment step and which can be considered for energy recovery</strong>&lt;br&gt;This parameter is calculated as the sum of the remaining masses that can potentially be used for energy recovery after determination of the previous ( m_p, m_D, m_M ) and ( m_{Tr} ).</td>
</tr>
</tbody>
</table>
Figure 1.1. Scheme for the calculation method for recyclability/recoverability indicators (from [ISO 22628, 2002])

<table>
<thead>
<tr>
<th>Calculation steps (subclause)</th>
<th>Vehicle elements</th>
<th>Assumptions</th>
<th>Mass of vehicle elements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>General character</td>
<td>List</td>
<td>Reusable or Recyclable</td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>Component parts</td>
<td>All fluids</td>
<td>Reusable recyclable or both</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Batteries</td>
<td></td>
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<td></td>
<td></td>
<td>Oil filters</td>
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<td>LPG tanks</td>
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<td>CNG tanks</td>
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<td>Tyres</td>
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<td></td>
<td></td>
<td>Catalytic converters</td>
<td></td>
</tr>
<tr>
<td>Dismantling</td>
<td>Component parts</td>
<td>As declared by vehicle manufacturer</td>
<td>Reusable recyclable or both</td>
</tr>
<tr>
<td>Metal separation</td>
<td>Materials</td>
<td>Metals (ferrous and non-ferrous)</td>
<td>Recyclable</td>
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<tr>
<td></td>
<td></td>
<td>Glass</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Polymers (excluding elastomers)</td>
<td>Recyclable, recoverable or both</td>
</tr>
<tr>
<td>Non-metallic residue treatment</td>
<td>Materials</td>
<td>Elastomers</td>
<td>Recyclable, recoverable or both</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MONM</td>
<td>Recyclable, recoverable or both</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Others</td>
<td></td>
</tr>
</tbody>
</table>

\[
\text{Recyclability rate, } R_{22628} \text{ } (\%) = \frac{m_P + m_D + m_M + m_{Tr}}{m_V} \times 100
\]

\[
\text{Recoverability rate, } R_{2268} \text{ } (\%) = \frac{m_P + m_D + m_M + m_{Tr} + m_{Te}}{m_V} \times 100
\]

Vehicle mass, \( m_V \)
Figure 1.2. Scheme for the material breakdown and presentation of data (from [ISO 22628, 2002])
1.1.4 Compliance to the Directive 2005/64

The Directive 2005/64 forms part of the “Whole Vehicle Type Approval (WVTA)” regime established by the Directive 70/156 [ECC, 1970]. This last provides the framework under which motor vehicles are approved as meeting a range of harmonised technical requirements such that they can then be placed on the European market. Any vehicle, independently from the country of production, has to be preventively authorized and the Ecodesign thresholds set in the Directive 2005/64 about recyclability and recoverability are part of the authorisation procedure.

It is established that “the manufacturer should make available to the approval authority all relevant technical information as regards constituent materials and their respective masses in order to permit verification of the manufacturer's calculations in accordance with the standard ISO 22628” [EU, 2005b]. “The manufacturer's calculations can be properly validated at the time of the vehicle type-approval only if the manufacturer has put in place satisfactory arrangements and procedures to manage all information he receives from his suppliers” [EU, 2005b]. Furthermore, concerning the labelling of plastics and elastomers, specifications are provided by the Decisions of 27th February 2003 [EC, 2003].

The procedure for the compliance to the Directive and the achievement of the ‘vehicle’s type approval’ is here synthesized [EU, 2005b]

1. First of all, the manufacturer has put in place satisfactory arrangements and procedures to ensure handling Reusability, Recyclability and Recoverability in accordance with the Directive. The manufacturer has therefore to take the necessary measures:

   - to collect appropriate data through the full chain of supply, in particular the nature and the mass of all materials used in the construction of the vehicles, in order to perform the calculations required;
   - to keep at his disposal all the other appropriate vehicle data required by the calculation process such as the volume of the fluids, etc.;
   - to check adequately the information received from suppliers;
   - to manage the breakdown of the materials;
   - to be able to perform the calculation of the recyclability and recoverability rates in accordance with the standard ISO 22628;
   - to mark the component parts made of polymers and elastomers in accordance with Commission Decision [EC, 2003]
   - to verify that no component part listed in Annex V\(^7\) of Directive 2005/64 is reused in the construction of new vehicles.

\(^7\) The Annex V list a series of parts and components that are non reusable for safety and environmental reasons (e.g. airbags, catalytic converters, etc.).
2. The manufacturer is then subjected to a ‘preliminary assessment’ by the competent body that validates the provided information and verifies the appropriateness of the adopted procedures. At the end of this assessment, the competent body releases a “certificate of compliance”. At this stage the manufacturer shall also recommend “a strategy to ensure dismantling, reuse of component parts, recycling and recovery of materials”;

3. Successively the manufacturer has to provide the calculation of the ‘Recycling and Recoverability Rates’ in accordance with ISO 22628. This calculation shall be accompanied by a “listing of the dismantled component parts, declared by the manufacturer with respect to the dismantling stage, and the process he recommends for their treatment”.

4. In the final stage, the automotive manufacturer will have to pass the ‘type approval’, as part of the Whole Vehicle Type Approval (WVTA). Manufacturers have to ensure the compliance to the thresholds for the Recycling and Recoverability Rates. The failure to meet such thresholds results in the failure to obtain the Whole Vehicle Type Approval (WVTA), and consequently the interdiction to sale the vehicle in the EU market.

The verification of the compliance of the requirements is therefore mostly based on self-assessed/calculated information, indicators, and on supporting documentation and labelling. In particular, the manufacturer has to establish procedures to collect, monitor and check relevant data (concerning the composition of supplied material and content of hazardous substances) through the full supply chain, including also procedures “to react adequately where the data received from the suppliers indicate non-compliance” [EC, 2009]. These procedures can be also parts of the larger quality and environmental ‘management systems’ of the company (as in compliance with ISO 9001, ISO 14001 or EMAS).

In order to facilitate the compliance to the ELV Directive and the Directive 2005/64, the most important international vehicles manufacturers created the “International Material Data System” (IMDS), a web-based electronic system created to account data about material composition of vehicles and their components. Through the IMDS, direct and indirect suppliers can compile a specific “Material Data Sheet” compliant with the requirements of Directive 2005/64. The substances to declare are those included in the Global Automotive Declarable Substance List and include all the most important substances in the manufacture of vehicles and all the substances regulated by the current legislation.

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8 The competent body is an entity (e.g. a technical service or another existing body) notified by a Member State to carry out a preliminary assessment of the manufacturer.
9 Website: http://www.mdlss.com/
10 Website: http://www.americanchemistry.com/s_plastics/blank.asp?CID=1106&DID=9290
1.1.5 Possible interactions between Directives about the EoL of vehicles and the general Ecodesign policies

As above presented, the ELV Directive and the following related Directives and Commission Decisions have several “contact points” with the Ecodesign of products in general. For both, in fact, the aim is at fixing some requirements that would push manufacturer toward more ecological products and production process. Requirements are applied at the Design stage of the products in order to prevent the growth of environmental impacts.

Although the above described Directives are specifically set on vehicles, some general hints can be formulated for other designed products, as:

- the recyclability/recoverability of products is assessed by means of specific “rates” that represent the mass fraction in percentage that is potential recyclable or recoverable;

- the starting point for the analysis is the material breakdown. Only with a detailed picture of the product’s components and their composition and mass, it is possible to assess/estimate the potential recyclability/recoverability rates of the products at the design stage;

- the assessment of recyclability/recoverability is demanded to the manufacturer that has, anyway, to provide sufficient additional information to support their assumptions. This includes information about the typology of the employed materials, the accessibility of the components for dismantling/disassembly and the availability of feasible technology for the material recycling/recovery. In order to encourage the dismantling and recycling of products, companies have also to provide additional information concerning the products (including, for example, the contents and labelling of hazardous substances);

- a competent body is responsible to verify the truthfulness of the manufacturer’s assertions and to validate the provided information and the calculation of the rates. Such controls are periodically renewed and they are necessary to obtain the preliminary “approval certificate” for the product’s commercialisation.

The methodological approach employed in the Directive 2005/64 is general and its structure can be adapted to other product typologies. In particular, the indicators of “recyclability and recoverability” rates can be applied also to other designed products.

The conceptual diagram flow for the assessment and verification of recyclability/recoverability potentials of products is described in Figure 1.3.

It is important to note that the methodological steps and the reference data format and factsheets, as described in the ISO 22628, have been modelled on the vehicle case study. Adaptation on other designed products is however feasible, based on the specific material breakdown and composition of such products.
1.1.6 Further development of ISO methodology on recyclability of vehicles

The imposed EU recyclability targets are based on the average weight of vehicles. The masses and composition of the car’s components at the time of production determine this weight.

Anyway authors detected some points for the further develop of such approach [Verhoef et al., 2003; van Schaik et Reuter, 2004]. The ISO 22628 calculation method, in fact, is a single value, static approach, which is not based on a detailed knowledge of end-of-life separation technology and metallurgical processing.

The defined calculation method for the recyclability and recoverability of passenger vehicles assumes that the metal content of the car is recovered for 100%. However, due to the interrelation between grade and recovery of a mechanical separation process (which implies that both high recovery and grade requirements cannot be fulfilled at the same time), the recovery of materials will always be lower than 100%, if the quality of recycled materials has to be increased by mechanical separation.

Furthermore, modern products contain a combination of metals that are not linked in the natural resource systems. As a consequence, these materials are not always compatible with the current processes in the metals production network, which was developed for the processing of primary natural resources and therefore, optimized for the processing of the primary metal and all mineralogical associated valuable and harmful minor elements. The formation of complex residue streams or undesired harmful emissions that cannot be handled in the current system inhibits thus the processing and recycling of those products at their end-of-life and will immediately result in decreasing the recycling rates of these products.
Finally, the methodology for the assessment of the recyclability of vehicles takes into consideration mostly technical considerations (about material composition, and technological feasibility of disassembly and recycling). No considerations, instead, are included about environmental benefits/drawbacks of recycling, costs for the recycling and ‘quality’ of the recycled outputs.

A synthesis of main advantages and limitations related to ISO approach for recyclability/recoverability are shown in Table 1.2.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>- easy to apply and verify</td>
<td>- specifically conceived for vehicles, but potentially extensible to other product categories</td>
</tr>
<tr>
<td>- applicable at the design stage of the vehicle</td>
<td>- mostly based on material composition and their technical recyclability. Some components (as metals) are considered 100% recyclable, without further considerations.</td>
</tr>
<tr>
<td></td>
<td>- Disassembly is marginally investigated, while material contamination and environmental drawback/impacts of recycling are not considered.</td>
</tr>
</tbody>
</table>

The scope of the Directive 2005/64 is to promote the vehicles’ recyclability/recoverability at the design stage, in order to improve their effective recycling/recovery at the EoL. It is however important to note that that the “recyclability” concept differs from the effective “recycling”: recyclability (and analogously reusability and recoverability) are a ‘potential’ of the product.

A product can be therefore “potentially” fully recyclable/recoverable, but not be recycled/recovered at the EoL. Several other external factors can influence the recycling (e.g. the collection rate, the availability of facilities for treatments, the behaviours of the consumers). It is however expected that improving the ‘recyclability’ even the ‘recycling’ will be more desirable and effectively increased.

High recycling and recovery rates can be achieved and maintained through the identification and assessment of the complex interactions among physical, technological, environmental and economic variables. Therefore a key point of the current research is to assess if and how some of these parameters can be introduced in the calculation method for recyclability.

1.2 The Directive on the Restriction of Hazardous Substances (RoHS)

The list of banned substances includes: lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE).

The list of restricted substances and the list of exemptions have to be periodically checked and reviewed in order to grant the consistency and adaptation of the Directive to the scientific and technical progress. Several review studies have been carried out in the last decade [Gensch et al., 2009; Öko-Institut, 2008; Gensch et al., 2007].

The Directive also included some exemptions for some product categories (e.g. medical devices that are out of the scope) and to some specific applications (listed in the Directive’s Annex).

In particular, a subsequent amending decision established that “a maximum concentration value of 0.1 % by weight in homogeneous materials for lead, mercury, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE) and of 0.01 % by weight in homogeneous materials\(^{11}\) for cadmium shall be tolerated” [EC, 2005c].

The exemptions have been continuously amended by several Commission Decisions\(^{12}\) and adapted to the technical progress. This process is expected to be continued in order to assess if substitution is technically or scientifically practicable or where the negative impacts of substitution outweigh the positive ones. A summary table of all the regulated exemptions is shown in Table 1.3.

Whereas estimations on overall quantities of the hazardous substances due to the exemptions are difficult to obtain, the most relevant ones as regards quantities seem to be lead in glass of cathode ray tubes (more than 50,000 tons of lead), mercury in lamps (4.3 tons/yr) and in LCD panels as backlights (2.8 tons/yr) [EC, 2008c].

Anyway, neither the RoHS nor the subsequent documents refer to specific compliance procedures, certificates or testing methods to be used for demonstrating compliance. Therefore, the Member States are fully responsible for setting compliance rules [EC, 2005d]. A detailed description of the compliance to the RoHS requirements is discussed in Chapter 5.

The RoHS Directive is currently under recast process [EC, 2008; EC, 2008e]. Concerning the exempted product categories, the main chances concerned the progressive inclusion of new product categories (as medical devices and monitoring and control instruments) which are regulated by the Directive.

The Commission also studied the need to adapt the list of regulated substances on the basis of scientific facts and taking the precautionary principle into account. However, at the current state of knowledge, no new substances have been identified for restrictions.

\(^{11}\) Homogeneous material in RoHS terms means a component or material that cannot be mechanically disjointed into different materials by unscrewing, cutting, crushing, grinding, abrasive processes and similar procedures.

\(^{12}\) For a complete list of RoHS legislation, see: http://ec.europa.eu/environment/waste/weee/legis_en.htm
<table>
<thead>
<tr>
<th>No.</th>
<th>Exemption</th>
<th>No.</th>
<th>Exemption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1*</td>
<td>Mercury in compact fluorescent lamps not exceeding 5 mg per lamp</td>
<td>2*</td>
<td>Mercury in straight fluorescent lamps for general purposes not exceeding:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- halophosphate 10 mg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- triphosphate with normal lifetime 5 mg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- triphosphate with long lifetime 8 mg</td>
</tr>
<tr>
<td>3*</td>
<td>Mercury in straight fluorescent lamps for special purposes</td>
<td>4*</td>
<td>Mercury in other lamps not specifically mentioned in this Annex</td>
</tr>
<tr>
<td>5*</td>
<td>Lead in glass of cathode ray tubes, electronic components and fluorescent tubes</td>
<td>6</td>
<td>Lead as an alloying element in steel containing up to 0.35 % lead by weight, aluminium containing up to 0.4 % lead by weight and as a copper alloy containing up to 4 % lead by weight</td>
</tr>
<tr>
<td>7</td>
<td>- Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead), - lead in solders for servers, storage and storage array systems, network infrastructure equipment for switching, signalling, transmission as well as network management for telecommunications, - lead in electronic ceramic parts (e.g. piezoelectronic devices).</td>
<td>8</td>
<td>Cadmium and its compounds in electrical contacts and cadmium plating except for applications banned under Directive 91/338/EEC (1) amending Directive 76/769/EEC (2) relating to restrictions on the marketing and use of certain dangerous substances and preparations</td>
</tr>
<tr>
<td>9*</td>
<td>Hexavalent chromium as an anti-corrosion of the carbon steel cooling system in absorption refrigerators.</td>
<td>9b</td>
<td>- DecaBDE in polymeric applications.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Lead in lead-bronze bearing shells and bushes</td>
</tr>
<tr>
<td>11</td>
<td>Lead used in compliant pin connector systems</td>
<td>12</td>
<td>Lead as a coating material for the thermal module c-ring</td>
</tr>
<tr>
<td>13</td>
<td>Lead and cadmium in optical and filter glass</td>
<td>14</td>
<td>Lead in solders consisting of more than two elements for the connection between the pins and the package of microprocessors with a lead content of more than 80 % and less than 85 % by weight</td>
</tr>
<tr>
<td>15</td>
<td>Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit Flip Chip packages</td>
<td>16*</td>
<td>Lead in linear inductance lamps with silicate coated tubes</td>
</tr>
<tr>
<td>17*</td>
<td>Lead halide as radiant agent in High Intensity Discharge (HID) lamps used for professional reprography applications</td>
<td>18*</td>
<td>Lead as activator in the fluorescent powder (1 % lead by weight or less) of discharge lamps when used as sun tanning lamps containing phosphors such as BSP (BaS2O5: Pb) as well as when used as specialty lamps for diazo-printing reprography, lithography, insect traps, photochemical and curing processes containing phosphors such as SMD ((Sr,Ba)2MgSi2O7:Pb).</td>
</tr>
<tr>
<td>19*</td>
<td>Lead with PbSn-Hg and PbSn-Hg in specific compositions as main amalgam and with PbSn-Hg as auxiliary amalgam in very compact Energy Saving Lamps (ESL).</td>
<td>20*</td>
<td>Lead oxide in glass used for bonding front and rear substrates of flat fluorescent lamps used for Liquid Crystal Displays (LCD).</td>
</tr>
<tr>
<td>21</td>
<td>Lead and cadmium in printing inks for the application of enamels on borosilicate</td>
<td>22**</td>
<td>Lead as impurity in RGO (rare earth iron garnet) Faraday rotators used for fibre optic communication systems until 31 December 2009</td>
</tr>
<tr>
<td>23</td>
<td>Lead in finishes of fine pitch components other than connectors with a pitch of 0.65 mm or less with NiFe lead frames and lead in finishes of fine pitch components other than connectors with a pitch of 0.65 mm or less with copper lead frames</td>
<td>24</td>
<td>Lead in solders for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors</td>
</tr>
<tr>
<td>25*</td>
<td>Lead oxide in plasma display panels (PDP) and surface conduction electron emitter displays (SED) used in structural elements; notably in the front and rear glass dielectric layer, the bus electrode, the black stripe, the address electrode, the barrier ribs, the seal frit and frit ring as well as in print pastes.</td>
<td>26*</td>
<td>Lead oxide in the glass envelope of Black Light Blue (BLB) lamps.</td>
</tr>
<tr>
<td>27</td>
<td>Lead alloys as solder for transducers used in high-powered (designated to operate for several hours at acoustic power levels of 125 dB SPL and above) loudspeakers.</td>
<td>28**</td>
<td>Hexavalent chromium in corrosion preventive coatings of unpainted metal sheetings and fasteners used for corrosion protection and Electromagnetic Interference Shielding in equipment falling under category three of Directive 2002/96/EC (IT and telecommunications equipment). Exemption granted until 1 July 2007.</td>
</tr>
<tr>
<td>29</td>
<td>Lead bound in crystal glass as defined in Annex I (Categories 1, 2, 3 and 4) of Council Directive 69/495/EEC (1).</td>
<td>30</td>
<td>Cadmium alloys as electrical/mechanical solder joints to electrical conductors located directly on the voice coil in transducers used in high-powered loudspeakers with sound pressure levels of 100 dB (A) and more</td>
</tr>
<tr>
<td>31*</td>
<td>Lead in soldering materials in mercury free flat fluorescent lamps (which e.g. are used for liquid crystal displays, design or industrial lighting).</td>
<td>32</td>
<td>Lead oxide in seal frit used for making window assemblies for Argon and Krypton laser tubes</td>
</tr>
<tr>
<td>33*</td>
<td>Lead in solders for the soldering of thin copper wires of 100 µm diameter and less in power transformers.</td>
<td>34</td>
<td>Lead in cermet-based trimmer potentiometer elements</td>
</tr>
<tr>
<td>35**</td>
<td>Cadmium in photoresistors for optocouplers applied in professional audio equipment until 31 December 2009.</td>
<td>36**</td>
<td>Mercury used as a cathode sputtering inhibitor in DC plasma displays with a content up to 30 mg per display until 1 July 2010.</td>
</tr>
<tr>
<td>37</td>
<td>Lead in the plating layer of high voltage diodes on the basis of a zinc borate glass body.</td>
<td>38</td>
<td>Cadmium and cadmium oxide in thick film pastes used on aluminum bonded beryllium oxide.</td>
</tr>
<tr>
<td>39*</td>
<td>Cadmium in colour-converting II-VI LEDs (&lt; 10 µg Cd per mm² of light-emitting area) for use in solid state illumination or display systems until 1 July 2014.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Exemptions related to EuP that have been also regulated by Implementing Measures under the Ecodesign Directive

** Exemptions already expired
1.3 The EU Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)

In 2006 the EU adopted the Regulation 1907/2006 [EU, 2006] concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)\(^{13}\).

One of the main reasons for developing and adopting the REACH Regulation was that a large number of substances have been manufactured and placed on the market in Europe for many years, sometimes in very high amounts, and there is still insufficient information on the hazards that they pose to human health and the environment. There is a need to fill these information gaps to ensure that industry is able to assess hazards and risks of the substances, and to identify and implement the risk management measures to protect humans and the environment.

The aim of the REACH Regulation is therefore to improve the protection of human health and the environment through the better and earlier identification of the intrinsic properties of chemical substances. The REACH Regulation places greater responsibility on industry to manage the risks from chemicals and to provide safety information on the substances. Manufacturers and importers are required to gather information on the properties of their chemical substances, which will allow their safe handling, and to register the information in a central database. The Regulation also calls for the progressive substitution of the most dangerous chemicals when suitable alternatives have been identified.

1.3.1 Identification of Substances of Very High Concern (SVHC)

The REACH fixes the criteria for the identification of substances to be subjected to authorisation and restrictions. In particular, the REACH focus on “Substances of Very High Concern” (SVHC) meaning substances that, following the precaution principle, need to be subject to careful attention and further investigated/studied. A substance may be proposed as an SVHC if it meets one or more of the following criteria (art. 57):

- It is carcinogenic;
- It is mutagenic;
- It is toxic for reproduction;
- It is persistent, bioaccumulative and toxic (PBT)\(^{14}\);
- It is very persistent and very bioaccumulative (vPvB)\(^{15}\);
- There is scientific evidence of probable serious effects to human health (as disruptive endocrine effects or having properties as PBT and vPvB) or the environment which gives rise to an equivalent level of concern to other previous categories and which are identified on a case-by-case basis.

\(^{13}\) For further details see: [http://ec.europa.eu/environment/chemicals/reach/reach_intro.htm](http://ec.europa.eu/environment/chemicals/reach/reach_intro.htm)

\(^{14}\) For criteria about assessment of PCT substance, see Annex XIII of the REACH Regulation [EU, 2006]

\(^{15}\) For criteria about assessment of vPCT substance, see Annex XIII of the REACH Regulation [EU, 2006]
SVHC will be gradually included in a “List Of Substances Subject To Authorisation” (Annex XIV of the REACH Regulation). Once included in that Annex, they cannot be placed on the market or used after a date to be set (referred to as “sunset date”) unless the company is granted an authorisation.

The authorisation process consists of four steps\(^\text{16}\).

- **Step 1: Identification of SVHC (by authorities):** SVHC can be identified on the basis of the previously described criteria. This will be done by Member State Competent Authorities or the European Chemicals Agency (on behalf of the European Commission). The outcome of this identification process is a list of identified substances, which are candidates for prioritisation (the “candidate list”).

- **Step 2: Prioritisation process (by authorities):** The substances on the candidate list are prioritised to determine which ones should be subject to authorisation. At the end of the prioritization process, the following decisions are taken:
  - whether or not the substance will be subject to authorisation;
  - which uses of the included substances will not need authorisation (e.g. because sufficient controls established by other legislation are already in place);
  - the “sunset date”.

- **Step 3: Applications for authorisation (by industry):** Applications for authorisation need to be made within the set deadlines for each use that is not exempted from the authorisation requirement. They must include among others:
  - a chemical safety report covering risks related to use of the substance;
  - an analysis of possible alternative substances or technologies.

- **Step 4: Granting of authorisations (by the European Commission):** Authorisations will be granted if the applicant can demonstrate that the risk from the use of the substance is adequately controlled. If the risk is not adequately controlled, an authorisation may still be granted if it is proven that socio-economic benefits outweigh the risks and there are no suitable alternative substances or technologies.

Priority for the inclusion to the list should normally be given to substances with (art. 58):

- a) PBT or vPvB properties; or
- b) Wide dispersive use; or
- c) High volumes.

A candidate list of SVHC is provided and continuously updated by the European Chemicals Agency\(^\text{17}\).

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1.3.2 Interaction between REACH and RoHS

The REACH Regulation and the RoHS directive can have several potential interactions, as following [EC, 2008]:

- “The REACH is based on the demonstrated risk of a substance resulting from its use, while RoHS is founded on a preventive approach, based on the hazard profile of the substances (as opposed to only demonstrated risk from their use)”.  

- “Synergies between the RoHS Directive and REACH [...] are particularly relevant. REACH focuses on the chemical substances while RoHS is product legislation dealing only with hazardous substances in Electrical and Electronic Equipments (EEE). The complementarity consists in that, if a substance that is subject to authorization under REACH is restricted under RoHS, such application will be exempted from the REACH requirements; it explains why RoHS and the subsequently adopted REACH were meant to coexist and ensures that any conflict between REACH and RoHS is avoided”.  

- “Substances that are relevant for RoHS (used in some cases in low or very low amounts, large share of imported products) may not be a priority for REACH, which does not aim to meet the RoHS objectives. Authorization under REACH captures incorporation of substances into articles only if this is done inside the EU, thus potentially reducing protection from imported products. Should restrictions on whole groups of substances used in EEE be deemed necessary, they can be made more easily via RoHS”.  

- “For many of the substances that could be handled by RoHS, more information will become available in the forthcoming years due to the notification and registration requirements of REACH; this will facilitate decision making on appropriate risk management measures, including restrictions under REACH for the hazardous substance satisfying the REACH criteria”.  

Since REACH is subsequent to RoHS, and much wider and elaborate in scope, certain provisions of RoHS could be clarified or further elaborated upon in the light of REACH. In fact, “while RoHS simply states that further prohibitions can be decided based on available scientific evidence, and the substitution of those substances by more environment-friendly alternatives [...] without providing any definition of these criteria, REACH provides for a detailed risks identification for substances and their substitutes” [EC, 2008].

On such purpose, the proposal for the recast of the RoHS Directive assumes that the introduction of new substance bans in RoHS will be in line with the REACH methodology [EU, 2008e]. In particular the proposal states that “As soon as scientific evidence is available and taking into account the precautionary principle, the prohibition of other hazardous substances and their substitution by more environmentally friendly alternatives which ensure at least the same level of protection of consumers should be examined, paying attention to coherency with other Community legislation, and in particular to Regulation (EC) No 1907/2006 [...] (REACH)” [EU, 2008e].
Following the above comments it can be stated that, although the REACH and RoHS are different tools, “*substances meeting the criteria for classification as substances of very high concern (SVHC) in accordance with REACH could be used to identify additional hazardous substances to be regulated under the RoHs*” [EC, 2008].

Studies supporting the revision of the RoHS Directive work on this direction. An example is the study financed by the European Commission concerning the “Hazardous Substances in Electrical and Electronic Equipment, Not Regulated by the RoHS Directive” [Öko-Institut, 2008]. The study considers the meeting of the criteria for the classification as SVHC as one of the criteria for the selection of the substances to be studied. Details of the study’s outcomes and a list of substances to be potentially regulated are discussed in Chapter 5.3.

### 1.3.3 Possible interactions between the RoHS / REACH and the Ecodesign policies

The ‘environmental conscious’ design of a product has also to take into account the potential harmfulness of the used substances. These, in fact, could represent a risk for the users or the environment at the different stages of the product’s life-cycle. Furthermore, hazardous substances can hamper the product’s recycling and could cause toxicological and environmental problems at the product’s end-of life (EoL). On this purpose, the RoHS and the *REACH* can represent a support to identify and regulate the use of potential hazardous substances, and therefore influencing the design and manufacture of the new generation of products.

The Ecodesign Directive\(^{18}\) “*aims at improving the overall environmental performance of selected groups of EEE, while considering economic feasibility. Reducing toxicity of the product, e.g. by avoiding hazardous substances could be considered but restricting the use of substances is not an aim of the Directive. [...] To the contrary, the RoHS Directive aims primarily at avoiding the banned substances for all EEE within its scope. Exemptions are only possible if substitution is technically or scientifically impracticable or where the negative impacts of substitution outweigh the positive ones*” [EC, 2008].

Requirements concerning the use of hazardous substances (even including those not regulated by the *REACH* and RoHS) could be included into Ecodesign implementing measures as well as into environmental labelling schemes\(^{19}\). Example of requirements could be:

- Declaration by the manufacturer of the content of hazardous substances into the product (or some specific components);
- Threshold limits on the use of the hazardous substances into the product (or into some specific components);

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\(^{19}\) Examples of requirements concerning the restriction of the use of hazardous substances have been introduced by the EU Ecolabel scheme. For details, see Chapter 1.7.
Labelling/marking of components containing hazardous substances, in order to simply/improve their identification at the EoL;

Accessibility and easy disassembly of components containing hazardous substances.

It is important to remind that the use of hazardous substances is also related to the adopted technology and to the achieved product’s performances. Therefore, any restriction of the use of hazardous substances has to consider the ‘life-cycle perspective’, assessing all the potential burdens and benefits arising throughout the product’s life-cycle, and assessing also the potential burdens related to e.g. the use of alternative technologies free of the considered hazardous substance.

Possible requirements about the restriction of the substances for the manufacturing of the product should be case-by-case evaluated and linked to the specific product group and to the available technologies.

1.4. The Waste Directive

The European Directive 2008/98/EC sets the basic concepts and definitions related to the waste management. In particular the Directive “lays down measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use” [EU, 2008].

In particular the Directive is based on some key principles as the "polluter pays principle" and the "waste hierarchy".

“The polluter-pays principle is a guiding principle at European and international levels. The waste producer and the waste holder should manage the waste in a way that guarantees a high level of protection of the environment and human health” [EU, 2008]. “In accordance with the polluter-pays principle, the costs of waste management shall be borne by the original waste producer or by the current or previous waste holders” [EU, 2008].

“The waste hierarchy generally lays down a priority order of what constitutes the best overall environmental option in waste legislation and policy” [EU, 2008]. The following waste hierarchy shall apply as a priority order in waste prevention and management legislation and policy:

(a) prevention;
(b) re-use;
(c) recycling;
(d) other recovery, e.g. energy recovery; and
(e) disposal.
The Directive promotes the prevention of waste, supporting those “measures taken before a substance, material or product has become waste, which reduce:

(a) the quantity of waste, including through the re-use of products or the extension of the life span of products;
(b) the adverse impacts of the generated waste on the environment and human health;
(c) the content of harmful substances in materials and products”.

The Directive also provides definitions of ‘Re-use’, ‘Recycling’ and ‘Recovery’. These definitions will be discussed in Chapter 2.1 and they will be used for the development of the project’s methodologies.

1.4.1 The Waste Directive and the Ecodesign Policies
The scopes of the present project are strictly related with the principles promoted by the waste Directive. The promotion of the product’s Reusability/Recyclability/Recoverability and the product’s recycled content is in line with the above mentioned waste hierarchy. Furthermore, the definition of resource efficiency requirements will also aim at the waste prevention.

The design of the product should, in fact, take into account the EoL of the product in order to minimize the production of wastes; then environmental conscious design of the product should apply on how to identify and implement strategies for the reuse and recycling, and finally it should enable/facilitate the partial recovery of the energy contents of materials.

Disposal becomes the last option, but nevertheless Ecodesign requirement could also identify solutions to management even those materials/components which reuse/recycle/recovery is not feasible/practicable at the current state of the technology.

Here following are synthesized some possible Ecodesign strategies and their possible interaction with the waste hierarchy (Figure 1.4):

- The (1) Adoption of an Environmental conscious manufacturing should focus on minimizing the production of wastes during the production process. This strategy is also linked to the (2) efficient use of resources, avoiding e.g. the use of not needed materials (also into additional parts, as brochures and packaging), boosting the employment of renewable or recycled materials.

- The waste prevention is also achieved by (3) Improving the expected product’s lifetime and lifetime performances and the reduction of the release of wastes due to breakages, worn-out materials or premature discard/substitution of the products. It is basic that the products would guarantee their functions and efficiency over the time: a fast loss of performances could, in fact, banish all the benefits due to the initial accomplishment of the environmental requirements. Lifetime prolongation has a potential especially for products with a generally limited lifetime of up to a few years.
However, criteria concerning the durability of products should also consider the ongoing technological progress.

- Even the (4) Maintenance improvement is a key issue for the waste prevention/minimisations, due to the link with the product’s life length and its extension. The design of product should study solutions to strengthen parts/components mostly affected by breakages/damages/wear. Companies should provide in the market the main spare parts of a product for a sufficient time. Key components should be easy accessible and potential replaceable.

- The adoption of (5) BAT can be a key issue to improve the manufacturing of the product or to improve the performances of products over their lifetime. BAT, in particular, can contribute to prevent the waste generation, for example avoiding the consumption of energy and materials or extending the product’s lifetime.

- The (6) Limited use of hazardous substances is also a way to prevent the production of hazardous and toxic wastes. On the other side, products at the EoL that are free of hazardous substances can be more easily re-used/recycled. In some case, the presence of hazardous substances can make waste unsuitable even for the energy recovery.

- The (7) Design for disassembly is related to the conceptual and technical study on how to enable the separation of main product’s components, in order to make them available for re-use, recycling and recovery. A correct design for disassembly can also help the product’s maintenance (e.g. enabling an easy access to main worn-out parts/components), contributing therefore to the waste prevention, the maintaining of performances and the prolongation of the useful life. The easy access to component is also an important criterion that influence their reusability, recyclability and recoverability;

- The strategies for the (8) Design for reuse include the possibility to re-introduce into the manufacturing process those used components that are still in good conditions (for example parts that generally are not highly subjected to wear or worthy materials/components);

- The (9) Design for recovery/recycling focuses on the adoption of solutions that facilitate the product reuse/recycling/recovery. It includes design solutions e.g.:
  - limiting the number of different employed materials (e.g. “mono-materiality”);
  - avoiding the contamination among employed materials that make difficult their disassembly/separation;
  - use of materials that can be easily recycled without sensible quality loss;
  - reduction of welding and glues, and optimized use of screws and other fastening options;
  - easy access to hazardous and/or to “worthy” components;
  - modular manufacturing.
It is noted that the above criteria are not always suitable or beneficial for every product category, but they have to be evaluated case-by-case. Finally, designers should also foresee the possibility that components with appreciable energy content could be separated and addressed to energy recovery processes.

- A final consideration regards the (10) Availability of information for stakeholder (with a particular care to users, maintainers and companies working at the end-of-life of the products). The provision of information is, in fact, a very easy and efficacious way to address stakeholders to adopt best environmental behaviours, including:
  
  o optimal use of the products to minimize consumption during the use-phase;
  o information about maintenance and its relevance for the extension of the product’s lifetime and the maintenance of its performances over the time;
  o information about how to disassemble the product at the end-of-life, enabling the access to reusable/recyclable part,
  o information about how and where to dispose off the product or it's consumable parts;
  o list and characterization of employed product’s materials/components (including Bill of Materials and the labelling of hazardous and other critical components). Such information could be useful to identify components that are worthy to be recycled or recovery.

Note that the provided information can concern all the life-cycle phases of the product and could contribute to the improvement of all the different levels of the waste hierarchy.

Figure 1.4 Links among Ecodesign strategies and the waste hierarchy
1.5 The Directive on the Waste Electrical and Electronic Equipment (WEEE)

The European Directive 2002/96/EC aims at “the prevention of waste electrical and electronic equipment (WEEE), and in addition, the reuse, recycling and other forms of recovery of such wastes so as to reduce the disposal of waste” [EU, 2002b].

The Directive established that “when supplying a new product, distributors shall be responsible for ensuring that such waste can be returned to the distributor at least free of charge”. Furthermore, “producers or third parties acting on their behalf, set up systems to provide for the treatment of WEEE using best available treatment, recovery and recycling techniques”.

This represents an application of the Producer Responsibility Principle where it is considered that “manufacturers and importers of products bear a degree of responsibility for the environmental impacts of their products throughout the products’ life-cycles, including upstream impacts inherent in the selection of materials for the products, impacts from manufacturers’ production process itself, and downstream impacts from the use and disposal of the products”. [Gary 1994]. Producers accept their responsibility when they design their products to minimize the life-cycle environmental impacts and when they accept legal, physical or economic responsibility for the environmental impacts that cannot be eliminated by design [Gary, 1994].

Furthermore, “the costs of collection, treatment and environmentally sound disposal shall not be shown separately to purchasers at the time of sale of new products” [EU, 2002b].

Concerning recycling and recovery of WEEE, producers shall meet the minimum targets showed in Table 1.4. Product categories exempted by the Directive are:

- luminaries in households;
- filament bulbs (e.g. incandescent and halogen lamps)
- large-scale stationary industrial tools.

However, article 13 of the Directive establishes the need to adapt exemptions to the technological progress, and to evaluate the possibility to include luminaries in households, filament bulbs and photovoltaic products (i.e. solar panels) into the framework of the Directive.
Table 1.4. Minimum recycling and recovery targets of WEEE [EU, 2002b]

<table>
<thead>
<tr>
<th>Product category</th>
<th>Reuse/Recycling rate</th>
<th>Recovery rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large household appliances</td>
<td>75%</td>
<td>80%</td>
</tr>
<tr>
<td>Automatic dispensers</td>
<td>75%</td>
<td>80%</td>
</tr>
<tr>
<td>IT and telecommunications equipment</td>
<td>65%</td>
<td>75%</td>
</tr>
<tr>
<td>Consumer equipment</td>
<td>65%</td>
<td>75%</td>
</tr>
<tr>
<td>Small household appliances</td>
<td>65%</td>
<td>75%</td>
</tr>
<tr>
<td>Lighting equipment</td>
<td>50%</td>
<td>70%</td>
</tr>
<tr>
<td>Electrical and electronic tools (with the exception of large-scale stationary industrial tools)</td>
<td>50%</td>
<td>70%</td>
</tr>
<tr>
<td>Consumer equipment</td>
<td>65%</td>
<td>75%</td>
</tr>
<tr>
<td>Monitoring and control instruments</td>
<td>50%</td>
<td>70%</td>
</tr>
<tr>
<td>Gas discharge lamps</td>
<td>50%</td>
<td>70%</td>
</tr>
</tbody>
</table>

Member States shall also ensure that producers or third parties would treat WEEE “using best available treatment, recovery and recycling techniques. The systems may be set up by producers individually and/or collectively. […] The treatment shall, as a minimum, include the removal of all fluids and a selective treatment in accordance with Annex II“ (the list of minimum treatment is shown in Table 1.5).

Table 1.5. Selective treatments for materials and components of WEEE

<table>
<thead>
<tr>
<th>The following substances, preparations and components have to be removed from any separately collected WEEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>polychlorinated biphenyls (PCB) containing capacitors […],</td>
</tr>
<tr>
<td>mercury containing components, such as switches or backlighting lamps,</td>
</tr>
<tr>
<td>batteries,</td>
</tr>
<tr>
<td>printed circuit boards of mobile phones generally, and of other devices if the surface of the printed circuit board is greater than 10 square centimetres,</td>
</tr>
<tr>
<td>toner cartridges, liquid and pasty, as well as colour toner,</td>
</tr>
<tr>
<td>plastic containing brominated flame retardants,</td>
</tr>
<tr>
<td>asbestos waste and components which contain asbestos,</td>
</tr>
<tr>
<td>cathode ray tubes,</td>
</tr>
<tr>
<td>chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) or hydrofluorocarbons (HFC), hydrocarbons (HC), gas discharge lamps, liquid crystal displays (together with their casing where appropriate) of a surface greater than 100 square centimetres and all those back-lighted with gas discharge lamps,</td>
</tr>
<tr>
<td>external electric cables,</td>
</tr>
<tr>
<td>components containing refractory ceramic fibres […],</td>
</tr>
<tr>
<td>components containing radioactive substances with the exception of components that are below the exemption thresholds set in Article 3 of and Annex I to Council Directive 96/29/Euratom […],</td>
</tr>
<tr>
<td>electrolyte capacitors containing substances of concern (height &gt; 25 mm, diameter &gt; 25 mm or proportionately similar volume).</td>
</tr>
<tr>
<td>The following components of WEEE that is separately collected have to be treated as indicated</td>
</tr>
<tr>
<td>cathode ray tubes: The fluorescent coating has to be removed,</td>
</tr>
<tr>
<td>equipment containing gases that are ozone depleting or have a global warming potential (GWP) above 15, such as those contained in foams and refrigeration circuits: the gases must be properly extracted and properly treated. Ozone-depleting gases must be treated in accordance with Regulation (EC) No 2037/2000 […].</td>
</tr>
<tr>
<td>gas discharge lamps: The mercury shall be removed.</td>
</tr>
</tbody>
</table>
1.5.1 The revision process of the WEEE Directive

The European Commission estimated that approximately “65% of electrical and electronic equipment (EEE) placed on the market is separately collected, but less than half of this is treated and reported according to the requirements of the Directive; the remainder potentially leaks out to substandard treatment and is illegally exported to third countries, among which non-OECD countries. This leads to losses of valuable secondary raw materials and increases the risk of release of hazardous substances into the environment” [EC, 2008b]. Furthermore, there are no targets for the re-use of whole appliances in WEEE Directive.

Concerning hazardous substances, these are and will be still present in WEEE, despite RoHS requirements. This is due to several reasons as [EC, 2008c]:

– The RoHS restrictions only apply to new EEE put on the market as from 1 July 2006. Since the average life time of an EEE is varying but can be up to 15 years, the returning waste streams will consists of pre-RoHS waste until at least 2020;
– In addition to the substances covered by the RoHS Directive, other potential hazardous substances are annually being used in EEE in considerable amounts including TBBP-A, HBCDD, DEHP and beryllium oxide;
– The RoHS Directive allows for the presence of the restricted substances at a low level;
– Furthermore, the RoHS included various exemptions for specific applications where substitution is "technically or scientifically impracticable". These contribute to introduce in the market large quantities of hazardous substances that have to be carefully treated at the product’s EoL;
– Evidence on enforcement of the RoHS Directive indicates that significant volumes of non-compliant equipment have been placed on the market illegally, which will later enter the waste steam.

On the other side, the European Commission estimated that other relevant legislation, such as RoHS, and Ecodesign Directive “are not assumed to have an immediate impact on the level of collection. They can however in the future positively impact on treatment efforts (and thereby indirectly on the attractiveness of collection) if design requirements and substance choices in favour of better recycling are established [EC 2008c].

The WEEE Directive is currently under revision process [EC, 2008b; EC, 2008c]. The expected objectives of the revision are:

– To reduce administrative costs through the removal of all unnecessary administrative burdens, without lowering the level of environmental protection.
– To improve effectiveness and implementation of the Directive through increased compliance and reduced free-riding.
– To reduce impacts on the environment from the collection, treatment and recovery of WEEE at the levels where the greatest net benefit to society results.

The main proposed changes regard [EC, 2008b]:

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to set a 65% WEEE collection rate, defined in function of the average amount of EEE placed on the market in the two preceding years. This target reflects the amounts of WEEE which are currently already separately collected in the Member States and takes the variations in EEE consumption in individual Member States into account. Therefore, it will encourage Member States to come to the most optimal separate WEEE collection. The proposed collection rate should be achieved annually, starting in 2016.

to set minimum inspection requirements for Member States to strengthen the enforcement of the WEEE Directive. Minimum monitoring requirements are proposed for shipments of WEEE.

to include the re-use of whole appliances into the recycling target and set a new target for medical devices.

to harmonize producer registration and reduce unnecessary administrative burden

1.5.2 The WEEE Directive and the Ecodesign policies

The WEEE Directive contributed to the increase of the collection rate and recycling of EEEs. The prevention of waste generation is one of the main objectives of the Directive, to be achieved also through a correct design of the products oriented on their environmental performance.

Article 4 states that: “Member States shall encourage the design and production of electrical and electronic equipment which take into account and facilitate dismantling and recovery, in particular the reuse and recycling of WEEE, their components and materials”. On this purpose, the introduction of requirements at the design stage of the products could contribute into improving the environmental performance of products.

In particular, designers should evaluate solutions to foster the product’s recyclability including for example: to design products with a lower content of hazardous and non-recyclable substances/materials, to simplify the management of the product’s EoL (e.g. improving the disassembly and ‘separability’ of components), to use materials that keep their physical/chemical properties after long time and that are suitable for recycling, etc. The general idea, as also underlined by some authors and designers, is that by improving the recyclability, recycling could be improved over time (although several other factors take place).
1.6 Ecodesign Directive and Implementing Measures

A preliminary survey about already adopted IMs has been here carried out. The scopes of the survey was to depict a general overview of adopted requirements and their typology, especially in relation with the other requirements introduced by the above mentioned WEEE and RoHS Directives.

Eleven IMs have been already approved/adopted by the European Commission. The first adopted IM concerned the energy consumption of products in standby mode. Due to its general characteristic, this IM does not configure itself as “sector specific” but can be considered as “transversal” to several products. The other IMs, instead, regard specific product categories and introduce several requirements for Ecodesign (presented in Table 1.7).

Among this eight product categories, lighting devices, televisions and refrigerators are also under the WEEE and the RoHS directive.

The survey showed that, concerning the regulated products, requirements regarding recyclability, recoverability and reusability; use of recycled materials and limitation of the use of priority resources have been not selected. That means that these were identified in the IM process as not relevant or efficient for these product categories and hence did not find their way to the IMs.

Concerning the content of hazardous substances, some requirements are set. These include the request to report the content/presence of lead into television and the content mercury into lamps and televisions.

The IMs also introduce some general requirements for producers to publish, on the products or in the manuals or website, information about the energy and environmental performance of the products. The provision of information is meant for ‘greening’ the market, addressing users in the ‘environmental conscious’ choice of the products. In order to have a more general overview, requested information has been grouped into the following categories (Table 1.7):

- **General information about technical characteristics of the product;**

- **Information about consumptions and efficiency:** this category grouped all the requirements about the energy efficiency and efficacy indexes, and the power consumptions under various configurations; **Information on product’s lifetime and operational time:** including indexes about: average product’s lifetime, survival factor, performances of the products over the time, etc;

- **Information about disassembly and End-of-life of the product:** suggestions to consumers about how to manage the End-of-life of the products and information about waste treatment plants on how disassembly and recycle system components;

- **Content of Hazardous substance:** it includes requirements about publishing the typology and quantity about hazardous substances;

- **Benchmark about BAT:** Best Available Technology labelled or showed into the product or websites.
### Table 1.7. Requirements introduced by adopted Implementing Measures

<table>
<thead>
<tr>
<th>Product category</th>
<th>Simple set-top boxes</th>
<th>Domestic lightings</th>
<th>Tertiary sector lightings</th>
<th>External power supplies</th>
<th>Circulators</th>
<th>Electric motors</th>
<th>Domestic refrigeration</th>
<th>Televisions</th>
<th>Dishwasher</th>
<th>Washing machine</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Specific and general requirements</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Power consumption limits</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>- Stand-by function available</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>- Automatic power down function</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Information to consumers about consumption of active and stand-by mode</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

#### Information to be provided to the consumers

- General information: normal luminous flux, nominal lifetime, number of switching cycles before failure, colour temperature, Warm-up time, A warning if the lamp can not be dimmed, if designed for optimal use in non-standard conditions, lamp dimensions, regulated claiming equivalence to incandescent lamps (to be provided into packaging or websites);
- Technical parameters as: rated wattage, rated luminous flux, rated lamp lifetime, Lamp power factor, Lumen Maintenance factor, starting time, colour rendering (to be provided by websites);
- If the lamp contains mercury: Hg content, indication about to clean debris in case of breakage, recommendations on how to dispose the lamp.

- Nominal and rated lamp wattage.
- Nominal and rated lamp - luminous flux.
- Rated lamp efficiency.
- Rated lamp Lumen Maintenance Factor.
- Rated lamp Survival Factor.
- Lamp mercury content.
- Colour Rendering Index.
- Colour temperature.
- Ambient temperature at which the lamp was designed to maximize its luminous flux.
- Energy efficiency index (lamp ballast).
- For luminaries: lamp efficiency or ballast efficiency, and compatibility with lamps and luminaires (depending on how the luminaries are placed on the market) disassembly instruction; maintenance instruction.

### Table 1.8. Energy Efficiency Index of Circulators

<table>
<thead>
<tr>
<th>Circulator Type</th>
<th>Energy Efficiency Index</th>
<th>Power Consumption</th>
<th>Ambient Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot Water</td>
<td>0.75</td>
<td>0.5</td>
<td>50 °C</td>
</tr>
<tr>
<td>Cold Water</td>
<td>0.80</td>
<td>0.6</td>
<td>20 °C</td>
</tr>
</tbody>
</table>

#### Information to be provided to the consumers

- The energy efficiency index.
- Information about the benchmark most efficient circulators.
- Information concerning disassembly, recycling, or disposal at end-of-life of components and materials.
- If the circulators is suitable for drinking water only.
- Information on how to install, use and maintain the circulator in order to minimize its environmental impact (on websites).

- General information: nominal efficiency, efficiency level, year of manufacture, manufacturer’s name or trade mark, commercial registration number and place of manufacturer, product’s model number, number of poles of the motor, the rated power output(s), the rated input frequency(s) of the motor, the rated voltage(s); the rated speed(s);
- Information relevant for disassembly, recycling or disposal at End-of-life;
- Information on the range of operating conditions for which the motor is specifically designed.
- Manufacturers shall provide information in the technical documentation on any specific precautions that must be taken when motors are assembled, installed, maintained or used with variable speed drives.

- Information about the optimal use and setting of the refrigerator.
- The on-mode power consumption data.
- The standby and/or off-mode power consumption data (for televisions without forced menu) information about the peak luminance.
- If the television contains mercury or lead: the content as XX mg and the presence of lead.

- Information on the standard programme as the most efficient.
- Information on the other programmes.

- Information to easy identify programs at 40° and 60°, and availability of program at 20°C.
- Detailed of the power consumption.
- Details of the programmes.
- Use of detergent.

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### Table 1.8. Implementing Measures about EuP - Requirements on information to be provided to consumers

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>General information about technical characteristics</td>
<td>☒</td>
<td>✔</td>
<td>✔</td>
<td>☒</td>
<td>☒</td>
<td>✔</td>
<td>☒</td>
<td>✔</td>
<td>✔</td>
<td>✓</td>
</tr>
<tr>
<td>Information about consumptions and efficiency</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>❌</td>
<td>✔</td>
<td>❌</td>
<td>❌</td>
<td>✔</td>
<td>✔</td>
<td>✓</td>
</tr>
<tr>
<td>Information about optimal use</td>
<td>☒</td>
<td>✔</td>
<td>✔</td>
<td>☒</td>
<td>✔</td>
<td>✔</td>
<td>✓</td>
<td>✔</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Information on lifetime and operational life; decay of performances or failures, etc</td>
<td>☒</td>
<td>✔</td>
<td>✔</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
</tr>
<tr>
<td>Information about disassembly, recycling, disposal</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>❌</td>
<td>✔</td>
<td>✔</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
</tr>
<tr>
<td>Content of hazardous substances</td>
<td>☒</td>
<td>✔</td>
<td>✔</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
</tr>
<tr>
<td>Benchmark for the BAT</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>☒</td>
<td>✔</td>
<td>✖</td>
<td>✖</td>
<td>✖</td>
<td>✖</td>
<td>✖</td>
</tr>
</tbody>
</table>

- ✔ Information to be provided
- ☒ Information not significant
1.7 EU Ecolabel and Ecodesign: two complementary schemes

In the current legislation, the Ecodesign Directive's Implementing Measures (IM) and the ecological criteria for the award of the EU Ecolabel represent two complementary schemes for the sustainable production and consumption policies. In fact, the former aims at fixing a set of minimum requirements that all the products have to accomplish; the latter, instead, qualifies the environmental excellence in the market (Figure 1.5).

Both the tools have to be considered as “dynamic”, meaning that they have to be periodically revised and upgraded, in order to push and drive the market towards more sustainable production and consumption patterns, following the approach of the continuous improvement. It is therefore important that the IM and the EU Ecolabel criteria would be developed in harmony, in order to improve their consistency and to strengthen their synergic use in the European legislation. Furthermore, IM and Ecolabel criteria can contribute to the improvement the Green Public Procurement (GPP), in particular to the definition of criteria for the establishment of selecting and award criteria for the public purchasing.

![Figure 1.5 Ecodesign requirements and Ecolabel criteria as tools for the sustainability](image)

On this purpose, the EC commissioned a study to evaluate the extent to which the evidence base gathered for Energy Using Product (EuP) groups could be used to support the Ecolabel criteria development; in other words how the Ecolabel could make best use of and secure added value from EuP activities [Dolley and Pell, 2008].

The first step in the assessment was to compare and contrast the Ecolabel and EuP. The comparison concluded that in both cases, an evidence base of information is generated to inform development of IM and Ecolabel criteria. Both bases share similar characteristics whereby they:

- Clearly set out a product group definition,
- Are life cycle based,
Consider the EU market in terms of sales,
Identify differences between technologies in a product group,
Identify best practice,
Identify consumers as being important in the delivery of environmental improvement,
Involve stakeholder consultation.

It was also assessed a great similarity between the EuP and Ecolabel evidence bases. Any EuP is a potential candidate for the Ecolabel scheme. Furthermore, the EuP verification system includes test methods and standards that can be very helpful to the Ecolabel scheme.

The study concluded then about the need of an ‘ad-hoc’ working group to discuss and help steer the development of Ecolabel criteria based on EuP information. This would contribute to save both time and resources. A second step of the study foresees to develop/revise Ecolabel criteria for six priority EuP categories:

1. Personal Computers – desktop and Computer Monitors
2. Personal Computers – laptops
3. Televisions
4. Domestic refrigeration
5. Imaging equipment: Copiers, faxes, printers, scanners, multifunctional devices
6. Office lighting & domestic lighting products

1.7.1 Ecolabel criteria and project’s key issues

The current paragraph analyzes the Ecolabel criteria in relation with the project’s key parameters: recyclability/reusability/recoverability; recycled content; priority resources; hazardous substances.

The survey regarded the EUP categories that have been included in the Eco-label scheme (including also previously developed criteria that are now under revision). The criteria have been showed in Table 1.9. It is possible to observe that:

- several criteria regard recyclability/reusability. These include among others:
  - obligation for some manufacturer to take back for free the product for refurbishment or recycling;
  - use of compatible polymers to enhance recyclability;
  - possibility to separate labels and metal parts from plastic components;
  - ‘design for disassembly’ of products, sufficiently supported by manufacture’s reports;
  - information to be provided about product recycling;

---

20 The table present a synthesis of the requirements related to the project key issues. For a precise and complete list of requirements readers can refer to the European Commission decisions on the ecological criteria for the award of the Community Ecolabel.
- in few cases (personal computer and portable computer) a recyclability requirement about plastic and metal are set;

- for almost all the product categories, restrictions on hazardous materials and substances have been set. In addition to the materials regulated by the RoHS Directive, the criteria restricted some flame retardants and other substances classified as health hazard or environmentally hazardous;

- criteria about the recycled content are partially inserted, concerning only some packaging. In particular, cardboard packaging, when used in some product categories, shall consist of at least 80 % recycled material;

- the criteria do not include requirements about priority resources. Few restrictions have been included regarding only some refrigerants due to their global warming potential or their ozone depleting potential.

Table 1.10 reports the verification methods that have been adopted to assess the compliance with some of the above Ecolabel requirements.

It is interesting to note that, concerning personal computers and portable computers, a recyclability requirement has been set. This established that **90% (by weight) of the plastic and metals in the products has to be technically recyclable.** The Commission decision on Ecolabel criteria [EC, 2005b] establishes that: **“The applicant shall declare the compliance of the product with these requirements”**. Anyway, no further details are provided about what is intended for “technically recyclable” and how manufacturer have to demonstrate their conformity.

For the completeness of the information and of the comparison, Table 1.11 shows the requirements about recycling/recovery rate as set by the WEEE Directive for the previous described product categories under the Ecolabel regulation
Table 1.9. Ecolabel criteria for EuPs concerning project’s key issues

<table>
<thead>
<tr>
<th>Product category</th>
<th>Recyclability / recoverability / reusability</th>
<th>Recycled content</th>
<th>Priority resources</th>
<th>Hazardous substances</th>
</tr>
</thead>
</table>
| Personal computers and portable computers<sup>1, 2</sup> | - The manufacturer shall offer free of charge the take-back for refurbishment or recycling of the product, and for any component being replaced;  
- one qualified person alone shall be able to dismantle the product;  
- the manufacturer shall check the disassembly of the unit and provide a disassembly report that shall be made available to third parties on request;  
- 90 % (by weight) of the plastic and metal materials in the housing and chassis shall be technically recyclable;  
- producers have to provide information about the fact that the product has been designed to enable proper reuse of parts and recycling and should not be thrown away;  
- all packaging components shall be easily separable by hand into individual materials to facilitate recycling;  
- if labels are required, they shall be easily separable or inherent;  
- 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;  
- plastic parts shall contain no metal inlays that cannot be separated by a single person using simple tools. | Where used, cardboard packaging shall consist of at least 80 % recycled material. | Where used, cardboard packaging shall consist of at least 80 % recycled material. | - The background lighting of the LCD monitor shall not contain more than 3 mg of mercury on average per lamp;  
- the display of a personal data assistant (PDA) shall contain no mercury. (for portable computer only);  
- batteries shall not contain more than 0,0001 % of mercury, 0,001 % of cadmium or 0,01 % of lead by weight of the battery;  
- hazardous materials shall be separable;  
- plastic parts shall have no lead or cadmium intentionally added;  
- plastic parts shall not contain poly-brominated biphenyl (PBB) or poly-brominated diphenyl ether (PBDE) flame retardants;  
- plastic parts shall not contain chloroparaffin flame retardants with chain length 10 to 17 carbon atoms and chlorine content greater than 50% by weight;  
- plastic parts heavier than 25 grams shall not contain flame retardant substances that are classified with the following risk phrase: R45, R46, R60, R61, R50, R50/53, R51/53 as defined in Council Directive 67/548/EEC. |
| Washing machine<sup>3</sup>                          | - The manufacturer shall offer the take-back, free of charge, for recycling of the washing machines and of components being replaced by himself or by any commissioned company  
- the manufacturer shall take into account disassembly when designing and shall check the disassembly of the washing machine and provide a disassembly report. | | | - Plastic parts heavier than 5 grams shall not contain some flame retardants (as listed)  
- plastic parts heavier than 25 grams shall not contain flame retardant substances that are classified with the following risk phrase: R45, R46, R60, R61, R50, R50/53, R51/53 as defined in Council Directive 67/548/EEC. |

<sup>1</sup> 2005/341/EC;  <sup>2</sup> 2005/343/EC;  <sup>3</sup> 2000/45/EC;
Table 1.9 (continue). Ecolabel criteria for EuPs concerning project’s key issues

<table>
<thead>
<tr>
<th>Product category</th>
<th>Recyclability / recoverability / reusability</th>
<th>Recycled content</th>
<th>Priority resources</th>
<th>Hazardous substances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat pump&lt;sup&gt;4&lt;/sup&gt;</td>
<td>- The manufacturer shall offer free of charge, the take-back for recycling of the appliance and of components being replaced; - the manufacturer shall take into account the disassembly of the appliance and provide a disassembly report; - the type of refrigerant and foaming agent used for the insulation shall be indicated on the appliance, near to or on the rating plate, to facilitate possible future recovery; - all packaging components shall be easily separable by hand into individual materials to facilitate recycling.</td>
<td>The global warming potential (GWP) for the refrigerant must not exceed GWP value &gt; 2 000 over a 100 year period.</td>
<td>- The secondary refrigerant, brine or additives must not be substances classified as environmentally hazardous or constituting a health hazard as defined by Council Directive 67/548/EEC</td>
<td>- cadmium, lead, mercury, chromium 6⁺ or the flame retardants, i.e. polybrominated biphenyl (PBB) or polybrominated diphenyl ether (PBDE) flame retardants may not be used</td>
</tr>
<tr>
<td>Refrigerators&lt;sup&gt;5&lt;/sup&gt;</td>
<td>- Plastic parts shall not contain PBB or PBDE flame retardants. Plastic parts shall not contain chloroparaffin flame retardants with chain length 10-13 carbon atoms and chlorine content &gt; 50% by weight</td>
<td>Where used, cardboard packaging shall consist of at least 80% recycled material.</td>
<td>- Where used, plastic parts shall contain PBB or PBDE flame retardants. Plastic parts shall not contain chloroparaffin flame retardants with chain length 10-13 carbon atoms and chlorine content &gt; 50% by weight</td>
<td>- plastic parts heavier than 25 grams shall not contain flame retardant substances that are classified with the following risk phrase: R45, R46, R60, R61, R50; R50/53, R51/53 as defined in Council Directive 67/548/EEC</td>
</tr>
<tr>
<td>Television&lt;sup&gt;6&lt;/sup&gt;</td>
<td>- The manufacturer shall demonstrate that the television can be easily dismantled by professionally trained recyclers using the tools usually available to them, - plastic parts shall be of one polymer or be of compatible polymers for recycling - metal inlays that cannot be separated shall not be used.</td>
<td>The refrigerants in the refrigerating circuit and foaming agents used for the insulation of the appliance shall have an ozone depletion potential equal to zero.</td>
<td>- The total amount of mercury (Hg), in all lamps, per screen, shall be no greater than 75 mg for screens with a visible screen diagonal of up to and including 40 inches</td>
<td>- cadmium, lead, mercury, chromium 6⁺ or the flame retardants, i.e. polybrominated biphenyl (PBB) or polybrominated diphenyl ether (PBDE) flame retardants may not be used</td>
</tr>
</tbody>
</table>

<sup>4</sup> 2007/742/EC; <sup>5</sup> 2004/669/EC; <sup>6</sup> 2009/300/EC
Table 1.9 (continue). Ecolabel criteria for EuPs concerning project’s key issues (continued)

<table>
<thead>
<tr>
<th>Product category</th>
<th>Recyclability / recoverability / reusability</th>
<th>Recycled content</th>
<th>Priority resources</th>
<th>Hazardous substances</th>
</tr>
</thead>
</table>
| Light bulbs<sup>7</sup> | • For single-ended light bulbs, all cardboard packaging must contain a minimum of 65% recycled material (by weight).  
• for double-ended light bulbs, all cardboard packaging must contain a minimum of 80% recycled material (by weight). | | | • Thresholds for mercury content are set  
• plastic parts heavier than 5 grams shall not contain some flame retardants (as listed)  
• plastic parts heavier than 5 grams shall not contain flame retardant substances that are classified with the following risk phrase: R45, R46, R60, R61, R50; R50/53, R51/53 as defined in Council Directive 67/548/EEC |
| Vacuum cleaner<sup>8</sup> | • The manufacturer shall check the disassembly of the product and provide a disassembly report that shall be made available to third parties on request.  
• the electrical parts shall be mechanically connected so as to facilitate disassembly and recycling.  
• the metal parts shall be easily accessible so as to facilitate disassembly and recycling.  
• plastic parts shall contain no metal inlays that cannot be separated.  
• the manufacturer shall offer the take-back for recycling of the product, and of any component being replaced, except dust bags and filters.  
• information about the fact that the product has been designed to enable proper recycling and should not be thrown away. Advice on how the consumer can make use of the manufacturer's take-back for recycling offer | | | • The vacuum cleaner (including the power nozzle and the hose) shall not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBBs) and/or polybrominated diphenyl ethers (PBDEs);  
• plastic parts heavier than 25 grams shall not contain chloroparaffins with chain length 10-13 C atoms, chlorine content > 50 % by weight  
• plastic parts heavier than 25 grams shall not contain flame retardant substances that are classified with the following risk phrase: R45, R46, R60, R61, R50; R50/53, R51/53 as defined in Council Directive 67/548/EEC |

<sup>7</sup> 2002/747/EC;  <sup>8</sup> 2003/121/EC
Table 1.10. Verification methods for Ecolabel requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Assessment and verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 % (by weight) of the plastic and metal materials in the housing and chassis shall be technically recyclable</td>
<td>The applicant shall declare the compliance of the product with these requirements and shall provide to the competent body assessing the application a copy of the disassembly report.</td>
</tr>
<tr>
<td>The type of refrigerant and foaming agent used for the insulation shall be indicated on the appliance, near to or on the rating plate, to facilitate possible future recovery</td>
<td>The applicant shall declare compliance of the appliance with this requirement. The applicant shall provide the Competent Body assessing the application with a copy of the disassembly report. The applicant and/or his supplier or suppliers, as appropriate, shall indicate to this Competent Body, which refrigerants and foaming agents have been used.</td>
</tr>
<tr>
<td>The metal parts shall be easily accessible so as to facilitate disassembly and recycling</td>
<td>The applicant shall provide a declaration to this effect together with appropriate supporting documentation, indicating the design of the product and accessibility of the metal parts. The disassembly report provided by the applicant shall confirm this.</td>
</tr>
<tr>
<td>The manufacturer shall demonstrate that the television can be easily dismantled by professionally trained recyclers using the tools usually available to them.</td>
<td>A test report shall be submitted with the application detailing the dismantling of the television. It shall include an exploded diagram of the television labelling the main components as well as identifying any hazardous substances in components. It can be in written or audiovisual format.</td>
</tr>
<tr>
<td>Where used, cardboard packaging shall consist of at least 80 % recycled material.</td>
<td>The applicant shall declare compliance with the requirement and provide a sample(s) of the packaging to the awarding competent body as part of the application.</td>
</tr>
<tr>
<td>Plastic parts heavier than 25 grams shall not contain flame retardant substances that are classified with the following risk phrase: R45, R46, R60, R61, R50; R50/53, R51/53 as defined in Council Directive 67/548/EEC.</td>
<td>The applicant shall declare the compliance of the product with these requirements. The flame retardants that are used, if any, shall not have been assigned any of the above risk phrases nor shall they be named in Annex 1 to Directive 67/548/EEC or its subsequent amendments regarding the classification, packaging and labelling of dangerous substances. This requirement does not apply to flame retardants that on application change their chemical nature to no longer warrant classification under any of the R-phrases listed above, and where less than 0.1 % of the flame retardant in the treated part remains in the form as before application. Any flame retardants that are used in plastic parts &gt;25g must be specified in the application documentation by giving their name and CAS number.</td>
</tr>
</tbody>
</table>

Table 1.11. Recycling/recovery rates foreseen by the WEEE Directive for the investigated products categories under the Ecolabel regulation

<table>
<thead>
<tr>
<th>Product category</th>
<th>Reuse/Recycling rate (WEEE)</th>
<th>Recovery rate (WEEE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washing machine</td>
<td>75%</td>
<td>80%</td>
</tr>
<tr>
<td>Heat pump</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refrigerators</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personal computers and portable computers</td>
<td>65%</td>
<td>75%</td>
</tr>
<tr>
<td>Television</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light bulbs</td>
<td>50%</td>
<td>70%</td>
</tr>
<tr>
<td>Vacuum cleaner</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1.7.2 Recyclability in the Ecolabel Criteria: the case study of wooden furniture

The survey about Ecolabel criteria concludes with the analysis of non-EuP. The wooden furniture represents an interesting example on how recyclability requirements have discussed.

In a preliminary study about the labelling of wooden furniture products, authors observed that recycling requirements on product level are very limited in existing schemes, while most recycling requirements are on a material level [CREM, 2004]. Possible requirements about recyclability include:

- Reference to national/international legislations on recycling and waste management;
- Fixing obligation to the manufacturer/importer, including e.g. take-back initiatives or minimum requirement of recycling/recovery of waste produced during manufacture,
- Information to consumers about how to manage the product end-of-life.

Authors therefore proposed the following requirement about the recyclability of the wooden furniture [CREM, 2004]:

“The eco-labelled product shall be easily disassembled making possible the recovery and recycling of materials used. In order to facilitate recycling of the materials used in products, the following materials have to be easy separable:

- • All aluminium
- • Steel, if it composes ≥10% by weight of the eco-labelled product.
- • Glass, if it composes ≥10% by weight of the eco-labelled product;
- • Plastic, if it composes ≥50% by weight of the eco-labelled product.

Assessment and verification: The applicant shall provide appropriate documentation showing full compliance with this criterion, including an instruction for disassembly and where it is explained how aluminium, steel, glass and plastic parts can be disassembled. Furthermore, the applicant shall provide appropriate information on the construction and composition of the product on the basis of which the certifying institute can assess whether the product is separable”.

This requirement has been partially inserted in the adopted criteria for the Ecolabel of wooden furniture [EC, 2009b]. Here it is asserted that:

“The product must be easily recyclable. A detailed description of the best ways to dispose of the product (reuse, recycling, take back initiative by the applicant, energy production) shall be given to the consumer, ranking them according to their impact on the environment. For each option the precautions to be taken to limit the impact on the environment will have to be clearly stated”.

Concerning the assessment and verification criteria, the EC decision states that [EC, 2009b]:

”The applicant and/or his supplier shall provide a sample of the information which will be supplied and a justification of the recommendations”.

This requirement is similar to that above mentioned concerning personal computers. However the requirement about wooden furniture applies to the full product after its useful life; furthermore the requirement is more detailed about the information that the manufacturer (or the suppliers) has to provide in order to demonstrate the recyclability of the product. Such information is also addressed to
consumers (about how to dispose the product and profit by the take back initiatives) and to people that have to manage the recycling (concerning the technologies to adopt and the related impacts).

1.7.3 Conclusion regarding Ecodesign and Ecolabel requirements
Several Ecolabel requirements concerned the key question of the present project, including recyclability/recoverability, recycled content and hazardous substances. These last, in particular, included several restrictions, going further the requirements of the RoHS Directive.

The compliance to the requirements is based on “self declared” statements supported by sufficient technical documentation, including:

- Product composition and detail;
- Disassembly report;
- Declaration from suppliers;
- Use of labelling.
Chapter 2. Recyclability, Reusability and Recoverability

2.1 Definitions

2.1.1 Definitions in the legislation
Here following are presented and discussed some definitions of *Recyclability*, *Reusability* and *Recoverability* and related issues, as introduced into the European legislation (Table 2.1 and Table 2.2).

It is possible to observe that concerning the recycling and recovery definition, there is a substantially agreement. Some considerations that arise are:

- Recycling, reuse and recovery aims at reducing waste disposal into landfill, accordingly to the “waste hierarchy” [EU, 2008];
- Recycling includes the re-processing of products (or components) into the same or different production process, but not as energy source;
- Reuse implies that product (or components) are used for the same purpose they were conceived. Reuse of components for other purposes are instead classified as recycling;
- Re-use does not constitute a recovery option, in view of the fact that a re-used product has not been discarded.

Concerning the definitions of recyclability/recoverability/reusability, it arises that:

- all the three issues are described as a “potential”, “characteristic” or “ability” of components or materials of a products at the EoL;
- such potentials are not detailed into the definitions, relating to standards for further details.
### Table 2.1. Definitions of Recycling/Reuse/Recovery in the EU legislation

<table>
<thead>
<tr>
<th>Recycling</th>
<th>Definition</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Recycling’ means the reprocessing in a production process of the waste materials for the original purpose or for other purposes but excluding energy recovery. Energy recovery means the use of combustible waste as a means to generate energy through direct incineration with or without other waste but with recovery of the heat;</td>
<td>[EU, 2000; EU, 2002b]</td>
<td></td>
</tr>
<tr>
<td>‘Recycling’ means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations</td>
<td>[EU, 2008]</td>
<td></td>
</tr>
<tr>
<td>‘Recycling’ means the reprocessing in a production process of the waste materials for the original purpose or for other purposes, but excluding energy recovery</td>
<td>[EU, 2009]</td>
<td></td>
</tr>
<tr>
<td>‘Reuse’ means any operation by which component parts or materials diverted from an EoL vehicle</td>
<td>[EU, 2005b]</td>
<td></td>
</tr>
<tr>
<td>‘Reuse’ means any operation by which WEEE or components thereof are used for the same purpose for which they were conceived, including the continued use of the equipment or components thereof which are returned to collection points, distributors, recyclers or manufacturers</td>
<td>[EU, 2002b]</td>
<td></td>
</tr>
<tr>
<td>‘Reuse’ means any operation by which a product or its components, having reached the end of their first use, are used for the same purpose for which they were conceived, including the continued use of a product which is returned to a collection point, distributor, recycler or manufacturer, as well as reuse of a product following refurbishment</td>
<td>[EU, 2009]</td>
<td></td>
</tr>
<tr>
<td>‘Re-use’ means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived;</td>
<td>[EU, 2008]</td>
<td></td>
</tr>
</tbody>
</table>

#### Recovery

Recovery operation listed in Annex II B:
- R 1 Use principally as a fuel or other means to generate energy
- R 2 Solvent reclamation/regeneration
- R 3 Recycling/reclamation of organic substances which are not used as solvents (including composting and other biological transformation processes)
- R 4 Recycling/reclamation of metals and metal compounds
- R 5 Recycling/reclamation of other inorganic materials
- R 6 Regeneration of acids or bases
- R 7 Recovery of components used for pollution abatement
- R 8 Recovery of components from catalysts
- R 9 Oil re-refining or other reuses of oil
- R 10 Land treatment resulting in benefit to agriculture or ecological improvement
- R 11 Use of wastes obtained from any of the operations numbered R 1 to R 10
- R 12 Exchange of wastes for submission to any of the operations numbered R 1 to R 11
- R 13 Storage of wastes pending any of the operations numbered R 1 to R 12 (excluding temporary storage, pending collection, on the site where it is produced)

‘Recovery’ includes several treatment operations, as provided in the Annex II B of the Directive 442/75 | Annex II B of the [EEC, 1975] |

‘Recovery’ means any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy. | [EU, 2008] |


### Table 2.2. Definitions of Recyclability/Reusability/Recoverability in the EU legislation

<table>
<thead>
<tr>
<th>Definition</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recyclability</td>
<td>‘Recyclability’ means the potential for recycling of component parts or materials diverted from an EoL vehicle;</td>
</tr>
<tr>
<td>Reusability</td>
<td>‘Reusability’ means the potential for reuse of component parts diverted from an EoL vehicle</td>
</tr>
<tr>
<td>Recoverability</td>
<td>It means the potential for recovery of component parts or materials diverted from an EoL vehicle</td>
</tr>
</tbody>
</table>
2.1.2 Definitions in the International standards and other technical guidance documents

Tables 2.3 and 2.4 show some definitions derived from international standards and other technical guidance documents (about the International Organization of Standardization – ISO; The Institute of Electrical and Electronics Engineers - IEEE, the American Society for Testing Materials – ASTM and the Joint Research Centre - JRC).

Table 2.3. Definitions of Recycling/Reuse/Recovery in key standards

<table>
<thead>
<tr>
<th>Definition</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycling</td>
<td>‘Recycling’: reprocessing in a production process of the waste materials for the original purpose or for other purposes, excluding processing as a means of generating energy</td>
</tr>
<tr>
<td></td>
<td>‘Recycling’: A process by which materials or components are processed to be put back into productive use as a material or component, not including energy recovery</td>
</tr>
<tr>
<td>Reuse</td>
<td>‘Re-use’: use of a product more than once in its original form. (Note: in view of the fact that a re-used product has not been discarded, re-use does not constitute a recovery option)</td>
</tr>
<tr>
<td></td>
<td>‘Re-use’ is any operation by which component parts of end-of-life machines are used for the same purposes for which they were conceived. (Note: Reuse includes ‘remanufacturing’ defined as: “process by which value is added to component parts of end-of-life machines in order to return them to their original same-as-new condition or better”).</td>
</tr>
<tr>
<td>Recovery</td>
<td>Recovery is the ‘reprocessing in a production process of the waste materials for the original purpose or for other purposes, together with processing as a means of generating energy’.</td>
</tr>
<tr>
<td></td>
<td>‘Recovery’: processing of waste material for the original purpose or other purposes including energy recovery</td>
</tr>
</tbody>
</table>

Table 2.4. Definitions of Recyclability/Reusability/Recoverability in key standards and guidance documents

<table>
<thead>
<tr>
<th>Definition</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recyclability</td>
<td>‘recyclability’: ability of component parts, materials or both that can be diverted from an end-of-life stream to be recycled</td>
</tr>
<tr>
<td></td>
<td>‘recyclable’: Materials or components that can be removed or recovered from the whole product or package and put back into productive use as a material, not including energy recovery, using standard technologies, or as otherwise demonstrated</td>
</tr>
<tr>
<td></td>
<td>“The recyclability is the % of the amount of end-of-life product or waste that is found in the secondary good(s)”. […] the “Recyclability is to integrate all losses that occur for whatever reason. This covers all process from the point when the waste is generated or the end-of-life product is reaching the end of its useful life to the point of the produced secondary good. This includes e.g. loss due to incomplete collection, sorting, recovery, during recycling processing, rejection, etc”</td>
</tr>
<tr>
<td>Reusability</td>
<td>‘reusability’: ability of component parts that can be diverted from an end-of-life stream to be reused</td>
</tr>
<tr>
<td></td>
<td>‘reusable’: Components or systems of components that can be removed or recovered from the whole product or package and put back into productive use as a component or system of components, not including energy recovery, using standard technologies, or as otherwise demonstrated</td>
</tr>
<tr>
<td>Recoverability</td>
<td>‘recoverability’: ability of component parts, materials or both that can be diverted from an end-of-life stream to be recovered</td>
</tr>
</tbody>
</table>
Comparing these definitions to the previous ones, it can be observed that:

- The definitions of recycling, reuse and recovery are very similar to those proposed in the EU legislation. Some references specified that the re-use includes also refurbishment and remanufacturing, where “value is added to the products (or components) after minor treatments”;

- Concerning recyclability, recoverability and reusability, these are still considered as ‘potentials’ or ‘attitudes’ of the product. These are related to useful physical or chemical properties that the components have after serving their original purpose;

- Recyclability, recoverability and reusability are also related to the “recycling rate” and to the availability of technologies.

The analyzed standards also translate these definitions into operative indicators (see, for example, the paragraph 1.1.3 about the ISO 22628). However, some considerations are necessary. Concerning the “potential to be recycled” of materials, it is possible to generalize that more or less every material can be diverted by the EoL of a product and be addressed to some recovery/recycling process. In fact some specific technologies can be available for the treatment and recycling of the majority of the materials.

Furthermore, all the materials that have a “feedstock energy”\(^{21}\) content can be sent to a plant to be incinerated with heat recovery, and therefore can be considered as “recoverable”.

Therefore, basing the analysis exclusively on its composition, a product could be considered as potentially (i.e. theoretically) “fully” recyclable or recoverable.

*However, the aggregation of “potential” recyclable materials into a product does not necessarily imply a “recyclable product”. It causes that a product considered as fully potential recyclable will be not necessarily recycled or recovered. Several materials, after the use, are affected by structural changes and loss of properties that cause a “decay” of the material itself. Then several factors can influence the recycling of a products including e.g. how and what materials are together assembled, contamination of materials, disassembly times, costs for the recovery and treatment of the waste, esthetical issues.*

*Recyclability, recoverability and reusability, to be better assessed, have to be linked to the products characteristics and their assembly.*

The ISO also standardized claims about recyclability [ISO 14021 1999]:

*Recyclability is “a characteristic of a product, packaging or associated component that can be diverted from the waste stream through available processes and programmes and can be collected, processed and returned to use in the form of raw materials or products.*

*[…] Qualification: “If collection or drop-off facilities for the purpose of recycling the product or packaging are not conveniently available to a reasonable proportion of purchasers, potential purchasers and users of the product in the area where the product is sold, then the following shall apply.*

a) *A qualified claim of recyclability shall be used.*

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\(^{21}\) For more detail on the feedstock energy content see Chapter 2.5.
b) The qualified claim shall adequately convey the limited availability of collection facilities.

c) Generalized qualifications, such as "Recyclable where facilities exist", which do not convey the limited availability of collection facilities are not adequate.

[…] Use of a symbol: “If a symbol is used for recyclable claim, it shall be the Mobius loop” (see Figure 2.1).

[…] Evaluation methodology for recyclability claims: Manufacturers shall provide information including evidence of the following:

a) The collection, sorting and delivery systems to transfer the materials from the source to the recycling facility are conveniently available to a reasonable proportion of the purchasers, potential purchasers and users of the product.

b) The recycling facilities are available to accommodate the collected materials.

c) The product for which the claim is made is being collected and recycled” [ISO 14021 1999].

Figure 2.1. “Mobius loop” to be adopted into recyclability claims

Another note concerns the definition of the “recyclability rate” as introduced by the ISO 22628 and adopted by the Directive 2005/64 [EU, 2005b]. This, in fact, includes both the potential recyclable and reusable materials/components (see paragraph 1.1.3). Analogously, the “recoverability rate” includes reusable, recyclable and thermally recoverable materials/components. On the other side, as shown in the previous definitions, reuse is not generally considered as a recycling option. These aspects could lead to some confusion and inconsistency among the definitions and the calculation indexes and rates.

We therefore carried out a survey of the scientific publications about recyclability/recoverability/reusability to identify those issues and characteristics that influence them. This survey represents the basis for the development of measurement methods and verification systems.

2.2 Survey of the scientific publications

The survey of the scientific publications about recyclability, reusability and recoverability showed a great discussion on these issues, with a large variety of positions and approaches.

In general recyclability, reusability and recoverability are jointly analyzed, showing that these issues are influenced and based on the same key issues. In particular, some common elements are:
- improvement of the ‘Design for disassembly’ as a key point to enhance recyclability, reusability and recoverability. Worth of note is the efficiency and quality of different disassembly approach;

- analysis of material compositions and material properties after their useful life;

- analysis of costs related to the collection, disassembly and treatment of EoL products.

The survey revealed a generally larger interest on the recyclability topics. This was also pushed by the requirements introduced in the current legislation (in particular the WEEE and Directive 2005/64, which are often cited in the introductory part of the studies).

The majority of the studies are addressed to manufacturers and organizations, with the scope of providing useful tools (e.g. calculation methods, indicators, checklist, and software) for the improvement of the environmental recyclability of the products. These tools are generally quite complex, including several parameters and are intended to be flexible, in order to assess the incidence of different design options. Finally the tools are generally intended for various product categories but the largest part of the presented case studies relate to EUPs, with particular care to electric and electronics.

The analyzed studies about reusability mostly regarded specific ‘single’ case study experiences of reuse of components by manufacturers. The modelling of reusability is instead related to some aspects as “modularity” and “design for disassembly”.

Recoverability had, instead, a lower relevance in the scientific publications, and this topic is generally discussed as corollary to recyclability. This reflected also the waste hierarchy as introduced by the EU legislation, where the energy recovery is intended as preferable only to the disposal.

Here following some definitions are presented, jointly with the description of those issues that authors recognized as “key points” for their studies. A big heterogeneity of the suggested definitions was observed, especially concerning the recyclability. This also reflects the complexity of the topic and the different point of views of the authors.

Analogously to the legislation and standards, recyclability is often intended as a potential related to the composition materials, as:

Recyclability is the “rate or percentage of recyclable material in a product composition” [Huisman et al., 2003].

Anyway, in some cases it is related to the technical properties of the materials:

‘Recyclability’ is the “characteristic of materials that still have useful physical or chemical properties after serving their original purpose and that can, therefore, be reused or remanufactured into additional products” [EIONET, 2010]

‘Recyclability’ is “the ability of a material to reacquire the properties that it had in its virgin state, where virgin state refers to the material in its purest form before being processed or shaped for a specific use” [Villalba et al., 2002].
In other cases, the recyclability is related to the effective recycling of the products, the efficiency of the recycling, or the recycling rate:

Recyclability is “the rate of recyclable materials in the product. [...] Since the percentage of recyclable materials in the product is not equal to the percentage of materials recycled from the product, it is necessary in product design to take into account not only the percentage of recyclable materials but also the applicable mode of recycling. [...]The gap between recyclable materials in the production phase and recycled materials in the disposal phase is due to the material degradation in the usage phase. In order to estimate the actual recyclability of a product, it is necessary to consider the material degradation” [Oyasato et al., 2001].

“Recyclability measures the efficiency of material recycling. [...] Recyclability assessments rely on indicators of the technologies of recovery, economics of the recycling processes, legislative support for recycling, quality of recycled materials, and environmental impact of waste” [Vassilis et al, 2005 ].

Some authors enlarge the definition, including also other related aspects:

“The recyclability is the comprehensive evaluation on the product recycling rate, the economic benefit and the environment benefit in the recycling process. [...] To evaluate the product recyclability, only the material recycling benefit is not enough. So the environment benefit in the recycling process should also been considered” [Yunhui et al., 2005]

Several authors focus their attention on the role played by economic variables into recyclability:

‘Recyclable’ is an “items with value and which can be sold for utilization”. The product recyclability is therefore defined as “the recycling rate, which is the mass of the recovered valuable items divided by the whole product mass”. [Nishi et al. 1999]

Other definitions are more comprehensive, and include a list of the main influencing factors, as much as strategies to achieve it:

“Recyclable products are those that are manufactured to be recycled at the end of their useful life. In other words, mono-materials are used, the toxic and hazardous substances are eliminated and a modular manufacturing system is used that produces easily-dismantled products, compatible materials are used, material that is difficult to use is identified by means of codes, and so on” [Junta de Residus, 2001].

Several studies also analyzed possible criteria for recyclability. Some variables are often introduces in the developed “Ecodesign” methods, as (not exhaustive list) [Ishii, 1996]:

- **Use of recyclable materials.** Design products using materials that can be recycled and for which materials collection and recycling technologies currently are available and commonly used. Generally, metals are easier to recycle than non-metals, and thermoplastic resins are more desirable than thermoset plastics.

- **Reduce the number of different materials used within an assembly.** Reducing the number of materials also simplifies the separation process and supports recycling. The
The author also underlined that the “number of different materials used in a product family is the most influential factor that determines the material recovery and scrap rate” [Ishii, 1996].

- **Use of compatible materials within an assembly.** Select materials that do not need to be separated for recycling. Generally, mixtures of dissimilar plastics cannot be recycled. Similarly, nonferrous metals (e.g., aluminium, chromium, or zinc) can contaminate and thus decrease the recyclability of ferrous metals (i.e., iron and steel), and vice versa. Layers of paint or plated metal over a base material also represent contaminants not compatible with recycling. If a coating on metal cannot be removed, the paint or metal plating will be a contaminant that decreases the metal's recyclability and/or the applications for which the recycled metal can be used.

- **Make it easy to disassemble.** Also called Design for Disassembly, this criterion guides a designer away from complicated products and assembly processes. Using snap fits and nut/bolt assembly techniques whenever possible assists in disassembly, as does avoiding adhesives, particularly when bonding two incompatible materials or if the adhesive will contaminate the materials so they cannot be recycled. Dismantling analyses can be used to assess the recyclability of a vehicle and its parts.

- **Mark parts for simple material identification.** Standard material identification codes should be used. Although this process is most feasible for plastic parts, it can be expanded to metals, composite materials, and coatings currently used in vehicle manufacturing.

Among the several recognized influencing factor, three elements are often discussed as “priority parameters” and included in the calculation methods. These are:

- Disassemblability;
- Material degradation after recycling;
- Contamination of materials into assemblies.

These three will be discussed more in detail in the following paragraphs.

### 2.2.1 Disassemblability

The “disassemblability” can be defined as “the potential of a component to be extracted from a product” [Tsai-Chi Kuo, 1997]. It is influenced by several parameters, even themselves related, as:

- the costs of disassembly and separation;
- the reuse/salvage/resale values
- time necessary for disassembly;
- needed tools and knowledge to carry out the disassembly
- number of different components and materials;
- typology and number of fasteners and solders.
In particular, fasteners directly influence the ease of the disassembly process, because they contribute to the disassembly time and cost. Factors are the number of fastener types, and ‘disassemblability’ of fasteners. For example, some authors suggest that is a good design principle to use a single type of fastener [Tsai-Chi Kuo, 1997]. Moreover, they recommended to use snap fit, bond, spring clips, or speed clips to join components because they are relatively inexpensive to manufacture and have attractive mechanical properties.

Graphical representations can be useful to assess the ‘disassemblability’. In the past decades, the representation of the assembly process (called the assembly fishbone diagram) has effectively assisted engineers to conduct “design for assembly” and “process failure modes and effects analysis”. On the other hand, environmentally conscious manufacturing requires engineers to make advanced planning for product retirement.

Ishii and Lee therefore investigated the use of a ‘reverse fishbone diagram’ to model the disassembly and reprocessing sequence of a product at the end of its useful life [Ishii and Lee, 1996]. This diagram (Figure 2.2) reports all the disassembly steps, starting from the finish product and then going back to each components. The reverse fishbone method of describing and dissecting such sequences promotes a structured approach to advance planning of the disassembly and sorting process. The diagram encourages the designer to qualitatively "walk through" the disassembly process, identify difficulties, focus on cost driving disassembly tasks and steps that may lead to defects, and iterate towards solutions. [Ishii and Lee, 1996].

![Figure 2.2. Conceptual example of reverse fishbone diagram (from [Ishii et Lee, 1996])](image)

The concept of ‘reverse fishbone diagram’ appears very simple and effective. Actually, similar suggestions have been also implemented in the ISO 22628 and Ecolabel criteria. These schemes require that the manufacturers have to self-evaluate and document the disassembly of the key components of their products. In particular, the Ecolabel criteria for some products (e.g. personal and portable computers, washing machines, vacuum cleaners, refrigerators) require manufacturers to provide a ‘disassembly report’ (see Table 1.4), without anyway further specifications on how this should be undertaken.

The size and shape of the reverse fishbone tree reflect the complexity and cost associated with the disassembly process. Reverse fishbone diagram can therefore represent an effective way to structure the ‘disassembly report’ and to assess the potential to disassembly product’s components.
Similar ideas about disassembly diagrams and trees have been proposed by other authors, including also additional information, as the time for disassembly or the employed tool [Kim et al., 2006].

2.2.2 Material degradation after use and recycling
The change of material properties after use or due to the recycling technology can deeply influence the potential recyclability of a product/component. Concerning the allocation procedures for reuse/recycling, the ISO 14040 explicitly mentions that:

“Changes in the inherent properties of materials shall be taken into account. [...] Reuse and recycling may change the inherent properties of materials in subsequent use” [ISO 14040, 2006].

Designers have also to be aware of the maintaining of products’ and materials properties over the time, for example enhancing testing. This “can occur on multiple levels, including material properties, wear resistance, functionality, quality, lifetime” [ISO 14062, 2002]

Furthermore, “the technical properties of a material or part can be unfavourably changed in the refurbishing, recycling or recovery process [...]. This “down-cycling” can mean that the secondary good cannot replace the primary produced material or part, or only in certain applications. In addition or alternatively this can mean that the secondary good can replace it only after additional measures have been performed, and/or to a limited degree, or for a limited duration” [JRC, 2010]. To take into account such changes of properties and material degradation, a “value correction” approach could be applied, e.g. by using the market-price ratio between the secondary good and the primary material [JRC, 2010].

Metals may be recycled many times, but performance of metals declines because of contamination by tramp elements included through the recycles [Oyasato et al., 2001]. As tramp elements cannot be eliminated through refinement, recycled materials with tramp elements are inappropriate for horizontal material recycling. Therefore, if the unit is made of metals, which does not contain any tramp elements, then it should be recyclable in practice.

Concerning thermoplastics, moulding material consisting of immiscible plastics causes degradation of strength [Oyasato et al., 2001]. Destruction of the moulding material easily develops from a crack on a surface composed of different polymers. Hence, material recycling is difficult to apply. For that reason, recyclable condition for plastics is specified according to miscibility of polymers and polymer blends on the market. It was observed that:

“What does “highly recyclable” mean for plastic housings? Ideally, the plastic housing would be separated at End-of-Life from the other fractions, ground, mixed with a certain percentage of virgin material and used again for the same or similar application. In practice a maximum amount of 20-30% of recycled material is likely” [Schnecke et al, 2004].

A further differentiation about recycling processes of plastics has been introduced. Some authors distinguish among [Di Marco et al., 1994]:

- **Primary recycling** refers to reprocessing material back into a form that can be used in another "high" value product.
Secondary recycling refers to reprocessing material into a "low" value product, (such as fence posts, toys, concrete filler, etc).

Tertiary recycling is the chemical decomposition of a polymer down to its basic elements, or monomers. This leads to either new plastics, or other products.

Similarly, the ISO 15270 introduces three different routes for the recycling [ISO15270, 2008]:

- **Mechanical recycling** is the processing of plastics waste into secondary raw material or products without significantly changing the chemical structure of the material;
- **Organic (or biologic) recycling** is a controlled microbiological treatment of biodegradable plastics waste under aerobic or anaerobic conditions;
- **Feedstock (or chemical) recycling** is the conversion to monomer or production of new raw materials by changing the chemical structure of plastics waste through cracking, gasification or depolymerisation, excluding energy recovery and incineration.

### 2.2.3 The role of materials contamination into recyclability

The term contaminant can be defined as “unwanted substance or material” [ISO 15270, 2008]. Contaminants in ‘recyclates’ includes, for example, tramp elements, but also polymeric (e.g. the inclusion of different polymers or of different grades and compounds of the same polymer) or non-polymeric (e.g. the presence in the original polymers of various functional additives, reinforcements or fillers). They may also be undefined as in the case of adventitious contaminants such as labels, closures, metal inserts, dirt and residual contents of plastics containers or packaging.

Contamination of material is an important issue for metal (as underlined in the previous paragraph), but it is a key issue especially for plastic. Different types of plastic resins are not always compatible, not easily identified or sorted, and require chemical or physical removal of labels, paints, and other contaminations to recycle [Ching et al, 1996]. These conditions have severely reduced stream sizes of particular plastic materials and greatly increased recovery cost. The labour cost to remove the contamination can be also quite high compared to the value of the recycled material [Di Marco et al., 1994].

Excessive levels of contamination may degrade the quality of ‘recyclates’ to the extent of rendering the recovered materials useless because of problems such as deterioration of their physical properties, incompatibility and unacceptability of odour.

It is important for the recycler that the materials received are as pure as possible. E.g. if a plastic part contains too many contaminations, additives or penalty elements it is not possible to recycle it or it decreases value [Janssen and Stevels, 2001]. Authors also suggested a list of potential material combination hampering recycling:

- contamination in the materials;
- inserts;
- coatings;
- use of additives;
- penalty elements: intending those substances in a part or component of the product that increase the costs to recycle that part or material.

Contamination levels may be minimized by a number of means, including the following [ISO 15270, 2008]:

- clear identification and efficient sorting of materials and products;
- careful handling in the collection, separation and sorting phases;
- effective separation and washing processes;
- use of melt filtering or other filtering systems, where appropriate.

An interesting overview of compatibility among some common thermoplastics is shown in Table 2.5 [ECM-341, 2008]. Following such scheme, “designers should verify identified compatibilities and recheck them with the polymer vendors. The listed polymers have many different characteristics depending on the used additives that need a thorough analysis of the suggested compatibility on the material level, especially when they are not marked to be compatible. Therefore, further analysis may be necessary”.

Table 2.5. Example of compatibility among thermoplastics [ECMA-341, 2008]

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<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
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</tr>
<tr>
<td>SAN</td>
<td>+</td>
<td>+</td>
<td>@</td>
<td>+</td>
<td>+</td>
<td>@</td>
<td>@</td>
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<td>@</td>
<td>@</td>
</tr>
<tr>
<td>TPU</td>
<td>+</td>
<td>+</td>
<td>@</td>
<td>+</td>
<td>+</td>
<td>@</td>
<td>@</td>
<td>@</td>
<td>@</td>
<td>@</td>
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<td>@</td>
<td>@</td>
<td>@</td>
<td>@</td>
<td>@</td>
</tr>
</tbody>
</table>

**Legend of the acronyms:** ABS (Acrylonitrile-butadiene-styrene); ASA (Acrylonitrile-styrene-acrylate); PA (Polyamide); PBT (Poly butylene terephthalate); PC (Polycarbonate); PE (Polyethylene); PET (Poly ethylene terephthalate); PMMA (Poly methyl methacrylate); POM (Poly oxymethylene); PP (Polypropylene); PPE (Poly phenylene ether); PS (Polystyrene); PVC (Poly vinyl chloride); SAN (Styrene-acrylonitrile); TPU (Thermoplastic polyurethane)
2.2.4 General considerations on recyclability, reusability and recoverability

Recyclability, reusability and recoverability have been introduced in several different contexts. It is therefore important to continue the research starting from already successful experiences.

One of the main objectives of the project is the set of definition of recyclability, reusability and recoverability in line with those already introduced by the European legislation. Concerning the calculation methods, a useful starting point is represented by those already introduced by the international standards/guidelines (and in particular, the method proposed by the ISO 22628). It is however expected to go further the current ‘state of art’, adapting the methods to above identified key issues (disassembly, material contamination and degradation) and aggregating different interesting suggestions and tips coming from different sources.

The target is the development of a methodology that, although scientifically simplified, could grant a sufficient grade of reliability in the assessment of the recyclability, reusability and recoverability.

The following paragraphs show a synthesis of some of the most important methods to handle recyclability/reusability/recoverability, with the purpose to identify approaches suitable for the scopes of the project.

2.3 Methodologies for the measurement of the ‘recyclability’

Several methodologies have been found in the scientific literature concerning the assessment of the recyclability. These included several different models applied to different tools (software, checklists, and spreadsheet). It is important to note that their complexity was extremely variable, ranging from very simple methods that analyzed a restricted number of parameters, to very complex ones. Even the scopes were very heterogeneous (design tool, policy maker support, third part communications).

Three different methods are below described in detail.

- The first method refers to an assessment of the recyclability by means of economic indicators. The general idea was to use economic variables to depict the complexity of the factors related to the recyclability of the products.

- The second method is combination of economic and environmental data to assess the recyclability of a product and to drive decision makers in the choice of best strategies for the recycling.

- The third method assesses the recyclability rate of a product, starting from qualitative and quantitative information.

Finally, it is also presented a study about those parameters that influence the recycling of a products and the prediction of the recycling rate.

2.3.1 A recyclability index of materials related to the value of the product

An interesting discussion concerning recyclability of materials has been described in [Villalba et al., 2002]. Authors define the recyclability as: “the ability of a material to reacquire the properties that it
had in its virgin state, where virgin state refers to the material in its purest form before being processed or shaped for a specific use”.

Many materials cannot be considered as properly “recyclable” because once they go through a recycling process; they no longer have the properties they had in their virgin state. Therefore, it is important to come up with a way to measure the degree of recyclability of these materials, defined as ‘recycling index’.

For example, recycled copper can achieve the same properties and qualities of copper of primary production such as thermal conductivity, malleability. Therefore, copper is generally considered as ‘recyclable’.

Recycled paper, on the other hand, does not have the same qualities or properties as virgin paper such as the purity of the colour or fibres elasticity. Paper has a lower recyclability index than copper. As a consequence, the second application of recycled paper is different than the first.

Normally the potential of a material to be recycled is not related to its attitude to be reused. Glass, for example, has a low recycling index although it has high reusability. In fact, the glass conserve it properties for long time and this allow to reuse glass components and products. On the other hand, recycled glass has a low value because it does not have the same properties (i.e. colour, thermal properties) as virgin glass.

An interesting option to measure the recycling index is that the recyclability of materials can be reflected by their monetary value [Villalba et al, 2002]. In other words, if a recycled material has a high recycling index, this is shown by its price being close to the price of the virgin material. The greater the difference between these two prices, the lower the recycling index of the material.

The key parameters of this “recyclability metric” can be defined as (Figure 2.3):

- \( V_M \): Minimum value of a material ($/kg). This is the minimum value of the material before being treated or shaped for a specific use (i.e. metals in ingots, polymers in granules);
- \( V_r \): Residual value of material ($/kg) at the End of Life (EoL) of the product, and before any further treatment and processing. This is the price at which the recycler buys the used material;
- \( V_P \): Post-recycle value of a material ($/kg). This is the value that a given material has after it has been recycled and is ready for its second use, before being treated or shaped for a specific use. If a material has a high recyclability as defined here, then \( V_P \) is approximately \( V_M \).

![Figure 2.3. Definition of value parameter (from [Villalba et al., 2002])](image)
As closest is \( V_F \) to \( V_M \), as closer is the recycled material to the virgin one. Instead if \( V_M \) is much higher than \( V_F \), it is expected that the material would not be recycled or would be addressed to a lower quality production for secondary uses.

The “Recyclability (R)” index can be therefore defined as [Villalba et al, 2002]:

\[
2.1) \quad R = \frac{V_F}{V_M}
\]

“For materials, value (i.e., price) reflects 1) quality, 2) production cost or use (including energy consumption) and 3) scarcity rent. A such, even with the omission of significant externalities, value does provide significant information about the effectiveness with which resources are reclaimed and returned to productive use” [Gregory et al., 2006].

The values “\( V_F \)” and “\( V_M \)” are also related to other key factors including:

- availability and feasibility of technologies for the material recycling;
- loss of technical properties of the material after recycling;
- availability of the material, compared to other replaceable (substitutable) materials.

Note that, economic variables can be also influenced by situation not directly related to the technological recyclability of a material (e.g. geopolitical situations, international markets, economic speculations). It was anyway observed that ‘as the international steel market goes, so goes the demand for scrap’ [Sandoval, 1992]. As observed, scrap and virgin material prices decrease or increase almost simultaneously and this causes an almost constant value of the recyclability ratio \( R \) [Villalba et al, 2002].

The recyclability ratio \( R \), as previously defined, can therefore represent a useful index to describe the potential attitude of material to the recycling.

### 2.3.2 Recyclability assessed through economic and environmental variables

Another interesting method to assess the recyclability of products has been described in [Huisman et al., 2003] and [Huisman et al., 2004].

Authors criticizes that recyclability has mostly been calculated on a weight basis, “which is a poor yardstick from an environmental perspective” [Huisman et al., 2004]. These methods “can lead to incorrect conclusions regarding the initial environmental goals. Calculations based on weight-based recyclability are likely to lead to incorrect decisions, especially when materials are present in low amounts, but with high environmental and economic values like precious metals” (e.g. into electric and electronic products).

The description of treatment performance and evaluation of recyclability targets, should instead also take place in environmental terms. This notion has led to the development of the “Quotes for environmentally WEighted RecyclabiliTY concept” (QWERTY) concept for calculating product recyclability on a real environmental basis.
Following the Life Cycle Assessment (LCA) methodology, the environmental analysis of product End of Life scenario is carried out. The QWERTY therefore starts at the point of disposal till the ‘end of the end-of-life’ phase, without considering all the upstream stages.

The concept and the key parameters of the method are (Figure 2.4):

1. **Minimum Environmental Impact and Minimum Costs**: These values are defined as all materials being recovered completely without any environmental impact or economic costs of end-of-life treatment steps, thus representing an environmental substitution value and the economic value for newly extracted and produced materials. (Usually, both are negative values, maximum environmental gain as negative environmental impacts and maximum revenues as negative costs). These values are theoretical values: in practice, there will always appear (environmental) costs connected to separation of materials, energy consumption, and transport;

2. **Maximum Environmental Impact and Maximum Costs**: These values for end-of-life treatment are defined as every material ending up in the worst possible (realistic) end-of-life route, including the environmental burden of pre-treatment: collection, transport, disassembly, and shredding and separation into fractions. The realistic end-of-life scenarios under consideration are controlled and uncontrolled landfill, incineration with or without energy recovery, and all subsequent treatment steps for material fractions, like copper, iron, and aluminium smelting, glass oven, and plastic recycler. Also, this value cannot easily be exceeded;

3. **Actual Environmental Impacts and Costs**: These values based on the actual environmental performance of the end-of-life scenario under consideration are compared with the two boundary conditions and expressed as percentages. This actual value is obtained by tracking the behaviour of all materials over all end-of-life routes and by taking into account all costs and environmental effects connected to this.

![Figure 2.4. QWERTY method for recyclability [Huisman et al., 2004]](image)

The QWERTY calculations require ‘environmental values’. These values can be derived from any comprehensive environmental assessment model (weighted indexes) that provides these scores, but also from methods focusing on a single environmental effect, like for instance, Global Warming Potential (GWP).
The economic and environmental burdens/revenues of each scenario are then plotted into graphic in order to choose the best option/strategies. Although the method was intended as a support to decisional process, it is interesting how environmental and economic data are jointly used. Author applied the method to electronic product [Huisman et al., 2004; Huisman, 2004] and he arrived to interesting conclusion as:

- sometimes the costs associated to some recycling option are not counterbalanced by enough environmental benefits;
- on the other side some material in small quantities (e.g. precious metals) can play a significant role both from the environmental point of view and the costs/revenues form recycling;

Authors conclude that a higher environmental attention should be given to the relation between recyclers creating the right fractions for the right secondary processors who are closing material loops with these fractions.

2.3.3 Recyclability assessment by means of “Recyclability” and “Separability” ratings

An interesting recyclability assessment method was developed by the US Vehicle Recycling Partnership 22. Their mission is to conduct collaborative research and undertake collaborative pilot programs to “promote an integrated and sustainable approach to improving the technical and economic feasibility of vehicle recycling for current and future vehicles produced by U.S. automakers for the global marketplace”23.

To make a recyclability assessment, a four step approach should be followed [Coulter et al. 1996; Bell et al, 2005]:

- Step 1) Data collection (identify the components, materials, and fastening mechanism in the assembly to be rated).
- Step 2) Rate the components according to the rating scheme.
- Step 3) Calculate the percentage recyclability by weight.
- Step 4) Identify areas for improvement

These steps are below described in detail.

**Step 1. Material breakdown**

The main objective of the first step is to list of all materials used within each component. After the list is constructed, it should be reviewed to ensure that none of the materials raise concerns from a health and safety point of view for either humans or the environment.

Most of the needed information can be obtained from the details of a Bill of Materials (BOM). A proper identification of the materials used in a component is essential for the assessment of the product.

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22 The partnership is an “umbrella organization” for collaborative research among Chrysler Group LLC, Ford Motor Company and General Motors Company

23 From the Vehicle Recycling Partnership website: [www.uscar.org](http://www.uscar.org)
recyclability. Surface treatments (like paints, varnishes) and bonding agents (glues) must also be identified because they can represent a source of contamination for materials (especially plastics) to be recycled. For instance, in recycling plastics, a material contamination of only 1% (in weight) can ruin an entire charge of high-grade material.

The next biggest factor is the determination of the fastening mechanisms used to piece all of the different materials together; this is because these mechanisms identify the separation mechanisms required for either re-use or material recycling. For instance, permanent joining mechanisms, such as welding, almost always require the use of a mechanical separation technique, which are typically destructive. Non-permanent connections, like bolts and screws, can be removed manually, but this technique is usually uneconomical unless the fastener material(s) are sources of contamination. Therefore the fastener material should not be overlooked in the initial material study.

**Step 2. Recyclability and ‘separability’ assessment**

In step two, each component is rated on two different classification systems to determine its overall recyclability. These classification systems are referred as the “Recyclability Rating” and the “Separability Rating”.

The scales of each rating system are such that the lower is the number the better is the rating (with 1 being the best). Ratings 1 through 3, for both classifications, are perceived as acceptable for the market and should be used as a benchmark. Ratings 4 through 6 are considered poor and do not represent a recyclable component.

Table 2.6 provides an overview of the conditions that are required to be met for each “Recyclability Rating”. The conditions and definitions of the material “Separability Rating” system are shown in Table 2.7.

**Table 2.6. Recyclability Rating (from [Coulter et al., 1996])**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Part is remanufacturable</td>
</tr>
<tr>
<td>2</td>
<td>Material in part is recyclable - with a clearly defined technology and infrastructure.</td>
</tr>
<tr>
<td>3</td>
<td>Material is technically feasible to recycle - infrastructure to support recycling is not available.</td>
</tr>
<tr>
<td>4</td>
<td>Material is technically feasible to recycle with further process or material development required.</td>
</tr>
<tr>
<td>5</td>
<td>Material is organic - can be used for energy recovery but cannot be recycled.</td>
</tr>
<tr>
<td>6</td>
<td>Material is inorganic with no known technology for recycling.</td>
</tr>
</tbody>
</table>
**Table 2.7. Separability Rating (from [Coulter et al., 1996])**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>May be disassembled easily manually. Approximate disassembly time is less than one minute.</td>
</tr>
<tr>
<td>2</td>
<td>May be disassembled with effort manually. Approximate disassembly time one to three minutes.</td>
</tr>
<tr>
<td>3</td>
<td>May be disassembled with effort requiring some mechanical means or shredding to separate component materials. The process has been fully proven.</td>
</tr>
<tr>
<td>4</td>
<td>May be disassembled with effort requiring some mechanical separation or shredding to separate component materials. The process is currently under development.</td>
</tr>
<tr>
<td>5</td>
<td>Cannot be disassembled. There is no known process for separation.</td>
</tr>
</tbody>
</table>

**Step 3.**

The recyclability index for an entire assembly is calculated on a “percent recyclability by weight” basis. If both the ratings for an item are less than ‘3’, than the item can be considered recyclable.

Successively, the weights of all components with a recyclability rating of 1-3 and a separation rating of 1-3 are summed. The resulting weight number is then divided by the total weight of all components in the assembly. The subsequent number represents the percentage (by weight) of the assembly that is technically feasible to recycle. This can be expressed as:

\[
\text{Recyclability index} = \frac{\text{total weight of materials with both ratings enclosed in range } 1 \div 3}{\text{total weight of the product before disassembly}}
\]

**Step 4.**

In general, any components with recyclability and/or ‘separability’ ratings of 4 are immediate candidates for improvement, especially if a component’s recyclability rating is 3 but its ‘separability’ rating is 4.

Furthermore, components with a relatively large weight should be investigated first since they provide the (potential) highest increase in percent recyclability by weight.

Some “rules of thumbs” have been also developed to support the assessment of the ratings (Table 2.8 and 2.9).

The above described “rating” methodology was realized for the automotive sector. However, *its general structure is suitable even for other applications*. Examples of application to electronics are shown in [Kalyan-Seshu et Bras, 1998; Bell et al, 2005].
### Table 2.8. Rules of thumb to assess the ‘Recyclability Rating’

<table>
<thead>
<tr>
<th>Component/Assembly material</th>
<th>Recyclability Rating</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Single metal</td>
<td>2</td>
<td>Technology and recycling infrastructure in place.</td>
</tr>
<tr>
<td>2 Single thermo-plastic</td>
<td>3</td>
<td>Technology available, but no infrastructure in place.</td>
</tr>
<tr>
<td>3 Single thermoset</td>
<td>4, 5</td>
<td>Some technology under development. Incineration may be possible.</td>
</tr>
<tr>
<td>4 Multiple metals</td>
<td>2</td>
<td>Technology and recycling infrastructure in place.</td>
</tr>
<tr>
<td>5 Single or multiple metals with single thermoplastic</td>
<td>3, 4</td>
<td>Shredding and magnetic separation allow for separation of metals, depending on number and types. Resulting residue consists of a single plastic which may be recyclable.</td>
</tr>
<tr>
<td>6 Multiple thermo-plastics: All compatible</td>
<td>3, 4</td>
<td>Technology is available or under development to recycle this plastic mix, but no infrastructure exist.</td>
</tr>
<tr>
<td>7 Multiple thermo-plastics: Incompatible</td>
<td>4, 5, 6</td>
<td>At best, technology is under development to recycle/separate this mixture. Incineration may be possible, dependent on composition.</td>
</tr>
<tr>
<td>8 Multiple thermosets</td>
<td>4, 5, 6</td>
<td>At best, some technology is under development to recycle/separate part of this mixture. Incineration may be possible, dependent on composition.</td>
</tr>
</tbody>
</table>

### Table 2.9. Rules of thumb to assess the ‘Separability Rating’

<table>
<thead>
<tr>
<th>Situation</th>
<th>Separability Rating</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Fasteners are made of same, material as part being joined.</td>
<td>1</td>
<td>No disassembly required. All can be recycled as a single part. Preferred situation.</td>
</tr>
<tr>
<td>2 Fasteners are made of material compatible with material of parts being joined.</td>
<td>1</td>
<td>No disassembly required. All can be recycled as a single part.</td>
</tr>
<tr>
<td>3 Fasteners are incompatible with parts being joined, but easily removable.</td>
<td>1, 2</td>
<td>Fasteners can be removed manually. Part material can be separated manually.</td>
</tr>
<tr>
<td>4 Fasteners are incompatible with parts being joined, but removable by force (e.g., rivets or heatstakess)</td>
<td>3, 4, 5</td>
<td>Fasteners can be removed manually. Part material can be separated manually or mechanically if material properties allow.</td>
</tr>
<tr>
<td>5 Fasteners are made of ferrous material and easily removable and parts being joined are made of compatible or same plastic.</td>
<td>1, 2, 3</td>
<td>Fasteners can be removed manually or by shredding and magnetic separation. Choice depends on time required. Plastic parts are recycled as a mix.</td>
</tr>
<tr>
<td>6 Fasteners are non removable/permanent/molded in, but made of ferrous material and parts being joined are made of compatible or same plastic.</td>
<td>3</td>
<td>Fasteners can be removed by shredding and magnetic separation. Plastic parts are recycled as a mix.</td>
</tr>
<tr>
<td>7 Fasteners are non removable/permanent/molded in, but made of ferrous material and parts being joined are made of incompatible plastics.</td>
<td>3, 4, 5</td>
<td>Fasteners can be removed by shredding and magnetic separation. Plastics may be separated through density separation, if number and densities allow.</td>
</tr>
<tr>
<td>8 Fasteners and part materials are incompatible and fasteners are absolutely non-removable (e.g., adhesives)</td>
<td>4, 5</td>
<td>No separation possible and fastener will cause part material contamination if shredded. In limited cases, (chemical) separation technologies are under development.</td>
</tr>
<tr>
<td>9 Part materials are same or compatible, but incompatible with fastener. However, fastener mass is so small that realistically no contamination will occur.</td>
<td>1</td>
<td>All can be recycled as a single part. Advice from Materials Engineering should be sought, because 1% contamination is already unacceptable in some cases.</td>
</tr>
</tbody>
</table>
2.3.4 Prediction of the product recycling rate
Some authors focused on the study of key factor influencing the recycling of EEE, and in particular on the prediction of the recovery and disposal mix of a used EEE based on product properties [Abele et al. 2005].

The product’s mass flows can be qualitatively schematized as in Figure 2.5. The recycling rate can be calculated as:

\[
2.3) \quad r_{rec} = \frac{m_{RW}}{m_w}
\]

where:
- \(r_{rec}\) = recycling rate (including
- \(m_{RW}\) = mass of recycled parts of the product
- \(m_w\) = Total mass of the product

Authors identified five factors that influence the distribution of the material flows:

I. separate collection rate of WEEE,

II. volume of removed hazardous components,

III. volume of dismantled product components,

IV. processing of dismantled components and

V. efficiency of material recovery in mechanical processing.

The separate collection of waste (\(m_{colW}\)) is the first parameter that influences the WEEE recycling. WEEE that are disposed of in dustbins or through bulky waste (\(m_{DispW1}\)) enter instead the residual waste steam and end up in municipal waste treatment plants.
Availability and functionality of a collection system for WEEE is one precondition of recycling. Other factors are represented by the consumer’s willingness in contributing to the correct waste management. Unfortunately, “consumers tend to choose product disposal options requiring the least effort” [Abele et al. 2005]. The deciding parameter is often represented by the product’s size. It was generally observed that the recycling rate is decreasing with the products size. Table 2.10 shows some estimated collection rates for different EEE.

Products of the categories "very small" and "small" are easy to carry and transport, however they can be also easily placed in a residual waste bin. As a result only very limited collection rates can be achieved for these products. The highest separate collection rates are achieved for large appliances.

Table 2.10. Estimated average collection rates [Abele et al. 2005]

<table>
<thead>
<tr>
<th>Category</th>
<th>Volume [dm³]</th>
<th>Weight [kg]</th>
<th>Example</th>
<th>Separate collection rate %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very small products</td>
<td>&lt;1</td>
<td>&lt;0.5</td>
<td>Mobile phone, watch</td>
<td>20%</td>
</tr>
<tr>
<td>Small products</td>
<td>1÷15</td>
<td>0.5÷3</td>
<td>Telephone, coffee machine</td>
<td>35%</td>
</tr>
<tr>
<td>Middle size products</td>
<td>15÷75</td>
<td>3÷15</td>
<td>Vacuum cleaner PC</td>
<td>60%</td>
</tr>
<tr>
<td>Large products</td>
<td>&gt;75</td>
<td>&gt;15</td>
<td>Refrigerator, washing machine</td>
<td>98%</td>
</tr>
</tbody>
</table>

The second parameter influencing the recycling rate of a product is the amount of hazardous components removed from it (\(m_{HazW}\)). The removal leads to a significant decontamination of the WEEE. The removed hazardous components are forwarded to specific treatments according to the type of pollutant. The more efficient is the hazardous removal, the higher is the recyclability of the product. Figure 2.6 shows, for example, the decontamination effect due to the removal of individual hazardous parts of WEEE.

![Figure 2.6. Decontamination effect due to the removal of individual hazardous parts of WEEE [Abele et al. 2005]](image-url)
Dismantling is the third parameter influencing the distribution of material flows. This is the amount of the product components that can be separated from the waste stream. “The volume of these components is known to a product developer”.

Dismantled components can be therefore addressed to further processing treatments. These can include specific treatment (as specialized shredder plants, sorting plants or directly to smelter) or generic mechanical treatments (shredders24). Here the treatment of the entire post-consumer product is concerned. The efficiency of material recovery ($r_{\text{shred}}$) represent the ratio of masses that can be separated after the treatment. Average recovery ratio in shredder for some metals is given in Table 2.11.

Materials separated by shredders can be addressed to recycling, through smelters.

Table 2.11. Recovery rates in shredder for some metals [Abele et al. 2005]

<table>
<thead>
<tr>
<th>Component material</th>
<th>Part of the total product (% mass)</th>
<th>Recovery rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>0÷2%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>2÷75%</td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td>75÷100%</td>
<td>98%</td>
</tr>
<tr>
<td>Aluminium</td>
<td>0÷15%</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>15÷80%</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>80÷100%</td>
<td>98%</td>
</tr>
<tr>
<td>Copper</td>
<td>0÷40%</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>40÷85%</td>
<td>85%</td>
</tr>
<tr>
<td></td>
<td>85÷100%</td>
<td>90%</td>
</tr>
</tbody>
</table>

It was observed that shredders can mostly separate metals. Small EEE are instead characterized by larger fractions of plastics that cannot be efficiently separated by such mechanical treatments. In particular, the masses of residues from the dismantling ($m_{\text{ERe/DispW2}}$) and the shredders ($m_{\text{ERe/DispW3}}$) have generally a large energy content (with and higher calorific values of about 14 MJ/kg [Abele et al. 2005]), and they can be still addressed still to energy recovery (depending on the energy content of materials). “However, the higher contamination level by heavy metals and halogenated compounds, exceeding the existing limits for secondary fuels, disqualify this kind of utilisation”.

Shredder residues can be minimised by further mechanical treatments to separate fractions suitable for the energy recovery. Such methods are however not commons for their higher costs.

Improvements of the recycling rates are therefore dependant on: design parameters (e.g. allowing an easier separation of components or a lower contamination of substances), enforcing the measures for the separate collection of waste, and also adopting more efficient technologies for the material sorting for recycling/recovery.

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24 Shredders are mechanical devices used to smash and cut the waste into small fractions and allow to separate mostly ferrous metals, non-ferrous metals and plastics.
2.4 Reusability

The reusability of a system can be defined as “the capability for it to be repeatedly applied from one type or generation of products to another after the initial use” [Ko et al., 2005].

Product reuse is generally both economically and environmentally desirable due to a number of benefits including:

- previously used products are diverted from landfill or other means of disposal,
- fewer natural resources are consumed in new production,
- fewer environmental impacts due to the production,
- savings of financial resources.

“Reuse” options can be subdivided into (Figure 2.7):

1. **Repairing.** This is the process of rectifying a number of given faults with a product and returning it to useful service. It can be considered as an extension of the useful life of products, otherwise addressed to the waste flows. Repairing includes the elimination of secondary damage such as worn components or cosmetic damage. Repairing a product minimizes the energy and material needed to keep it in use at the expense of not offering an updated or improved functionality.

2. **Reconditioning.** This is the process of putting a product back into prime condition. Examples are overhauls of machinery, or restoring of furniture. It can be described as the rebuilding of major components to a working condition rather than as new. Components which have either failed or are expected to fail are replaced or rebuilt.

3. **Remanufacturing.** This is an industrial process whereby products are restored to useful life. During this process, the product (or some of its components) passes through a number of manufacturing steps, e.g. inspection, disassembly, cleaning, part replacement/refurbishment, reassembly and testing to ensure it meets the desired product standards.

![Figure 2.7. Different options for ‘reuse’ (modified from [King et al., 2005])]
remanufactured items possess a warranty which is equal to that of equivalent new products. For these reasons, the study focused mainly on this option for the assessment of reusability of products.

2.4.1 Remanufacturing “key issues”

A key feature for remanufacturing is the “modularity”, where different products are designed to use the same modules for specific functions (e.g. housings, supports, packaging). Product modularity is particularly important for electromechanical products such as computers, telecommunication devices, and peripherals [Ishii, 1996]. The short technology life-cycle of many of the functions in these products, combined with the customer demand for wide variety of features, necessitates product designers to optimize the modularity of components for manufacturability and serviceability [Ishii, 1996].

Remanufacturing is particularly relevant to the reuse of complex electronic equipments. These are characterized by having a ‘core’ part, which, when recovered, possesses an added value that is high in comparison to their actual market value and to their original value [Barker and King, 2007].

Some authors describe the remanufacturing as constituted by the following activities [King et al., 2005]:

1. Receive the “core”, that is the parts of the product to be remanufactured.
2. Strip and clean the core into individual elements. As the used parts may be dirty, they are dismantled and appropriately cleaned. A visual inspection would discard badly damaged elements.
3. Estimate & quote remanufacturing costs. As many remanufacturing companies are subcontractors of manufacturer, the cost of remanufacturing is often estimated on each product to determine the appropriate rectification strategy.
4. Remanufacture. If the component were suitable, the appropriate machining/fabrication processes would be used to remanufacture the component to an “as new” specification.
5. Build, test and dispatch. Finally, the remanufactured components are reassembled (together with necessary replacement components) to build the new product. After appropriate quality testing, the product would be dispatched for sale.

2.4.2 Barriers to remanufacturing

Several barriers to remanufacturing have been detected. These include [Parlikad et al, 2005; Baker and King, 2007]:

- uncertain product condition after usage, including cleaning/corrosion problems;
- availability and cost of replacement parts;
- difficulty to assess the degree to which a component has worn or distorted;
- product diversity;
- product disassembly (that should be fast, non-destructive and feasible by normal technicians with common tools);
- design related issues (complexity, fastening methods, increased part fragility);
- need of preliminary expert inspection before reuse.

Other important barriers concern also the perception of the product, including:

- Acceptance by users, that can perceive the remanufactured as “second-hand” products;
- Remanufactured products relate generally to previous generation of technology and can difficulty compete with new designed products.
- Manufacturers are sometimes afraid that bad remanufactured product may damage the image of the brand. Furthermore, manufacturers are reluctant to offer the same guarantees of new manufactured products.

This last point has been detected as critical, because damage to the product/brand image could be incalculable, especially when third-party companies undertake the remanufacturing. Some authors showed, for example, that sometime companies specifically design products to be non-reusable in order to avoid such problems [Baker and King, 2007].

### 2.4.3 Conclusions about reusability

Compared to recyclability, reusability appears as a more complex task, generally related and confined to the company design process. Even tools for the assessment of reusability are mostly lacking. Generally authors described some special case-studies where remanufacturing was applied. One of the most well-known example concerns the Rank Xerox [EC, 2001]. They developed technology to make remanufactured copiers, for which demand now outstrips supply by about 50%. Of the 80 000 copiers recovered per year, 75% are remanufactured and the rest are taken apart for reuse or recycling.

The assessment of the potential reuse of products ‘cores’ is therefore mostly related to a ‘self-assessment’ of manufacturers. They can therefore calculate reusability as the percentage in weight of the product that has been properly designed to be re-inserted into the production chains.

### 2.5 Recoverability

As defined into the legislation and standards, recoverability includes the potential of a product to be recovered.

As discussed in Chapter 2.1, the definition of the recovery includes several different treatments. For example, the possible recovery options include [EU, 2008]:

R1. Use principally as a fuel or other means to generate energy

R2. Solvent reclamation/regeneration

---

25 This includes incineration facilities dedicated to the processing of municipal solid waste only where their energy efficiency is equal to or above of 0,65 (for installations permitted after 31 December 2008).
R3. Recycling/reclamation of organic substances which are not used as solvents (including composting and other biological transformation processes)\textsuperscript{26}

R4. Recycling/reclamation of metals and metal compounds

R5. Recycling/reclamation of other inorganic materials\textsuperscript{27}

R6. Regeneration of acids or bases

R7. Recovery of components used for pollution abatement

R8. Recovery of components from catalysts

R9. Oil re-refining or other reuses of oil

R10. Land treatment resulting in benefit to agriculture or ecological improvement

R11. Use of waste obtained from any of the operations numbered (from R1 to R10)

R12. Exchange of waste for submission to any of the operations numbered R1 to R11

R13. Storage of waste pending any of the operations numbered R1 to R12

Therefore the definition of the waste recovery is very wide at it includes also the reuse and the recycling. To differentiate the recovery from the other options, more specific definitions of the recovery are provided, referring to some specific treatment options. These will be further discussed in the following sections.

2.5.1 Energy Recovery by incineration

The ‘energy recovery’ is defined as the “production of useful energy through direct and controlled combustion” [ISO 15270, 2008]. Therefore all the materials that have ‘intrinsic’ energy content can be addressed to an incineration plant with energy recovery are at potentially recoverable. This energy content is often defined as ‘feedstock energy’ or “the heat of combustion of a raw material input that is not used as an energy source to a product system, expressed in terms of higher heating value or lower heating value”\textsuperscript{28} [ISO14040, 2006]. The feedstock energy quantifies therefore the potential of materials to release energy when they are burned with heat recovery after their useful life. It is calculated as:

\begin{equation}
2.4) \text{feedstock} = \sum_i M_i \cdot H_v_i
\end{equation}

\textsuperscript{26} This includes gasification and pyrolisis using the components as chemicals.

\textsuperscript{27} This includes soil cleaning resulting in recovery of the soil and recycling of inorganic construction materials.

\textsuperscript{28} There are two ways to define the energy content of combustibles in common use: Higher Heating Value (HHV) and Lower Heating Value (LHV). HHV of a fuel is defined as the amount of heat released by a specified quantity at reference temperature) once it is combusted and the products have returned to the environment temperature. LHV is instead the amount of heat released by combusting a specified quantity of fuel (at reference temperature) and returning the temperature of the combustion products at 150 °C. The LHV is determined by subtracting the heat of vaporization of the water vapor from the HHV.

In the technical and scientific studies both values are generally used for different purposes. Anyway, it is generally accepted that concerning life cycle assessment studies, the interest is in the total energy resource that is extracted in order to support any system. This is measured by the gross calorific value. Using the net calorific value underestimates this resource demand.
where: \( M_i \) = mass of the generic ‘i’ material [kg]

\[ \text{Hv}_i = \text{Heating value (lower or higher) of the generic ‘i’ material [MJ/kg]} \]

Anyway, due to the thermodynamic losses, feedstock energy can be only partially recovered. The efficiency of the energy recovery depends on the technical characteristic of the used plant. The Energy Recoverability (ER) can be defined as:

\[ 2.5) \; ER = feedstock \cdot \rho \]

where: \( \rho \) = efficiency of energy recovery [%]

A design for the ‘energy recovery’ approach would expect that product’s components with the higher feedstock energy content, that are not addressed to recycling/reuse, could be easily disassembled and separated. Therefore, analogously to the recycling and reuse, the potential for the energy recovery is related to the ‘disassemblability’ of the product as previously discussed (see chapter 2.2.1).

Furthermore, recoverability is linked also to the material contamination (see chapter 2.2.2). It is preferable that components addressed to the energy recovery would not be contaminated by substances (as heavy metals or chlorine) that could cause the production of hazardous compounds during the incineration.

### 2.5.1 Recovery by anaerobic digestion

The ‘anaerobic digestion’ (AD) is a process that encourages the breakdown of organic matter by bacteria in the absence of oxygen.

The AD occurs naturally when bacteria breaks down organic matter in environments with little or no oxygen. The recovery option here described refers to a controlled and enclosed version of such breakdown of organic waste.

The AD is generally performed into special plants, called digesters, where optimal conditions for digestions are applied (with particular care to the control of the process parameters e.g. temperature, pH and moisture content). Anaerobic digestion can also occur with less control levels, for example inside landfills for organic waste.

Almost any organic material can be processed with AD, including waste paper and cardboard, grass clippings, leftover food, industrial effluents, sewage and animal waste.

The output of the digestion is the ‘biogas’ with a variable composition. Generally biogas is composed of about 55–65% of methane and 30–45% of CO2. Values of the net calorific value of biogas range from 4,800 to 6,900 kcal/m³ (20-28.8 MJ/m³) [Harasimowicz et al., 2007].

Biogas can be used as a combustible for various scopes, including the production of electricity. Depending on the utilized combustion plant, biogas should be purified by e.g. adsorption, reducing technical problems caused due to the presence of H₂S and lowering the CO₂ content in the fuel [Lastella et al., 2002].

The quantity of biogas produced per kg of waste is largely variable, and it depends on several parameters (e.g. carbon/nitrogen/phosphorous ‘C:N:P’ ratios; moisture content; bacteria involved;
digester parameters). For example, the optimal C:N:P ratio for microbial activity involved in bioconversion of vegetable biomasses to methane is 100–128:4:1 [Kivaisi and Mtila, 1998].

Example range of biogas production from fruit residual is 48.7 - 67.5 litre per kg, with a net calorific value of 21.5 – 24.4 MJ/m^3 [Lastella et al., 2002]. In this example, the specific energy producible per kg of treated waste amounts to 1.1 – 1.6 MJ/kg.

Concerning the AD of paper and cardboard, the quantity of produced biogas strongly varies with the biodegradability of the substance. In particular, it depends on the content of organic matter that can be assumed linearly dependant to the lignin content [Pommier et al., 2010]. Authors observed an average production of 0.143 m^3 of methane per kg of dry matter (considering a mix of office paper, newspaper, cardboard and corrugated cardboard). Assuming an average calorific value of methane (35.8 MJ/ m^3) it results that the potential energy producible amounts to about 5 MJ per kg of dry matter.

Note that this value is sensible higher than those related to food residual because this latter has higher moisture content. Furthermore, the energy recoverable by AD, in the case of paper, is lower than the net calorific value of the substance (that generally amount to about 17 MJ/kg).

Furthermore the energy balance for the production of biogas should also include the energy consumption for the running of the AD process (including the energy consumption to control the temperature in the digesters).

2.5.2 Recovery by pyrolysis and gasification

Both pyrolysis and gasification and plasma technologies are thermal processes that use high temperatures to break down organic and synthetic materials. Whereas incineration completely transforms the combustible input into energy and ash, gasification and pyrolysis deliberately limit the conversion so that combustion does not take place directly. Instead, they convert the combustible into valuable intermediates that can be further processed for materials recycling and energy recovery.

Gasification is a partial oxidation process in which the majority of the carbon is converted into the gaseous form, called ‘syngas’\(^\text{29}\), by partial combustion of a portion of the fuel in the reactor with air, pure oxygen, oxygen-enriched air or by reaction with steam. Relatively high temperatures are employed: 900–1100°C with air and 1000– 1400°C with oxygen. Air gasification is the most widely used technology, but it results in a relatively low energy gas containing up to 60% nitrogen [Saft, 2007].

Pyrolysis is the thermal degradation of carbonaceous materials. It occurs at lower temperatures than gasification (typically 400– 800°C), either in the complete absence of oxygen, or with such a limited supply that gasification does not occur to any appreciable extent. Such processes decompose solid (organic) materials by heat. The products of pyrolysis include gas, liquid and solid char. Their relative proportions depend on the method of pyrolysis and reaction parameters such as temperature, pressure and residence time. Lower temperatures produce more liquid product and high temperatures produce mostly syngas [Saft, 2007].

As pyrolitic gases are not diluted by nitrogen or by combustion products, the calorific value of pyrolitic gases is higher than syngas from gasification.

\(^{29}\) Syngas is composed mainly of carbon monoxide and hydrogen, with smaller quantities of carbon dioxide, nitrogen, methane and various other hydrocarbon gases.
There is a strong correlation among the carbonisation products and the main process parameters such as final temperature, pressure, heating time and residence time [Jung et Fontana, 2007]. Furthermore, the outputs of gasification/pyrolysis strongly depend on the composition of input materials. Examples of combustible outputs from the gasification/pyrolysis of a ton of a plastics mix\(^{30}\) are [Jung and Fontana, 2007]:

- **By Pyrolysis:**
  - 890 kg/t pyrolytic gas (32 MJ/kg)
  - 110 kg/t of char (30.9 MJ/kg)

- **By Gasification:**
  - 1020 kg/t of gas (31.9 MJ/kg)

The European legislation includes pyrolysis, gasification and other thermal treatment of waste among the incineration processes “in so far as the substances resulting from the treatment are subsequently incinerated” [EU, 2000b]. There are, however, examples of outputs of pyrolysis used to synthesize chemicals [Czernik and Bridgwater, 2004].

It is however necessary a detailed energy and mass balance of the pyrolysis/gasification to effectively assess the potential benefits/drawbacks, as it would be undesirable to have systems consuming more energy than that generated.

However results in the scientific literature are not concordant. Some authors declare that “pyrolysis/gasification of hazardous waste (paints) showed better scores for most of the considered impact categories. […] A better energy efficiency for pyrolysis/ gasification leads to less fossil energy consumption” [Saft, 2007].

Concerning pyrolysis of biomass (corn residues) some authors assessed a positive energy balance of about 4 MJ per ton of biomass treated, and an emission saving of 0.8 kg\(\text{CO}_2\) per ton [Roberts et al., 2010].

Other authors instead noted a negative energy and emission balance concerning the treatment of other waste (as plastic or urban wastewater) [Houillon and Jolliet, 2005; Perugini et al., 2005].

The great variability of the results is related to the difference of: process parameters and technologies, typology of treated waste, study assumptions (with particular relevance of the study’s system boundaries). The benefits of syngas and char production are in fact related to what fuels they are substituting.

Furthermore, the use of syngas with normal engines can cause various problems. “The raw syngas from the coal gasifier contains a number of solid and fluid contaminants which have to be removed at the highest possible temperature to achieve an optimum cycle efficiency and protect downstream process equipment and catalysts” [Sharma et al., 2008]. Therefore, syngas impacts due to syngas purification have to be considered in the environmental assessment.

\(^{30}\) Average mass composition: LDPE 10%; HDPE 10%; PS 20%; PUR 10%; PVC 10%; PET 20%; PP 20%.
2.6 Conclusions
Various different approaches have been undertaken in the international standards, guidance documents and the scientific literature to assess the product recyclability/recoverability/reusability at the design stage. From this survey some general suggestions arise that are potentially applicable to scopes of our project.

First of all, due to the broad range of definitions in use for recyclability/reusability/recoverability and the other parameters, a clarification is necessary to avoid miscommunication.

Afterwards, the proposed methods have to be as simple and general as possible, allowing their applicability to different product categories. It was, in fact, observed that the majority of the analyzed methods refer to specific products. Furthermore, methods published in the scientific literature are generally very complex, and mostly designed for the companies purposes, in order to address the decision makers in the choice of better design solutions and alternatives.

It was also observed that some ‘key issues’ are recurrent in the proposed methods. Among the others, three have been observed as significantly influencing the recyclability, recoverability and reusability of products: 1) the physical/chemical properties of the materials, 2) the product’s disassembly issues, and 3) the potential contamination of materials in a product.

In particular, concerning the product’s disassembly:
- it is important to grant an easy access, ‘separability’ and ‘dissassemblability’ of materials and components;
- disassembly down to the module level should be generally possible using commonly available tools and performed by normal technicians;
- the number and variety of welds, glued joints, and connections should be reduced;
- it is necessary to grant an easy and safe separation of parts containing hazardous substances and preparations;

Concerning the material contamination, designers should:
- limit the number of different materials (especially polymers) used in the product;
- check the compatibility of materials for recycling, avoiding when possible, combinations of non-compatible materials which cannot readily separated;
- use labels and other identification marks compatible with the labelled product or component;

Concerning the technical characteristics of the products, designer should:
- identify the potentially valuable and/or re-usable parts;
- prefer, when possible, materials and components that are technically and economically viable for the recycling;
- identify the parts containing hazardous substances and preparations and the location of such parts;
- define special handling and disposal precautions;
- provide additional information about the product’s End-of Life.
It is therefore expected to focus on these three parameters in the following steps of the project to define a measurement method for recyclability/reusability/recoverability.

Finally, being this measurement method applicable at the design stage, this should be based on information available at this stage. This includes, among all, a detailed material breakdown of the products (Bill of Materials – BOM), the assembly/disassembly plans, and the assessment of available and viable technologies for the waste treatment and recycling.
Chapter 3. Recycled Content of products

3.1 Definition of the recycling content

The studied internationally standards generally agree into defining the ‘recycling content’ as the fraction in weight of a product that is made of recycled materials. Some definitions are below presented in Table 3.1.

<table>
<thead>
<tr>
<th>Definition</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion, by mass, of recycled material in a product or packaging.</td>
<td>[ISO 14021, 1999]</td>
</tr>
<tr>
<td>Percentage by weight of recyclate in a material or product</td>
<td>[ASTM D7209, 2006]</td>
</tr>
<tr>
<td>Percentage by weight of recycled material in a product</td>
<td>[EN 15343, 2007]</td>
</tr>
<tr>
<td>A percentage number calculated by dividing the weight of recycled material of the type of material being measured, divided by the full weight of the material in the part or product. For example, if filler materials or additives are used in recycled plastics, the calculation of the recycled plastic content shall be made by dividing the weight of the recycled plastic in the part by the full weight of the plastic material, including additives and fillers, in the part or product. Additives or fillers shall not be considered recycled plastic, except in the case where the additives or fillers are derived from a recycled plastic feedstock</td>
<td>[IEEE, 2009].</td>
</tr>
</tbody>
</table>

What is therefore important is how the recycled content can be assessed. In particular, as below detailed, no physical or chemical method is currently available to determine absolute recycled content of a finished product. Some test methods have been developed to assess the presence of specific substances as hazardous [IEC 62321, 2008] or to verify the biobased content [ASTM D6866, 2008]. But it not possible to directly measure the percentage of recycled materials, which have to be indirectly estimated.

Some examples of requirements about minimum ‘recycled content’ for packaging have been implemented in the European legislation, in particular into Ecolabel criteria (see chapter 1.4 for further details). Here the verification is left to the documental proof that manufacturers have to provide.

The following paragraphs report a survey of the international standards facing with the topic of the measurement of the recycled content.
3.1.1 Recycled content into a CEN standard
The European Committee for Standardization (CEN) investigated the assessment of the recycled content of plastics [EN 15343, 2007]. It stated that “at present there are no reliable technologies for an analytical determination of the recycled content in a material or product”. Consequently the traceability information from both the recycled and the virgin materials are needed to estimate the recycled content of the product. This last can be calculated using the formula:

\[
3.1) \quad \text{Recycled content} = \frac{\text{Mass of recycled material in the product}}{\text{Total mass of the product}} \cdot 100
\]

Only pre-consumer and post-consumer materials shall count towards recycled content. Material that is recovered within the same manufacturing process that generated it, shall not count towards recycled content. Furthermore, any claim concerning recycled content that implies an environmental benefit shall be supported by appropriate evidence.

Concerning the characteristic of the documentation to be provided, the CEN standard makes a reference to the ISO 14021, following described.

3.1.2 Self-declared environmental claims (ISO 14021)
The ISO 14021 standardized the self-declared environmental claims [ISO 14021, 1999]. As previously mentioned (Table 3.1), the recycled content represents the proportion, by mass, of recycled material in a product or packaging.
Pre-consumer and post-consumer materials can be considered in the recycled content, where:

- **Pre-consumer material**: Material diverted from the waste stream during a manufacturing process. Excluded is reutilization of materials such as rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it.
- **Post-consumer material**: Material generated by households or by commercial, industrial and institutional facilities in their role as end-users of the product which can no longer be used for its intended purpose. This includes returns of material from the distribution chain.

Where a claim of recycled content is made, the percentage of recycled material shall be stated. In particular, if a symbol is used for a recycled content claim, it shall be the Mobius loop accompanied by a percentage value stated as "X%" (Figure 3.1), where X is the recycled content. The percentage recycled content for products and packaging shall be separately stated and shall not be aggregated.

![Figure 3.1. Mobius loop for recycling rate claim](image-url)
“As there are no methods available for directly measuring recycled content in a product or packaging, the mass of material obtained from the recycling process, after accounting for losses and other diversions, shall be used” [ISO 14021, 1999].

Similarly with the CEN standard (see formula 3.1), the recycled content can be assessed as:

\[ 3.2) \text{Recycled content} \quad (X\%) = \frac{\text{Mass of recycled material}}{\text{Mass of the product}} \times 100 \]

The verification of the source and quantity of the recycled materials may be carried out through the use of purchasing documentation and other available records. The documentation shall be available for the period that the product is on the market, and for a reasonable period thereafter, taking into account the life of the product.

The provided information and documentations shall be:

- accurate and not misleading;
- substantiated and verified;
- relevant to that particular product, and used only in an appropriate context or setting;
- clear, transparent and scientifically sound

Furthermore, the following criteria have to be accomplished:

- The claimant shall be responsible for evaluation and provision of data necessary for the verification of self-declared environmental claims.
- A self-declared environmental claim shall only be considered verifiable if such verification can be made without access to confidential business information. Claims shall not be made if they can only be verified by confidential business information.
- The claimant may voluntarily release to the public the information necessary for verification of an environmental claim. If not, the information necessary to verify the claim shall be disclosed, upon request, at a reasonable cost (to cover administration), time and place, to any person seeking to verify the claim.
- Evidence that the claimant's evaluation gives assurance of the continuing accuracy of the self-declared environmental claim during the period over which the product is on the market, and for a reasonable period thereafter, taking into account the life of the product.

3.1.3 Validation of recycled content into packaging

The American Society for Testing Materials (ASTM) developed a standard guide for validating the recycled content in packaging [ASTM D5663, 2003]. It provides an approach for both the calculation and the substantiation of recycled content.

The guide recommends a mass balance approach for use of manufacturers “since no physical or chemical test method is currently available to determine absolute recycled content of a finished paper product”.
A first important point is that the recycled content of packaging paper and paperboard products should be agreed upon between the buyer and the seller. In particular, the agreement should concern some key issues as:

- the class and type of the product,
- the percentage of recycled fibres,
- the time period during which recycled content is to be calculated,
- the format and frequency of recycled content substantiation and reporting.

Recycled fibre content should be calculated as the ratio of recycled fibre weight to total fibre weight in a given quantity of packaging paper or paperboard product and expressed as a percentage. The basic calculation method is as follows:

\[
3.3 \) \text{Recycled fiber content} = \frac{RF_u}{VF_u + RF_u} \cdot 100
\]

Where:

- \( RF_u = \text{recycled fibre used [kg]} \),
- \( VF_u = \text{virgin fibre used [kg]} \).

The calculation of recycled content should be for a fixed time period agreed upon between the buyer and the seller. All measures of recycled content should be on a dry weight (0 % moisture) basis.

The recycled content for a composite packaging paper or paperboard product composed of two or more components (for example, corrugating medium plus liner board) should be calculated as the weighted mean recycled content of each of its components, as follows

\[
3.4 \) \text{Recycled content} = \frac{\sum X_i \cdot P_i}{100}
\]

Where:

- \( X_i = \text{weight of recycled material in the } i^{th} \text{ component, calculated using equation 3.3 [\%]} \)
- \( P_i = \text{weight of the } i^{th} \text{ component in a composite packaging material [\%]} \).

Further details about the documentation to support the assessment of the recycled content have been provided in the ASTM standard about the use of recycled polymers into products [ASTM D7209, 2006]. Here is stated that the product or material purchaser “may require certification of the percentage and type (pre-consumer material or postconsumer material or both) of recycled content. Certifications of recycled content should be supported by purchasing records and manufacturing records for finished products”.

Procedures to collect supporting data for certifications of recycled content can be incorporated in quality assurance, formulation, and quality control records.
3.1.4 Recycled content into the IEEE standard and US EPA guidelines

The Institute of Electrical and Electronics Engineers (IEEE) introduced some requirements about recycled content in its standards for the environmental assessment of Electronic products [IEEE, 2009; IEEE, 2010].

First of all, it is expected that manufacturers shall declare whether their packaging contains recycled content or does not. Manufacturer also shall declare approximate recycled content (by weight or volume specified by manufacturer) in the packaging materials used, with the approximate range of recycled content in each material.

The verification requirements for the ‘recycling content’ include:

a) Declaration from manufacturer
b) Supplier letter
c) Declaration of recycled content

Furthermore as optional criterion, it is expected that packaging shall meet or exceed the minimum postconsumer content (see Table 3.2) as established by the U.S. EPA\(^{31}\), over the course of a year using a weighted average [EPA, 2007].

Table 3.2. U.S. EPA’s recommended recovered fibre content levels for paperboard and packaging products [IEEE, 2009]

<table>
<thead>
<tr>
<th>Item</th>
<th>Postconsumer fibre (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrugated containers</td>
<td>25 to 50</td>
</tr>
<tr>
<td>Solid fibre boxes</td>
<td>40</td>
</tr>
<tr>
<td>Folding cartons</td>
<td>40 to 80</td>
</tr>
<tr>
<td>Industrial paperboard (e.g., tubes, cores, drums, and cans)</td>
<td>45 to 100</td>
</tr>
<tr>
<td>Miscellaneous (e.g., pad backs, covered binders, book covers, mailing tubes, protective packaging)</td>
<td>75 to 100</td>
</tr>
<tr>
<td>Padded mailers</td>
<td>5 to 15</td>
</tr>
<tr>
<td>Carrierboard</td>
<td>10 to 15</td>
</tr>
<tr>
<td>Brown papers (wrapping paper and bags)</td>
<td>5 to 20</td>
</tr>
</tbody>
</table>

3.1.5 US guidelines on the use of environmental market claims

Analogously to the ISO, the Federal Trade Commission of the USA developed some general guidelines about the use of environmental market claims [FTC, 1998].

“A recycled content claim may be made only for materials that have been recovered or otherwise diverted from the solid waste stream, either during the manufacturing process (pre-consumer), or after consumer use (post-consumer)”.

The manufacturer or advertiser must have substantiation for concluding that the pre-consumer material would otherwise have entered the solid waste stream.

“In asserting a recycled content claim, distinctions may be made between pre-consumer and post-consumer materials. Where such distinctions are asserted, any express or implied claim about the specific pre-consumer or post-consumer content of a product or package must be substantiated”.

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\(^{31}\) The U.S. EPA also developed similar guidelines about the recycled content for other product categories. For further information see the website: [www.epa.gov/cpg/products.htm](http://www.epa.gov/cpg/products.htm)
It is deceptive to misrepresent, directly or by implication, that a product or package is made of recycled material, which includes recycled raw material, as well as used, reconditioned and remanufactured components. Unqualified claims of recycled content may be made if the entire product or package, excluding minor, incidental components, is made from recycled material.

For products or packages that are only partially made of recycled material, a recycled claim should be adequately qualified to avoid consumer deception about the amount, by weight, of recycled content in the finished product or package. Additionally, for products that contain used, reconditioned or remanufactured components, a recycled claim should be adequately qualified to avoid consumer deception about the nature of such components.

3.2 Conclusion about the assessment of the recycled content

The previous paragraphs showed a substantially agreement of the main organizations for standardization about the definition and measurement of the recycled content.

First of all it is recognized that at present there are no reliable technologies for an analytical assessment of the recycled content in a material or product. Consequently this assessment has to be calculated indirectly, collecting data about the production process and information from the suppliers.

The recycled content of a material can be therefore defined as a percentage ratio between the use of recycled materials and the overall material mass. When the product is composite, including several different materials, the recycled content can be defined as the weighted ratio among the various recycled contents of the single materials.

Almost all the cited standards and guidelines underline that the recycled content relates to post-consumer recycling and pre-consumer recycling. Materials that are recovered within the same manufacturing process that generated it, should instead not count towards recycled content.

Anyway it is expected that the requirements about recycling content of product will push mostly in the direction to increase the quotas of post-consumer recycling (as done by US EPA for packaging and other products).

About the verification methods, all the cited standards converge on the documental proof that manufacturers have to provide in order to support their calculations and claims. The documentation has to comply with the general quality and transparency requirements as adopted for the environmental labelling schemes. A detailed description of such requirements can be found in the ISO 14021 about self-declared environmental schemes.
Chapter 4. Limitation of the use of priority resources

4.1 Introduction
The European Commission in its communication about the “Raw Material Initiative” [EC, 2008d], underlined that “the EU is highly dependent on imports of strategically important raw materials which are increasingly affected by market distortions”. Various issues concern the prioritisation of the resources including, for example, the specific technological/economic effects of resource scarcity, the import dependency ("critical resources") and the relevancy of some "strategic resources" for some specific sectors.

In line with the requirements of the Administrative Arrangement, this project will address priority resources with Resource depletion indicators and other environmental impact indicators as used in the Life Cycle Impact Assessment. These will be discussed more in detail in Deliverable 2 in relationship with the methodologies for the measurement of RRR. However, the present Deliverable 1 provides an overview of different approaches for the prioritisation of the resources.

From a global geological perspective, there is no indication of imminent physical shortage of the majority of raw materials in the world. However, geological availability does not necessarily mean access to these raw materials for EU companies. In particular, concerning the high-tech metals, this dependence can even be considered critical in view of their “economic value and high supply risks”.

The possible initiatives to be undertaken are based on the following three pillars:

1. To ensure access to raw materials from international markets under the same conditions as other industrial competitors;
2. To set the right framework conditions within the EU in order to foster sustainable supply of raw materials from European sources;
3. To boost overall resource efficiency and promote recycling to reduce the EU’s consumption of primary raw materials and decrease the relative import dependence.

Concerning this last point, resource efficiency, recycling, substitution and the increased use of renewable raw materials should be promoted in view of easing the critical dependence of the EU on primary raw materials, reduce import dependency, and improve the environmental balance, as well as meeting industrial needs for raw materials.

Recycling contributes also to energy efficiency, particularly in the case of metals where production on the basis of secondary raw materials (scrap) is generally more energy efficient compared to primary raw material.

The current project focused therefore to the following topics:

- Increase resource efficiency and foster substitution of raw materials
- Promote recycling and facilitate the use of secondary raw materials in the EU
The following paragraphs show a survey of the recent progress on the prioritization of resources in order to identify key issues that could be related to the project’s tasks and aims.

4.1.1 UNEP research on priority products and materials
In the last years, the UNEP (United Nations Environment Programme) launched some projects to identify and assess critical raw material.

A first study focused on the identification and prioritization of metals that are considered as ‘critical’ for future sustainable technologies\textsuperscript{32}, such as renewable energies and energy efficient technologies [Buchert et al., 2009]. The following critical materials have been identified: Indium, Germanium, Tantalum, Platinum group metals (such as ruthenium, platinum and palladium), Tellurium, Cobalt, Lithium, Gallium and rare earths.

Authors decided to prioritize the metals on the basis of the following criteria:

(1) Demand growth;
(2) Supply risks;
(3) Recycling restrictions.

The descendant order of the criteria also reflects the major/minor importance given to them.

Results of the analysis are shown in Figure 4.1. Priority Materials are those concentrated in the overlapping area of the three circles. In particular, the assessment to the short, medium and long terms, showed the following results:

- For the short term (5 years): Indium, Gallium and Tellurium.
- For the medium term (10 years): Rare earths, Lithium, Tantalum and platinum group metals.
- For the long term (40 years): Germanium and Cobalt.

\textbf{Figure 4.1.} Prioritization of critical metals [Buchert et al., 2009]

\textsuperscript{32} As authors pointed out, there is not an official definition of sustainable technologies. These were intended therefore as technologies that “replace an obsolete technology and hereby reduce environmental impacts; lead to emission reductions; provide power efficiency during the production or consumption phase; can be used to monitor political or social behavior causing negative environmental effects” [Buchert et al., 2009].
Buchert et al. (2010) therefore focused the attention on the current and possible future recycling technologies for such metals. “A successful recycling of the assessed critical metals is very important regarding increase of resource efficiency, avoidance of possible scarcities and reduction of the overall environmental impacts linked with the life cycles of the critical metals”.

Compared to pre-consumer recycling already well developed by manufacturers, post-consumer recycling\(^3^3\) is that giving the higher problems. These are mostly related to low metal concentrations in waste flows (dissipative effect), and the contamination with several other material in complex composite components. In particular WEEE contributes sensibly to dissipate critical metals like palladium and indium.

On the other side, WEEE can be an important source of ‘secondary materials’, with also interesting recycling characteristics. Typical electronic scraps, like circuit boards, contain a large spectrum of metals (e.g. copper, tin, cobalt, gold, silver, indium, palladium and platinum). Due to their complexity electronic scraps are a really challenging task for recycling technologies.

For some metals like tantalum in dissipative applications (cell phones), lithium (e.g. batteries), rare earths (broad spectrum of applications), gallium and germanium, there are until today none recycling technologies in commercial scales running or at most first steps in small (pilot) plants are initiated.

Furthermore some applications of critical metals are so new, that relevant mass flows of post-consumer materials will reach the waste management sector not until in a few years. Interesting recycling rates have been instead achieved for platinum metals groups used into catalyst: in 2007, 28 tons of platinum and 31 tons of palladium have been recovered.

Recycling characteristics of critical metals have been synthesized in Table 4.1.

\(^{3^3}\) Concerning the definition of pre-consumer and post-consumer recycling, see chapter 3.1.2
Table 4.1. Recycling characteristics and potential for critical metals [Buchert et al., 2009]

<table>
<thead>
<tr>
<th>Material</th>
<th>Recycling peculiarities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tantalum</td>
<td>Recycling technical problems arise concerning post-consumer scrap (cell-phones etc.); tantalum oxidizes easily and moves into slag phases. Applications in EEE devices are very dissipative, and recovery is therefore technically and economically difficult.</td>
</tr>
<tr>
<td>Indium</td>
<td>From a technical point of view the post-consumer recycling of indium from mixed scraps is feasible and less difficult compared with tantalum for instance. Concerning the recycling, one problematic aspect is the lack of a focused collection and reconditioning of indium-containing products in many regions of the world. Recycling facilities for Indium-containing old scrap are only partly installed and initiated.</td>
</tr>
<tr>
<td>Ruthenium</td>
<td>Ruthenium is very suitable for recycling. Pre-consumer recycling of ruthenium is becoming common since about two years. Post-consumer recycling of ruthenium is already initiated, but has just played a minor role in the past due to small total amounts of ruthenium in products like EEE applications and catalysts.</td>
</tr>
<tr>
<td>Gallium</td>
<td>There are already high recycling capacities for pre-consumer gallium from production. Currently, no common post-consumer recycling is instead known. Potentials for a post-consumer recycling might be realized when the gallium input in recycling plants will rise and when gallium prices will deliver economic incentives.</td>
</tr>
<tr>
<td>Tellurium</td>
<td>There is almost no potential for tellurium recovery from dissipative applications (e.g. alloys). However, there is a potential for tellurium recovery from electronic scrap, if the scrap is processed in appropriate smelting plants. Some facilities have been developed in Europe for the treatment and recycling of thin film solar cells based on cadmium telluride and for tellurium from EEE scrap.</td>
</tr>
<tr>
<td>Germanium</td>
<td>Pre-consumer recycling is quite common. Concerning post-consumers scraps, as most Germanium products and devices contain very small amounts of the metal, it is technical and economical difficult and complex to recovery secondary germanium from this type of scrap.</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Cobalt recycling of new scrap can be regarded as common. Cobalt post-consumer recycling is widely common. It focuses on rechargeable batteries, spent catalysts and also on alloys.</td>
</tr>
<tr>
<td>Lithium</td>
<td>Pre-consumer recycling of lithium is insignificant. Post-consumer recycling is not common and until today just a kind of niche activity. One reason is the quite low price of lithium and the often quite low lithium concentrations in products and compounds due to the low atomic weight of lithium.</td>
</tr>
<tr>
<td>Platinum</td>
<td>Pre-consumer recycling is very common for platinum since many years due to the high economic value of platinum. Post-consumer recycling of platinum is very common in many applications due to the advantageous chemical characteristics of platinum and its high value. In the case of consumer applications the overall recycling quotas are much lower currently. The reason is not due to technical recycling problems but due to difficulties in the collection systems for dissipative applications like EEE.</td>
</tr>
<tr>
<td>Palladium</td>
<td>Pre-consumer recycling is very common for palladium since many years due to its high economic value. The post-consumer recycling of palladium is in a ripe status and common.</td>
</tr>
<tr>
<td>Rare earths</td>
<td>In the USA small quantities of rare earths, mostly from permanent magnet scrap, are recycled. There is no information on any current activities in the post-consumer recycling. There is probably only a low potential in postconsumer recycling due to the widespread use in low concentrations and the frequent use in alloys. Furthermore, the rare earths hold a disposition to slag (as oxides) in smelter plants. This impedes the recycling in WEEE smelting plants.</td>
</tr>
</tbody>
</table>
Another interesting on-going UNEP study regards the environmental impacts of consumption and production of priority products and materials [Hertwich et al, 2010]. It aims at evaluating already concluded studies to assess the environmental and resource impacts of consumption categories and materials at the national, continental or global level.

Authors observed that there is still a shortage of data and scientific analysis addressing technological issues of substitution, resource requirements of new technologies, recycling potential of metals and other critical materials, and economic and environmental costs of decreasing ore grades.

Concerning the production perspective, the overexploitation of resources is related mainly to: the production processes, involving fossil fuel combustion, the agriculture and biomass using activities, and the fisheries.

Concerning the consumption perspective, the largest environmental pressures are related to: food sector, housing, mobility and manufactured products (particularly electrical appliances).

From the analysis of resource categories and materials, the following conclusions have been drawn:

- Fossil fuel extraction is one of the most important material flow in mass terms, and it is also one of the most important sources of environmental degradation.
- Agricultural materials, especially animal products, are also a very important material flow in terms of their contribution to a large number of impact categories.
- Extracting and refining materials that are used for their structural or material properties and not as energy source, contribute significantly to a number of pollution and resource-related impact categories, although it’s overall importance is less than that of fossil fuels or agricultural materials. Plastics, iron, steel and aluminium are the most important materials in terms of their contribution to environmental impacts.

### 4.1.2 Defining Critical Raw Materials for the EU

The European Commission recently started a still on going research about the definition of critical raw material for the EU [EC, 2010].

First of all the study investigated the availability of resources and reserves, concluding that the “geological scarcity is not an issue for determining the criticality of raw materials in the considered time horizon of the study”. In fact, the “published reserve figures do not reflect the total amount of mineral potentially available and compilation of global reserve figures are not reliable indicators of the long-term availability of a metal. Estimates of ‘reserves’, ‘resources’ and the ‘reserve base’, and the static life time of mineral raw materials calculated from them, should not be used in the assessment of future mineral availability as they are highly likely to give rise to erroneous conclusions” [EC, 2010].

The analysis looks therefore into the assessment of the criticality of material and the related risks that may arise taking into account a time perspective of 10 years. The assessment was based on the following three indexes:
- **Economic importance (EI)**. This reflects the role that each material has into economic sector, taking into account the end uses of a raw material and the value of the sectors into which they flow.

- **Supply risk (SR)**. This reflects the dependency of EU from import and the potential risks of supply from political unstable countries. This risk is mitigated by characteristic of the material as recyclability and substitutability.

- **Environmental risk (ER)**. This encloses the risks that some environmental measures may be taken impeding access to deposits. A number of raw materials originate from countries which are characterized by poor environmental management and performance. It is assumed that such a situation may lead to measures being taken by the producing country that would in fact restrict the access to these materials.

The values of the tree indexes are plotted in Figure 4.2 (concerning the EI and SI) and Figure 4.3 (concerning the ER). The identified critical values are listed in Table 4.2 with the related three indicators values (estimated values from the draft report).

**Figure 4.2. Supply Risk (SR) and Economic importance (EI) of critical raw material [EC, 2010]**
**Figure 4.3.** Environmental Risk \((ER)\) of critical raw material [EC, 2010]

**Table 4.2.** Economic importance, Supply Risk and Environmental Risk values for critical raw materials (adapted from [EC, 2010])

<table>
<thead>
<tr>
<th>Material</th>
<th>Economic Importance</th>
<th>Supply Risk</th>
<th>Environmental Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>0.0138</td>
<td>0.2</td>
<td>0.7</td>
</tr>
<tr>
<td>Antimony</td>
<td>0.0096</td>
<td>2.2</td>
<td>4.22</td>
</tr>
<tr>
<td>Bauxite</td>
<td>0.013</td>
<td>0.25</td>
<td>0.64</td>
</tr>
<tr>
<td>Borate</td>
<td>0.0092</td>
<td>0.6</td>
<td>0.86</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.015</td>
<td>0.8</td>
<td>1.05</td>
</tr>
<tr>
<td>Cobalt</td>
<td>0.0119</td>
<td>0.9</td>
<td>1.2</td>
</tr>
<tr>
<td>Copper</td>
<td>0.0132</td>
<td>0.15</td>
<td>0.4</td>
</tr>
<tr>
<td>Fluorspar</td>
<td>0.0116</td>
<td>1.6</td>
<td>1.65</td>
</tr>
<tr>
<td>Gallium</td>
<td>0.0104</td>
<td>1.8</td>
<td>2.95</td>
</tr>
<tr>
<td>Germanium</td>
<td>0.0097</td>
<td>1.7</td>
<td>3.44</td>
</tr>
<tr>
<td>Graphite</td>
<td>0.0136</td>
<td>1.3</td>
<td>2.72</td>
</tr>
<tr>
<td>Indium</td>
<td>0.0106</td>
<td>1.5</td>
<td>1.95</td>
</tr>
<tr>
<td>Iron</td>
<td>0.0141</td>
<td>0.25</td>
<td>0.62</td>
</tr>
<tr>
<td>Limestone</td>
<td>0.0094</td>
<td>2.1</td>
<td>2.34</td>
</tr>
<tr>
<td>Lithium</td>
<td>0.0085</td>
<td>0.8</td>
<td>1.11</td>
</tr>
<tr>
<td>Magnesite</td>
<td>0.013</td>
<td>1.05</td>
<td>1.35</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.0095</td>
<td>2.05</td>
<td>3.1</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.0156</td>
<td>0.3</td>
<td>0.57</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>0.0142</td>
<td>0.35</td>
<td>0.9</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.0151</td>
<td>0.2</td>
<td>0.45</td>
</tr>
<tr>
<td>Niobium</td>
<td>0.0149</td>
<td>2.45</td>
<td>3.18</td>
</tr>
<tr>
<td>PGM</td>
<td>0.0106</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Rare earths</td>
<td>0.0089</td>
<td>4.85</td>
<td>5.1</td>
</tr>
<tr>
<td>Rhenium</td>
<td>0.0119</td>
<td>0.55</td>
<td>0.82</td>
</tr>
<tr>
<td>Tantalum</td>
<td>0.0119</td>
<td>1.4</td>
<td>3.22</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.0085</td>
<td>0.1</td>
<td>0.55</td>
</tr>
<tr>
<td>Tungsten</td>
<td>0.0141</td>
<td>1.2</td>
<td>2.93</td>
</tr>
<tr>
<td>Vanadium</td>
<td>0.0156</td>
<td>0.9</td>
<td>1.54</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.0151</td>
<td>0.1</td>
<td>0.58</td>
</tr>
</tbody>
</table>
4.2 Assessment of the resource depletion

Resource depletion in itself is not a well-defined concept. “The concept of resources is highly dependent on the presence of a user, the needs and skill of the user, expectations about the future and perceptions about what constitutes the depletion problem. Which resources and resource properties are valuable and need to be observed or preserved depends on what we think we or succeeding generations may need in the future” [Steen, 2006].

Resources are elements (or mixtures of elements) and are therefore not depleted in an absolute sense. The problem is their dispersion and the consequent loss of their practical use. “Abiotic resource depletion is the decrease of availability of the total reserve of potential functions of the resources” [van Oers et al., 2002].

Methods for the assessment of the resource depletion have been grouped in the following four categories [Lindeijer et al., 2002]:

1. *Those based on energy or mass*. They simply add all abiotic resources on the basis of mass or energy suggests that they are exchangeable and equally important with respect to their mass or energy content.

2. *Those based on the relations among use and deposits*. These indexes relate to the reserve deposits with the current consumption rates.

3. *Those based on future consequences of resource extractions*. The basic idea here is that extracting high concentration resources today will force future generations to extract lower concentration resources leading to an increased impact on environment and economy.

4. *Those based on exergy consumption or entropy production*. Authors argued that that matter will not be depleted, but exergy will. Exergy is therefore the ultimate limiting resource because it has an associated energy cost that will be limiting to some extent when it becomes too high.

Models based on the second categories have been the most diffused. The general idea of resource scarcity is that the resource availability is limited and, sooner or later, it will be depleted. This problem is particular evident for fossil fuels, but instead is perceived as less important for non-emery resources. As above mentioned, the experience of the last decades proved that the technological evolution and the geological researches allowed to continuously discover new reserves. There are no signals at present that some resources would be depleted in the considered time horizons.

Anyway the dispersion of resources causes several problems, first of all the increase of costs. “In the beginning there may be a learning process, which may compensate for the cost of mining lower grade ores, but as the learning process levels out, there will be a net cost increase. As costs increase, use and production volumes will decrease. Ultimately, the production cost per mass unit will level out as we approach the average concentration in the crust of the earth” [Steen, 2006].

Various authors refer, in fact, to the bedrock as a reference value about resource availability and it is used to assess the resource depletion [Guinée et Heijungs, 1995; van Oers et al., 2002]. Following this assumption, depletion potentials of abiotic resources have been calculated, assuming antimony as the reference element.

On the other side, the resource depletion is also related to the exploitation of continuously lower concentrated ores, with higher related environmental impacts. “The additional environmental
interventions expected from future mining of lower grade ore deposits, if added to the current LCA inventory in order to represent the scarcity of the currently used high-grade deposits of the resource, may be called "virtual" environmental interventions. [...] The ecological scarcity of currently used high grade deposits of metal ores can be weighted in life cycle impact assessment by calculating the "surplus energy" per kg of metal on base of lower ore grades mined in future, and by replacing the ore quantity actually used in the LCA inventory by the "virtual environmental interventions” of future mining” [Müller-Wenk, 1998].

Finally it is important to underline that many authors have a fairly optimistic view on the human ability to cope with resource depletion and see substitution, recycling and general development of economy and technology as efficient means for resource housekeeping. In particular, the public promotion of recycling systems is motivated not only by the reduction of wastes and mining process emissions but also by the aim to reduce the extractions of materials from the earth [Muller-Wenk, 1998].

The stocks of material into economy (i.e. those from which secondary materials can be recycled) can represent important “sources” for resources production in the future. The reserves in landfills have a special position in this field. Technically elements can be recycled from waste and in many cases the resource, even if a mixed waste, is richer than into average rocks. However, “the availability for recycling depends on a large number of conditions, including e.g. the concentration of a material in a products, the ease to collect the products for recycling, the possible technologies to refine the material form the discarded products, the loss of potential functions during the recycling cascade, the economic incentive to recycle, etc” [van Oers et al., 2002].

Therefore it is necessary the promotion of product’s recycling through the creation of favourable conditions for its applicability.
4.3 Conclusions

The survey about the prioritizations of raw materials showed that the geological resource scarcity is generally not considered as critical for non-energy materials. The scientific community, in fact, observed that the availability of resources in the earth crust is still enormous and the technological evolution and the new geological surveys allowed in the last decades to continuously discover and exploit new deposits.

The highest criticalities are instead related to the supply risks, geopolitical tensions, and other possible barriers and restriction that could threaten the normal trade market. Even the environmental issues represent a key issue. The decrease of resource concentration into ores is cause of larger environmental impacts for the mining and the resource transformation.

The recycling of raw material can represent therefore an important way to face resource depletions. In fact, recycling allows:
- To reduce the supply needs and to ease the dependency from imports;
- To reduce environmental impacts due to the production of materials and the pressure on the natural ecosystems;
- To reduce production costs.

The international community is still working on the scientific prioritization of products from an environmental sustainability point of view, to provide scientific and authoritative assessment studies about resource flows. The expected goal is the greening of the resources supply, evaluating the environmental impacts of the resource extraction and processing, assessing the different available technologies, and improving the resource efficiency (realizing better performing products with fewer resources). In such context, the LCA methodology can represent the scientific basis for these evaluations and comparisons. The output of such assessment can therefore drive the definition of policies and technical choices.

The improvement of product ‘recyclability’ can contribute to the resource efficiency and the recycling of critical resources. Especially for the metals, the material recycling is often more hampered by economic problems than the technological feasibility. A correct ‘design for recycling’ (improving the accessibility and identification of priority resources, and their disassembly) can contribute to the reduction of recycling costs and effort and foster the recycling.
Chapter 5. Hazardous substances

5.1 Introduction
As previously described in Chapter 1.2, the RoHS Directive aimed at restricting the use of hazardous substances in EEE. It is also expected to update the list of restricted substances, following the technological evolution and the new scientific evidences.

Concerning new possible hazardous substances to be inserted into the RoHS, some potential candidate substances have been identified. However at the current stage, the European Commission established that “given the lack of sufficient information on substitutes, which does not allow a clear view on whether they are environmentally safer or, in cases where environmentally safer alternatives do exist, whether replacement costs are proportionate to environmental benefits, it is not considered feasible to propose new hazardous substances in the scope of RoHS” [EC, 2008].

Even in cases where possible substitutes materials or the necessary design changes are technically available (e.g. substituting PVC with other polymers which need less or no plasticizers such as phthalates), these can be not viable due to the higher costs [EC, 2002].

The following paragraphs focused on some hazardous substances commonly used in EuP. In particular the first part (Chapter 5.2) refers to procedures for the compliance to requirements about the use of regulated hazardous substance. The second part (Chapter 5.3) focuses, instead, on other potential hazardous substances that have been not regulated.

It is also important to note that the use of some hazardous substances can improve, in some case, the performance of the products. This is generally related to the adoption of specific technologies. The assessment of the use of hazardous substances should be, therefore, based on a life-cycle approach, accounting for the overall benefits/drawbacks. This topic will be discussed in Chapter 5.4.

5.2 Compliance to the RoHS requirements
As discussed in Chapter 1.2, neither the RoHS nor the subsequent documents refer to specific compliance procedures, certificates or testing methods to be used for demonstrating compliance. The burden of the proof of compliance belongs anyway to the manufacturers.

It is a producer’s corporate responsibility to keep up to date with the regulations and to make sure they have the appropriate documentation demonstrating compliance before placing the electrical product on the market [NMO, 2008]. Furthermore, it is expected that such documentation will be available also after the production was stopped.
5.2.1 Key issues for the compliance

In order to help companies to grant the compliances to the Directive requirements, guidelines and schemes have been developed. Table 5.1 shows, for example, some key issues for the compliances as established by the UK's national RoHS enforcement body [NMO, 2008].

<table>
<thead>
<tr>
<th>Key issue</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testing</td>
<td>▪ To be assured of compliance the product is highly likely to have undergone some level of testing at some point along its production process.                                                                                           ▪ Holding test reports in a technical file alone does not guarantee compliance, although test reports do help to provide validation of the levels of compliance claimed and help generate a level of confidence in the compliance programmes of suppliers.</td>
</tr>
<tr>
<td>Test Format</td>
<td>▪ The used test method shall be clearly stated. ▪ All test reports should have a date printed indicating when the report was issued and when the test was conducted. Final product often changes over time, so if the report was written before any alterations to the electrical equipment then it may not give an indication of full compliance. ▪ Good practice suggests any result that shows a homogeneous material to contain above its restricted limit of a banned substance should be accompanied by a note explaining the non-compliance or listing its relevant exemption.</td>
</tr>
<tr>
<td>Component</td>
<td>▪ The results of the testing should be specific to each component and not show general areas of the product to be compliant. ▪ It is the producer’s responsibility to recognise that the report demonstrates the testing of homogeneous materials in order to represent satisfactory compliance information. ▪ A test report should list the levels of the hazardous substances in each component, either detected in parts per million, expressed as a percentage, or both.</td>
</tr>
<tr>
<td>Surveillance</td>
<td>▪ As part of the compliance regime, there is a responsibility for the organisation to assess and target those areas of bringing the product to market where there may be the greatest likelihood of failure. It is the producer’s responsibility to take all reasonable steps to minimise the risk of non-compliant product being placed on the market. ▪ Critical production processes shall be controlled, because they can change over time and become accidentally incompliant. For example, solder baths used have the potential to become contaminated if there is no process control in place to ensure clean processes. ▪ Producers should have an awareness of the processes used in the manufacture of their products (especially when provided by external companies) and have an awareness of possible problems. ▪ Inspections and audits (better if third-party audits) should also be extended to suppliers, external manufacturers, and, in general, to all those activities that have been identified as critical for the compliance assessment.</td>
</tr>
<tr>
<td>Corrective actions</td>
<td>▪ Corrective actions and procedures have to be established when not conformities have been detected.</td>
</tr>
<tr>
<td>Declaration of compliance</td>
<td>▪ Manufacturers can sign a declaration of compliance. This has to be detailed in all the provided data and key issues for the compliance. ▪ Declarations shall be enough supported by test results and other documentation.</td>
</tr>
</tbody>
</table>

First of all, a particular attention is needed for the testing. There can be different methods of testing for each hazardous substance and these should be listed on the report. On this purpose the IEC 62321
standard [IEC 62321, 2008] has been developed to provide test procedures and methods that allow to
determine the levels of regulated substances (lead, mercury, cadmium, chromium(VI) and their
compounds, PBB and PBDE) in electric products on a consistent global basis. Some exemplary testing
methods are shown in Table 5.2.

The surveillance of all the processes is another key issue of the compliance demonstration. The
company has to provide enough evidence that all the critical processes are sufficiently controlled and
adequate corrective actions have been set. The compliance verification system could be also conceived
as a part of the global company’s management system (e.g. that standardized by the ISO 9001).

Finally a key issue is represented by the assessment of the company’s supply-chain exposure. “The
company needs to look very closely at components and parts that it purchases to determine where
RoHS restricted substances may exist within its covered product lines. […] A company’s restricted
substance specification, updated to include the RoHS substance maximum concentration values, is an
appropriate compliance metric for suppliers. Product-specific assessments are necessary to identify:
1) components at greatest risk for compliance and 2) key suppliers of those components” [Evans and
Johnson, 2005].

<table>
<thead>
<tr>
<th>RoHS Substances</th>
<th>RoHS Limits</th>
<th>Typical Testing Approaches</th>
</tr>
</thead>
</table>
| Cadmium         | 100 ppm     | • Wet chemical digestion followed by ICP (Inductively coupled plasma) or AAS (atomic absorption spectroscopy)  
|                 |             | • XRF (X-ray fluorescence spectroscopy) |
| Lead            | 1000 ppm    | • Wet chemical digestion followed by ICP or AAS  
|                 |             | • XRF |
| Hexavalent Chromium | 1000 ppm | • Wet chemical digestion followed by UV-VIS (ultraviolet and visible absorption) spectroscopy  
|                 |             | • XRF (for elemental Cr only) |
| Mercury         | 1000 ppm    | • Wet chemical digestion followed by AAS  
|                 |             | • XRF |
| PBB/PBDE        | 1000 ppm    | • Solvent extraction followed by GC/MS (gas chromatography/mass spectroscopy)  
|                 |             | • XRF (for elemental Br only) |

5.2.2 Compliance to requirements about hazardous substance in the IEEE 1680.1
The Institute of Electrical and Electronics Engineers (IEEE) introduced some requirements about
hazardous substances content in its standards IEEE1680.1 for the environmental assessment of
Electronic products [IEEE, 2009].

First of all, the standard includes some mandatory requirements that are equal to those set by the RoHS
Directive. Differently form the RoHS, the IEEE foresees some verification requirements as [IEEE, 2009]:

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b. Demonstration of European RoHS Directive compliance according to European RoHS Directive requirements.

c. Evidence of certification from component manufacturers that is based on either empirical data demonstrating compliance or analytical test data demonstrating compliance”.

Then, some additional requirements are added. For example is stated that “traces of cadmium shall not exceed 50 ppm in homogeneous materials unless it can be shown that the cadmium is present above this threshold due to the use of recycled content”.

Another requirement regards also the identification of components containing hazardous substances. It states that: “Circuit boards >10 cm² (measured on the largest face), batteries, and other components—any of which contain hazardous materials—shall be safely and easily identifiable and removable”.

The verification of these requirements is based on:

a) “Declaration from manufacturer

b) Supporting documentation that the design maximizes the safe and easy identification and removal of components containing hazardous materials. Examples of documentation could be:

   1) A list of the commonly available tools required to remove components containing hazardous materials, and instructions for disassembly that show how the components containing hazardous materials can be safely and easily identified and removed, or

   2) A statement from a minimum of three recyclers individually, or at least one recycler working under an independent entity with electronics recycling expertise that is not a trade organization, confirming that the product design meets the requirements”.

Finally, a requirement is also introduced to regulate toxics in packaging. It states that “Heavy metals shall not be intentionally added to any packaging or packaging component, with the exception of the recycled content exemption cited in References and details. For incidental presence, the sum of the concentration levels of lead, cadmium, mercury, and hexavalent chromium present in any package or packaging component shall not exceed 100 ppm by weight (0.01%)”.

Even in this case, the verification of this requirement is provided with a declaration of manufacturer supported by a supplier letter.

5.3 Potential hazardous substances in the EEE not regulated by the RoHS

An interesting study about potential hazardous substances present in EEE has been recently carried out [Ökolnstitut, 2008]. This study aims at selecting candidate substances for a potential inclusion into the RoHS Directive, evaluating possible substitutes, and proposing policy options for each candidate substance.

The following criteria were applied for the selection of the hazardous substances:

Incidental presence is defined as “the presence of a regulated metal as an unintended or undesired ingredient of a package or packaging component” [IEEE, 2009].
1. Substances meeting the criteria for classification as dangerous in accordance with Directive 67/548/EEC.

2. Substances meeting the criteria for classification as substances of very high concern (SVHC) in accordance with REACH (see Chapter 1.2).

3. Substances which have been found as contaminants in humans and biota.

4. Substances which can form hazardous substances during the collection and treatment of waste electrical and electronic equipment.

Authors observed that “there are a number of substances not meeting criteria 1 to 3, but nevertheless holding the risk to cause harm to man and the environment during their life cycle. These substances can be described as ‘potentially dangerous substances’. As an example, substances which can form dangerous degradation or reaction products during their life cycle (e.g. during incineration of waste EEE) are to be considered as ‘potentially dangerous’.”

In addition to the identified substances, the authors of have therefore included in the research some potentially hazardous materials (as PVC) as well as the group of organobromine and organochlorine substances. Actually PVC is not a substance but a polymer and most of the organobromine/organochlorine substances have not yet been classified as dangerous. Nevertheless they are considered to fulfil selection criterion 4 because they could lead to the formation and emission of hazardous substances such as organic chlorine compounds, dioxins and furans during incineration of waste EEE.

The identified priority hazardous substances have been further evaluated with regard to their use in EEE, their share of use in EEE with regard to total production volume, and the risk for the environment and human health arising from their use in the different life stages of EEE, as well as bioaccumulation of these substances in humans and other living organism.

Data on substitutes have been also collected. Substitutes have been evaluated as far as information on their technical suitability, their (eco-) toxicological and environmental properties were available.

The available data suggest that for a large number of applications in EEE, substitutes and/or alternative technologies exist and that the potential adverse effects on environment and human health of the proposed substitutes are less than those of the priority hazardous substances. However, while hazard classifications exist for most of the substitutes, in many cases comprehensive risk assessments do not. In specific cases, further data and investigations are thus necessary before being able to give a full assessment on the adverse effects of substitutes. The indentified substances, their characteristics and their risk assessment are reported in Table 5.3.

The requirements about the hazardous content have, anyway, to consider the potential benefits related to the substance use. On this purpose, the ISO 14062 underlined that “trade-offs between environmental, technical and/or quality aspects, e.g. design decisions related to use of a particular material might negatively impact the reliability and durability of a product, even though it produces environmental benefits” [ISO 14062, 2002].

Similar conclusions were presented in a study about the LCA of PVC in different applications:

“LCA comparisons should be undertaken at application level rather than at material level, particularly for political decision-support. LCAs on application level are more...
comprehensive and draw a complete picture of the environmental impacts over the life cycle. At application level, LCAs can show correlations of production phase, use phase and end-of-life treatment. [...] Comparisons made solely on the basis of mass (e.g. 1kg PVC vs. 1kg wood) tend to be misleading in this context. It is important to take into account the application type and the influence on use and end-of-life when making environmental comparisons. [...]The influential phases of an application throughout a life cycle must be identified individually according to the situation” [Baitz et al. 2004].

It is therefore not possible to state in general if the use of PVC has to be restricted or not, but it has to be evaluated case-by-case. Similar considerations can be extended to all the below mentioned substances and materials (Table 5.3).
Table 5.3: Main potentially hazardous substances to be regulated [ÖkoInstitut, 2008]

<table>
<thead>
<tr>
<th>Substance</th>
<th>Classification</th>
<th>Substitutes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beryllium</strong></td>
<td>- R49: (cat. 2) possible carcinogenic effects by inhalation</td>
<td>Not investigates in the study</td>
</tr>
<tr>
<td></td>
<td>- R26: very toxic through inhalation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- R25-48/23: toxic if swallowed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- R36/37/38: irritation to eyes, respiratory organs and skin</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- R43: allergisation if skin contact</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- R51-53: toxic to aquatic organisms</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Beryllium is toxic (fulfil the REACH criteria to be very high concern substance) but it is not bioaccumulable</td>
<td></td>
</tr>
<tr>
<td><strong>Polyvinyl chloride (PVC)</strong></td>
<td>PVC resin is not classified as dangerous, but dangerous are the main substances involved in producing PVC polymer:</td>
<td>Available</td>
</tr>
<tr>
<td></td>
<td>- Vinyl chloride monomer (VCM): R45 (cat. 1) May cause cancer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Ethylene Dichloride: R40: Limited evidence of a carcinogenic effect; R20 harmful by inhalation</td>
<td></td>
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<tr>
<td></td>
<td>Burning PVC also produces a large number of by-products of combustion, including carcinogens such as vinyl chloride, polychlorinated biphenyls (PCBs), chlorobenzene and other aromatic hydrocarbons such as benzene, toluene, xylene, and naphthalene. PVC involves risks associated with their production, processing and especially with their disposal and incineration (with can produce organic chlorine compounds and the associated emissions of dioxins and furans).</td>
<td></td>
</tr>
<tr>
<td><strong>Bisphenol-A</strong></td>
<td>- R62 - Possible risk of impaired fertility</td>
<td>Not investigates in the study</td>
</tr>
<tr>
<td></td>
<td>- R37: Irritating to respiratory system</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- R 41: Risk of serious damage to eyes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- R43: - May cause sensitisation by skin contact</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- R52: Harmful to aquatic organisms</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- endocrine disrupting properties</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Bisphenol-A fulfils the criteria for a substance of very high concern as defined by REACH</td>
<td></td>
</tr>
<tr>
<td><strong>Tetrabromobisphenol-A (TBBP-A)</strong></td>
<td>- R50-53: - Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment</td>
<td>Available</td>
</tr>
<tr>
<td></td>
<td>- There are indications of potential effects on the endocrine system</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- TBBP-A is considered to be persistent (P) or potentially very persistent (vP) based</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- TBBP-A does not fulfil the criteria for substances of very high concern as defined by REACH.</td>
<td></td>
</tr>
<tr>
<td><strong>Antimony trioxide</strong></td>
<td>- R40: (cat. 3) limited evidence of carcinogenic effect</td>
<td>Not investigates in the study</td>
</tr>
<tr>
<td></td>
<td>- Antimony trioxide is not considered as toxic substance and it does not fulfil the REACH criteria</td>
<td></td>
</tr>
</tbody>
</table>

Beryllium is mainly used as beryllium metal and composites, beryllium alloys and beryllium oxide. Beryllium metal and composites are rarely used in consumer electrical and electronic equipment. Since beryllium oxide is very expensive the beryllium industry aims at recycling it.

Polyvinyl chloride (PVC) is not used as pure resin in EEE applications, but mainly in form of flexible PVC material that contains various additives (as phthalate DEHP, or flame retardants such as MCCPs) many of them classified as dangerous. PVC recycling is problematic because:
- high separation and collection costs;
- loss of material quality after recycling;
- the low market price of PVC recycled compared to virgin PVC;

Bisphenol-A is a chemical intermediate mainly used for the production of polycarbonate, epoxy resins and used as an anti-oxidant in PVC processing. Only residual amounts of bisphenol-A are present in the final products. Concerning polycarbonates, waste material may be directly processed into articles of inferior properties. Epoxy resins are assumed to be not recycled. By incineration any free bisphenol-A in the product will be destroyed.

Tetrabromobisphenol-A (TBBP-A) is the most widely used brominated flame retardant (for printed circuit boards and polymeric material in housings and packaging) and is produced in the largest volume. For disposal by incineration and landfill, metal recycling and accidental fires, TBBP-A is a source of bromine and it can contribute to the formation of halogenated dibenzo-p-dioxins and furans.

Antimony trioxide is generally used as flame retardant in plastic, rubbers and textiles.
<table>
<thead>
<tr>
<th>Substance</th>
<th>Classification</th>
<th>Substitutes</th>
</tr>
</thead>
</table>
| **Hexabromocyclododecane (HBCDD)**            | - R50-53: Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment  
- HBCDD has persistent, bioaccumulable and toxic properties.  
- HBCDD meets the criteria of a substance of very high concern as defined by REACH. | Available   |
| HBCDD is a brominated flame retardant mainly used in the polymer and textile industries (as in polystyrene) |                                                                                                                                                                                                             |             |
| **Medium-chained chlorinated paraffins (MCCP)** | - R64: May cause harm to breastfed babies.  
- R66: Repeated exposure may cause skin dryness or cracking  
- R50-53: Very toxic to aquatic organisms; may cause long-term adverse effects in the aquatic environment  
- endocrine disrupting properties  
- some components of the technical MCCP products could be persistent, bioaccumulative and toxic.  
- MCCPs meet the criteria for substances of very high concern as defined by REACH. | Available   |
| MCCP is mainly used as secondary plasticizer in PVC, to cause an enhancement of the plasticizing effects, metal working fluids, paints and varnishes, adhesives/sealants, flame retardants, leather fat liquors, carbonless copy paper. Incineration is likely to completely destroy MCCPs; uncontrolled fires MCCP can lead to the formation of dioxins and furans. |                                                                                                                                                                                                             |             |
| **Short-chained chlorinated paraffins (SCCPs)** | - R40: Possible risk of irreversible effects.  
- R66: Repeated exposure may cause skin dryness or cracking  
- endocrine disrupting properties  
- SCCPs are toxic substances and are considered to be persistent and very persistent. | Available   |
| The main uses of SCCPs have been in metal working fluids, sealants, as flame retardants in rubbers and textiles, in leather processing and in paints and coatings. |                                                                                                                                                                                                             |             |
| **Bis (2-ethylhexyl) phthalate (DEHP)**        | - R60: May impair fertility  
- R61: May cause harm to the unborn child  
- endocrine disrupting properties  
- Not considered as PBT substance, but border-line case; has the potential to bioaccumulate | Available   |
| DEHP is mainly used as a plasticizer in polymer products. The municipal landfills are identified to emit DEHP mainly through the leakage water. Incineration emits DEHP through the air. |                                                                                                                                                                                                             |             |
| **Butyl benzyl phthalate (BBP)**               | - R50: Very toxic to aquatic organisms  
- R53: May cause long-term adverse effects in the aquatic environment  
- R61: May cause harm to the unborn child  
- R62: Possible risk of impaired fertility  
- endocrine disrupting properties | Available   |
| The main use of BBP is as a softener in PVC products. BBP is also used as plasticizer in EEE e.g. in connector wires. |                                                                                                                                                                                                             |             |
| **Dibutylphthalate (DBP)**                     | - R50: Very toxic to aquatic organisms  
- R61: May cause harm to the unborn child  
- R62: Possible risk of impaired fertility  
- endocrine disrupting properties                                                                 | Available   |
| The largest usage of DBP is as a plasticizer in resins and polymers such as PVC, and also in adhesives and in printing inks. |                                                                                                                                                                                                             |             |
| **Nonylphenol**                                | - R22: Harmful if swallowed  
- R43: May cause sensitisation by skin contact  
- R62: Possible risk of impaired fertility  
- R63: Possible risk of harm to the unborn child  
- evidence of endocrine disrupting activity  
- nonylphenol is very toxic for aquatic organisms. Bioaccumulation potential has been found in fish. Nonylphenol does not fulfil the persistency (P) criterion.  
- It fulfils REACH criteria for very high concern substance | Available   |
| Nonylphenol is used for nonylphenol ethoxylates production which is used as surfactants in electrical and electronic engineering industry to a small extent. |                                                                                                                                                                                                             |             |
5.4 Hazardous substances and EuP
Small amounts of certain hazardous substances can contribute to improve the performance of the products. This is generally related to the adoption of specific technologies. The assessment of the use of hazardous substances should be based on a life-cycle approach, accounting for the overall benefits/drawbacks.

Some technologies that use hazardous substances are characterized by better energy performance, with lower consumption during the product’s lifetime. It should also be considered that the production of electricity causes the release of various hazardous substances into air and water: therefore the energy saving allows also the saving of hazardous pollutants. Quantifying these opposite effects is key issue, in order to determine where and in which amount the use of specific hazardous substances in products can be environmentally advantageous..

The use and technical effect of hazardous substances, mainly mercury (Hg) and lead (Pb), in EuPs have been discussed in detail in the preparatory study for Implementing Measures of the respective EuP. In the following, it is presented a summary of the results concerning the product categories ‘television’, ‘domestic lighting’ and ‘public street lighting’.

5.4.1. Preparatory study on television: content of hazardous substances
The use of hazardous substances in television and the adopted technology have been analyzed in the preparatory study for the definition of the implementing measures for televisions [Fraunhofer IZM, 2007].

With regards to television and following requirements of WEEE - Annex II, as a minimum the following substances, preparations and components have to be removed from any separately collected WEEE:

- Mercury containing components, such as switches or backlighting lamps,
- Plastic containing brominated flame retardants,
- Cathode Ray Tubes,
- Liquid Crystal Displays (together with their casing) of a surface greater than 100 square centimetres and all those back-lighted with gas discharge lamps,

The RoHS applies to televisions as well and prohibits the use of the heavy metals lead, mercury, cadmium, hexavalent chromium, and brominated flame retardants in new electrical and electronic equipment placed on the market after 1 July 2006. There are some exemptions in annex to RoHS concerning televisions, as:

- Use of lead for shielding in glass (CRT) and mercury in florescent lamps in LCDs from 13 February (2002/95/EC),
- Use of lead and cadmium in optical glasses and glass filters relevant for television displays from 21 October 2005 (2005/747/EC),
• Use of lead oxide in glass used for bonding front and rear substrates of flat fluorescent lamps used for Liquid Cristal Displays (LCDs) from 21 April 2006 (2006/310/EC).

• Lead oxide in plasma display panels (PDP) and surface conduction electron emitter displays (SED) used in structural elements; notably in the front and rear glass dielectric layer, the bus electrode, the black stripe, the address electrode, the barrier ribs, the seal frit and frit ring as well as in print pastes.

Concerning flame retardants, brominated compounds have been used into plastic to reduce fire risk. Due to their compatibility to a large set of plastics, brominates flame retardants have been largely employed in the past. “Phosphorus flame retardants” represents nowadays the main substitute of brominated flame retardants being used in TVs.

Concerning the lead this is mostly contained into cathode ray tube (CRT). They use “heat to create light by striking large numbers of electrons against glass. [...] The outer glass allows the light generated by the phosphor out of the monitor, but (for colour tubes) it must block dangerous X-rays generated by high energy electrons impacting the inside of the CRT face. For this reason, the glass is leaded. [...] Because of leaded glass, other shielding, and protective circuits specifically designed, the X-ray emission of modern CRTs is well within approved safety limits” [Fraunhofer IZM, 2007].

The technology of the CRT is considered as consolidated and with few or none potentials of improvement.

Lead is also contained into Plasma Display Panel (PDP). “Lead in PDP is current exempted from the RoHS Directive. Lead-oxide glass is used in the dielectric layer, electrodes, glass sealant and other structural elements, primarily because of its capability to stabilize production yield and quality”.

According to the preparatory study, a manufacturer has announced the elimination of all of the about 70 grams of lead normally used in a 37” PDP [Fraunhofer IZM, 2007].

Mercury in LCD backlights has been exempted from the RoHS substance ban due to the fact that the mercury provides long-term efficient light generation. Mercury is mostly present into the following LCD technologies [Fraunhofer IZM, 2007]:

• Back-Light Engines for Rear Projection Displays. Rear projection TVs work on the principle of projecting a full-colour image from a smaller screen through a projection lens on a larger display screen. All of these projection systems are currently using Ultra High Pressure (UHP) lamp as a light source. The UHP lamps contain mercury and are said to have a limited lifetime, making replacement a necessity. Some UHP lamps have normally a mercury content of 0.01 – 0.023grams;

• Cold Cathode Fluorescent Lamp (CCFL). The tube is phosphor coated and filled with inert gases (Ar/Ne) and a slight amount of mercury (approx. 4 mg Hg per lamp) that is essential for the operation of the component. When a voltage is applied to the electrodes, the gas is ionized allowing the electrical current to flow. The collision of moving ions inject energy to the mercury atoms, which lets the atoms jump to a higher energy level followed by emitting ultraviolet photons when falling back into their original energy level;
- **External Electrode Fluorescent Lamp (EEFL).** EEFL differs from the previous Cold Cathode Fluorescent Lamp because it contains less mercury per lamp (<4mg Hg per lamp). On the other side, more lamps are necessary for the operation of the TV.

The technology evolution focused in the development of mercury-free lamps. Flat Florescent Lamp (FFL) is an example of a third backlight ‘mercury free’ technology that has entered the market. However this is characterized by some critical issues as [Fraunhofer IZM, 2007]:

- “Assumed higher power consumption in comparison to ‘Cold Cathode Fluorescent Lamp’ and ‘External Electrode Fluorescent Lamp’ technologies;
- Moderate brightness efficiency;
- Supply limited for larger back-light units (>32’’).”

The preparatory study concludes suggesting that the introduction and application of new technologies need to focus on the further reduction of potentially hazardous materials. Such measures should not, however, reduce energy efficiency. Industry should also investigate design options to improve recycling or EoL treatments. It is also under study the possibility to “increase the amount of mercury per lamp in order to achieve higher efficiency of backlights, to reduce material resources and power consumption” [Fraunhofer IZM, 2007].

Similar conclusions have been formulated by studies of the US-EPA [EPA, 2010].”Life-cycle mercury emissions are similar for CRTs and LCDs. The mercury emitted from the generation of power consumed by the CRT during manufacturing and use (7.75 mg), is slightly greater than the entire amount of mercury emissions from the LCD, including both the mercury used in LCD backlights (3.99 mg) and the mercury emissions from electricity generation (3.22 mg). Although this was not expected because mercury is intentionally incorporated into LCDs, but not in CRTs, the results are not surprising because mercury emissions from coal-fired power plants are known to be one of the largest anthropogenic sources of mercury”.

### 5.4.2. Preparatory study on lighting systems: content of hazardous substances

Two separate studies discussed the energy and environmental performance of ‘Public street lighting’ [Van Tichelen et al., 2007] and ‘Domestic lighting’ [Van Tichelen et al., 2009]. Concerning the requirements introduced by the current legislation, the WEEE directive defines that:

- gas discharge lamps have to be collected,
- minimum 80% by weight of the lamps has to be reused/recycled and,
- all contained mercury shall be removed.

About the content of hazardous substances into lamps, some exemptions have been introduced for by the RoHS Directive:

- mercury in compact fluorescent lamps not exceeding 5mg per lamp;
- mercury in straight fluorescent lamps for general purposes not exceeding:
  - halophosphate 10mg.
o triphosphate with normal lifetime 5mg.
o triphosphate with long lifetime 8mg.
- mercury in straight fluorescent lamps for special purposes;
- mercury in other lamps not specifically mentioned in this annex;
- lead in glass of fluorescent tubes.

There are, instead, no exemptions for luminaries and ballasts.

Concerning street lighting, “High Pressure Mercury (HPM) is the oldest High Intensity Discharge (HID) lamp technology and it was introduced in early 1930. The lamp produces, in an inner arc tube, partially visible light and a high amount of UV-radiation besides; the arc tube is enclosed in an outer bulb coated with fluorescent powder that converts most UV into visible light”. No significant progress has been reported in the last decades.

In the mid 1960s the first commercial Metal Halide (MH) lamp appeared on the market. “MH lamps were very similar to HPM lamps but the major difference being that the arc tube contains various metallic halides in addition to mercury and argon. They have the advantage to produce white light without the need for a phosphor coated outer envelope and have therefore an improved efficiency”.

Although the quantity of mercury in the present generation of gas discharge lamps is small, the lamp industry has been encouraging the development of cost effective, practical and environmental sound methods for managing the EoL of gas discharge lamps since early 90s. A typical mercury content of High Pressure Mercury (HPM) is 20-25 mg; for High Pressure Sodium (HPS) 10-15 mg; for Ceramic Metal Halide (CHP) 1-5 mg.

The mercury-content of the High Pressure Mercury lamps increases with the power of the lamps. Into High Pressure Sodium lamps the mercury-content is instead almost fixed for all lamps, independent of their power, due to the fact that for HPS-lamps mercury serves only as a carrier.

Instead of all other High Intensity Discharge (HID) lamps High Pressure Sodium (HPS) lamps can also be obtained without mercury content. The mercury free HPS lamps however have a lower lamp efficacy and thus increased energy consumption.

In the preparatory study on street lighting, various future scenarios compared to the current base-case scenario have been analyzed concerning the adoption of best available technologies (as the progressive substitution of High Pressure Mercury lamps with High Pressure Sodium lamps). It has been estimated that, as a consequence of this substitution, the fugitive and dumped mercury will be between 15 and 60 kg per year (lower than the quantity of 23-95 kg estimated for the base-case scenario based on the current use of technologies).

Concerning the domestic lighting systems, Compact Fluorescent Lamps (CFL) represent nowadays one of the most spread technologies. Mercury is an essential component for fluorescent lighting. It is therefore important to recycle such lamps because of their potential to pollute. Collected CFLs at end of life are crushed in a closed installation and sieved; the mercury containing fraction is distilled at 600°C to separate the mercury; the pure metallic mercury can be used again by lamp industry.

However the preparatory study observed that “many people don’t know what to do with their used lamps, moreover they don’t even know that compact fluorescent lamps are containing mercury” [Van
Tichelen et al., 2009]. 80% of the total mercury content is nowadays assumed to be fugitive and dumped.

Mercury content in CFL is independent on lamp power but differences can be made between different technologies e.g. use of amalgam (mercury-lead) or not (only mercury). The threshold for the mercury content into fluorescent lamps is fixed by the RoHS into 5 mg. However experimental tests carried out during the preparatory study show that, in some examined samples, the mercury content was very low (0.28 mg), instead in other examples it reached high values (up to 6.4 mg), even over the legislative limits [Van Tichelen et al., 2009]. “This is probably caused by the cheap but inaccurate method of mercury filling (drip filling) that seems to be very common in most small far eastern production plants”. An average value of 4 mg of mercury content has been estimated by the study.

Authors of the preparatory study also observed that a higher energy efficiency allows a lower emission of mercury during the use (mercury in fact is released during the production of electricity in some facilities, mostly coal-fired plants). On this purposes, Compact Fluorescent Lamps are the best choice in terms of mercury emissions due to low electricity consumption per lumen and per hour. Improvements can be expected for recycling CFL in order to increase the share of CFL recycled (only 20 % nowadays).

Most manufacturers already produce CFLs with a reduced mercury content compared to the maximum level of 5 mg specified in the ROHS directive. It is also possible to add substances (e.g. mercury amalgam) to fluorescent lamps that reduce the impact of mercury from disposal of fluorescent lamps that might leach into surface and subsurface water. On this purpose, the U.S. Environmental Protection Agency established a maximum concentration level for mercury at 0.2 milligrams of leachable mercury per litre of extract fluid.

Amalgam (a lead/mercury alloy) ensures a high light output, regardless the ambient temperature. The lead/mercury alloy increases also the melting point compared to pure mercury, being not liquid at room temperature. An additional benefit is, therefore, that in case of breakage of a cold lamp, mercury cannot dissipate in the environment.
5.5 Conclusions
The RoHS Directive established requirements about a minimum content of some hazardous substances. Although some other substances have been identified as potentially hazardous, they have been not inserted into the regulations yet. This was mostly due to:

- the lacking of enough evidences about their hazardous effects;
- the lacking of economically or technically viable substitutes.

The requirements about the hazardous content have, anyway, to consider the potential benefits related to the substance use. Some of them, in fact, are related to specific innovative technologies that allow to reduce impacts during the product’s useful life. *Requirements about the content of hazardous substances have therefore to be based on a life-cycle perspective, evaluating environmental impacts and benefits throughout the product life-cycle.*

It can be reiterated the conclusion from [Baitz et al. 2004] noting that “LCA comparisons should be undertaken at application level rather than at material level, particularly for political decision-support. LCAs on application level are more comprehensive and draw a complete picture of the environmental impacts over the life cycle. At application level, LCAs can show correlations of production phase, use phase and end-of-life treatment. […]”.

Concerning the verification of the manufacturer’s compliance to the requirements, this is generally based on a self-declared statement supported by sufficient tests and other documentation. In particular, manufacturer have also to provide evidence that they continuously control and audit every critical process and components, including also the control of the company’s supply-chain exposure.

Analogously, the RoHS Directive adopted some exemptions for specific products and components (e.g. concerning lamps and televisions). These exemptions are related to the use of specific technologies. The evaluation of the use of hazardous substances should therefore be based on a life-cycle approach, accounting the overall benefits/drawbacks related to the adopted technologies. In fact, it was observed that some technologies that use hazardous substances are characterized by better energy performance, with lower consumption during the product’s lifetime. Because also the production of electricity causes the release of hazardous substances into air and water: the energy saving allows also the saving of emission of hazardous pollutants.
References


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Abstract
The present Deliverable 1 reports the scientific survey on the implementation of resource efficiency and waste management criteria into product’s design. In particular, the survey aims at identifying the ‘key issues’ concerning the following parameters:

- Recyclability/Recoverability/Reusability (RRR);
- use of recycled materials/recycled content;
- limitation of the use of priority resources;
- restriction of the use of hazardous substances.

The first part of the deliverable concerns the analysis of the European legislation that already implemented the concepts of ‘resource efficiency’ and ‘waste management’. The second part focuses on the international standards and the scientific literature.
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