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Integration of resource efficiency and waste management criteria in European product policies – Second phase

Report n° 3

Refined methods and Guidance documents for the calculation of indices concerning Reusability / Recyclability / Recoverability, Recycled content, Use of Priority Resources, Use of Hazardous substances, Durability (final)

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September 2012

Report EUR 25461 EN

Joint Research Centre

European Commission
Joint Research Centre
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JRC73188

EUR 25461 EN

ISBN 978-92-79-25931-9

ISSN 1831-9424

doi: 10.2788/42590

Luxembourg: Publications Office of the European Union, 2012

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Printed in Italy

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Executive Summary

The present Report refines the methods for the assessment of the following parameters: reusability/recyclability/recoverability-RRR, use of relevant resources, recycled content, use of hazardous substances, durability. These methods are derived from those developed during the first phase of the project (Ecodesign Phase 1 – EP1[1]), refined according to comments received from stakeholders[2] and according to the application to new product groups (see Report n° 2) and in alignment with newly published studies and/or studies currently under development. The report is structured in 5 chapters, one for each method. Each chapter is then subdivided into:

- Introductory part, which analyzes additional relevant references for the revision of the method;
- Developed method, including the description of main indices and potential variants;
- Procedure for the verification of the calculation of indices
- Guidance documents (in the Annexes) summarizing methods and main indices

Key issues of each method are synthesized in the next sections.

Reusability/Recyclability/Recoverability (RRR)

The method for the assessment of RRR has been largely revised, aligning them as far as possible to the IEC/TR 62635[3], technical report developed by the International Electrotechnical Commission. In particular the method is structured as following:

- Definition of the End-of-Life scenario for the considered product. This scenario summarizes the treatments that each product's parts will undergo. In particular, product parts are subdivided into: reusable parts; parts for selective treatments; parts for selective recycling; difficult to process parts; other parts (for material separation).
- Identification of the recycling/recovery rates for each product's parts for the selected scenario
- Calculation of the 'RRR rate' indices (fraction in mass of the overall product mass that is reusable/recyclable/recoverable)

Some deviations and advancements compared to the IEC/TR 62635 are proposed, also based on the outcomes from the application to the case-studies.

Use of relevant Resources

Analogously to the EP1 project, the prioritisation of resources has been performed on the basis of potential environmental impacts/benefits related to the potential reuse/recycling/recovery of the

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[1] Project: "Integration of resource efficiency and waste management criteria in the implementing measures under the Ecodesign Directive". http://lct.jrc.ec.europa.eu/assessment/projects

[2] See Annex 7 for details of the preliminary feedback and the "Final Executive summary" for the list of feedback received during the stakeholder consultation 17th August – 21st September)

[3] The International Electrotechnical Commission (IEC). Technical Report IEC/TR 62635. "Guidelines for End of Life information provision from manufacturers and recyclers, and for recyclability rate calculation of Electrical and Electronic Equipment". June 2012

product. A set of environmental indices have been developed, named ‘RRR Benefit Rates’. These indices are based on RRR rates previously introduced including, in addition, the life-cycle data about the manufacturing of the product, the production of primary materials, the impact for the recycling and production of secondary materials, the disposal and the transport during each phase.

The ‘RRR Benefit Rates’ can be calculated for various life-cycle impact categories, and can be used to identify product ‘hot spots’ (as Discussed in Report n° 2).

The present Report also introduces some data-sheets for the indices aimed at simplifying their calculation and verification.

Recycled content

The method for the calculation of the recycled content is substantially consolidated and standardised (e.g. the ISO 14021[4]). The method proposed does not largely deviate from the one discussed in the EP1 project. However, the present report focused more on the development of a robust procedure for verification, based on technical documents to be provided to support declaration from manufacturers. To this end, references for the documental verification have been added, including some standards (e.g. the EN 15343[5] and the standard for recycled content by the Scientific Certification System[6]).

Finally a new index for the ‘Recycled content benefit’ has been introduced. Similarly to the RRR and RRR Benefits indices, this index allows the calculation, in a life-cycle perspective, of the environmental benefits (for certain impact categories) that can be achieved by introducing some recycled materials during the manufacturing of the product.

Use of hazardous substances

The method for the use of hazardous substances has been largely modified compared to that introduced by the EP1. In particular, following an extensive review of the scientific literature, it has been recognised that this aspect can have different interpretations, including: a) to assess the potential hazardousness of the substances; b) the use of hazardous substances in the product and their limitation/substitution; c) the reduction of the risks of use of hazardous substances in some processes (e.g. the End-of-Life treatments of the products).

The present report focused on this last point. The scope is, according to the current End-of-Life treatments of the product, to identify ‘key’ parts and components that have a content of hazardous substances that is critical for the identified End-of-Life treatments. The steps of the procedure are the followings:

1. Definition of the set of substances to be considered.
2. Identification of components embodying the considered substances.
3. Identification of treatments for the End-of-Life of the component and potential risks.

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[4] ISO 14021 - Environmental labels and declarations — self-declared environmental claims (Type II environmental labelling). International Organization for Standardization. 1999

[5] European Committee for Standardization. EN 15343. Plastics. Recycled plastics. Plastics recycling traceability and assessment of conformity and recycled content. 2007

[6] Scientific Certification System (SCS) - California Corporation.. Environmental Certification Services: “Recycled Content Standard”. Version 5-0. 2011

4. Identification of key components.

The treatment of key components therefore requires special attention to reduce the risk at the End-of-Life for workers and the environment. Also design alternatives of the product, including the improvement of the disassemblability of the parts, can be identified and can contribute to reduce such risks.

Durability

The method for the environmental assessment of durability is new, it was not yet part of the project EP1. The method is illustrated in the present report and it will be further discussed in Report n° 1 (including its exemplary application to a case-study).

The method aims to identify if and to what extent a potential extension of the operating time of the product could be relevant in terms of life-cycle environmental benefits.

The environmental assessment of the durability of a considered product is based on the comparison of two different scenarios, following a life-cycle approach:

- Base-case Scenario: it is assumed that product “A” is substituted, after its average operating time, by a new product “B”.
- Durability Scenario: it is assumed that the operating life of product “A” is extended by an additional time frame, and only afterwards it is substituted by a new product “B”.

The assessment aims to answer the following questions:

- How large are the environmental benefits (if any) of extending the operating life of the considered product by a given additional time-frame?
- How relevant are the environmental benefits (if any) compared to product’s life cycle impacts?

It is highlighted that the method does not take into account consumer behaviour (e.g. "fashion items")[7].

A general index for the durability of the product is then introduced. An additional simplified index is also discussed to overcome some potential calculation problems that could arise, especially concerning the availability of life-cycle data for the product. Although simplified, this index is scientifically robust for the scope of the assessment, as proved by similar applications in the scientific literature. It is highlighted that a full assessment can however only be possible when additional data of the case-study are available (through e.g. estimations and/or extrapolations).

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[7] These aspects can be part of further researches.

Abbreviations

CLP - Classification, Labelling and Packaging (CLP) of substances and mixtures
EC – European Commission
ECHA - European Chemical Agency
EP1 – “Ecodesign Phase 1” project[8]
EEE – Electrical and Electronic Equipment
ErP – Energy Related Product
EuP – Energy Using Product
GWP – Global Warming Potential
IEC - International Electrotechnical Commission
LCA – Life Cycle Assessment
MEErP - Methodology for the Ecodesign of Energy-related Products
PCB - Printed Circuit Board
REACH - Registration, Evaluation, Authorisation and Restriction of Chemicals
RRR – Reusability / Recyclability / Recoverability
RCR - Recycling rate
RVR - recovery rate
SVHC – Substance of very high concern
TR – Technical Report
WEEE – Waste of Electrical and Electronic Equipment

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[8] Project between JRC/IES and DG Environment titled: “Integration of resource efficiency and waste management criteria in the implementing measures under the Ecodesign Directive”. Reports of EP1 available at: http://lct.jrc.ec.europa.eu/assessment/projects

Introduction

The relevance of ecodesign requirements about the product end-of-life has been stated into various European policy documents and legislation.

In order to promote further sustainable consumption and production, the European Commission (EC) announced in its "Roadmap to a Resource Efficient Europe" the will to "*address the environmental footprint of products […] including through setting requirements under the Ecodesign directive, to boost the material resource efficiency of products (e.g. reusability/recoverability/recyclability, recycled content, durability)*" [EC, 2011].

Also the European Council supported such considerations in its "conclusions on tackling the challenges on raw materials and in commodity markets", "inviting the Commission to further promote innovation and research and development efforts in the raw materials value *chain, including exploration, extraction, processing, recycling, ecodesign, resource-efficient production and substitution*" [European Council, 2011]. In particular the Council emphasizes that "*recycling strongly contributes to the preservation of resources by stimulating design for disassembly and converting waste into products and materials, and by applying this to the entire life-cycle of products and materials*" [European Council, 2011].

Recently also the European Parliament expressed similar considerations in the document summarizing its position on the recast of Waste of Electrical and Electronic Equipment (WEEE) Directive [EU, 2012]. In particular, the Parliament declared that "*Ecodesign requirements facilitating the re-use, dismantling and recovery of WEEE should be laid down in the framework of measures implementing Directive2009/125/EC. In order to optimise re-use and recovery through product design, the whole life-cycle of the product should be taken into account*" [EU, 2012].

On this subject, the EC stated about the position of the EU Parliament on the recast of the WEEE Directive that [EU, 2012]:

> "*Eco-design measures can help to facilitate meeting the targets of the Directive on waste electrical and electronic equipment in line with the Roadmap on Resource Efficiency (COM(2011)571). The Commission will, if and when introducing new or reviewing the implementing measures adopted pursuant to Directive 2009/125/EC on products also covered by the WEEE Directive, take into account the parameters for re-use and recycling as set out in Annex 1 part 1 of the Directive 2009/125/EC, and assess the feasibility of introducing requirements on re-usability, easy dismantling and recyclability of such products*".

In particular, the article 4 of the recast WEEE Directive states that [European Council, 2012]:

> "*Member States shall, without prejudice to the requirements of Union legislation on the proper functioning of the internal market and on product design, including Directive 2009/125/EC, encourage cooperation between producers and recyclers and measures to promote the design and production of Electrical and Electronic Equipment (EEE), notably in view of facilitating re-use, dismantling and recovery of WEEE, its components and materials. In this context, Member States shall take appropriate measures so that the eco-design requirements facilitating re-use and treatment of WEEE established in the framework of Directive 2009/125/EC are applied […]*".

Also the availability of raw materials and their efficient use are some of the key issues that the EC is currently tackling. In its communication on "”tackling the challenges in commodity markets and on raw materials" the Commissions stated that "*as worldwide demand for raw materials increases, greater efforts will have to be made on recycling. Higher recycling rates will reduce the pressure on demand for primary raw materials, help to reuse valuable materials which would otherwise be wasted, and reduce energy consumption and greenhouse gas emissions from extraction and processing*" [EC, 2011b]. Therefore the Commission proposes as solution, among the other, "*to analyse the feasibility of developing ecodesign instruments (i) to foster more efficient use of raw materials, (ii) ensure the recyclability and durability of products and (iii) promote the use of secondary raw materials in products, notably in the context of the Ecodesign Directive*"

Possible measures to tackle challenges in the supply of relevant raw materials include, among the others, the promotion of the "*extraction, recycling, research, innovation and substitution inside the EU*" [EC, 2011c]. Furthermore, in the 'Roadmap to a Resource Efficient Europe', the EC expects as milestone that by 2020 "*more materials, including materials having a significant impact on the environment and critical raw materials, are recycled*" [EC, 2011].

The European Parliament in a "Motion for a European Parliament resolution on a resource-efficient Europe" identified as priority actions the launch, among the other, of "*calls on the Commission to extend the scope of the eco-design directive to non-energy related products and to come forward with additional eco-design requirements on the performance of products, including recycled content, durability and reusability, in order to improve their environmental impact and promote recycling markets*" [EU, 2011c]. Furthermore, on the same document the Parliament promotes also the development of "*incentives that encourage companies to measure, benchmark and continuously improve their resource efficiency, as well as measures to extend the producer responsibility principle*" [EU, 2011c].

Based on the previous considerations, the present report discusses and develops methods for improvement of resources efficiency of products and to support the development of requirements on the performance of products to improve their environmental impact. Requirements should be assessed considering the whole life cycle of the product, including use phase and any other relevant phase, in order to minimize trade-off and optimize global environmental benefits (according also to recommendations of [ISO/TR 14062, 2002]).

The Report is based on the revision[9] of methods already introduced and discussed by the previous project 'Ecodesign Phase 1'[10] concerning:

- reusability / recyclability / recoverability;
- use of priority resources;
- recycled content;
- use of hazardous substances.

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[9] Revision has been based also on received preliminary feedback from stakeholders (see Annex 7 for details).

[10] Project between JRC/IES and DG Environment titled: "Integration of resource efficiency and waste management criteria in the implementing measures under the Ecodesign Directive". Reports of EP1 available at: http://lct.jrc.ec.europa.eu/assessment/projects

In addition to the above aspects, the present report also introduces a draft original method for the assessment of the durability.

1. Revision of the method for Reusability, Recyclability and Recoverability

1.1 Introduction

The scope of the present chapter is the revision/refining of the method for the assessment and verification of the "Reusability / Recyclability / Recoverability (RRR)" of products[11], based on preliminary comments received by stakeholders (see Annex 7 for details) and the most recent progresses on the scientific literature.

The chapter will first perform a literature review to identify new references potentially relevant for the revision/refining. Afterwards modification of the method will be discussed.

The final outcome of the chapter is the drafting of guidance documents for the RRR, as illustrated in Annex 1.

1.2 Literature review

1.2.1 The Technical Report IEC/ TR 62635

The International Electrotechnical Commission (IEC) recently developed[12] a technical report (TR) concerning the provision of End-of-Life (EoL) information for EEE and the calculation of the recyclability rate [IEC/TR 62635, 2012]. The purpose of the TR is to provide sufficient data to "*allow recyclers*[13] *to safely recycle and to improve their processes and accurately calculate and inform downstream manufacturers and customers of recyclability rates*". The TR consists of three parts:

- Part I describes EoL principles and introduces generic treatment processes of WEEE.
- Part II focuses on products and EoL treatment scenario information exchange for manufacturers and recyclers.
- Part III describes method of recyclability and recoverability calculation.

These three parts will be summarized in the following sections.

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[11] The methodologies for the assessment of RRR indices (developed in EP1 – Report n° 2 – Section 2) introduced a set of mass-based indices that assess the percentage of product that is potentially suitable for reuse / recycling / recovery. The indices are based on sub-indices that take into account the disassemblability of components, the recyclability / recoverability / reusability of materials and the contamination among the materials.

[12] The technical report has been approved on June 2012 and it publication is forthcoming at the time of this report.

[13] Recycler is defined by the IEC/TR 62635 as the "organisation with the facility to carry out recycling and / or recovery operations" [IEC/TR 62635, 2012].

1.2.1.1 Part 1: End of Life principles (Section 2, 3 and 4)

The TR first defines main terms adopted. Among these it is interesting to mention the following:

Recyclability: ability of waste product to be recycled, based on actual practices[14]

Recyclability Rate: ratio of recyclable product mass to total product mass

Recoverability: ability of a waste product to be recovered, based on actual practices

Recoverability Rate: ratio of recoverable products, product parts, materials mass to total waste product mass reprocessed

It is also highlighted that these definitions are coherent with definitions provided in the previous project "Ecodesign - phase 1" (EP1)[15]. Both the methods consider the recyclability/recoverability as 'potentials' or 'abilities' of the product. However, the IEC/TR 62635 bases the calculation on the current scenario, while the EP1 project highlights that the recyclability/recoverability of product can change over the time (by assuming different possible treatments and technologies)[16].

Afterwards the TR subdivides the possible treatments for WEEE into 4 different groups (Figure 1):

- *Pre-treatments*, which include a selective manual separation of some parts. Manual disassembly is worth in various situation, including:
    - separation of reusable parts
    - separation of parts containing potential hazardous substances or that require a selective treatment due to regulation (de-pollution);
    - parts that requires a manual disassembly, if separately collected, can grant higher recycling rates (e.g. parts suitable for reuse, parts mostly homogeneous and constituted by a single recyclable materials);
- *Material separation* through mechanical, thermal or chemical separation.
- *Energy recovery* (production of useful energy through direct and controlled combustion or other processing of waste));
- *Disposal* of residues into landfills.

The IEC TR assumes as "re-usable" parts that fulfil the following conditions [IEC/TR 62635, 2012]:

a) "*It is possible to separate the part from the product while maintaining the part or component's functional integrity. In practice, this implies the product design allows accessibility and that binding systems are reversible.*

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[14] The recyclability of a product implies profitable and environmentally sound process based on the current practices and market.

[15] "Integration of resource efficiency and waste management criteria in the implementing measures under the Ecodesign Directive", Report n° 2- section 2.2.5.

[16] This concept is the basis of the setting of different scenarios for the analysis (including potential future scenarios) as illustrated in section 1.3.2.1.

b) *The manufacturer can provide evidence that a commercial reuse and refurbishment system has been established for that part that take into consideration regulation and market expectations. This can take the form of contracts with commercial partners, availability of refurbished parts in the marketplace, or other evidence that there is an established system*".

Furthermore, 'parts made of a single recyclable' are relevant for recycling if [IEC/TR 62635, 2012]:

a) "The size of the part and nature of material is such that there is an economical interest for dismantling. […]

b) There is a specific EoL channel for these materials with higher recycling rates compared to the results obtained after material separation".

The TR also includes in the 'Annex A' an indicative list of materials and parts to be identified for selective treatments. The list currently includes around 15 components, but the list is expected to be continuously updated to be in line to the technological and legislative development.

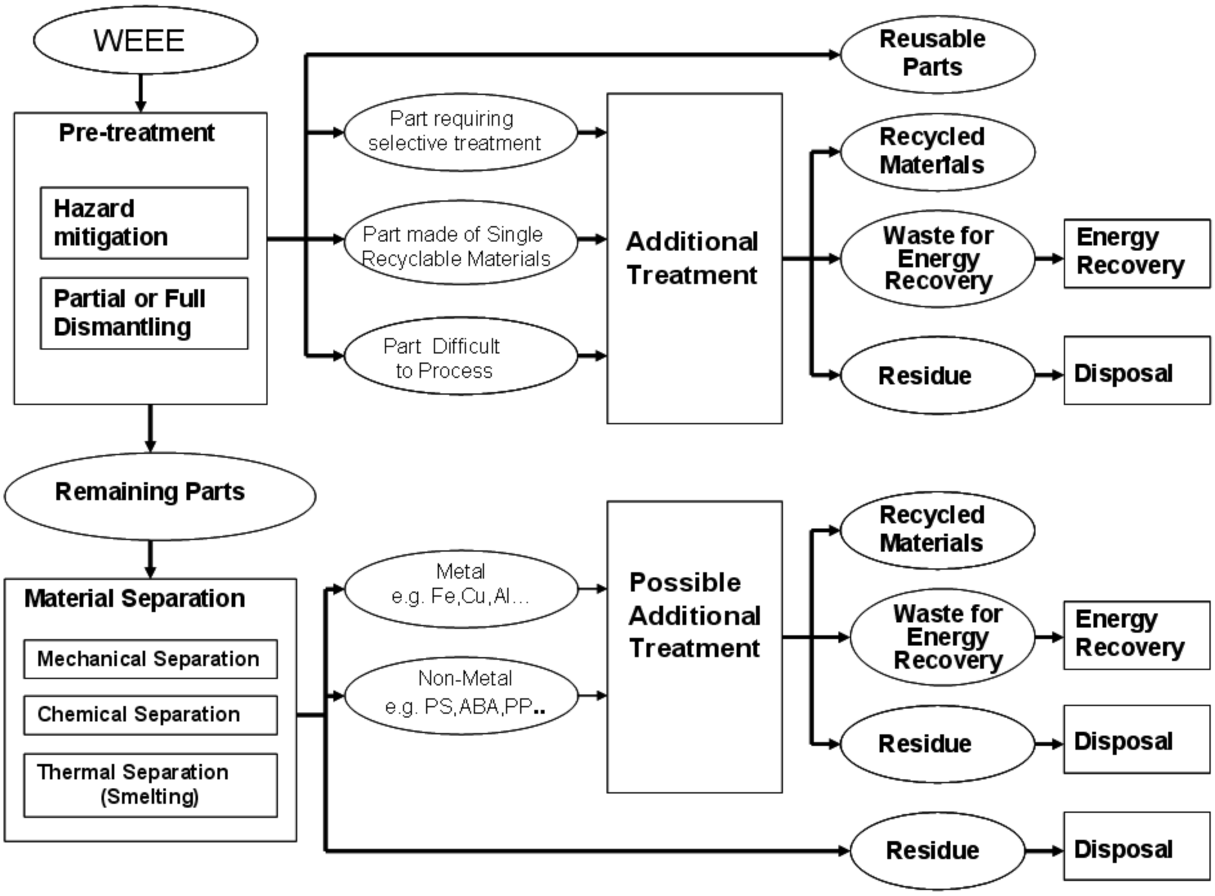

Figure 1. EoL treatments for WEEE [IEC/TR 62635, 2012]

Compared to the treatments foreseen in the EP1 project[17], The TR is more detailed in the description of the '*Pre-treatments*' and in particular in the subdivision of product's components into different categories depending on their characteristics (homogeneity, presence of hazardous substances or presence of parts difficult to be processed.

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[17] "Integration of resource efficiency and waste management criteria in the implementing measures under the Ecodesign Directive", Report n° 2- section 2.2.5 (available at: http://lct.jrc.ec.europa.eu/assessment/projects)

The selection of parts addressed to manual disassembly and parts to be addressed to shredding is based on the evaluation of the manufacturer (and not based on preset tables, as foreseen in the EP1). This is also in line with the voluntary approach followed by the TR.

Furthermore, the IEC considers the contamination among materials as an important factor that influences the selection of the suitable treatments. However, also the contamination is based on a self-evaluation of the manufacturer and not on a specific index (as foreseen in the EP1).

1.2.1.2 Part 2: Information provision from manufacturers and recyclers (Section 5 and 6)

TR provides a method for manufacturers and recyclers to make EoL product information available to each other and to other relevant stakeholders Only with a cooperation and information exchange among the different subjects it is possible to achieve higher improvement.[18] In particular, manufacturers need to know the processes taking place at the recyclers and recyclers need to know some specific information, such as parts to be treated selectively, to carry out effective treatments. Information can be provided on paper or / and in electronic form.

Two sections are specifically set in TR concerning the exchange of information_[IEC/TR 62635, 2012]:

- '*Section 5*' concerning the "provision of product information" (from the manufacturer or the product supplier to relevant stakeholders);
- '*Section 6*' concerning the "*provision for EoL treatment information*" (from the recyclers to manufacturers).

Information to be provided by manufacturers includes:

- product's mass and dimensions
- information to mitigate potential risks for personnel that have to recycle/recovery the product
- identification of parts for which dismantling is recommended, including a detail of their composition (bill of materials) and of the dismantling procedure (dismantling steps, tools, etc.)
- material content description for remaining parts.

The manufacturer should also identify, and provide information, about components that require special pre-treatments (see Figure 1), as:

- Information concerning reusable parts, which should be easier to identify.
- Information for parts made of a single material that can be dismantled.

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[18] The provision of information is therefore relevant criterion for the ecodesign of products. This conclusion is analogous to that formulated in the EP1 project.

- Information for parts that are difficult to process and that require further processing[19]. For these, the manufacturer should provide dismantling instructions. The recyclability of these parts has to be assessed on the basis of feedback from the recyclers.

Information to be provided by recyclers should focus on the performance of the end of life treatments (including the recycling/recovery rates of the different parts). This information is necessary for manufacturers for the calculation of the recyclability / recoverability rates (see section 1.2.1.3).

In particular, "*Recyclers should identify critical issues affecting material separation such as difficulty to shred, material mixing incompatibility impairing recycling performances or dismantling costs. This aids the manufacturer in obtaining feedback on the practicality, feasibility, and any issues with EoL treatment*".

Information provided by recyclers should consist of the input and output statistics for the reporting facility using the reported process and products. Average recycling rates may be given when the product is processed in a mixed stream.

The TR also includes in 'Annex B' a factsheet for the provision of information for use by recyclers or treatment facilities[20], and in 'Annex C' a factsheet for the synthesis of information from recyclers[21].

1.2.1.3 Part 3: method of recyclability and recoverability calculation (Section 7 & 8)

The IEC/TR defines two indices for the calculation of the recyclability and recoverability rates [IEC/TR 62635, 2012]:

Formula 1
$$R_{cyc} = \frac{\sum (m_i \cdot RCR_i)}{m_{EEE}} \cdot 100 \qquad [\%]$$

Formula 2
$$R_{\text{cov}} = \frac{\sum (m_i \cdot RVR_i)}{m_{EEE}} \cdot 100 \qquad [\%]$$

Where:

- R_{cyc} = Recyclability rate
- R_{cov} = Recoverability rate
- m_{EEE} = total product mass
- m_i = mass of the i^{th} part
- RCR_i = recycling rate of the i^{th} part
- RVR_i = recovery rate of the i^{th} part

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[19] Examples of parts that may require removal are castings, wire or cable and refrigerator motors.

[20] Factsheets in Annex B include, among the others the description and location of: parts containing hazards, reusable parts, components that necessitate of selective treatment, single recyclable material parts, and Parts difficult to process.

[21] Factsheets in Annex B include, among the others: recycling process description, Product parts affecting treatment capabilities or requiring specific treatment, treatment for single material parts, Material separation effectiveness and pollution prevention.

Values of “RCR” and “RVR” should be estimated by the manufacturers on the basis of references and information from recyclers. The standard also introduces a procedure for the calculation flow of the rates (see Figure 2).

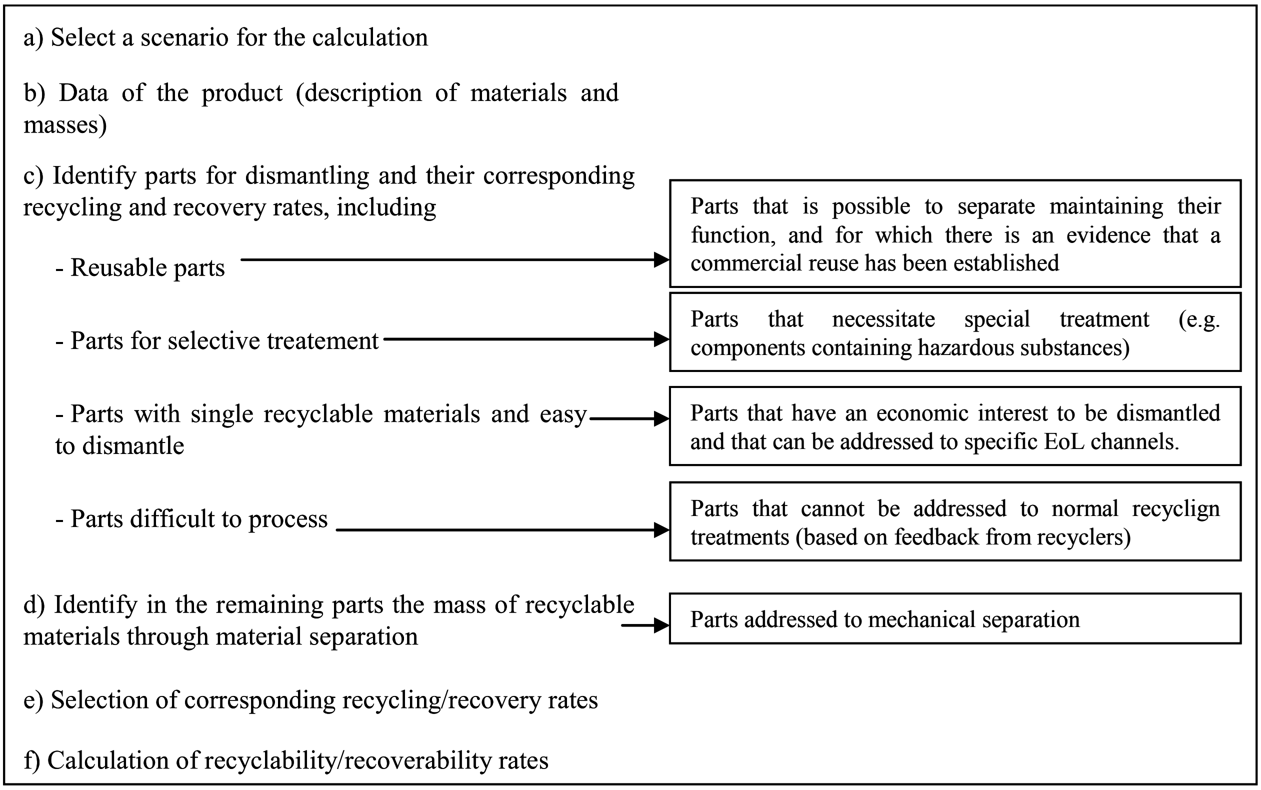

Figure 2. Calculation flow of the recyclability/recoverability rates (adapted from [IEC/TR 62635, 2012]).

Annex D and Annex E of the IEC/TR 62635 illustrate some examples for the calculation of the recyclability and recoverability of products.

In particular, Annex D provides some exemplary set of data related to European scenario for large household appliances, small household appliances, IT and telecommunications equipment, consumer equipment. Although providing an extensive list of materials and parts, the annex sometimes is missing information about some specific materials and parts[22].

Examples of recycling and recovery rates of product parts which require selective treatment are:

- Printed circuit boards - PCB: RCR= 10%; RVR = 80%;
- Power cable: RCR= 25%; RVR = 90%;
- Liquid crystal display (LCD): RCR= 0%; RVR = 0%.

Annex E instead illustrate the exemplary calculation of the recyclability rate for a refrigerator based on data provided in Annex D. It is calculated that the ‘Recyclability rate’ of the refrigerator is 75.3%, while the ‘Recoverability rate’ is 81.9%.

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[22] The need to extend and/or update the database has been also evidenced by the analysis of case-studies (Report n°2). In particular, this update should be performed including recent data collected by recycling operators (e.g. by using tools such as the WF-RepTool [WEEE Forum, 2012]).

It is however underlined that data provided in Annexes D and E are only illustrative of the proposed method: more robust and representative data for the European context are needed.

Comparing the method introduced by the IEC TR with that introduced by the EP1 project, it is observed:

- There is substantially agreement on the structure of the formulas.
- Both methods assume an EoL scenario for the calculation of the recyclability/recoverability indices.
- There is also an agreement on the identified key issues that influence the recyclability and recoverability, including:
    - The composition of the product
    - Manual disassembly of the key components and the efficiency of the shredding process;
    - The technical and economical feasibility of the recycling/recovery of the materials (i.e. availability of plants for their treatment and economical viability of the processes);
    - The homogeneity of the components (e.g. parts made of a single recyclable material) and the contamination of components (e.g. due to hazardous substances) that affect the recyclability/recoverability.

However, some differences occur, as follows:

- In the IEC the reusable components are included in the calculation of the Recyclability/Recoverability rates[23] (while in the EP1 project these have been considered separately for the Reusability index). Furthermore, the recoverability index in the IEC TR includes all the recovery options, while the EP1 project developed a specific index for the energy recoverability of the products;
- The setting of the EoL scenario in the IEC method is set by the analyst on the basis of his experience and the feedback from recyclers. However, the TR does not provide further detail on how this scenario should be set. In the EP1 the EoL scenario (namely the disassembly scheme) is driven by tables that include parameters as the "time for disassembly" or the "costs for disassembly".
- In the IEC method it is necessary to identify case-by-case the recycling rates of the product's components addressed to shredding, based on available references and information from the recyclers, or suing data provided for a few materials / components according to the Annexes. In the EP1 average value have been selected, for example, concerning the efficiency of the mechanical separation of materials.

It can be noticed that the approach followed by the IEC relates to the specific product (based on specific information representative for the area where the product is treated at the EoL). Such information is case-by-case dependant and has to be transparently declared. The IEC method is particularly suitable for a voluntary approach in which the manufacturer decides to calculate and

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[23] On this purpose, the IEC defined recycling "any operation by which waste products are reprocessed into products, product parts, materials, or substances whether for the original or other purposes. It includes the reuse, the reprocessing of material but does not include the energy recovery". [IEC TR 62635-62650, 2012]

communicates the product performances. *Unless a specific public scenario is specified,* the IEC method, how established now, is instead less suitable for binding requirements (e.g. minimum thresholds to be achieved) due to site-specific information that the manufacturer may collect.

On the other side, methods illustrated in the EP1 project have been conceived to reduce possible choices during the calculation (for example, for the calculation of the 'disassemblability' or concerning the efficiency of the shredding process). This approach results more general and suitable for binding requirements, but on the other side it requires reference tables, which have to be agreed among stakeholders.

It is therefore noticed that the development of agreed pre-set data for the recyclability/recoverability of different components, representative for the European context, could be useful to make the IEC method more robust and suitable for European product policies.

1.2.1.4 Method comparison between the IEC/ TR 62635 and "Ecodesign - phase 1" project

The main analogies and differences between the IEC/TR 62635 and the method from EP1 are summarized in Table 1.

Table 1 Method comparison between the IEC/TR 62635, 2012 and Report n° 2 (EP1 [Ardente et al., 2011])

	Analogies	Differences
Definitions	Definitions concerning recyclability and recoverability are similar (recyclability and recoverability as ability/potential)	The IEC TR mentions that the Recyclability and Recoverability are "based on actual practices", while for EP1 this is not specified.
Provision of information	The provision of information is fundamental to improve the waste management.	The 'Ecodesign phase 1' considers the provision of information as a potential relevant requirement for manufacturers. The IEC TR assumes the provision of information as a necessary step for the calculation of the recyclability/recoverability
Disassembly scenario	Both the document assume the setting of an EoL scenario of the product as the first step for the calculation of the recyclability / recoverability	The IEC TR assumes that the EoL scenario is defined by the manufacturer based on references and feedback from recyclers (few details/guidance provided on how the scenario should be set). The Ecodesign phase 1 assumes that the scenario is set by the manufacturer on the basis of the disassembly time and (potentially) other parameters (e.g. value of the components, costs for treatments, complexity of the disassembly). In addition, according to EP1, the analysis of the recyclability is also dependant on possible alternative treatments and technologies[24].
Contamination among materials	Considered as one of the key issue influencing the potential of components to be recycled/recovered	The Ecodesign Phase 1 assesses the 'contamination' by a specific index (calculated from reference tables). The IEC TR considers the assessment of contamination among materials as a preliminary analysis for the setting of the EoL scenario
Technical recyclability of the materials	A material is considered recyclable if there are available and economic viable plants for their treatments	The Ecodesign Phase 1 includes the technical recyclability in the indices for the calculation of the recyclability. The IEC TR considers the technical recyclability as requisite for the setting of the EoL treatment
Method for the calculation of reusability of products	Components can be assumed reusable if these are specifically designed to be reused and if there are evidence of their commercial reuse for the manufacturing of new products.	The Ecodesign Phase 1 develops a specific index for reusability. The IEC TR calculates the reusability of components but this is then included in the calculation of Recyclability/Recoverability indexes.
Method for the calculation of recyclability of products	The two methods adopt formulas structurally equal	The Ecodesign Phase 1 calculates the recyclability of each component on the basis of tables based on: 'disassemblability', material contamination and technical recyclability of materials (based on average reference tables). The IEC TR assumes that the recycling rate of each components is assumed by the manufacturer on the basis of reference and feedback from the recyclers (case-by-case calculation)
Method for the calculation of recoverability of products	The two methods adopt formulas structurally equal	The Ecodesign Phase 1 refers only to the energy recoverability. The IEC include in the recoverability also recyclable and reusable components.

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[24] The analysis of possible alternative EoL scenarios and of potential future scenarios will be illustrated in the section 1.3.2.1.

1.2.2 Assessment of ‘disassemblability’

The ‘disassemblability’ can be defined as the “degree of easy disassembly” [Mok et al., 1997] or the potential of a component to be extracted from a product” [Tsai-Chi Kuo, 1997].

The key role of ‘disassemblability’ for RRR has been largely discussed in the scientific literature. For example Ishii, 1996 stated that “Design for Disassembly […] 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” [Ishii, 1996].

Furthermore, according to Desai and Mital, 2003, the following factors affect disassemblability:

- Use of force: Minimal use of force is recommended.
- Mechanism of disassembly: A simple mechanism is preferable.
- Use of tools: Ideally, disassembly should take place without the use of tools (e.g. via simple push/pull processes).
- Repetition of parts: Part repetition should be minimized to enable quick and easy identification of parts at each stage of disassembly.
- Recognisability of disassembly points: Disassembly points are defined as those joints, which need to be disjointed so as to affect disassembly. Easy recognisability of such points is advisable especially in the case of complex product structures or products that incorporate snap fits as well as in the case of products that accumulate internal dirt during their useful life.
- Product structure: The simpler a product structure, the better it is from the disassembly point of view.
- Degree of accessibility of components and fasteners: Easy access is a prerequisite for quick and efficient disassembly operation.

Disassembly can be addressed to the product as a whole, or to a “selective disassembly” that allows reusable, non-recyclable and hazardous subassemblies to be selectively separated from recyclable ones [Gungor and Gupta, 1997].

Methods for the assessment of ‘disassemblability’ have been developed, based on diagrams (e.g. the ‘reverse fishbone diagram’ [Ishii and Lee, 1996]), Computer Aided Design (CAD) models (e.g. in [Ishikawa et al., 2000]) or rating systems (e.g. the assessment of ‘separability’ for some specific product categories based on ‘rules of thumbs’ from the experiences of manufacturers as in [Coulter et al., 1996])[25].

The EP1 already discussed these topics and a method for the assessment of ‘disassemblability’ has been proposed[26]. The method combined information about the product (BOM and disassembly scheme) with technical information about the disassembly (timing and/or costs for the disassembly). The method is affected by some limits as:

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[25] For further details on the ‘disassemblability’ see also: EP1 – Report n° 1 – Section 2.2.1 and Section 2.3.3.

[26] EP1 -Report n° 2 – Section 2.5.2.

- existence of various possible disassembly routes;
- information not always available, especially concerning the disassembly tree;
- need of tables (agreed among designers and recyclers) about the correlation of the time and costs for disassembly with ‘disassemblability’.

The ‘disassemblability’ has been also discussed within the IEC/TR 62635. However the TR does not introduce a method for the ‘disassemblability’, but it relates to the assumptions on the EoL scenario of the product, including:

- Amount of components that can will be manually separated;
- Efficiency of the mechanical separations of materials (e.g. through shredding).

This approach leaves large decisional freedom to the manufacturer, and it is flexible, applicable to every product category, and it implies communications between manufacturers and recyclers.

On the other side, Tables concerning the efficiency of the mechanical separations should be provided in order to simplify the assessment and to be in-line to the developments/progresses of the technologies.

A proposal of a method for the assessment of ‘disassemblability’ is illustrated in the present report, in Section 4.3.1.2.

1.3 Revision of the method for the calculation of the reusability, recyclability and recoverability rates

In Report n° 2 of EP1 project indices for the calculation of reusability, recyclability, recoverability rates have been developed. However the current development of the IEC/TR 62635 represented a fundamental progress in the standardisation process of methods for the calculation of these rates.

Therefore, it has been decided to revise the method of EP1 to be in line, with recommendation of IEC/TR 62635.

The revised method will be discussed in the next section and synthesized in Annex 1.

1.3.1 Revision of the method for the Reusability rate

The growing interest on re-use issues has been evidenced in various policy documents, including among the others, the recent recast of the WEEE Directive [EU, 2012], the Ecodesign Directive 125/2009/EC and the Roadmap on Resource Efficiency [EC, 2011].

Also the IEC/TR 62635 recognises that “reuse of parts often gives maximum environmental benefits. When a stable reuse system is in place and a market exists, reuse becomes economically viable”. However the IEC/TR 62635 includes the reuse among processes for recycling[27], and subsequently reusable parts contribute to the calculation of the recyclability/recoverability rates.

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[27] Recycling is defined as “*any operation by which waste products are reprocessed into products, product parts, materials, or substances whether for the original or other purposes. It includes the reuse, the reprocessing of material but does not include the energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations*” [IEC TR 62635-62650, 2012].

However, according to EP1, it is important to develop a dedicated index for reusability. Formulas froEP1 can be however revised and simplified to be in line

A revised “reusability rate” index can be defined as:

Formula 3

$$R_{use} = \frac{\sum_{i=1}^{N} m_{reuse,i}}{m} \cdot 100 \qquad [\%]$$

Where:

- R_{use} = Reusability rate [%];
- m = total product mass [kg];
- $m_{reuse,i}$ = mass of the i^{th} reusable part [kg];
- N = number of reusable parts.

A product’s part is assumed as “reusable” when the following two conditions are fulfilled [IEC/TR 62635, 2012]:

a) “*It is possible to separate the part from the product while maintaining the part or component’s functional integrity”.*

b) *The manufacturer can provide evidence that a commercial reuse and refurbishment system has been established for that part that take into consideration regulation and market expectations”.*

It is highlighted that the reusability index focuses only on post-consumer waste parts that are specifically designed to be reused in the remanufacturing of new products[28]. Other options of reuse (including second-hand markets) are here not considered[29].

The calculation of the Reusability rate can be done with specific calculation data-sheet[30] (as in Table 2).

Table 2 Calculation data-sheet for the Reusability rate

Product Details			
Product	**Mass (m) of the product [kg]**		
Reusable parts:			
Part	**Mass ($m_{reuse,i}$) [kg]**	**Detail of the disassembly of the part**	**Evidences for the reuse of the part**
Sum of reusable parts ($\Sigma m_{reuse,i}$) [kg]			
Reusabiliy rate (*Ruse*) [%]			

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[28] This includes preparing-for-reuse treatments (as checking, cleaning or repairing operations) [EU, 2008e], by which components of the product that have become waste are prepared so that they can be re-used in new products.

[29] See also EP1 – Report n° 2 – Section 2.2.4.

[30] Calculation sheet developed similarly to those introduced by the ISO 22628 and IEC 62635/62650.

1.3.2 Revision of the method for the Recyclability rate

In this revision an index for recyclability is proposed, accounting only for recyclable parts Some alternative recyclability indices have been discussed in Section 1.3.2.2, including an index extended to both reusable and recyclable parts (in line with IEC recommendations).

The Recyclability rate (R^*_{cyc}) can be defined as:

Formula 4
$$R^*_{cyc} = \frac{\sum_{i=1}^{P} \left(m_{recyc,i} \cdot RCR_i \right)}{m} \cdot 100 \qquad [\%]$$

Where:

- R^*_{cyc} = Recyclability rate [%];
- m = total product mass [kg];
- $m_{recyc,i}$ = mass of the ith recyclable part [kg];
- RCR_i =recycling rate of the ith part (estimated by the analyst performing the calculation on the basis of reference values and communications with recyclers; see below for details on the calculation) [%];
- P = number of recyclable parts.

Details for the calculation of the Recyclability Rate are illustrated in the following section.

1.3.2.1 EoL scenario and calculation of the Recyclability rate

Concerning the calculation of the recycling rate of each part (RCR_i), the calculation flow illustrated by the IEC/TR 62635 is adopted. In particular, the analyst performing the calculation has to define an EoL scenario identifying:

1) Parts for selective treatments. These could include:
    a. parts that have to be treated in line with legislative prescriptions (e.g. for the extraction of potentially hazardous substances)
    b. Parts containing other relevant materials (e.g. critical raw materials according to the EU classification[31]).
2) Parts for selective recycling[32]. These include parts with single recyclable materials and parts made by various recyclable materials, which are worth to be recycled separately. Conditions to be fulfilled are:
    a. The mass of the part and nature of embodied materials is such that there is an economical interest for dismantling.
    b. There is a specific EoL channel after dismantling for these materials with higher recycling rates compared to the results obtained after material separation.

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[31] http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm

[32] Note that the IEC only mentions "parts with single recyclable materials", while the sub-category was here enlarged including also parts with more recyclable materials.

3) Parts difficult to process[33].
4) Other parts for material separation. These include parts not in the previous bullet points, which are made of materials that can be separated by mechanical treatments (e.g. shredders) and recycled.

Finally, the analyst should define the corresponding recycling rate for parts belonging to the previous points. The IEC provides a preliminary list of recycling and recovery rates for some materials and parts for the European context. However, this is not exhaustive. For missing data, analyst should refer to other data sets[34] or available information from the literature and/or from recyclers[35].

The calculation of the Recyclability rate can be done with specific calculation data-sheet[36] (as in Table 3).

Table 3 Calculation data-sheet for the Recyclability rate

Product Details					
Product	**Mass (m) of the product [kg]**				
Parts for selective treatment:					
Part	**Recyclable materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
Parts for selective recycling:					
Part	**Recyclable materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
Parts difficult to process:					
Part	**Recyclable materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
Other parts (for material separation):					
Part	**Recyclable materials**	**Mass ($m_{recycl,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**($m_{recycl,i}$*RCR_i) [kg]**	**References/details for the (RCR)**
Sum of recyclable parts ($\Sigma\ m_{recyc,i}$ * RCR_i) [kg]					
Recyclability rate ($R^{*}cyc$) [%]					

Some additional considerations about the EoL are following discussed. In particular, the setting of this scenario is the basis for the calculation of the Recyclability rate. Differences in the EoL scenario can deeply influence the final results.

Analysts should take into consideration information from manufacturer and recyclers, and follow the calculation flow previously illustrated. On the other hand, the IEC/TR 62635 leaves a large freedom

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[33] Parts difficult to process include, for example, parts that generally are too large for the capacity of a shredder or are incompatible with the material sorting process at a particular facility even after size reduction.
[34] For example, the IEC provides a set of data of extra-EU context related to Korean studies.
[35] The availability of robust and representative data concerning the recycling rates of materials and parts is a key issue of the recyclability index. It is here noted that further research is needed on this subject, by developing more comprehensive and representative data sets.
[36] Calculation sheet developed similarly to those introduced by the ISO 22628 and the IEC 62635/62650.

for the setting of the scenario. Although this approach is suitable for a voluntary approach (including voluntary communication to the users or analysis of product for ecodesign purposes), it is not in line with European product policies, where the comparison of performance of products should be based on robust and consistent data.

Furthermore, it is noticed that in some cases, different EoL scenarios are possible, as representative of different EoL treatments and adopted technologies and procedures related for, example, to different areas of the EU. It his case it is recommended that possible alternative scenarios would be explored[37]. Finally and "average" EoL scenario should be set, taking into account different alternatives, weighted according to their relevance in the market. The relevance could be calculated as the mass fraction of waste products that undergo to the different typologies of existing facilities.

Finally, it should be also considered that the EoL scenarios can change over the time due to different reasons as: technological developments; changes in the market; policy requirements and constraints that drive the treatments. For these reasons, EoL scenario should also be 'dynamically' accounted in a future perspective way, by estimating possible future development scenarios.

For the setting of the Recyclability index, it is therefore recommended that:

- the EoL scenario (or scenarios) should be defined for each considered product groups, before the setting of potential product requirements.
- the EoL scenario should be set on the basis of a survey of the suitable EoL treatments and complemented by information from manufacturer and recyclers.
- when different scenarios are feasible, it should be defined and 'multiple-weighted' scenario, by taking into account different alternatives, weighted according to mass flows of waste that undergo to the different treatments (this is the "multiplicity" nature of EoL scenario).
- When there are evidence that the EoL scenario could be modified in the next future, possible alternative scenario/s should be estimated and investigated (this is the "dynamic" nature of EoL scenario).

Currently associations of recycling are working on the development of standards for the setting of requirements for the EoL handling, transportation, storage, sorting and treatments of WEEE household appliances. These standards could represent the reference for the setting of EoL scenarios of products and recycling rates of different materials and components. A standard concerning fridges and other appliances containing volatile fluorocarbons or volatile hydrocarbons has been published [CENELEC 50574, 2012]. It also noticed that, according to communication from association of recyclers, EoL standards concerning other WEEE are currently under development.

The setting of the EoL scenario can be supported by other ongoing initiatives concerning the collection and homogenisation of information from recyclers. For example, the WEEE Forum has designed software programmes and background data sources to calculate the recycling and recovery rates achieved by recyclers in the EU on the basis of the same data structure and an agreed classification of treatment technologies [WEEE Forum, 2012]. Harmonised data sets can be promoted across Europe in order to level the reporting of information.

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[37] On such purpose, information from recyclers

1.3.2.2 Possible alternative recyclability indices

An alternative index for recyclability (extended also to reusable parts) can be defined as:

Formula 5 $$R_{cyc} = \frac{\sum_{i=1}^{N} m_{reuse,i} + \sum_{j=1}^{P} \left(m_{recyc,j} \cdot RCR_j \right)}{m} \cdot 100 \qquad [\%]$$

Where:

- R_{cyc} = Extended Recyclability rate [%];
- m = total product mass [kg];
- $m_{reue,i}$ = mass of the i^th reusable part (calculated according to method set in section 1.3.1) [kg];
- $m_{recyc,j}$ = mass of the j^th part that is not reusable but it is recyclable [kg].
- RCR_j =recycling rate of the j^th recyclable part, estimated by the manufacturer on the basis of reference values and communications with recyclers; see below for details on the calculation) [%];
- N = number of reusable parts;
- P = number of recyclable part that are not reusable.

Note that Formula 5 is the analogous to that introduced by the IEC/TR 62635.

The introduced indexes for recyclability are linked as follows:

Formula 6 $$R_{cyc} = R_{use} + R^{*}_{cyc}$$

Where:

- R_{cyc} = Extended Recyclability rate (corresponding to the recyclability rate index introduced by the IEC/TR 62635) [%];
- R_{use} = Reusability rate (as defined in Formula 3) [%]
- R^{*}_{cyc} = Recyclability rate (as defined in Formula 4) [%]

A last consideration is about the focusing of the previous Recyclability rate index (of Formula 4) to certain materials or components. The advantage of the introduction of such indices is to focus on the flows of some materials whose recyclability is intended to be analyzed / improved. Some possible examples could be:

- Recyclability index of plastics: the calculation of the Recyclability rate is restricted only to plastics embodied in the product.
- Recyclability index of some critical raw materials: the index illustrates what percentage of the mass of a considered critical raw material in the product is potentially suitable for recycling[38].

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[38] This index could be referred to the overall amount of critical material contained in the product (in the denominator of the formula) or, alternatively, to the whole mass of the product. However, we assume the first option as the most relevant. In fact, it allows to measure what is the fraction of critical material that is potentially recyclable. Critical materials have, generally, a small mass and, therefore, could be negligible compared to the whole product mass.

1.3.3 Revision of the method for the Recoverability rate

The present section introduces an index for recoverability. The Recoverability rate is defined as[39]:

$$\textbf{\textit{Formula 7}} \qquad R_{\mathrm{cov}} = \frac{\sum_{i=1}^{Q} \left(m_{re\,\mathrm{cov},i} \cdot RVR_i \right)}{m} \cdot 100 \qquad [\%]$$

Where:

- R^*_{cov} = Recoverability rate [%];
- m = total product mass [kg];
- $m_{recov,i}$ = mass of the i^th recoverable part [kg];
- RVR_i = Recovery rate of the i^th part [%]
- Q = number of parts that are recoverable.

The calculation of the Recoverability rate needs the definition of an EoL scenario, analogous to that introduced for the recyclability rate. This scenario has to identify reusable / recyclable / energy recoverable parts. Energy recoverable parts are those with a feedstock energy, which can be recovered via incineration (e.g. plastics, cardboard. paper)[40].

Values of Recovery rates (RVR_i) for different parts should refer to representative data sets. Some exemplary data related to the European context are provided by the IEC/TR 62635. Data not available should refer to references and/or communications from recyclers.

The calculation of the Recoverability rate can be done with specific calculation data-sheet[41] (as in Table 4).

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[39] Formula 7 is in line with the recommendations of IEC TR 62635-62650 (see Section 1.2.1.3).

[40] Also other energy recovery options are suitable. For example, Report n° 2 of EP1 discussed other forms of energy recovery (e.g. pyrolysis, gasification, biodegradation). However their relevance for ErP is low for ERP and therefore they have been excluded from Formula 7.

[41] Calculation sheet developed similarly to those introduced by the ISO 22628 and the IEC 62635/62650.

Table 4 Calculation data-sheet for the Recoverability rate

Product Details					
Product	**Mass (m) of the product [kg]**				
Reusable Parts:					
Part		**Mass ($m_{reuse,i}$) [kg]**	**Evidences for the reuse of the part**		
Parts for selective treatment:					
Part	**Recoverable materials**	**Mass ($m_{recov,i}$) [kg]**	**Recovery rate (RVR_i) [%]**	**($m_{recov,i}$*RVR_i) [kg]**	**References/details for the (RVR)**
Parts for selective recovery:					
Part	**Recoverable materials**	**Mass ($m_{recov,i}$) [kg]**	**Recovery rate (RVR_i) [%]**	**($m_{recov,i}$*RVR_i) [kg]**	**References/details for the (RVR)**
Parts difficult to process:					
Part	**Recoverable materials**	**Mass ($m_{recov,i}$) [kg]**	**Recovery rate (RVR_i) [%]**	**($m_{recov,i}$*RVR_i) [kg]**	**References/details for the (RVR)**
Other parts (for mechanical separation):					
Part	**Recoverable materials**	**Mass ($m_{recov,i}$) [kg]**	**Recovery rate (RVR_i) [%]**	**($m_{recov,i}$*RVR_i) [kg]**	**References/details for the (RVR)**
Sum of recoverable parts ($\Sigma m_{reuse,i} + \Sigma m_{recov,i} * RCR_i$) [kg]					
Recoverability rate (*R cov*) [%]					

1.4 Verification of RRR rates

1.4.1 Verification of the Reusability rate

The verification of the reusability rate according to Formula 3 is based on the declaration of the analyst performing the calculation based on the specific calculation data-sheet previously provided. Calculation shall be supported by technical documentation, including:

- Mass and details of parts of the product that are reusable;
- Disassembly information, proving that binding systems are reversible and the reusable part/component can be accessed and disassembled;
- Provision of evidences that a commercial reuse and refurbishment system has been established. "*This can take the form of contracts with commercial partners, availability of refurbished parts in the marketplace, or other evidence that there is an established system*" [IEC/TR 62635, 2012].

1.4.2 Verification of the Recyclability rate

The verification of the "Recyclability rate" according to Formula 4 is based on the declaration of the analyst performing the calculation based on the specific calculation data-sheet previously provided. Calculation shall be supported by technical documentation, including:

- Bill of material of the product (evidencing mass, composition and disassembly information of parts for selective treatments, selective recovery, difficult to process and parts for material separation);
- Recycling rate (RCR) for each considered part (including the reference) related to the considered EoL scenario (developed according to procedure set in section 1.3.2).

The verification of the "Extended Recyclability rate" calculated according to Formula 5 is based on the declaration of the analyst performing the calculation supported by technical documentation, including:

- the documentation foreseen for the calculation of the "Recyclability rate" (see above);
- the documentation foreseen for the calculation of the reusability rate (see section 1.4.1).

1.4.3 Verification of the Recoverability rate

The verification of the "recoverability rate" according to Formula 7 is based on the declaration of the analyst performing the calculation based on the specific calculation data-sheet previously provided. Calculation shall be supported by technical documentation, including:

- Bill of material of the product (evidencing mass, composition and disassembly information of parts for selective treatments, selective recovery, difficult to process and parts for material separation);
- Recovery rate (RVR) for each considered part (including the reference) related to the considered EoL scenario.

1.5 Guidance documents on 'Reusability / Recyclability / Recoverability (RRR)'

Following the previous sections, guidance documents on the "Reusability / Recyclability / Recoverability (RRR)" have been developed. The documents are illustrated in Annex 1.

2. Revision of the method for the calculation of the ‘use of priority resources’

2.1 Introduction

The scope of the present chapter is the revision/refining of the method for the assessment and verification of the “use of priority resources” into products[42]. It is highlighted that the objective of the analysis is not the prioritisation of resources and the assessment of their relevance (as performed by other research projects[43]). The objective is instead the assessment of the environmental impacts of products to identify materials and parts that are relevant in a life-cycle perspective, with particular focus to the EoL.

The chapter will first perform a literature review to identify new references potentially relevant for the revision/refining. Afterwards modification of the method will be discussed.

The final outcome of the chapter is the drafting of guidance documents for the “use of priority resources”, as illustrated in Annex 2.

2.2 Literature review

Method developed in the previous chapter 1 focused on indices for RRR. These indices were in line with the current development of the scientific and technical literature, including the ongoing standardization processes. However, these indices are “mass based” meaning that they are focusing on the reuse/recycle/recovery of product’s parts with the largest mass.

This approach is targeted to the reduction of the overall amount of waste. On the other side it does not focus on the life-cycle environmental impacts of the materials. Components with a small mass are in fact generally negligible for the calculation of these indices, but could be relevant in terms of contribution to some environmental impacts.

The limits of mass based indicators for RRR have been already underlined by various authors in the scientific literature. For example, Atlee and Kirchain, 2006 observed that:

- mass is a weak indicator of environmental impact (e.g., impacts of toxicity)

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[42] The analysis of priority resources for the product’s life-cycle has been performed in the EP1 – Report n° 2 – Section 3, by introducing a set of environmental indices. These indices coupled the RRR indices previously introduced (EP1 - Report n° 2 – Section 2) with life cycle impacts of the products and impacts due to the reuse/recycling/recovery of materials. The RRR benefit indices represent the percentage of product life-cycle impacts that can be saved when the product if the product would be reused/recovered/recycled.

[43] See, for example, the European Commission “Defining Critical Raw Materials for the EU. A Report from the Raw Materials Supply Group ad hoc working group defining critical raw material” (http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm; access September 2012).

- the material “recovered” by the first recycler is landfilled by a subsequent processor
- the added cost of recovering additional material inhibits collection of end-of-life products
- the energy and environmental impact from recycling material can be greater than the impact of both disposal and the raw material it displaces.

Also the IEC recognized this potential limit, stating that “it is recognized that the calculation of recyclability rate based on the product mass approach is not the only the criteria to ensure a material efficient design (e.g. for rare materials)” [IEC/TR 62635, 2012]. This calculation may be for example complemented by the material depletion indices calculated according to LCA.

These concepts have been discussed in EP1[44] and also explored in Report n° 2[45].

It is therefore recognised the need of an advancement beyond the current state of art on mass based indices that combine life-cycle considerations with disassembly assessment.

However, an agreement in the scientific literature on how these considerations should be addressed is currently missing, as discussed in the EP1[46] . Furthermore, it is also missing an agreement in the LCA community on how the EoL of products should be modelled.

The next sections will firstly illustrate some recent developments in the modelling of EoL in the LCA. Afterwards, applications of life-cycle information for environmental-based RRR indices will be illustrated to identify priority materials and components of the product. Finally, potential benefits related to the improvement of disassembly routes for priority materials and components will be discussed.

2.2.1 Modelling of EoL within the LCA of a product

The following sections (sections 2.3 and following) discussed about the introduction of LCA considerations into the calculation of the RRR indices. However, the scientific community is currently debating on how reuse / recycling / recovery should be properly modelled into LCA and life-cycle based tools (as e.g. product labelling). According to recommendations of ISO 14044, reuse and recycling situations should be handled analogously to allocation problems. Special attention should be focused to their elaboration because [ISO 14044, 2006]:

- “*reuse and recycling […] may imply that the inputs and outputs associated with unit processes for extraction and processing of raw materials and final disposal of products are to be shared by more than one product system;*
- *reuse and recycling may change the inherent properties of materials in subsequent use;*
- *specific care should be taken when defining system boundary with regard to recovery processes*”.

Two approaches are suggested then [ISO 14044, 2006]:

a) “*A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the*

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[44] See Report n° 2 of EP1 – Chapter 3.

[45] Report n° 2 of the current project - Analysis of new product groups – Chapter 1.

recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials […].

b) *An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties*".

Although the contribution of ISO standards, the modelling of EoL in the LCA is currently debated[47].

Furthermore, it has been also evidenced the relevance of considering the down-cycling/degradation of the materials due to the recycling processes. However there is still no agreement on how this should included in the modelling.

The relevance of a down-cycling/degradation index in the calculation of the recyclability has been discussed in EP1[48]. The down-cycling/degradation index could be based on economic or physical variables, but currently the scientific community did not achieve a common understanding of the index. Recently the ISO ISO/DIS 14067 guidelines on the carbon footprint of products suggested, for the down-cycling index, the use of the ratio among the market values of recycled and virgin materials[49] [ISO/DIS 14067, 2012].

2.2.2 Integration of Life-cycle consideration into RRR indices

According to Huisman and Stevels "*the general focus on 'weight' can lead to incorrect conclusions regarding the initial 'environmental' goals of waste policies. 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*" [Huisman et al., 2003; Huisman and Stevels, 2004].

Huisman et al., 2003 therefore developed the concept of the "Quotes for environmentally WEighted RecyclabiliTY concept" (QWERTY) for calculating product recyclability on an environmental basis. In particular, the QUERTY is calculated in relationship with of two environmental elements [Stevels and Huisman, 2003][50]:

- "*A positive one: the environmental value of the materials which are replaced by the recycled materials in their second life (in this way the 'level of reapplication' is addressed as well.*
- *A negative one: all environmental loads due to collection (transport), treatment and materials upgrading including the material losses (waste to be discarded) in all these processes*".

The "*QWERTY scores in percentages are calculated on a scale comparing recovering all materials due to processing, the ideal situation) and the 'worst case' (for instance for WEEE dumping on a landfill). […] QWERTY gives a real environmental gain (for instance of recycling WEEE instead of dumping it on a landfill)*" [Stevels and Huisman, 2003].

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[46] See EP1 – Report n° 2 – Section 3.2

[47] On such purposes see for examples [Ekvall and Finnveden, 2000; Ekvall, 2000; Chen et al., 2010]

[48] EP1 - Report n° 1 - Section 2.2.2 and Report n° 2- Section 2.5.4.

[49] Note that in the ISO/DIS 14067 the down-cycling index is introduced in term of 'allocation factor' between the product system producing the waste and the product system using the waste after the recycling.

[50] For further detail on the QWERTY method, see also EP1-Report n° 1-Section 2.3.2.

The QWERTY methods, however, is based on the setting of two references scenarios, which however are geographical and temporal dependant. Furthermore, the environmental analysis is limited to the end-of life of the product[51] (considering only the recyclability of the product) and the "environmental gain" is based on the aggregated indicator 'Eco-Indicator'99' [Huisman et al., 2004].

Another environmental assessment method has been developed *Mathieux et al. 2008* for the assessment of the recoverability based on a comprehensive set of indicators including:

- A weight based Recovery Indicator
- An economic Recoverability Indicator,
- An Environmental Impact Recoverability Indicator.

The "Environmental Impact Recoverability Indicator" is structured as a ratio. The numerator "is the subtraction of environmental benefits, associated with the use of recycled materials/recovered energy in further product life cycles, from the environmental impact of all the processes" [*Mathieux et al. 2008*]. The denominator is the environmental impact according to a generic impact category I of the production/manufacture of the product.

Compared to the QWERTY, Mathieux et al. 2008 emphasises the necessity at the design stage of adopting a multi-criteria approach for the recoverability. For example, considering a scenario, the recoverability of a product can be satisfactory according to some criteria and not being acceptable for another one. Furthermore Mathieux et al. 2008 differentiate the recoverability, and the related environmental impacts, components by components on the basis of a product specific analysis.

Finally "Environmental Impact Recoverability Indicator" is referred only to the impacts of the production of the product, not considering the best/worst scenarios. On this point different approach are, however, feasible including the assessment of the whole life cycle impacts of the product.

Concerning environmental assessment methods it has been observed that these "can provide useful insights. Unfortunately, currently, they are not practically implementable by end-of-life electronics operators because of limited data availability and because they require detailed knowledge of product composition. As life-cycle data becomes more accessible and compositional databases become standardized, these weighting schemes should become more accessible. […] possibilities for impact weighting schemes would include embedded energy and toxicity" [Kirchain and Atlee, 2004]. It is also reminded that, in comparison with environmental weighted methods, also economic weighted indices have been developed and discussed as a progress to single mass based indices [Villalba et al., 2002; Kirchain and Atlee, 2004].

2.2.3 Influence of disassembly routes for recovery rates

The identification of priority resources (and priority components containing them) is a starting point for the improvement of the resource efficiency at the EoL of the product. In recovery rates of priority resources should be 'maximized', depending on the current technology level and economic constraints.

The influence of different disassembly and dismantling routes on recovery rates is key issue discussed by various authors. For example, Chancerel et al., 2009 observed that by adopting the shredding of

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[51] "The starting point of the QWERTY analysis is the point of disposal by consumers" [Huisman et al., 2004]

WEEE "despite the high recovery rates for mass relevant elements such as ferrous and copper, only a quarter of gold and palladium ends up in outputs from which precious metals may be recovered. This and a detailed insight in the process are relevant information for technical adaptations. A possible solution to reduce the losses of precious metals is to manually remove the relevant materials, for instance PCBs, to avoid shredding them and dispersing part of the metal content".

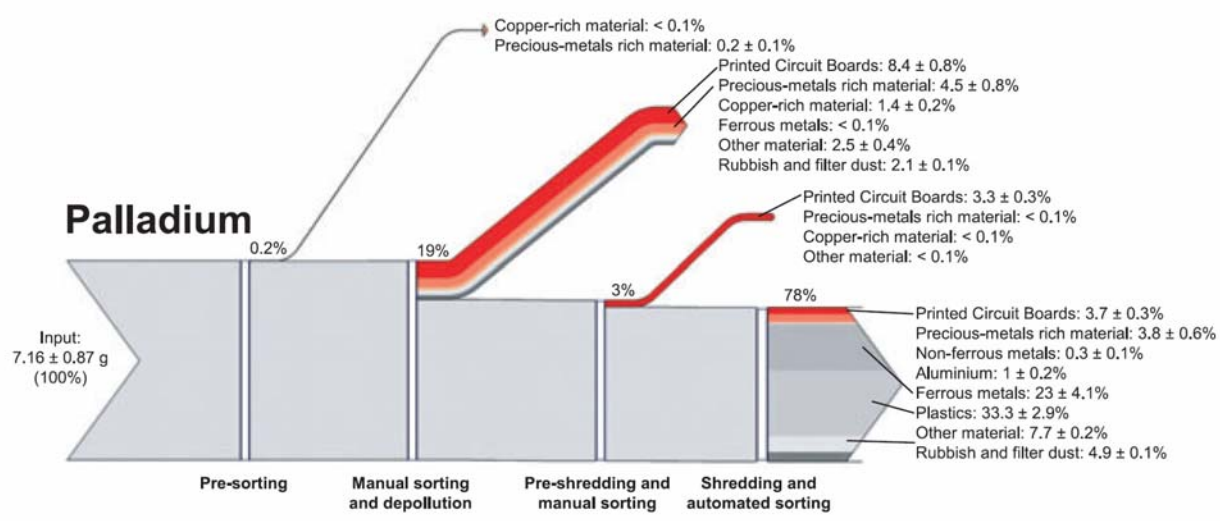

Figure 3 Flows of Palladium during the processing of one tonne of input WEEE [Chancerel et al., 2009]

Chancerel et al., 2009 analyzed the flow of some precious metals into WEEE, including some critical raw materials as Platinum Group Metals, and their recovery routes. It is estimated that a ton of treated WEEE contains on average 7.6 g of Palladium (Pd). According to Chancerel et al., 2009, the WEEEs undergo different processing as (Figure 3):

- Firstly a pre-sorting and a manual pre-sorting occur, during which "*visible hazardous and problematic components such as batteries, large metal sheets, and motors are manually removed from the end-of-life products. Furthermore the easy-to-remove PCBs are manually taken out*".
- Afterwards the waste are treated in a first shredder (pre-shredding) and "*a second manual sorting takes place to remove the remaining hazardous and disturbing components*".
- Finally, "*the rest of the scrap is shredded and sorted automatically*".

The fractions "Printed circuit boards" and "Precious-metals rich material" are sent to facilities for recovery of the precious metals. However, on average, only a minor portion of Pd "*is sent to a fraction where precious metals are recovered. The plastic output contains the biggest fraction of palladium (one third). Filter dust and rubbish (what was swept from the floor after the test) contain almost 5% of the palladium, which shows a tendency of palladium to be released into the air during shredding*" [Chancerel et al., 2009]. On such purpose, it has been noticed that palladium is largely affected by smashing, granulation and shredding as "*it is present in the form of ceramic compounds [….]. These are easily destructed and end up in dust fractions or stick to other metal fractions*" [Meskers et al., 2009]. Two phenomena became obvious [Chancerel et al., 2009]:

1. "*The low concentrations of precious metals in mass-relevant fractions (plastic and ferrous metals) generate high mass flows of precious metals in fractions that are not subsequently sold to processes for precious metals recovery.*

> *2. More shredding results in a decrease of the concentration of precious metals in PCBs. These two observations are supporting the hypothesis that an unselective fine shredding is causing unwanted losses of precious metals*".

Table 5 illustrates the mass fraction of precious metals that reach facilities where they can be potentially recovered.

Finally authors conclude that "*to reduce the losses of precious metals in pre-processing, in particular during shredding and subsequent sorting, the first and most straightforward approach is to reduce the quantity of precious metals entering the shredder. In this manner the distribution of precious metals over a large number of fractions during the automatic sorting will be minimized. This implies adjusting the manual sorting step at the beginning of the process to remove most precious metal-rich materials. This requires knowledge about the location of precious metals in WEEE, which is currently partially missing*" [Chancerel et al., 2009].

Table 5 Substance Flow Analysis of precious metal from WEEE [Chancerel et al., 2009]

	Recovery rate [%]			
	Cu	Ag	Au	Pd
Mass fraction potentially recoverable	60%	11.5%	25.6%	25.6%
Cu: Copper; Ag: silver; Au: gold; Pd: Palladium				

Similar results have been obtained by other authors. For example, Meskers et al., 2009 compared different scenarios of manual dismantling[52] and mechanical recovery[53.] It is possible to observe that manual dismantling allows always higher recovery rates (as described in Table 6, where for example the manual dismantling of some key components raises the recovery rate of Palladium from 28% to 66%). In the first step of manual dismantling good recoveries are already achieved (especially for gold), while a second dismantling step brings the recovery of silver (Ag), gold (Au), and palladium (Pd) above 90 % [Meskers et al., 2009].

Reasons for these losses are related to the mechanical treatments that smash the majority of contacts (containing large amounts of gold and silver) and ceramics (containing palladium), and dispersed in the dusts and in other shredding residues. Furthermore, hand-picking after shredding does not generally collect all PCB's parts. Similar losses occur also for other electronic components embodying other CRMs.

Table 6 Recovery of precious metals by different recovery routes [Meskers et al., 2009]

	Recovery [%]		
	Ag	Au	Pd
Mechanical process (	44%	51%	28%
Accurate manual dismantling	92%	97%	99%

Ag: silver; Au: gold; Pd: Palladium

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[52] Mechanical pre-treatment of WEEE with liberation and smashing of PCBs and subsequent hand-picking. PCBs pieces furthermore treated into granulators.

[53] Selective dismantling of main and secondary PCBs from personal computers.

Established the environmental convenience of a selective dismantling, some studies focused on what would be the optimal dismantling depth. For example Gmünder, 2007 analysed the treatment of WEEE in China. The results indicate that "*generally manual dismantling shows the highest eco-efficiency under Chinese settings. […] Focusing on the treatment of a low-grade Printed Wiring Board, it is also shown that the removal of big, precious metal-free components is worthwhile. This might also indicate that some of the other precious metals bearing fractions could be optimized by manual removal of similar components (precious metal-free Al, Cu and Ni parts)*" [Gmünder, 2007].

2.2.4 Conclusions from the literature review

Main conclusions that derive from the previous sections are:

- Mass-based indicators for RRR are limited. Introduction of environmental considerations in the formulas would be beneficial.
- Environmental considerations into RRR indices should include impacts and potential benefits from the reuse / recycling / recovery of materials.
- Environmental-based RRR indices should identify priority materials (and components) that are relevant not only in terms of mass but in terms of environmental impacts. These components therefore could be the target of potential requirements, including the improvement of the selective dismantling of the priority material / component.
- Life cycle information could support the development of Environmental based RRR indices. Some of these indices have been developed in the scientific literature, although there are not standardized examples (as for mass-based indices).
- Environmental-based RRR indices should also include considerations about down-cycling of recycled materials, to take into consideration the changes of their inherent properties.

2.3 Revision of the method for the calculation of RRR indices for the prioritisation of resources

Following the conclusions of the literature review, method of EP1 for the prioritisation of the resources will be revised in the next sections.

2.3.1 Revision of method for the Recyclability Benefit rate

The literature review illustrated some examples of modelling of EoL within the LCA methodology and their potential inclusion into environmental-based recyclability indices. In this paragraph the modelling of impacts of product's life-cycle including the recycling will be illustrated and a new recyclability index based on the environmental prioritisation of resources will be defined.

First of all, considering as baseline scenario that the product is disposed in a landfill at the EoL, the life cycle impacts can be calculated as following[54]:

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[54] This assumption is similar to the "worst scenario" introduced by [Huisman et al., 2003].

Formula 8 $$I_n = \sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot V_{n,i,j} + M_n + U_n + \sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot D_{n,i,j}$$

where:

- I_n = life-cycle impact of the product related to the nth impact category [unit][55];
- $m_{i,j}$ = mass of the ith material of the jth part[kg]
- $V_{n,i,j}$ = impact related to the 'nth' impact category for the production of the virgin material ith of the jth part [unit/kg];
- M_n = impact related to the nth impact category for the manufacturing of the product [unit];
- U_n = impact related to the nth impact category for the use of the product [unit];
- $D_{n,I,j}$ = impact related to the nth impact category for the disposal of the material ith of the jth part [unit/kg];
- P = number of parts of the product;
- N = number of materials in the jth part of the product.

Afterwards it is assumed that a part of the product will be recycled. Recycled materials will substitute primary materials (open loop recycling) considering a down-cycling index[56]. The life cycle impacts in this new recycling scenario can be calculated as following:

Formula 9 $$I'_n = \sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot V_{n,i,j} + M_n + U_n + \sum_{j=1}^{P}\sum_{i=1}^{N} m_{recy,i,j} \cdot \left(1 - RCR_{i,j}\right) \cdot D_{n,i,j} + \sum_{j=1}^{P}\sum_{i=1}^{N} m_{recy,i,j} \cdot RCR_{i,j} \cdot R_{n,i,j} - \sum_{j=1}^{P}\sum_{i=1}^{N} m_{recy,j,i} \cdot RCR_{i,j} \cdot k_i \cdot V_{n,i,j}$$

where[57]:

- I'_n = life-cycle impact of the product related to the nth impact category (recycling scenario) [unit];
- $m_{i,j}$ = mass of the ith material of the jth part [kg]
- $m_{recyc,i,j}$ = mass of the ith recyclable material of the jth part [kg]
- $V_{n,i,j}$ = impact related to the nth impact category for the production of the virgin material ith of the jth part [unit/kg];
- M_n = impact related to the nth impact category for the manufacturing of the product [unit];
- U_n = impact related to the nth impact category for the use of the product [unit];
- $D_{n,i,j}$ = impact related to the nth impact category for the disposal of the material ith of the jth part [unit/kg];
- $R_{n,i,j}$ = impact related to the nth impact category for the recycling of the material ith of the jth part[58] [unit/kg];

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[55] The unit of measure depends on the selected impact category. For example for the Global Warming Potential the unit of measure would be the [$kg_{CO2,eq.}$]

[56] The formula is structurally analogous to that proposed by the 'PAS2050 - Close loop approximation method' with in addition a down-cycling index as in the ISO/DIS 14067 to consider open loop recycling.

[57] Impacts for each term (i.e. V, M, U and D) include also impacts of transport during the phase.

- $RCR_{i,j}$ = Recycling rate of the material ith of the jth part (as calculated in Section 1.3.2) [%];
- k_i = downcycling index of the material ith (calculates as in Formula 10) [%];
- P = number of parts of the product;
- N = number of materials in the jth part of the product.

The down-cycling index "k" takes into consideration the loss of properties of the materials due to the recycling and can be calculated as[59]:

Formula 10 $$k_i = \frac{Q_r}{Q_p} \qquad [\%]$$

Where:

- k_i = down-cycling index of the ith material [%]
- Q_r = "quality" of the recycled ith material measured in terms of physical parameters (e.g. the tensile strength of the recycled material) or economic parameters (e.g. the value of the secondary material);
- Q_v = "quality" of the virgin ith material measured in terms of physical parameters (e.g. the tensile strength of the virgin material) or economic parameters (e.g. the value of primary material);

Afterwards, the benefits of the recycling scenario compared to the baseline scenario can be calculated as difference between Formula 8 and Formula 9:

Formula 11 $$I_n - I'_n = \sum_{j=1}^{P}\sum_{i=1}^{N} m_{recyc,i,j} \cdot RCR_{i,j} \cdot D_{n,i,j} + \sum_{j=1}^{P}\sum_{i=1}^{N} m_{recyc,i,j} \cdot RCR_{i,j} \cdot \left(k_i \cdot V_{n,i,j} - R_{n,i,j}\right)$$

Finally a Recyclability Benefit rate is defined as:

Formula 12 $$R'_{cyc,n} = \frac{\sum_{j=1}^{P}\sum_{i=1}^{N} m_{recyc,i,j} \cdot RCR_{i,j} \cdot D_{n,i,j} + \sum_{j=1}^{P}\sum_{i=1}^{N} m_{reyc,i,j} \cdot RCR_{i,j} \cdot \left(k_i \cdot V_{n,i,j} - R_{n,i,j}\right)}{\sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot V_{n,i,j} + M_n + U_n + \sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot D_{n,i,j}} \cdot 100$$

where:

- R'_{cyc} = Recyclability Benefit rate for the nth impact category [%];
- (other symbols as in Formula 8 and Formula 9).

It is important the selection of impact category for the calculation of Formula 12. The prioritisation of the resources can, in fact, substantially change depending on the considered impact category. For example, large amount of plastics and of some common metals (e.g. aluminium, steel) are generally relevant in terms of GWP or energy consumption; on the other side, precious metal and critical raw

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[58] It includes also impacts fro the sorting of materials (e.g. manual and/or mechanical sorting) and impacts for the processing of the secondary materials.

[59] The relevance of a down-cycling/degradation index in the calculation of the recyclability has bee discussed in EP1 – reports 1 and 2. Standard ISO 14044 suggested its introduction to consider the change of inherent properties of materials after recycling. The down-cycling/degradation index could be based on economic or physical variables, but currently the scientific community did not achieve a common understanding of the index.

materials, even if in small quantities, are generally very relevant for resource depletion (as for example the ‘Abiotic Resource Depletion Potential – elements’ [van Oers et al, 2002]. The selection of a set of representative indicators is therefore of outstanding relevance in the analysis, and has to be defined in line with the priorities and targets of the decision makers. Furthermore, a multi-criteria approach is preferable for a more comprehensive analysis.

Another important issue is related to the data availability. Concerning the terms in Formula 12 it can be observed that:

- Impacts due to virgin materials (V) can be generally found easily in the scientific literature and/or specialised environmental life cycle inventory databases. Some limitations occur for rare materials including some critical raw materials[60];
- Impacts due to manufacturing and use phase (M and U) can be calculated coupling information and estimations from the manufacturers with data from environmental life cycle inventory databases;
- Impacts due to the disposal of materials (D) are less common compared to the two categories of data above mentioned, but these can be derived from specialised environmental life cycle inventory databases;
- Impacts due to recycling of materials (R) are probably the most difficult data to obtain. Some data have been developed for common metals (although some of these data are aged). For some materials (as for example the majority of plastics and of critical raw materials) detailed inventory data are totally missing.
- The down-cycling index (k) can be referred to economic or physical data. Concerning the use of physical data very few references are available (method still under development). Concerning the use of economic data some information can be derived from references[61] or from private information from manufacturers/suppliers.
- The recycling rate of materials into product’s parts ($RCR_{i,j}$) has to be calculated according to the method illustrated in Section 1.3.2.

Some simplifications of Formula 12 are following suggested.

The down-cycling index is relevant because it improves the completeness of the calculation, taking into account factors that “depreciate” the quality of the materials after the recycling (including e.g. contamination among different materials and loss of physical performances due to the treatments). However, the availability of data for the calculation of the down-cycling index is still limited and potentially complex. A simplified approach can be adopted, considering: k = 1 (no loss of properties of materials due to recycling). The formula can be modified ad following:

Formula 13

$$R'_{cyc,n} = \frac{\sum_{j=1}^{P}\sum_{i=1}^{N} m_{recyc,i,j} \cdot RCR_{i,j} \cdot D_{n,i,j} + \sum_{j=1}^{P}\sum_{i=1}^{N} m_{recyc,i,j} \cdot RCR_{i,j} \cdot \left(V_{n,i,j} - R_{n,i,j}\right)}{\sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot V_{n,i,j} + M_n + U_n + \sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot D_{n,i,j}} \cdot 100$$

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[60] For example Report n° 2 – section 1.3.2 of the present project identified that life cycle inventory data are missing for six critical raw materials: Antimony, Beryllium, Germanium, Niobium, and Tungsten.

[61] See, for example, EP1 – Report n° 2 – Section 2.5.4.2.

The calculation of the Recyclability Benefit rate as introduced in Formula 13 can be done with specific calculation data-sheet (as in Table 7).

Table 7 Calculation data-sheet for the Recyclability Benefit rate

Product Details						
Product	**Mass (m) of the product [kg]**					
Impact category for the calculation						
Impact category (n)						
Unit of measure						
Recyclable parts:						
Recyclable part	**Mass ($m_{recyc,i}$) [kg]**	**Recycling rate (RCR_i) [%]**	**Impacts for the production of materials (V_i)**	**Impacts for the Disposal (D_i)**	**Impacts due to recycling (R_i)**	**$m_{recyc,i}$*RCR_i*(V_i+D_i-R_i)**
Life Cycle impacts of the product:						
A. Impacts due to the production of materials (Σm * $E_{v,n}$)			Details:			
B. Impacts due to the manufacturing of the product (M_n)			Details:			
C. Impacts due to the use of the product (U_n)			Details:			
D. Impacts due to the disposal of materials (Σm * $E_{d,n}$)			Details:			
Sum of the impacts (A +B+C+D)						
Sum of benefits due to recyclable parts $\Sigma m_{recyc,i}$*(RCR_i)*(V_i+D_i+R_i)						
Recyclability Benefit rate ($R'_{cyc,n}$) [%]						

Limitation in data availability, especially concerning the recycling of materials, can seriously limit the application of the Recyclability Benefit rate. As an additional simplification of the indices, impacts due to recycling could be neglected, assuming that impacts due to recycling are negligible compare to those related to the production of virgin materials[62]. Formula 12 could be therefore modified as following:

Formula 14

$$R''_{cyc,n} = \frac{\sum_{j=1}^{P}\sum_{i=1}^{N} m_{recyc,i,j} \cdot RCR_{i,j} \cdot D_{n,i,j} + \sum_{j=1}^{P}\sum_{i=1}^{N} m_{recyc,i,j} \cdot RCR_{i,j} \cdot \left(V_{n,i,j}\right)}{\sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot V_{n,i,j} + M_n + U_n + \sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot D_{n,i,j}} \cdot 100$$

Other simplifications can regard:

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[62] This assumption can be valid for some materials, as for example, some metals (e.g. aluminium, gold, and silver, platinum). For some materials and, in particular, in reference to some specific impact category, this assumption is however not valid. (for example marine ecotoxicity for steel recycling is higher than the ecotoxicity for the production of virgin steel).

- Benefits due to avoided disposal (D) are generally much lower compared to benefits due to the recycling (this is for example the case for the majority of metals and plastics). It could be assumed that 'D' is negligible compared to the other terms;
- The denominator of Formula 12 includes the whole life-cycle impacts of the product. However it implies a detailed study of the product in each life-cycle stage (especially the collection of information during the manufacturing and the estimation of the use phase). A simplified approach could refer only to the impacts for the production of virgin materials ($\sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot V_{n,i,j}$), not including the other factors. The advantage of such approach would be a much higher simplicity of calculation[63], but with a lower comprehensiveness.

By applying the above assumptions to Formula 12, it is introduced a simplified Recyclability Benefits rate (R'^{*}_{cyc}):

Formula 15 $$R'^{*}_{cyc,n} = \frac{\sum_{j=1}^{P}\sum_{i=1}^{N} m_{recyc,i,j} \cdot RCR_{i,j} \cdot \left(V_{n,i,j} - R_{n,i,j}\right)}{\sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot V_{n,i,j}} \cdot 100$$

where[64]:

- R'^{*}_{cyc} = simplified Recyclability Benefit rate for the nth impact category [%];
- (other symbols as in Formula 8 and Formula 9).

Formula 15 is largely approximated and its representativeness and applicability has to be verified case-by-case.

Finally it is highlighted that, mostly due to the availability of input data, the Recyclability benefit method here described is not directly implementable in product's requirements unless specific databases and tools would be developed. However, the method can be used for the analysis of EoL of products to identify product's 'hot spots' (key components and/or product parameters that are relevant in terms of relevant life-cycle impacts and/or improvement potential).

2.3.2 Revision of method for the Reusability Benefit rate

The reuse implies that the product (or some components) is re-used for the scope it was produced, after only minor treatments (e.g. quality checking, cleaning, repairing, etc.) that do not change the function of the product.

Following a substitution approach, it can be assumed that the reuse of a component would substitute the manufacturing of a new component. The benefits for the reuse of parts and component of a product can be calculated with a similar approach as that discussed for the Recyclability Benefit rate. The full or partial reuse of a product implies avoiding:

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[63] Note that in this simplified case it is not necessary to assess the impacts of the product in the whole life-cycle.

[64] Note that Formula 15 is equivalent to the Recyclability Benefits index as developed in developed in the EP1–Report n° 2 - Section 3.5.2.

- The impacts due to the production of raw materials embodied into the reusable product (or component);
- The impacts due to the manufacturing of the reusable product (or component);
- The impacts due to the disposal of the reusable product (or component).

In addition, the reuse of the product (or some of its components), can cause additional impacts for the treatments for reuse, including (list not exhaustive): cleaning, repairing, refurbishment / substitution, upgrading, etc.

The Reusability Benefit rate is therefore defined as:

Formula 16

$$R'_{use,n} = \frac{\sum_{j=1}^{K} m_{reuse,j} \cdot \left(V_{reuse,n,j} + M_{reuse,n,j} + D_{reuse,n,j} - T_{reuse,n,j}\right)}{\sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot V_{n,i,j} + M_n + U_n + \sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot D_{n,i,j}} \cdot 100$$

Where:

- $R'_{use,n}$ = Reusability Benefit rate for the n^{th} impact category [%]
- $m_{reuse,j}$ = mass of the j^{th} reusable part [kg]
- $V_{reuse,n,j}$ = impact related to the ‘n^{th}’ impact category for the production of virgin materials constituting the j^{th} reusable part [unit/kg];
- $M_{reuse,n,j}$ = impact related to the n^{th} impact category for the manufacturing of the j^{th} reusable part [unit];
- $D_{reuse,n,j}$ = impact related to the ‘n^{th}’ impact category for the disposal of the j^{th} reusable part [unit/kg];
- $T_{reuse,n,j}$ = impact related to the ‘n^{th}’ impact category for the treatments for reuse of the j^{th} reusable part [unit/kg];
- $m_{i,j}$ = mass of the i^{th} material of the j^{th} part of the product [kg]
- $V_{n,i,j}$ = impact related to the ‘n^{th}’ impact category for the production (as virgin) of the i^{th} material of the j^{th} part of the product [unit/kg];
- M_n = impact related to the n^{th} impact category for the manufacturing of the whole product [unit];
- U_n = impact related to the n^{th} impact category for the use of the product [unit];
- $D_{n,i,j}$ = impact related to the n^{th} impact category for the disposal of the i^{th} material of the j^{th} part of the product [unit/kg];
- K = number of reusable parts of the product;
- P = number of parts of the product;
- N = number of materials of the j^{th} part of the product.

The calculation of the Reusability Benefit rate can be done with specific calculation data-sheet (as in Table 8).

Compared to the Reusability Benefit index as illustrated in EP1, the index in Formula 16 is more comprehensive (including also the benefits due to the avoided manufacturing and disposal of reusable components), and the ratio refer to the whole life-cycle impacts of the product.

Furthermore, the index in Formula 16 does not include a computation of the 'disassemblability'. However, as discussed in Section 1.3.1, reusable parts have also to fulfil the following conditions [IEC/TR 62635, 2012]:

a) "*It is possible to separate the part from the product while maintaining the part or component's functional integrity"*.

b) *The manufacturer can provide evidence that a commercial reuse and refurbishment system has been established for that part that take into consideration regulation and market expectations"*.

In cases where the product is potentially reusable as whole, no disassembly occurs and, therefore, has only the previous condition 'b' has to be fulfilled.

Analogously to the Recyclability Benefit rate, also the Reusability Benefit rate as in Formula 16 can be simplified referring to the impacts due to the production of materials instead of the overall life-cycle impacts of the product:

Formula 17

$$R'_{use,n} = \frac{\sum_{j=1}^{K} m_{reuse,j} \cdot \left(V_{reuse,n,j} + M_{reuse,n,j} + D_{reuse,n,j} - T_{reuse,n,j}\right)}{\sum_{j=1}^{P} \sum_{i=1}^{N} m_{i,j} \cdot V_{n,i,j}} \cdot 100$$

Table 8 Calculation data-sheet for the Reusability Benefit rate

Product Details						
Product	**Mass (m) of the product [kg]**					
Impact category for the calculation						
Impact category (n)						
Unit of measure						
Reusable parts:						
Reusable part	**Mass ($m_{reuse,i}$) [kg]**	**Impacts for the production of materials (V_{Reuse})**	**Impacts for the Manufacturing (M_{Reuse})**	**Impacts for the Disposal (D_{Reuse})**	**Impacts for the treatments for reuse (T_{Reuse})**	**$m_{reuse,i}$*(V_i+M_i+D_i-T_i)**
Life Cycle impacts of the product:						
A. Impacts due to the production of materials ($\Sigma m * E_{v,n}$)		Details:				
B. Impacts due to the manufacturing of the product (M_n)		Details:				
C. Impacts due to the use of the product (U_n)		Details:				
D. Impacts due to the disposal of materials ($\Sigma m * E_{d,n}$)		Details:				
Sum of the impacts (A +B+C+D)						
Sum of benefits due to reusable parts $\Sigma m_{reuse,i}$* (V_i+M_i+D_i+T_i)						
Reusabiliy Benefit rate (*$R'_{use,n}$*) [%]						

2.3.3 Revision of method for the Recoverability Benefit rate

Recoverability includes the potential of a product to be reused, recycled and energy recovered. Prioritisation of resources for reuse and recycling has been already considered in the previous sections. The present section will consider therefore only the prioritisation for energy recovery, being that the prioritisation for reuse and recycling have been considered by indices introduced in the previous sections.

First of all, it is considered that energy recovery by incineration is the main energy recovery option for Energy Related Product (ErP). This also evidenced by the Ecodesign Directive that considers [EU, 2009b]:

> "*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*".

The present section will therefore illustrate a method for the assessment of the energy recovery by incineration. However, the method is potentially extensible also to other energy recovery options (e.g. gasification, pyrolysis, anaerobic digestion)[65].

The prioritisation of resources for energy recovery is based on the materials heating value, which represents their potential to release energy when incinerated. However, only a portion of the released

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[65] On such purposes, see the methodological discussion in EP1 – Report n° 2 – Section 3.4.2 and 3.4.3.

energy is potentially recoverable, depending on the efficiency "η"[66] of the energy conversion process in the incineration plant.

The energy recoverable via incineration is therefore:

$$\textbf{\textit{Formula 18}} \quad ER = ER_{el} + ER_{heat} = \left(\eta_{el} \cdot \sum_{i=1}^{Q} m_{recov,i} \cdot HV_i \right) + \left(\eta_{heat} \cdot \sum_{i=1}^{Q} m_{recov,i} \cdot HV_i \right)$$

Where:

- ER = Overall recoverable energy via incineration [MJ];
- ER_{el} = Energy recoverable for the production of electricity [MJ];
- ER_{heat} = Energy recoverable for the production of heat [MJ];
- $m_{recov,i}$ = mass of the i^{th} material recoverable [kg]
- HV_i = heating value of the i^{th} material recoverable[67] [MJ/kg];
- η_{el} = energy efficiency for the production of electricity[68] [%];
- η_{heat} = energy efficiency for the production of heat[69] [%];
- Q = number of energy recoverable materials.

Formula 18 represents the maximum energy recoverable, under the assumption that all the recoverable materials can be separated (by dismantling or shredding). Actually only a fraction is potentially separable, depending on the adopted technology. Analogously to the Recoverability rate in Section 1.3.3, Recovery rate (RVR) is introduced in Formula 18:

$$\textbf{\textit{Formula 19}} \quad ER = (ER_{el}) + (ER_{heat}) = \left(\eta_{el} \cdot \sum_{i=1}^{Q} RVR_i \cdot m_{recov,i} \cdot HV_i \right) + \left(\eta_{heat} \cdot \sum_{i=1}^{Q} RVR_i \cdot m_{recov,i} \cdot HV_i \right)$$

Where:

- RVR_i = Recovery rate of material i^{th} (calculated as discussed in Section 1.3.3) [%]

The environmental balance due to energy recovery can be calculated as the differences between the benefits due to the energy recovery and the impacts of the incineration. The benefits[70] are calculated assuming that heat and electricity produced by the incineration plant will substitute heat and electricity produced by normal plant.

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[66] The factor 'η' synthesizes the efficiency of the process of energy recovery and represents the percentage of the energy released that is usefully exploited for the production of electricity and heat.

[67] Two heating values are defined: the Lower Heating Values (LHV) and the Higher Heating Values (HHV). Data of LHV and HHV depend on the nature of the material and are reported in technical manuals. Both HHV and LHV can be used in Formula 18. However the use of the HHV is recommended (on this subject, see: EP1 – Report n° 1 – Section 2.5.1).

[68] The value of the energy efficiency factor for electricity depends on the characteristics of the incineration plant. On average a value of η_{el} =0.3 could be considered.

[69] The value of the energy efficiency factor for heat depends on the characteristics of the incineration plant. On average a value of η_{heat} =0.6 could be considered.

[70] It is underlined that the benefits have a very large variability depending on the technology mix of the considered region.

Formula 20 $$\mathrm{Recov}ery_n = Benefits_n - Incineration_n = (ER_{el} \cdot El_n) + (ER_{heat} \cdot Heat_n) - \sum_{i=1}^{Q} m_{re\mathrm{cov},i} \cdot I_{i,n}$$

Where:

- $\mathrm{Recovery}_\mathrm{n}$ = Environmental balance for the energy recovery (related to the nth impact category) [unit];
- $\mathrm{Benefits}_\mathrm{n}$ = Environmental benefits due to energy recovery for the nth impact category [unit];
- $\mathrm{Incineration}_\mathrm{n}$ = Environmental impacts due to incineration for the nth impact category [unit];
- ER_el = Energy recoverable for the production of electricity (see Formula 18) [MJ];
- $\mathrm{ER}_\mathrm{heat}$ = Energy recoverable for the production of heat (see Formula 18) [MJ];
- El_n = Average impact for the production of electricity for the nth impact category [unit/MJ];
- Heat_n = Average impact for the production of heat for the nth impact category [unit/MJ];
- $\mathrm{m}_\mathrm{recov,i}$ = mass of the ith material recoverable [kg];
- $\mathrm{I}_\mathrm{i,n}$ = Impact of the incineration of material ith for the nth impact category [unit/kg];
- Q = number of energy recoverable materials.

Concerning environmental data to be applied in Formula 20:

- Impacts due to incineration of materials ($\mathrm{I}_\mathrm{i,n}$) can be derived from life-cycle inventory databases[71];
- Impacts due to average production of electricity (El_n) are related to the considered geographical context for the analysis. Assuming to refer to the average European context, data related to the European energy mix can be used[72];
- Impacts due to average production of heat (Heat_n) are related to the considered average conventional plant for the production of heat. For example data about an average European boiler can be considered[73].

Finally the Energy Recoverability Benefit rate can be defined as the ratio between the environmental balance of the energy recovery (Formula 20) and the overall life cycle impacts:

Formula 21 $$ER'_{\mathrm{cov},n} = \frac{\left(\eta_{el} \cdot \sum_{i=1}^{Q} RVR_i \cdot m_{re\mathrm{cov},i} \cdot HV_i\right) \cdot El_n + \left(\eta_{heat} \cdot \sum_{i=1}^{Q} RVR_i \cdot m_{re\mathrm{cov},i} \cdot HV_i\right) \cdot Heat_n - \sum_{i=1}^{Q} m_{re\mathrm{cov},i} \cdot I_{i,n}}{\sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot V_{n,i,j} + M_n + U_n + \sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot D_{n,i,j}} \cdot 100$$

Where:

- $\mathrm{ER'}_\mathrm{cov,n}$ = Energy Recoverability Benefit rate for the nth impact category [%].

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[71] For example the ELCD database reports the impacts of various process of incineration [ELCD, 2012]

[72] Average European data can be referred to the module ‘Electricity Mix AC; consumption mix, at consumer; 1kV - 60kV’ of ELCD database [ELCD, 2012]

[73] Average European data can be referred to the module ‘Heat; residential heating systems from natural gas, condensing boiler, max. heat output 14,9 kW; consumption mix, at consumer; at a temperature level of 55°C’ of ELCD database [ELCD, 2012].

- (all other symbols as in Formula 12, Formula 19 and Formula 20)

The calculation of the Energy Recoverability Benefit rate can be done with specific calculation data-sheet (as in Table 9).

Compared to the Energy Recoverability index introduced in EP1[74], the index in Formula 21 includes also the benefits related to the energy recovery as heat and it relates to the whole life-cycle impacts of the product.

Analogously to the Recyclability Benefit rate and the Reusability Benefit rate, also the Energy Recoverability Benefit rate as in Formula 21 can be simplified considering the impacts due to the production of materials instead of the overall life-cycle impacts of the product:

Formula 22

$$ER'_{\mathrm{cov},n} = \frac{\left(\eta_{el} \cdot \sum_{i=1}^{Q} RVR_i \cdot m_{re\mathrm{cov},i} \cdot HV_i\right) \cdot El_n + \left(\eta_{heat} \cdot \sum_{i=1}^{Q} RVR_i \cdot m_{re\mathrm{cov},i} \cdot HV_i\right) \cdot Heat_n - \sum_{i=1}^{Q} m_{re\mathrm{cov},i} \cdot I_{i,n}}{\sum_{j=1}^{P} \sum_{i=1}^{N} m_{i,j} \cdot V_{n,i,j}} \cdot 100$$

Table 9 Calculation data-sheet for the Energy Recoverability Benefit rate

Product Details	
Product	**Mass (m) of the product [kg]**

Impact category for the calculation	
Impact category (n)	
Unit of measure	

Energy Recoverable parts:											
Energy Recoverable part	**Material**	**Mass ($m_{recov,i}$) [kg]**	**Recovery rate (RVR_i) [%]**	**Heating Value (HV_i) [MJ/kg]**	**efficiency for electricity (η_{el})**	**efficiency for heat (η_{heat})**	**Impact for electricity (El_n) [unit/MJ]**	**Impact for heat ($Heat_n$) [unit/MJ]**	**Impact for incineration ($I_{n,i}$) [unit/kg]**	**($m_{recov,i}$*RVR_i*HV_i)*(η_{el}*El_n + η_{heat}*$Heat_n$) - $m_{recov,i}$*$I_{n,i}$)**	**References and details**

Life Cycle impacts of the product:		
A. Impacts due to the production of materials ($\Sigma m * E_{v,n}$) [unit]		Details:
B. Impacts due to the manufacturing of the product (M_n) [unit]		Details:
C. Impacts due to the use of the product (U_n) [unit]		Details:
D. Impacts due to the disposal of materials ($\Sigma m * E_{d,n}$) [unit]		Details:
Sum of the impacts (A +B+C+D)		
Sum of benefits due to energy recoverable parts: $\Sigma(m_{recov,i}$*RVR_i*$HV_i)$*(η_{el}*El_n + η_{heat}*$Heat_n$) - $\Sigma m_{recov,i}$*$I_{n,i}$) [unit]		
Energy Recoverability Benefit rate (*$R'_{cov,n}$*) [%]		

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[74] EP1 – Report n° 2 – Section 3.5.3.

2.4 Verification of RRR rates

2.4.1 Verification of the Recyclability Benefit rate

The verification of the “Recyclability Benefit rate” according to Formula 12 is based on the declaration of the analyst performing the calculation, based on provided data-sheet. Calculation shall be supported by technical documentation, including:

- Bill of material of the product (evidencing parts that are potentially recyclable);
- (if considered) the values and references for the down-cycling index (k) for each considered material;
- Recycling rate (RCR) for each recyclable part (including the reference) estimated according to the method developed for the recyclability rate (see section 1.3.2).
- References used for the impacts of production of virgin materials (V), recycling of materials (R), and disposal of materials into landfill (D);
- Data and references used for the calculation of impacts due to the manufacturing of the product (M);
- Data and references used for the calculation of impacts due to the use phase of the product (U).

2.4.2 Verification of the Reusability Benefit rate

The verification of the “Reusability Benefit rate” according to Formula 16 is based on the declaration of the analyst performing the calculation based on provided data-sheet. Calculation shall be, supported by technical documentation, including:

- Bill of material of the product (evidencing parts that are potentially reusable);
- (in cases where the product is not reusable as whole) Disassembly information, proving that binding systems are reversible and the reusable part can be accessed and disassembled without damaging;
- Provision of evidences that a commercial reuse and refurbishment system has been established. “*This can take the form of contracts with commercial partners, availability of refurbished parts in the marketplace, or other evidence that there is an established system*” [IEC/TR 62635, 2012].
- References used for the impacts of production of virgin materials (V) and disposal of materials into landfill (D);
- Data and references used for the calculation of impacts due to the manufacturing of the product (M) and use phase of the product (U);
- Data and references used for the calculation of the impacts due to the treatment for reuse (T).

2.4.3 Verification of the Recoverability Benefit rate

The verification of the "Recoverability Benefit rate" according to Formula 22 is based on the declaration of the analyst performing the calculation based on provided data-sheet. Calculation shall be supported by technical documentation, including:

- Bill of material of the product (evidencing parts/components that are potentially recoverable);
- Recovery rate (RCR) for each recoverable part (including the reference) estimated according to the method developed for the recoverability rate (see section 1.3.3).
- References used for the heating values (HV) used for each recoverable materials;
- References used for the impacts of the incineration of recoverable materials (I);
- Reference used for the energy efficiency for the production of electricity (η_{el}) and the energy efficiency for the production of the heat (η_{heat});
- References used for the calculation of the average impact for the production of electricity (El);
- References used for the calculation of the average impact for the production of heat (Heat);
- Data and references used for the calculation of impacts due to the manufacturing of the product (M);
- Data and references used for the calculation of impacts due to the use phase of the product (U)
- References used for the impacts of production of virgin materials (V) and disposal of materials into landfill (D);
- Data and references used for the calculation of impacts due to the manufacturing of the product (M);
- Data and references used for the calculation of impacts due to the use phase of the product (U).

2.5 Guidance documents on 'Reusability / Recyclability / Recoverability Benefits' rates

Following the previous sections, guidance documents on the "Reusability / Recyclability / Recoverability (RRR) Benefit" rates have been developed. The documents are illustrated in Annex 2.

3. Revision of the method for the calculation of the ‘recycled content’

3.1 Introduction

The scope of the present chapter is the revision/refining of the method developed in EP1[75] for the calculation and verification of the “recycled content” of product.

The chapter will first perform a literature review to identify new references potentially relevant for the revision/refining. Afterwards modification of the method will be discussed.

The final outcome of the chapter is the drafting of a guidance document for the recycled content, as illustrated in Annex 3.

3.2 Literature review

3.2.1 Method for the calculation of the recycled content

Concerning the method for the calculation of the recycled content, the literature review did not evidenced any relevant modify compared to the analysis of EP1.

It is noticed a general agreement on the method for the calculation of the recycled content. In particular the ISO 14021 [ISO, 1999] and the EN 15343 [CEN 15343, 2007] calculate the recycled content as following:

Formula 23 $$\mathrm{Re}\,cycled\ content\quad (r_{Cont}) = \frac{Mass\ of\ recycled\ material\ in\ the\ product}{Total\ mass\ of\ the\ product}\cdot 100\qquad [\%]$$

As discussed in the EP1[76], differences can be observed concerning the typologies of waste input included in the analysis (e.g. ‘pre-consumers’ waste, ‘post-consumers’ waste or both) and typology of materials considered (recycled content related to all the materials or limited to some specific materials as, for example, plastics or glass).

It is also noticed that some authors propose some variations of the previous formula. For example, it is suggested introducing an additional percentage yield factor that “reflects the % decrease in mass of the input during the manufacturing process due to wastage” [WRAP, 2008]. However this factor makes the calculation more difficult, also due to data availability. It is therefore assumed to keep the original method as standardised by the ISO.

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[75] The method for the measurement of the recycled content of product, (developed in EP1 – Report n° 2 – Section 4) is based on a mass-based index, developed on the basis of recycled materials that is used to manufacture the product.

[76] See EP1: ‘Report n° 1 - Chapter 3’ and ‘Report n° 2 – Chapter 4’.

Also concerning the verification process there is a substantial agreement among standards [ISO, 1999; CEN 15343, 2007] and labelling/certification schemes [EU, 2009; IEEE, 2009; SCS, 2011]. Being not possible a direct instrumental measurement, the recycled content of a product is verified by the declaration of the analyst performing the calculation supported by sufficient technical documentation (including declarations of the suppliers). However, the standards and the certification/labelling systems prescribe different typologies of documentation that is required.

For example the EN15343 [CEN 15343, 2007] states 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 will be needed to calculate the recycled content*". Concerning the traceability, the EN 15343 establishes that the supplier of the recyclate shall provide data for: "control of input material" (carried out according to EN 15347 [CEN 15347, 2007]), "control of the recyclate production process" and "plastics recyclate characterisation" (following the relevant standards) [CEN 15343, 2007].

Concerning the "control of the recyclate production process" the standard further establishes that the "*control of the recycling process is required to guarantee proper functioning in line with good manufacturing practice. This will include:*

- *recording the process variables;*
- *quality control testing of the products delivered by the process;*
- *batch identification of the output.*

For specific applications, challenge tests will be required to demonstrate that the process is capable of delivering products that meet the requirements of the application" [CEN 15343, 2007].

Verification becomes therefore a key issue of recycled content claims. Prescriptions of standard EN15343 can be the basis for the verification. On such purpose some authors also state that "manufacturer should ensure that any data in support of the declaration can be made available to an independent verifier or challenger. Declaration of recycled content should be included on standard product data sheets alongside other environmental and technical data. It is anticipated that certification bodies will be able to offer a certification service based on this calculation to verify independently that the claims are correct" [WRAP, 2008]

EP1 already discussed the necessary documentation to support claims on the recycled content[77].

Further details about the verification process and required information will be discussed in Section 3.2.3 concerning a standard on the 'recycled content', which has been recently published and has been not part of the literature review of the EP1.

3.2.2 Materials suitable for recycled content requirements

The EP1[78] introduced some references about potential target materials for recycled content requirements. For example, the ILCD Handbook states that [EC, 2010]:

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[77] See EP1: 'Report n° 1 - section 3.1' and 'Report n° 2 – section 4.4'.

[78] For further details, see EP1: Report n° 2 – Sections 4.3 and 4.4.

"*Low price of the secondary good (compared to the one of the primary produced good) indicates at least one of the following:*

- *there is a high recycling rate for some reason that provides an excess of the secondary good, and/or*
- *the achieved technical quality of the secondary good is low […] and/or*
- *there is a limited demand for the secondary good for other reasons (e.g. "waste-image" perception, hygiene legislation, etc.).*

If the amount that is available via reuse/recycling/recovery is higher then the demand, and the market value is accordingly below zero, the main necessity is to increase the demand for the secondary good (i.e. recycled content) and/or its technical quality […], but not the simple recycling rate […]".

Therefore, in order to push for the recycling of secondary materials having a low price (compared to virgin one) by for example introducing minimum recycled content thresholds. Such requirement should increase the demand of the secondary material.

Recycled content requirements can be synergic with recyclability requirements. For example, the improvement of disassemblability of some materials can contribute to increase their technical quality when recycled (due e.g. to a lower content of contaminants).

On such purpose it has noticed in EP1 that pre-consumers materials (e.g. material diverted from the waste stream during the manufacturing process) have generally a higher 'quality' in terms of homogeneity and purity, which increase their 'attractiveness' for recycling.

On the other side, recycling of post-consumer waste needs to be encouraged because post-comers materials are those affected by lager downcycling when recycled.

According to previous considerations, requirements on recycled content should mainly focus on post-consumer plastics and technical glass[79, 80]. At the current stage, requirements on the recycled content of such materials could contribute to boost their recycling, in order to stimulate a market of post-consumer recycled materials.

Examples of requirements on the recycled content of plastics have been for example introduced by the EU Ecolabel for notebook and personal computers[81].

3.2.3 The standard SCS 2011

The "Recycled Content Standard" of the Californian "Scientific Certification System" represents one of the first worldwide examples of environmental certification systems for recycled content claims [SCS, 2011].

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[79] It is noted that metals are already recycled to high rates thanks to their high value and the fact that they do not lose their properties through recycling.

[80] It is here intended as "technical glass" the glass of higher quality used for some technical applications into products (e.g. the screen of televisions, framework of lamps, or glass insert into washing machines or oven). Technical glass is generally characterized by higher quality compared, for example, to glass used for packaging.

[81] For example, EU criteria for notebook and personal computer establish that "he external plastic case of the system unit, monitor and keyboard shall have a post-consumer recycled content of not less than 10 % by mass" [EC, 2011e; EC, 2011f]

The purpose of the Standard is to "describe the requirements for third-party substantiation of the recycled content claims asserted by companies with regard to specific products" [SCS, 2011]. In particular the Standard provides "the requirements for qualifying and quantifying materials that serve as the basis for recycled content claims asserted by companies about products". The main adopted definitions and formulas are referred to the [ISO 14021:1999].

The standard assumes that the calculations and the claim refer to a Data Review Period (12-month period). This is typically comprised of the four most recent consecutive quarters.

Section 5 of the Standard [SCS, 2011] describes general conformance requirements for manufacturers.

First of all, it is underlined the relevance of the traceability or "the ability to trace materials and/or products sequentially throughout a manufacturing process and/or value chain in a way that is verifiable through objective evidence. "Traceability practices shall be employed by the manufacturer to ensure that products conforming to the Standard can have their material basis tracked back to the origin of all input materials. […] Practices shall be employed by the manufacturer to assure that products" are traceable.

The required documentations to support the claims of recycled content are related to the 'material qualification' and 'material quantification'.

Concerning the 'material qualification' it is stated that [SCS, 2011]:

- "The manufacturer shall provide a diagram and description of the manufacturing process showing all inputs of materials, all internal material flows (e.g., reuse or recycling of scrap) and all material outputs";
- "The manufacturer shall provide letters of affidavit[82] from each supplier of recycled material. The affidavit shall include information about the material composition, the material source(s), and processes occurring before reaching the manufacturer. The affidavit shall be signed by a duly authorized representative of the supplier company";
- "The manufacturer shall maintain records that demonstrate it has an active business relationship with each supplier of recycled material. These records might include invoices, bills of lading, or delivery receipts". Furthermore the manufacturer "shall maintain records of current suppliers and supplies".

Concerning the 'material quantification is stated that [SCS, 2011]:

- "Summary data containing the amount of recycled material obtained from each supplier of material […] shall be maintained and provided […]. Data should be provided on a dry weight measurement basis";
- "The manufacturer shall provide the formulation/composition of each of the finished products […]. These data shall include a list of all components, the amount […] of each component in the finished product, and the percentage of each component in the finished product";
- "For the material used in each product […], the manufacturer shall maintain records […] of the amounts and units of measurement for scrap generated and reused and the waste generated and sent to disposal, incineration, or additional recycling";

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[82] Declaration of the manufacturer.

- "The manufacturer shall provide gross production totals (numbers of units and weight of units)";
- "The manufacturer shall maintain inventory records of the amount and types of recycled materials used in the product for the previous four consecutive quarters preceding the certification assessment".

The documentations above illustrated can be an interesting example of documentation to support potential ecodesign requirements on the recycled content of the products.

3.3 Revision of the method for the calculation of the recycled content

3.3.1 Post-consumer recycled content index

According to the previous section 3.2, the method for the calculation of the recycled content is[83]:

$$\textbf{\textit{Formula 24}} \qquad R_{Content} = \frac{\sum_{i=1}^{K} m_i \cdot r_{Cont,i.}}{m} \cdot 100 \quad [\%]$$

- $R_{Content}$ = Post-consumers recycled content of the product [%];
- $m_{i.}$ = mass of the i^{th} material of the product having a recycled content[kg];
- $r_{Cont,i}$ = post-consumers recycled content of the i^{th} material [%] (calculated according to Formula 23).
- $m_.$ = overall mass of the product [kg];
- K = number of materials of the product having a post-consumer recycled content.

3.3.2 Recycled Content Benefit index

Analogously to the RRR benefit indices introduced in the Chapter 2, a Recycled content benefit index is here defined.

The environmental benefits related to the use of post-consumer recycled materials for the manufacturing of the product are:

$$\textbf{\textit{Formula 25}} \qquad Benefits_n = \sum_{i=1}^{K} m_i \cdot r_{cont,i} \cdot \left(V_{n,i} - R_{n,i}\right)$$

Where:

- $Benefits_n$ = Environmental benefits for the n^{th} impact category related to the use of post-consumer recycled materials [unit];

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[83] The method for the calculation of the recycled content is the same developed in the EP1 – Section 4.2.

- m_i = mass of the i^{th} part of the product having a post-consumer recycled content [kg];
- $r_{Cont,i}$ = post-consumers recycled content of the i^{th} part [%];
- $V_{n,i}$ = Environmental impact for the n^{th} impact category for the production as virgin of the i^{th} material [unit/kg];
- $R_{n,i}$ = Environmental impact for the n^{th} impact category for the recycling of the i^{th} material [unit/kg];
- K = Number of parts of the product having a post-consumer recycled content.

The Recycled Content Benefits index is therefore defined as:

Formula 26
$$RCB_n = \frac{Benenfts_n}{Life\ cycle\ impacts_n} = \frac{\sum_{i=1}^{K} m_i \cdot r_{cont,i} \cdot \left(V_{n,i} - R_{n,i}\right)}{\sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot V_{n,i,j} + M_n + U_n + \sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot D_{n,i,j}} \cdot 100$$

- RCB_n = Recycled Content Benefits index of the product related to the n^{th} impact category [%];
- m_i = mass of the i^{th} part of the product having a post-consumer recycled content [kg];
- $r_{cont,i}$ = post-consumers recycled content of the i^{th} part [%];
- $V_{n,i}$ = Environmental impact for the n^{th} impact category for the production as virgin of the i^{th} material [unit/kg];
- $R_{n,i}$ = Environmental impact for the n^{th} impact category for the recycling of the i^{th} material [unit/kg];
- $m_{i,j}$ = mass of the i^{th} material of the j^{th} part [kg];
- $V_{n,i,j}$ = impact related to the n^{th} impact category for the production of the virgin material i^{th} of the j^{th} part [unit/kg];
- M_n = impact related to the n^{th} impact category for the manufacturing of the product [unit];
- U_n = impact related to the n^{th} impact category for the use of the product [unit];
- $D_{n,i,j}$ = impact related to the n^{th} impact category for the disposal of the material i^{th} of the j^{th} part [unit/kg];
- K = Number of parts of the product having a post-consumer recycled content;
- P = number of parts of the product;
- N = number of materials in the j^{th} part of the product.

3.4 Verification of 'recycled content' indices

The EP1 concluded that "The verification of the recycled content claims is based on self-declaration of the analyst performing the calculation supported by technical documentation e.g. materials flow declaration or chain of custody declaration from manufacturer and its suppliers. The documentation has to be available before the product is put into the market and provided on request (e.g. a check by the competent body)" [Ardente et al, 2011].

Following the previous analysis, relevant documentation to be provided could include[84]:

- documented practises that assure that the traceability of the product;
- records that demonstrate an active business relationship with each supplier of recycled material;
- inventory records of the amount and types of recycled materials used in the product for the previous four consecutive quarters preceding the declaration.

Concerning the verification of the "Recycled Content Benefits index" relevant documentation to be provided includes that foreseen for the "recycled content" claims and, in addition:

- References used for the impacts of production of virgin materials (V), recycling of materials (R), and disposal of materials into landfill (D);
- Data and references used for the calculation of impacts due to the manufacturing (M) and use (U) of the product.

3.5 Guidance document on 'Recycled content'

Following the previous sections, a guidance document on the "Recycled content" has been developed. The document is illustrated in Annex 3.

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[84] Similar documentation for verification has been proposed by the [CEN 15343, 2007] and the [SCS, 2011] (see Section 3.2)

4. Revision of the method for the ‘Use of ‘hazardous substances’

4.1 Introduction

The scope of the present chapter is the revision of the method developed in EP1[85] concerning the use of hazardous substances into ErP.

The chapter will first perform a literature review to identify new references relevant for the revision/refining. Afterwards modifications of the method will be discussed.

The final outcome of the chapter is the drafting of a guidance document for the use of hazardous substances, as illustrated in Annex 4.

4.2 Literature review

The following sections analyze legislation, reports and papers, not considered into EP1 or recent advancements/revisions, which can contribute to the revision process of the method for the ‘use of hazardous substance’.

4.2.1 The recast of the RoHS Directive

In July 2011 it has been published the Directive 2011/65/EU [EU, 2011], the recast of the previous RoHS Directive. The Directive did not change the list of six restricted substances nor the maximum allowed concentration[86].

The scope of the Directive has been instead extended to all EEE, including medical devices, monitoring and control instruments, and EEE products not covered under the previous ten categories (the eleventh general category of “Other EEE not covered by any of the categories above”), unless specifically excluded. Furthermore, it is specified that the provisions of the RoHS Directive applies to the EEE (including cables) and also to spare parts for its repair, its reuse, updating of its functionalities or upgrading of its capacity

The conformity to the RoHS Directive is based on a “declaration of conformity” draw up by the manufacturer. It is stated that (art. 7) [EU, 2011]: “manufacturers draw up the required technical documentation and carry out the internal production control procedure in line with module A of Annex

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[85] The method for the assessment of hazardous substances, (developed in EP1 – Report n° 2 – Section 6) is based on a multi-criteria life-cycle approach and it aims at assessing how the content of hazardous substances can affect the ecoprofile of a case-study product.

[86] Directive 2011/65/EU – Annex II - maximum concentration values tolerated by weight in homogeneous materials: Lead (0.1%); Mercury (0.1%); Cadmium (0.01%); Hexavalent chromium (0.1%); Polybrominated biphenyls (PBB) (0.1%); Polybrominated diphenyl ethers (PBDE) (0.1%).

II to Decision No 768/2008/EC". This decision states that the manufacturers should provide, among the others, the following information [EU, 2008]:

- "a general description of the product,
- conceptual design and manufacturing drawings and schemes of components, sub-assemblies, circuits, etc.
- a list of the harmonised standards and/or other relevant technical specifications […]
- results of design calculations made, examinations carried out, etc., and
- test reports".

Furthermore, manufacturers shall keep a register of non-conforming EEE and product recalls, and shall provide (in the product or its packaging) the contacts at which they can be contacted on

The compliance with the RoHS Directive is provided by the market surveillance mechanisms laid down by Regulation (EC) No 765/2008 [EU, 2008c].

4.2.2 The recast of the WEEE Directive

In January 2012 the European Parliament expressed his position about the recast of the WEEE Directive [EU, 2012]. In June 2012 the Directive has been adopted by the European Council [European Council, 2012].

According to these documents[87], the "content of hazardous components in EEE is a major concern during the waste management phase, and recycling of WEEE is not undertaken to a sufficient extent".

The recast of the WEEE Directive recognizes the key role of the provision of information. In Article 15 it is stated that, in order to facilitate the re-use, maintenance, upgrade, refurbishment and recycling, Member States "*shall take the necessary measures to ensure that producers provide information, free of charge, about preparation for re-use and treatment in respect of each type of new EEE […]. This information shall identify, as far as it is needed by centres which prepare for re-use and treatment and recycling facilities […], the different EEE components and materials, as well as the location of dangerous substances and mixtures in EEE. It shall be made available to centres which prepare for re-use and treatment and recycling facilities by producers of EEE in the form of manuals or by means of electronic media*".

Furthermore, in article 14, it is decided that Member States shall also ensure that users of EEE in private households are given the necessary information, among the others, about "the potential effects on the environment and human health as a result of the presence of hazardous substances in EEE".

However, it has been observed in the present study that the provision of such information is not always effective, for various reasons including for example:

- Recyclers are not always aware of such information, nor where information are available;
- WEEE Directive does not specify the detail and format of data to be provided;

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[87] http://www.europarl.europa.eu/sides/getDoc.do?type=TA&language=EN&reference=P7-TA-2012-0009#BKMD-9

- Other potentially relevant information could be included (e.g. amount of hazardous substances, chemical compounds that embody them, content of other compounds that could interfere with the recycling, relevant substances including CRMs, etc.);
- Potential difficulties for the data inquiries (including e.g. missing contact persons, information not easy to be identified in the websites, time consuming process, etc.).

Following these considerations, further development in the provision of information could be possible, also by enforcing potential ecodesign requirements. This is also in line with the article 4 of the recast WEEE Directive that establishes that "*Member States shall […] encourage cooperation between producers and recyclers and measures to promote the design and production of EEE, notably in view of facilitating re-use, dismantling and recovery of WEEE, its components and materials. In this context, Member States shall take appropriate measures so that the eco-design requirements facilitating re-use and treatment of WEEE established in the framework of Directive 2009/125/EC are applied*" [European Council, 2012].

4.2.3 The REACH Regulation

The Regulation 1907/2006 of the EU established a framework for the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) [EU, 2006].

Article 33 of the REACH Regulation states that suppliers of an article containing a substance meeting specific criteria (set in Article 57 of the Regulation) and identified on the candidate list for authorization according to Article 59 of the Regulation "in a concentration above 0.1 % weight by weight (w/w) shall provide the recipient of the article with sufficient information, available to the supplier, to allow safe use of the article including, as a minimum, the name of that substance"[88].

The criteria for the identification of hazardous substances include (Article 57)

a) substances meeting the criteria for classification as carcinogenic category 1 or 2 of Directive 67/548/EEC;

b) substances meeting the criteria for classification as mutagenic category 1 or 2 of Directive 67/548/EEC;

c) substances meeting the criteria for classification as toxic for reproduction category 1 or 2 of Directive 67/548/EEC;

d) substances which are persistent, bioaccumulative and toxic;

e) substances which are very persistent and very bioaccumulative;

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[88] It seems important to include here the information that, according to stakeholder feedback, currently in the EU two different opinions exists on how to interpret this requirement. While the European Chemical Agency (ECHA) and the EC supported by some Member States are of the opinion that the 0.1% threshold belongs to the whole „complex" article as placed on the market, other Member States interpret that the 0.1% is to be related to each subject that starts to be an article („first time article") and that does not stop to be an article even if merged with other (first time) articles to a complex product. In this case the 0.1% refers to each first time article (parts/components). The same principle should be applied to the requirement of Article 7(2) of REACH: the occurrence of a substance of very high concern (SVHC) in an article is to be notified if the concentration exceeds 0.1% and the total amount is above 1 t/a in all articles. According to the interpretation

f) substances - such as those having endocrine disrupting properties or those having persistent, bioaccumulative and toxic properties or very persistent and very bioaccumulative properties which do not fulfil the criteria of points (d) or (e) — for which there is scientific evidence of probable serious effects to human health or the environment which give rise to an equivalent level of concern to those of other substances listed in points (a) to (e) and which are identified on a case-by-case basis in accordance with the procedure set out in Article 59.

A list of so called “candidate substances” is established by a formal procedure according to Article 59, by which the fulfilment of the criteria for “substances of very high concern” is officially assessed. For candidate substances requirements for communication in the supply chain and notification to ECHA (under certain conditions) apply directly after inclusion in the candidate list. The list is periodically updated by ECHA[89].

Only substances from the candidate list may be inserted in Annex XIV the REACH and thereby become subject to the authorization procedure. The first list of regulated substances has been defined by the regulation EU 143/2011 [EU, 2011b] and following[90].

4.2.4 The Classification, Labelling and Packaging (CLP) Regulation

On January 2009 the Regulation on Classification, Labelling and Packaging (CLP) of substances and mixtures entered into force [EU, 2008d]. It aligns existing EU legislation on classification, labelling and packaging of chemicals to the Globally Harmonized System (GHS) of Classification and Labelling of Chemicals, as set by the United Nations[91].

The regulation introduces (Art. 42) among the others, the establishing and maintaining of a classification and labelling inventory in the form of a database by the ECHA. The classification includes among the others [EU, 2008d]:

- Hazard class and category codes
- Hazard statements
- Labelling codes

Although not a method for the assessment of substances, the CLP database represents an important tool for the classification of substances. It can be useful to verify whether a substance included in a product is classified and labelled as hazardous. So it can contribute to improve information to be provided for the EoL of products.

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of ECHA/EC the SVHC could be diluted in (complex) articles below 0.1% and would not have to be notified, whereas the content of SVHC on the candidate list in first time articles would have to be notified and could not be diluted.

[89] Currently around 84 candidate substances are identified (complete list available at website http://echa.europa.eu/candidate-list-table; updated June 2012)

[90] The list of substances subject to authorization can be found at: http://echa.europa.eu/web/guest/addressing-chemicals-of-concern/authorisation/recommendation-for-inclusion-in-the-authorisation-list/authorisation-list .

[91] The GHS is a United Nations system to identify hazardous chemicals and to inform users about these hazards through standard symbols and phrases on the packaging labels and through safety data sheets

4.2.5 The Ecolabel Regulation

The EU Regulation EC/66/2010 [EU, 2010] established the framework for the EU Ecolabel scheme. The label is awarded to products that comply with a set of criteria, which a re specifically defined for a product category.

The criteria refer, among the others, to "the use and release of hazardous substances". The EU Ecolabel should aim at substituting hazardous substances by safer substances, wherever technically possible. In particular article 6.6 states that:

"*The EU Ecolabel may not be awarded to goods containing substances or preparations/mixtures meeting the criteria for classification as toxic, hazardous to the environment, carcinogenic, mutagenic or toxic for reproduction, in accordance with Regulation (EC) 1272/2008 [EU, 2008b] on classification, labelling and packaging of substances and mixtures, nor to goods containing substances referred to in Article 57 of Regulation (EC) 1907/2006 (REACH)*"

The new developed criteria for product categories reproduce the prescriptions of Article 6.6, for example, the criteria for "All purpose cleaners and cleaners for sanitary facilities" [EC, 2011c] include a section concerning the "excluded or limited substances and mixtures", with the following requirements[92]:

a) "Specified list excluded substances;

b) Quaternary ammonium salts that are not readily biodegradable shall not be used;

c) The product or any part of it shall not contain substances (in any forms, including nanoforms) meeting criteria for classification with the hazard statements or risk phrases specified below in accordance with Regulation (EC) No 1272/2008 [EU, 2008b] or Council Directive 67/548/EEC [EEC, 1967] nor shall it contain substances referred to in Article 57 of REACH Regulation [EU, 2006].

Regarding the last point a list including the respective Hazard-statements and Risk-phrases from the CLP is used for the practical work while drafting the Ecolabel criteria.

Derogations to this restriction are foreseen for some substances;

d) No derogation may be given concerning substances identified as substances of very high concern and included in the list foreseen in Article 59 of Regulation (EC) No 1907/2006;

e) Limitation on the uses of biocides.

The verification of the compliance to the criteria is based on declarations (supported by technical documentation of substances when necessary). Furthermore, manufacturer has to provide "Safety Data Sheets" for regulated substances in accordance with the REACH Regulation.

Requirements restricting the use of mercury have been included in the Ecolabel criteria for "personal computer", "portable computers" and "light bulbs".

Some Ecolabel criteria also refer to the 'Design for disassembly' of components containing hazardous substances. For example, the Ecolabel criteria concerning "personal computer" [EC, 2011e] and "notebook computers" [EC, 2011f] establish that, in order to facilitate the dismantling of the product,

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[92] The requirements stated in (a), (b) and (c) below shall apply to each substance, including biocides, colouring agents and fragrances, that exceed 0,010 % by weight of the final product.

the manufacturer should provide "*data on the nature and amount of hazardous substances […] gathered in accordance with Council Directive 2006/121/EC (REACH) and the Globally Harmonised System of Classification and Labelling of Chemicals (GHS)*".

4.2.6 The IEC/TR 62635

Section 1.2.1 of the current report introduced the Technical Report (TR) n° 62635 of the IEC on the calculation or the recyclability / recoverability rates [IEC/TR 62635, 2012]. The TR prescribes for manufacturer the identification of pre-treatments that usually "includes operations to mitigate hazards and dismantling parts for selective treatment".

Furthermore the TR underlines the relevance of exchange of information to improve the efficiency of EoL treatments. Among this information a key role is about potential hazardous substances that could represent a risk for workers or that could interfere with the recycling process. On such purpose, the TR states that [IEC/TR 62635, 2012]:

- (section 5.3): "*Manufacturers should provide information which identifies the sources of potential hazards to recycling or recovery personnel.*"
- (section 5.4.3): "*Manufacturers should provide information which identifies parts that present potential hazards to the environment. For these parts, there are generally legal requirements that impose dismantling and separate treatment. If needed, manufacturers should indicate which operations should be done before further product dismantling and treatment. This will assist recyclers to take the appropriate measures to prevent potential hazards, or at a minimum mitigate it, before further dismantling or material separation operations*".

The TR does not set a specific framework for the verification process, but it provides a preferred format for data provision including information about the contained hazardous substances, their location and the needed treatment (see Table 10). On such purpose, the TR 62635 also presents in Annex 1 an "Indicative List of materials or parts to be identified for selective treatment" in order to ensure that waste treatment does not harm people health and environment.

Manufacturer should provide sufficient technical documentation and references to support the provided information.

Table 10 Example of data format to provide information to recyclers about hazardous substances in the product (modified from [IEC/TR 62635, 2012])[93]

Information for end of life treatment	**Items:**	**Location**
Hazards mitigation		
Selective treatment		

4.2.7 Voluntary initiatives for the assessment and management of hazardous substances

In recent years many individual declarable substance lists were developed by manufacturer to exchange information regarding the material and substance composition of products. The experience gained by manufacturer in using these multiple lists has shown that the declaration process could be improved by developing single, globally harmonized lists with clear criteria.

For example the automotive sector established the Global Automotive Stakeholder Group (GASG).The GADSL covers declaration of certain information about substances (regulated, projected to be regulated, or for it is scientifically demonstrated that their presence may create a significant risk to human health and/or to the environment) relevant to parts and materials supplied by the supply chain to manufacturers. In particular, substances are grouped into three categories[94]:

- "D" - Substance must be declared/reported if the threshold limits are exceeded, however the substance is not prohibited to be used in automotive parts.
- "D/P" - Prohibited in some applications and declarable in all other cases.
- "P" - Prohibited in all applications.

Further advancements of lists of controlled substances have been also developed. For example, one of these lists has been developed, and recently revised, by the "Green Screen for Safer Chemicals" method [Rossi and Heine, 2007; CPA, 2011] [95] for the benchmarking of chemical's hazard with the intent to guide decision making toward the use of the least hazardous options via a process of informed substitution.

The Green Screen defines four benchmarks on the path to safer chemicals, with each benchmark defining a progressively safer chemical [Rossi and Heine, 2007]:

- Benchmark 1: "Avoid—Chemical of High Concern".
- Benchmark 2: "Use but Search for Safer Substitutes".
- Benchmark 3: "Use but Still Opportunity for Improvement".
- Benchmark 4: "Prefer—Safer Chemical".

The belonging of a chemical to a benchmark is based on the compliance with a set of criteria.

The application of the Green Screen method involves three major steps [Rossi and Heine, 2007]:

1. Establish the list of hazard endpoints that are critical to evaluating the safety of a chemical. The list is based on assessment of government agencies (including US EPA) and assessment from chemicals policy legislations (including the European REACH Directive). The hazards of a chemical are defined by "its potential to cause acute or chronic adverse effects in humans or wildlife, its fate in the

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[93] The provision of information should be also aligned to requirements from the legislation in force as, for example, the Directive 2012/19/EU (WEEE) and the Regulation (EC) No 842/2006 on fluorinated greenhouse gases.

[94] Further information available at: http://gadsl.org/ (access March 2012).

[95] The Green Screen method claims to be based on the principles of Green Chemistry of the American Chemistry society [Anastas et Zimmerman, 2003] and the work of the US Environmental Protection Agency's (EPA's) Design for Environment (DfE) program (http://www.epa.gov/dfe/).

environment, and certain physical/chemical properties of concern to human health". The method has been recently revised, including 18 hazard endpoints [CPA, 2011].

2. Define the levels of concern. Each hazard is subdivided in: high, moderate, and low. Persistence and bioaccumulation have an additional level of concern of "very high", which reflects the growing international consensus in their assessment. Each level of concern (for each hazard) is defined by threshold values that are quantitative, qualitative, or based on expert references.

3. Specify the hazard criteria for each of the four benchmarks. The hazard criteria encompass a combination of hazards and threshold values. Criteria for each benchmark are illustrated in **Error! Reference source not found.**.

The "Green screen" method represents an interesting example on how designers can be supported in the selection of less harmful substances. However, the method:

- Requires detailed information on substances (including laboratory test) that are not easy to be collected (e.g. from already published studies)
- The method is mainly addressed to a voluntary approach (comparison of performances of different design alternatives) more than to a mandatory/regulatory scheme (no verification process is foreseen). For example, for substances belonging to "Benchmark 2 –Use but search for safer substitutes" it is not specified how this research requirements should be performed, nor how detailed/exhaustive it should be;
- Finally, the Green Screen method does not foresee verification procedures for the compliance.

4.2.8 Summary of the review phase

The following Table 11 summarizes the main findings of the previous review phase. Outcomes from the review phase will be used in the next section concerning the method revision.

Note that Table 11 also reports main consideration relating to the methods introduced in the present project (as following discussed in Section 4.3).

Table 11 Comparison of documents analyzed in the literature review on the use of hazardous substances

	RoHS	WEEE	REACH	Ecolabel	Green Screen	IEC TR 62635/62650	EP1	Present project
Adopted methodology and considered hazardous substances	Restriction of the use of six hazardous substances, based on scientific studies and impact assessment	Manufacturers shall provide relevant information to recyclers, including, among the other, the location of dangerous substances	List of regulated substances meeting fixed criteria (five SVHC currently regulated and about seventy candidate products)	Compliance to product specific criteria, with the restriction of the use of some hazardous substances (as indentified by other European legislation). Criteria are developed on the basis of preliminary analysis of the product category.	Benchmarking of substances	Manufacture identify substances that could interfere with recycling/recovery processes	Life cycle approach to assess substitutable hazardous substances embodied in a product group.	Identification of relevant hazardous substances (regulated and/or not) that can potentially interfere with EoL treatments of the product and development of a methodology to assess the separability.
Life cycle phases considered	Production and disposal	EoL	Production, use and disposal of regulated substance	All life cycle	Production and use	EoL	All the life cycle	EoL
Requirements	Maximum allowed thresholds for the use of regulated substances	Provision of information for recyclers and users	Measures concerning the use of some substances; - provision of information; - authorization for the use of regulated substances	Measures concerning: - restricted use of some hazardous substances (differentiated by product groups); - provision of data concerning the hazardous substances to facilitate the dismantling	Substances subdivided into: "safer", "use but still opportunity to improvement", "use but search for safer substitute", "Avoid"	Provision of key information (operation needed for the dismantling and associated risks)	Identification and provision of data about components containing the substances.	- Identification and provision of data about components containing the substances; - improvement of design for disassembly of components containing the substances
Verification	Declaration of conformity and check by the market surveillance mechanisms	Member States check compliance to the Directive	Member States check compliance to the regulation	Declarations of the manufacturer	No verification procedures are set	Manufacturer should provide sufficient technical documentation and references to support information.	Declarations of the manufacturer, supported by technical documentation	Declarations of the manufacturer, supported by technical documentation
Potential interaction with other EoL parameters (RRR, recycled content, use of priority resources, durability)	-	It is recognised the relevance that hazards can have on reuse/recycling	-	Interaction with Recyclability (via requirements on the design for disassembly of components containing hazardous substances)	-	It is recognised the relevance that hazards can have on recycling/recovery	The presence of hazardous substances interfere with the recyclability / recoverability of components	The presence of hazardous substances interfere with the recyclability / recoverability of components

4.3 Revision of the method for the 'Use of hazardous substances' into products

Following the previous review it is observed that currently the EU legislation is already dealing with the topic of identifying and assessing the potential hazardous substances and regulating their use (including the ban of some substances or their restricted uses under certain threshold).

The assessment of hazardous substances is therefore a topic already under discussion and it is beyond the scopes of the current guidance.

The previous review also noticed that the provision of information on hazardous substances is also taken into consideration by some legislation (i.e. article 11 of the WEEE Directive). However, it is not specified what information has to be provided and how this could support the recyclers at the EoL. On such purpose, it is instead particularly interesting the recommendation from the *IEC/TR 62635, 2012* (see Section 4.2.6) suggesting a format for the information needed to the support the handling of the product at the EoL and the improvement of recyclability / recoverability of the components containing hazardous substances.

Concerning the design for disassembly, some measures have been established by Ecolabel criteria, but they refer only to the provision of information that could simplify the disassembly (e.g. content and location of the hazardous substances in the product).

According to the previous issues, the method of EP1[96] have been revised focusing on how to improve the EoL treatments of the product and how to mitigate potential risk related to hazardous substances..

The revision of the method for the use of hazardous substances into products is following discussed.

4.3.1 Method for assessment of components using hazardous substances

The content of hazardous substances in a component does not represent itself a problem. Some hazardous substances can be, in fact, treated by specialized technologies that reduce at the minimum the risks for human and environment. Other substances are instead relevant because embodied in specific components that have to be extracted and separately treated. Such disassembly and treatments can be potentially harmful.

It should be noted that not all hazardous substances are problematic or could cause a risk to human health or the environment. Only, if there is an exposure to these substances, either because of emissions to the environment or workplace / indoor air or because of a direct (dermal / oral) contact of humans with the substances a potential risk could occur. Hence, the relation between the substances properties, the manner how it is included in an article (location, inclusion in matrices) and the conditions under which the waste treatment takes place (and leads to potential emissions) need to be combined to assess whether or not there is a risk.

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[96] The method developed by EP1 is affected by some limits as: it cannot be generalized for every products/technologies (when e.g. substitutable substances are not available) and it implies various computational problems (mostly related to the carrying out of the LCA of the product). For further details see: Ep1 – Report n° 2 – Chapter 6.

Therefore the identification of key components for their content of hazardous substances is based on the coupling of information about the component (BOM and disassembly) with information about the EoL treatments (including available technologies).

The method for the identification of key components is based on the following steps:

Step 1. *Definition of the set of substances to be considered*. The set of substances to be considered has to be defined in order to set potential requirements. The set can include regulated substances (e.g. by RoHS Directive and/or REACH Regulation) and additional substances[97] (e.g. substances identified as hazardous to human health and/or the environment as identified and listed by the CLP/GHS, the GASC or the Green Screen Initiative)[98].

Step 2. *Identification of components embodying the considered substances*. Once the set of considered substances has been defined, it is necessary to identify if these are contained in some components of the product. This "identification" process could also require the acquisition of information from the suppliers[99].

Step 3. *Identification of treatments for the EoL of the component and of potential risks*. For each component identified in the previous "Step 2", it is necessary to identify the recovery treatments that the components will undergo at EoL and potential risks related to them. This identification can be based on scientific literature or on direct feedback from the recyclers[100]. Information about the disassembly of the components is also necessary.

Step 4. *Identification of key components.* Key components are identified, based on results of previous steps. Key components are those components that have a content of hazardous substances that is critical for the identified EoL treatments.

Once key components are identified, their design should be investigated and potentially improved, in line with the identified recycling treatments/technologies. Suitable strategies for the improvement of key components could include:

- substitution and/or limitation of the hazardous substances (when technologically feasible and economically viable) with less hazardous alternative substances

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[97] It is highlighted that the analysis of regulated substances is priority. However, in a life perspective, other hazardous substances could be potentially relevant. For this reason the method has been defined more generic (potentially including both regulated and not regulated substances).

[98] As a minimum, substances listed on the REACH candidate list and identified as endocrine disrupter category 1 in the EU priority list should be considered. In an extended approach and in addition to that, all substances fulfilling the criteria of REACH Article 57 should be considered as well as substances classified as respiratory sensitisers.

[99] As already addressed in Section 4.2.3, the identification of components depends on the interpretation (and the enforcement) of the Article 33 of REACH (content of SVHC above 0.1%). To address a risk based approach, the manner of inclusion of relevant substances should be identified; i.e. where in the component is the substance included (outside surface or inside), if it is contained inside a physical barrier / container (e.g. batteries) and how it is included in the "main materials" (binding to matrices, dilution in matrices, metallic binding etc.). This type of information is beyond the information currently discussed under IEC/TR 62635. This can be an area for possible addition information requirements e.g. under the Ecodesign Directive.

- provision of relevant information (including amount of the hazardous substances and their location in the product's parts)
- improvement of the disassemblability of key components.

The identification of 'key components' and the assessment of their 'disassemblability' will be discussed in the following sections.

4.3.1.1 Provision of information

The identification of key components includes possible measures that the manufacturer can adopt to improve the EoL of the product. These measures can include, among the others:

- Provision of information on the components and their content of hazardous substances, as for example: typology of hazardous substance used, amount, list of key components containing the substances, location of the key components, possible risks, precautions for the handling of the key components, suggested technology for the treatment of the key components. Format for data provision could be provided, for example based on the proposal of IEC/TR 62635 or based on other more comprehensive formats.
- Labelling of 'key components' to improve their identification.

Note that the provision of information from manufacturers to recyclers has been regulated by article 15 of the WEEE directive (recast)[101]. However, the WEEE Directive does not provide detailed guidance on how detailed/structured should be this information. Consequently it has been observed that such information is sometimes not enough detailed and exhaustive.

Apart from some prescriptions from the WEEE directive and the labelling of plastics used for packaging purposes, no provisions exist to regulate the information flow from the product suppliers to the waste treatment sectors[102].

The IEC/TR 62635 recently discussed, among the others, relevant information that manufacturers should provide to recyclers, as well as some exemplary sheets for data exchange.

Finally, it is suggested that recycling companies and associations of recyclers should be involved in the definition of information to be provided.

4.3.1.2 Disassemblability of key components

The key role of 'disassemblability' for the EoL of products has been already discussed in Section 1.2.2, concerning the assessment of the manual disassembly and the mechanical separation for RRR indices. The present section will focus on the 'selective' manual disassembly.

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[100] For example the ECHA developed a method for the estimation of emissions, exposures and risks in waste treatment operations. This includes models and scenarios for releases of substances from products in different treatment technologies [ECHA, 2010]

[101] See section 4.2.2.

[102] Also under REACH, although information is generated on risks from the waste stage, this is normally not translated to the waste stage, as the communication chain on chemicals breaks when are produced. Based on some comments received by stakeholder, it seems that the provisions of Article 33 of the REACH Directive are currently not interpreted in a way that waste treatment information should be communicated with the article.

In the scientific literature, the measurement of 'disassemblability' has been generally based on qualitative/quantitative scoring systems. These methods often use qualitative judgements that can be affected by different subjective assessment.

However, it is generally recognized that the "time" necessary for the disassembly is one of the key factor [Kroll and Carver, 1999].

The advantages of using the "T_D - Time for disassembly" are various, including[103]:

- It is a factor that can be physically measured;
- It is linked to the costs for disassembly, which can be calculated as product of the disassembly time by the hourly cost of the personnel;
- It reflects the encountered difficulties during the disassembly process (time for disassembly as a proxy of other factors).

To establish if a component is "easy to disassemble" a feasible approach is the setting of a threshold of the time for disassembly ($T_{D,max}$) below which the component is assumed to be "easy to disassemble"[104].

4.4 Verification of the method for the 'Use of hazardous substances'

The method introduced in Section 4.3 for the assessment of components containing hazardous substances which could cause risks to humans and/or the environment aims at identifying key substances and components of the product. This method could be run when analysis of product groups are performed[105]. This method therefore does not foresee a verification process.

On the other side, verification is needed when specific measures are set to improve the EoL of key components. For examples, concerning measures to improve the 'disassembly of the key components', manufacturer should provide technical documentation detailing the disassembly process, including a procedure for a safe removal of the component and the necessary tools. The analyst shall also declare and prove (by documentation on laboratory tests) that the components can be manually disassembled by a technician in a time lower than a fixed threshold "$T_{D,\ max}$". The verification of is performed by the market surveillance authority, which can reproduce laboratory tests when necessary to verify the correctness of provided information.

4.5 Guidance document on 'Use of hazardous substances'

Following the previous sections, the guidance document on the 'use of hazardous substances' has been developed. The document is illustrated in Annex 4.

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[103] For further details, see also the discussion on the disassemblability in EP1 – Report n° 1 – Section 2.2.1 and Report n° 2 – section 2.5.2.

[104] Thresholds should be set based on the experience of designers and recyclers and taking into account also economic considerations (e.g. labour cost).

[105] For example, during the development of preparatory studies.

5. Method for the environmental assessment of 'durability' of products

5.1 Introduction

Differently from other parameters, the study of durability was not part of the analysis of EP1 and the method for the assessment of durability is original.

This implies potential higher uncertainties and limits related to this method. In particular the analysis focused only on the environmental assessment of potential impacts related to changes in the lifetime of the products. The method is based on the survey of scientific literature and the definitions provided in Report n°1. The following sections will introduce a brief summary of the literature review and, afterwards, the description of the proposed method and the illustration of some indexes.

5.2 Literature review

The concept of Durability has been largely discussed in scientific literature.

The durability is generally related to the conservation of the properties of product. For example, Mora, 2007 defines the durability as "the characteristic of those objects or materials that maintain their properties over time". The focus on the properties is especially common into standard defining the characteristic that the product/material should fulfil (e.g. the strength of the materials) and the testing condition to prove it. On such purpose, several ISO standards have been developed, mainly concerning building and building components (e.g. the [ISO 12543-4, 1998; ISO 15928, 2009]). These standards generally impose that the estimated service life of the product (e.g. the time frame during which the product satisfies the design conditions) shall meet or exceed the design life of the product (e.g. the specified period of time for which the product is to be used).

Also various standards on durability of furniture (e.g. [ISO 7170, 2005; ISO 21016, 2007]) have been developed. These focused on the standardised application of loads to observe the response of the product to external stress.

In some cases, standards have been developed concerning a specific product groups, modelling the probability of failure and the conservation of performance. This is the case, for example, of the standard CIE 097, which introduced a method concerning the maintenance of indoor electric lighting systems [CIE 097, 2005]. This method represents also an interesting example of correlation of durability to the functionality of the product (the energy output of the device).

The method of CIE 097 has been adopted by some implementing measures for lighting systems to introduce threshold requirements concerning the following parameters [EC, 2009; EC, 2009b]:

- *the 'lamp lumen maintenance factor', which is the ratio of the luminous flux emitted by the lamp at a given time in its life to the initial luminous flux*;

- *lamp survival factor', which is the defined fraction of the total number of lamps that continue to operate at a given time under defined conditions and switching frequency*;

These parameters represent a first important example of introducing durability considerations into Ecodesign measures for ErP.

The method of CIE 097 is however strictly focused on lamps and not directly transferable to other products.

As observed by some authors, durability could become counterproductive in some cases. For example concerning the building sectors, *Sneck* already evidenced several decades ago that [Sneck, 1981]:

"*Negative aspects of excessive durability are caused by the use of unjustifiably durable and usually much more expensive materials, construction techniques or designs. They can be counterproductive as the useful life of a building is often influenced by factors other than durability, i.e.:*

- *It may become uneconomic to continue operating it.*
- *Statutory requirements render it obsolete.*
- *The needs of the occupants may change to such an extent that the building is no longer suitable.*
- *Changed fashions or competition from newer buildings make it unacceptable*".

Similar considerations apply to ErP. In particular, the assessment of the durability shall also include an environmental analysis of the product. The assessment of durability has to be integrated with considerations on the life-cycle of the product[106].

For example, it has been observed that "lifetime extension is an important strategy in life cycle engineering. However, decreasing efficiency of worn-out products as well as technological progress embodied in new products imposes deviations on this general strategy. […] Determining the optimal lifetime is therefore a crucial step in life cycle engineering […]" [Dewulf and Duflou, 2004].

The extension of the operating time of a product can, in fact, reduce impacts due to the manufacturing and disposal of the product. On the other side, product 'obsolete' can be responsible of higher impacts during the use phase if compared with newer and more efficient products.

Main considerations from the literature review are:

- durability has to be related to the function/s of the product
- various parameters influence the useful lifetime of the product including design, legislation, costs and also fashion
- durability is a key issue of product that influence its environmental profile
- it is important to estimate the balance of benefits related to the longer lifetime with potential drawbacks due, e.g., to loss of efficiency.

A method for the environmental assessment of the durability of the products is illustrated in the following sections, comparing the potential environmental 'benefits' related to the improvement of the

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[106] A preliminary example of integration of durability of the product with the LCA methodologies have been introduced in: EP1 – Report n° 2 – Section .6.3.3.

durability of a product with the potential benefits and drawbacks related to its substitution/replacement.

5.3 Method for the environmental assessment of the durability of product

The present method for the environmental assessment of the durability of products has the scope to identify if and to what extent a potential extension of the operating time of the product could be relevant in terms of life-cycle environmental benefits[107]. In particular, the assessment of the durability aims at answering to the following questions:

- How large are the environmental benefits (if any) of extending the operating life of the considered product by a given additional time-frame?
- How relevant are the environmental benefits (if any) compared to product's life cycle impacts?

The following section will illustrate a general method for the assessment (Section 5.3.1) and afterwards a simplified approach (Section 5.3.2). The method is based on the survey of scientific literature and definitions provided in Report n°1.

5.3.1 A general method for environmental assessment of 'durability'

The environmental assessment of the durability of product is based on the comparison of two different scenarios (see Figure 4):

- **Base-case Scenario (1)**: it is assumed that the product "A" is substituted, after its average operating time "T", by a new product "B".
- **Durability Scenario (2)**: it is assumed that the operating life of product "A" is extended of an additional time frame "X", and only afterwards it is substituted by a new product "B".

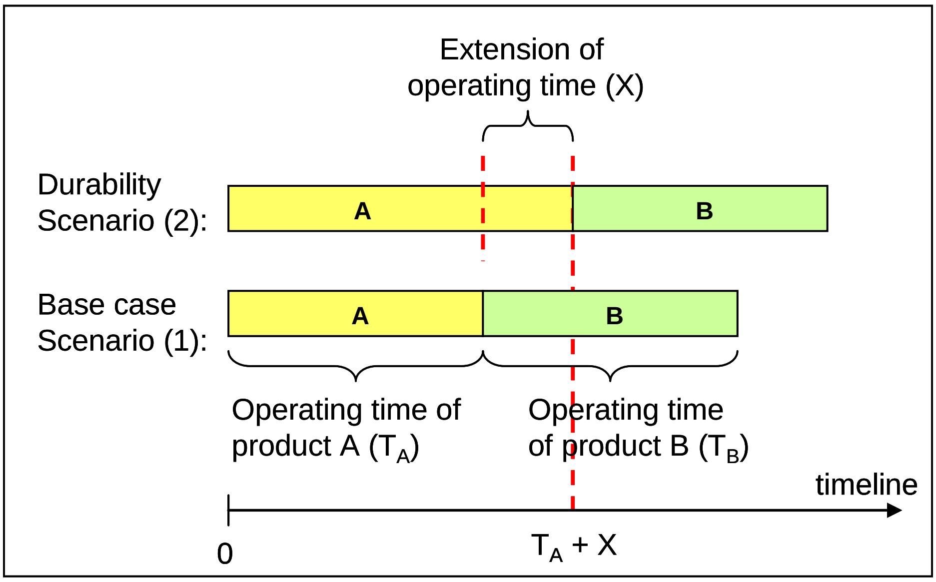

Figure 4. Assessment of durability – Setting of scenarios to be compared

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[107] The method on durability here illustrated focuses only on the extension of the operating time of a product. Reuse of the product and/or remanufacturing issues are not addressed. These will be part of the method for reusability.

First of all an environmental impact category "n" is selected for the assessment. It is important to note that different results can be obtained by considering different impact categories.

The extension of the operating time (X) is assumed/estimated by the analyst[108] based on the expert judgment upon the considered product. The parameter X is assumed as positive, referring to an 'extension' of the operating time of the product.

Being X only an assumed/estimated parameter, it is recommended performing a sensitivity analysis by considering a possible range of values. The results of the assessment will illustrate the potential benefits that could be achieved for different extensions of the operating time.

In order to grant the comparability of the two scenarios it is necessary to set equivalent references flows, in accordance to ISO standards for LCA [ISO 14040, 2006].

As underlined by the ISO/TR 14069, products can be "*regarded as comparable in spite of their difference in lifetime. This difference is simply taken into account in the calculation of the reference flow*" [ISO/TR 14069, 2012]. However, ISO/TR 14069 noticed that "*for long-lived products, such as refrigerators with lifetimes of 10 or 20 years, technology development may be a factor that cannot be disregarded. One refrigerator with a lifetime of 20 years cannot simply be compared to two successive, present-day refrigerators with a lifetime of 10 years. The refrigerators available 10 years from now are certain to be more energy efficient (i.e. lower energy input per functional unit) than the present, the energy efficiency of the second refrigerator of the 10 + 10 option is determined by a trend projection, while the energy efficiency of the 20 years option is fixed*" [ISO/TR 14069, 2012]. Therefore, considerations on different efficiency of products should be part of the assessment.

The reference flow is the provision of the functions[109] of the product for a selected time frame. This is set from the time 0 (starting of the use of product "A") up to the time '$T_A + X$'. In the comparison, the impacts due to the manufacturing of product A t is not considered because it affects equally both the systems in the two scenarios; analogous consideration relate to the energy used up to the time 'T_A'.

It is assumed that the disposal of product "A" at the time T and at the time '$T_A + X$' is the same[110].

In scenario 1, the product "A" is substituted by B at the time T_A. The additional burdens due to the manufacturing and disposal of the new product "B" have to be considered (proportionally to the average operating time of product B). The environmental impacts can be estimated by the following original formula:

Formula 27 $$I_{1,n} = \frac{P_{B,n}}{T_B} \cdot X + U_{B,n} \cdot X + \frac{D_{B,n}}{T_B} \cdot X$$

Where:

- $I_{1,n}$ = Environmental impact for category "n" in the base-case scenario 1 [unit];

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[108] Analysis is here intended that person performing the analysis including e.g., manufacturers, policy makers, scientists.

[109] In case a product would provide different functions, multi-functionality and allocation problems could raise. However, it is here considered to restrict the analysis to only one function of the product.

[110] This assumption is introduced to simplify the calculations. However, if the time extension 'X' is not too long, it is plausible to assume that there will be not substantial changes about the EoL of product A at the time T_A, and the treatment of the refurbished product A at the time T_A+X.

- $P_{B,n}$ = Environmental impact for category “n” for the production of product “B” (including the production of raw materials and manufacturing) [unit];
- T_B = Average operating time of product “B” [year];
- X = Extension of operating time of product “A” [year];
- $U_{B,n}$ = Environmental impact per year for category “n” for the use of product “B” [unit/year];
- $D_{B,n}$ = Environmental impact for category “n” for the disposal of product “B” [unit].

In scenario 2, the life of product “A” is extended. The environmental impacts of the product’s system are:

Formula 28 $$I_{2,n} = U_{A,n} \cdot X + R_{A,n}$$

Where:

- $I_{2,n}$ = Environmental impact for category “n” in the durability scenario 2 [unit];
- X = Extension of operating time of product “A” [year];
- $U_{A,n}$ = Environmental impact per unit of time for category “n” for the use of product “A” [unit/year];
- $R_{A,n}$ = Environmental impact for category “n” for additional treatments (e.g. repairing, refurbish) necessary for the extension of operating time T_A [unit].

The potential environmental benefits moving from scenario 1 to scenario 2, can be calculated as:

Formula 29 $$\Delta_n = I_{1,n} - I_{2,n} = \frac{P_{B,n}}{T_B} \cdot X + \frac{D_{B,n}}{T_B} \cdot X + \left(U_{B,n} - U_{A,n}\right) \cdot X - R_{A,n}$$

Where:

- Δ_n = Environmental benefits for category “n” calculated as difference of the base-case and the durability scenarios [unit];
- (other symbols as in Formula 28 and Formula 29).

If for a fixed value of “X”, it results that “$\Delta_n > 0$”, then there is a convenience in improving the durability; otherwise, if “$\Delta_n < 0$” then it is not convenient to extend the operating life[111]. On such purpose it is set the equation “$\Delta_n = 0$”:

Formula 30 $$X \cdot \left[\frac{P_{B,n}}{T_B} + \frac{D_{B,n}}{T_B} + \left(U_{B,n} - U_{A,n}\right)\right] - R_{A,n} = 0$$

or analogously:

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[111] The situation of “$B_n = 0$” represents the indifference between the two scenario, but this is a limit case that generally does not occur.

$$\textbf{\textit{Formula 31}} \quad X = \frac{R_{A,n}}{\frac{P_{B,n}}{T_B} + \frac{D_{B,n}}{T_B} + \left(U_{B,n} - U_{A,n}\right)}$$

According to Formula 31, 'X' can have positive or negative values, depending on the difference: $\left(U_{B,n} - U_{A,n}\right)$. Positive values of 'X' mean that there is an environmental convenience into extending the operating life of the product. On the other hand, negative values of X means that the extension of the operating life can also counterproductive (causing larger life-cycle impacts than benefits).

Observing Formula 31, ones observe that:

1. if the product "A" will be substituted by a new product "B" having the same (or even a larger) energy consumption during the use "U", then $\left(U_{B,n} - U_{A,n}\right) > 0$. Therefore X will have always positive values[112]. It means that the extension of the operating time is always beneficial. In particular, the environmental benefits "Δ_n" are larger the longer is the operating time extension.
2. If the product "A" will be substituted by a product "B" with lower energy consumption, it results that: $\left(U_{B,n} - U_{A,n}\right) < 0$. Then the benefits "$\Delta_n$" due to the extension are reduced by the loss in energy efficiency. In this case, X can have positive or negative values, depending on the term $\left[\frac{P_{B,n}}{T_B} + \frac{D_{B,n}}{T_B} + \left(U_{B,n} - U_{A,n}\right)\right]$.

Concerning the above clause 2), if $\left[\frac{P_{B,n}}{T_B} + \frac{D_{B,n}}{T_B} + \left(U_{B,n} - U_{A,n}\right)\right] > 0$, then there is an environmental convenience into extending the operating life when:

$$\textbf{\textit{Formula 32}} \quad X > \frac{R_{A,n}}{\frac{P_{B,n}}{T_B} + \frac{D_{B,n}}{T_B} + \left(U_{B,n} - U_{A,n}\right)}$$

Formula 32 defines the minimum value of X beyond which "$\Delta_n > 0$".

Finally, assuming that "$\Delta_n > 0$", a durability index can be defined as the ratio between the environmental benefits and the life-cycle impacts of product "A":

$$\textbf{\textit{Formula 33}} \quad D_n = \frac{\frac{P_{B,n}}{T_B} \cdot X + \frac{D_{B,n}}{T_B} \cdot X + \left(U_{B,n} - U_{A,n}\right) \cdot X - R_{A,n}}{P_{A,n} + U_{A,n} \cdot T_A + D_{A,n}} \cdot 100 \quad [\%]$$

Where:

- D_n = Durability index for the impact category "n" [%];
- $P_{A,n}$ = Environmental impact for category "n" for the production of product "A" (including the production of raw materials and manufacturing) [unit];
- $D_{A,n}$ = Environmental impact for category "n" for the disposal of product "A" [unit];
- (other symbols as in Formula 28 and Formula 29).

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[112] It is reminded that all the other factors in Formula 30 are always non-negative.

It is possible to set a "threshold of relevance (Y) [%]" over which the extension of operating time is relevant. It results that:

- *If* $D_n \geq Y$ *then is relevant to extend the operating life of the product.*
- *If* $D_n < Y$ *then is not relevant to extend the operating life of the product.*

The threshold of relevance (Y) should be set by the decision maker, according to the desired level of benefits that he wants to achieve.

5.3.2 A simplified method for environmental assessment of 'durability'

The calculation of Formula 33 implies the knowledge of the two systems of product "A" and "B" to be compared. In particular, the product "A" is the target of the analysis while the product "B" can represent a substituting product with higher efficiency (e.g. benchmark).

However, when the analysis is performed at the design stage of product "A", it could be difficult to collect information about the life-cycle of product "B". These difficulties rise especially for products having a large average operating time or products with a short technology cycle.

Therefore it is here introduced a simplified method that refers only to characteristic of product "A". The assumptions for the new method are:

1. First of all it is assumed that the two systems of product have the same average operating time ($T_A = T_B$). This assumption is generally plausible.
2. Afterwards it is assumed that the product A and B have the same impacts for production and disposal ($P_A = P_B$; $D_A = D_B$). This assumption is generally plausible for products that are similar in the constituting materials and manufacturing process.
3. Finally, the impact due to the use phase of product B is expressed in relation to the impact of product A. In particular, it is assumed that product "B", compared to product "A", has lower impacts during the use phase of a certain percentage "δ"[113]:

$$\textbf{Formula 34} \quad U_{B,n} = \delta \cdot U_{A,n} \qquad with: 0 < \delta < 1$$

The introduction of the parameters "δ" is plausible, because it implies comparing the product A with a product 'B' having lower impacts during the use phase. For example, if it s assumed that product B has 20% lower energy consumption during the use phase compared to product A, then it results: δ = 0.8.

The above assumption n° 3 is obviously the most important because it largely influences the results. The value of "δ" should be carefully set (for example based on the analysis of product category, or setting a hypothetical efficiency of the substituting product). It is furthermore recommended performing a sensitivity analysis of parameter "δ", especially when it is affected by large uncertainties.

Based on the above three assumptions, Formula 33 can be modified as following:

$$\textbf{Formula 35} \quad D'_n = \frac{\frac{P_n}{T} \cdot X + \frac{D_n}{T} \cdot X - (1-\delta) \cdot U_n \cdot X - R_n}{P_n + U_n \cdot T + D_n} \cdot 100 \quad [\%]$$

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[113] As discussed if Section 5.3.1, values of "$\delta_n > 0$" (meaning product "B" with larger impacts during the use phase) imply always a convenience into extending the operating time of the product.

Where:

- D'_n = Simplified Durability index of the considered product for the impact category “n” [%];
- P_n = Environmental impact for category “n” for the production of the considered product (including the production of raw materials and manufacturing) [unit];
- T= Operating time of the considered product [year];
- D_n = Environmental impact for category “n” for the disposal of the considered product [unit];
- X = Extension of operating time of the considered product [year];
- U_n = Environmental impact per unit of time for category “n” for the use of the considered product [unit/year];
- R_n = Environmental impact for category “n” for additional treatments (e.g. repairing, refurbish) necessary for the extension of operating time T of the considered product [unit].
- δ = Percentage representing the lower impacts of the use phase of a new product that could substitute the considered product [%].

5.3.3 Data quality for the environmental assessment of the ‘durability’

The environmental assessment of durability is strictly linked to the adopted reference data. The present section identifies data that are critical for the method. In particular, referring to Formula 33, it is necessary to select representative data concerning:

- the operating times (T) of product “A” and “B”;
- the extension (X) of the operating time of product “A”;
- the calculation of impacts due to the production (P), use (U) and disposal (D) of the product “B”;
- the calculation of impacts due to the treatments (R) for the extension of the product operating time of product “A”.

Referring to Formula 35 is necessary to select representative data concerning:

- the operating time (T) of the product;
- the extension (X) of the operating time of the product;
- the calculation of impacts due to the production (P), use (U) and disposal (D) of the product;
- the value of the factor δ.

5.4 Verification of the proposed method

The method developed in the previous section aims at identifying if and to what extent it is worth to extend the lifetime of a certain product. Once it is assessed that there is a convenience into extending the lifetime, some potential requirements could be set. Requirements for durability will be discussed in Report n° 1 and 2.

The durability indices of the previous sections are therefore not conceived to be directly used for some requirements. Therefore it is not necessary to set a procedure for their verification.

5.5 Guidance documents on the environmental assessment of the durability of product

Following the previous sections, a guidance document on the assessment of durability has been developed. The document is illustrated in the Annex.

Conclusions

The present Report presented the refined methods for the assessment of: reusability/recyclability/recoverability-RRR, use of relevant resources, recycled content, use of hazardous substances, durability. Based on results of the project EP1, the methods have been revised according to the outcomes of their application to some exemplary case-studies (see Report n° 2).

The methods have also been revised, as far as possible, to be in line with international standards published or currently under development and according to an extensive review of the scientific literature.

Concerning the *RRR*, the method from the EP1 has been largely revised to be in line with recommendations of the technical report IEC/TR 62635. However, some minor deviations and advancements compared to the technical report have been proposed:

- the definition of the EoL scenario is a key issue of the method, and it is not clearly specified in the technical report. Furthermore, several EoL scenarios could be relevant for the product and, in addition, these scenarios could feasibly change in the short/medium term (especially due to introduction of new technologies for the EoL treatments). The report therefore proposes a procedure for the setting of one (or more) representative EoL scenarios, based on information from manufacturers, recyclers and from the scientific literature. Future EoL scenario(s) can also be set to support a dynamic analysis of the evolution of the RRR indices.
- the IEC/TR 62635 considers the reusable parts within the calculation of the recyclability rates. In the current report a separate 'reusability rate' has been introduced
- the calculation of the RRR indices can also be 'restricted' to some components and/or materials (for example, for plastics or for EU critical raw materials). The scope is to focus the attention on the flows of some relevant materials whose RRR is intended to be analysed / improved. Some additional indices have therefore been proposed (e.g. the Recyclability rate for plastics).
- the 'recycling rate' and the 'recovery rates' are the key data needed for the calculation of the indices. The IEC/TR 62635 provides an exemplary list of values for some typical materials and product parts, however this list is not exhaustive. It is therefore suggested to develop a more comprehensive procedure and an updated list for the application of the method to ErP.
- IEC/TR 62635 procedure for the verification of the indices is based on the description of the products and their recycling process. In the present report, verification is instead based on some provided calculation data sheets supported by additional technical documentation.

Concerning *the use of relevant resources*, a set of environmental indices have been developed. These indices combine the indices for RRR with life-cycle data about impacts of production of primary and secondary materials. Compared to the methods involved in the project EP1, the RRR benefit rates here developed embody the full life cycle impacts of the product. The indices allow calculating the benefits potentially achieved by the reuse/recycling/recovery of product parts. Also procedures for the calculation and verification of the indices have been investigated. Some exemplary calculation data-sheets have been developed for such purpose, however, it is highlighted that the broad implementation of these indices via e.g. some requirements would require additional robust life-cycle inventory databases and a tool for the calculation. Consistency of these datasets with other available data in Ecodesign tools (e.g. the Methodology for the Ecodesign of Energy-related Products - MEErP ecoreport tool [VHK, 2011]), should be carefully checked. Furthermore, being based on RRR rates, the RRR benefit rates are also affected by the same uncertainties, including the definition of the EoL scenario(s) and the availability of the recycling/recovery rates.

Concerning *the recycled content* of product, the method from the EP1 for the calculation of the index has not been modified. The research therefore focused on the procedure for verification. A survey of available references, including various standards and labelling scheme, has been performed in order to identify potentially relevant and robust documentation to be provided in order to support claims from the manufacturer. An additional index has moreover been developed: the recycled content benefit. It allows assessing in a life-cycle perspective the potential environmental benefits related to the use of recycled materials. It is also highlighted that this index is suitable for integration into other existing tools used in policies (e.g. the MEErP ecoreport tool).

Concerning *the use of hazardous substances,* the method of the EP1 has been largely revised. In particular it has now been focused on the reduction of the risks of use of hazardous substances in the EoL of the product more than on the assessment of the limitation/substitution of substances in the product. The method has therefore been related to the composition of the product (BOM and disassemblability of parts) and EoL treatments that the product parts will undergo. The scope is the identification of criticalities in the EoL of key parts containing such substances. This analysis is preparatory to the identification of potential ecodesign solutions for the minimization of risks to humans and the environment at the EoL.

The method for *the environmental assessment of durability* is totally new compared to the EP1 and is still at an early stage of development and testing. The method is original and is based on approaches already present in the scientific literature for some case-study products. In particular the method is based on the comparison, in a life-cycle perspective, of different scenarios concerning the lengths of the useful life of the products and their potential substitution with better performing alternatives. Some general and simplified indices have been developed. It is highlighted that the method does not take into account consumer behaviour (e.g. "fashion items")[114]. The outcome of the method is the assessment if and to what extent it is environmentally sound to prolong the useful life of a given product. Once it is estimated that this convenience occurs and it is also relevant in the product life-cycle balances, some product requirements could potentially be enforced to underpin the extension of the product useful life.

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[114] These aspects can be part of further research.

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Annex 1 – Guidance Document on 'Reusability, Recyclability and Recoverability'

Guidance document on Reusability

Definitions:

- *Reuse:* Operation by which a product, or a part thereof, having reached the end of one use-stage is used again for the same purpose for which it was conceived. It does not include second-hand sales. [IEC/TR 62635, 2012]
- *Reusable part*: Part of the product that has been specifically designed to be potentially reused[115].
- *Reusability:* ability of component parts that can be diverted from an end-of-life stream to be reused [ISO 22628, 2002]
- *Reusability rate*: Index for the calculation of the reusability.

Method:

$$R_{use} = \frac{\sum_{i=1}^{N} m_{reuse,i}}{m} \cdot 100 \ [\%]$$

- R_{use} = Reusability rate of the product [%];
- $m_{.}$ = Overall mass of the product [kg];
- $m_{reuse,i.}$ = Mass of the ith reusable part of the product [kg];
- N = Number of reusable parts.

Verification:

The analyst performing the calculation shall provide a declaration of the reusability rate of the product (calculated according to data-sheet provided in Section 1.3.1). The declaration shall to be supported by the following documentation (to be provided on request by the market surveillance authority)[116]:

- Mass and details of parts of the product that are reusable
- Disassembly information, proving that binding systems are reversible and the reusable component can be accessed and disassembled by a technician.
- Provision of evidences that a commercial reuse and refurbishment system has been established. This can take the form of contracts with commercial partners, availability of refurbished parts in the marketplace, or other evidence that there is an established system.

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[115] Conditions for reusability are clarified in Section 1.3.1.

[116] Some additional details on the market surveillance authority are provided in Annex 6.

Guidance document on Recyclability

Definitions:

- *Recycling:* Means the reprocessing in a production process of the waste materials for the original purpose or for other purposes, but excluding energy recovery [EU, 2009b].
- *Recyclable part:* Part of the product that is potentially suitable for recycling.
- *Recyclability:* Ability of waste product to be recycled, based on actual practices [IEC/TR 62635, 2012]
- *Recyclability rate*: Index for the calculation of the recyclability of the product. It includes the reprocessing of material but it does not include the energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations

Method:

$$R^{*}_{cyc} = \frac{\sum_{i=1}^{P}\left(m_{recyc,i} \cdot RCR_i\right)}{m} \cdot 100 \qquad [\%]$$

- R^{*}_{cyc} = Recyclability rate [%];
- m = total product mass [kg];
- $m_{recyc,i}$ = mass of the i^{th} recyclable part [kg];
- RCR_i = recycling rate of the i^{th} part [%];
- P = Number of recyclable parts.

The analyst performing the calculation of the "Recyclability Rate" and the "Extended Recyclability Rate" shall define an EoL scenario of the product for the calculation of the recycling rates (RCR_i) according to the following procedure [IEC/TR 62635, 2012]:

1) The analyst should identify parts that have to be addressed to selective treatments (accomplishing to legislative prescriptions);
2) The analyst should identify parts for selective recycling. These include parts with one or more recyclable materials that can be easily dismantled and addressed to specific recycling channels. Condition to be fulfilled are:
   a) The size of the part and nature of embodied materials is such that there is an economical interest for dismantling. Special attention should be focused also on the content of critical raw materials according to the EU classification[117].
   b) There is a specific EoL channel for these materials with higher recycling rates compared to the results obtained after material separation.
3) The analyst should identify parts difficult to process.
4) The analyst should identify other parts for materials separation. These include materials not in the previous bullet points, which are recyclable and that can be separated by mechanical treatments (shredding).

Analyst should assess the corresponding recycling rate (RCR_i) for each part previously identified. Data from the IEC/TR 62635 relatively to the European context shall be used. When not available, analyst should refer to other available references and/or to information from recyclers.

Verification:

The verification of the "*Recyclability rate*" is based on the declaration of the analyst performing the calculation

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[117] http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm

(calculated according to data-sheet provided in Section 1.3.2), supported by technical documentation, to be provided on request by the market surveillance authority, including:

- Bill of material of the product (evidencing mass, composition and disassembly information of parts for selective treatments, selective recycling, difficult to process and parts for material separation);
- Recycling rate (RCR) for each considered part (including the reference) related to the considered EoL scenario (developed according to procedure set in the method section).

Guidance document on Recoverability

Definitions:

- *Recovery:* Means any of the applicable operations provided for in Annex II B to Directive 2006/12/EC of the European Parliament and of the Council of 5 April 2006 on waste [EU, 2009b].
- *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 [EU, 2009b].
- *Recoverable part:* Part of the product that is potentially suitable for recovery.
- *Energy recoverable part:* Part of the product that is potentially suitable for energy recovery.
- *Recoverability:* Ability of a waste product to be recovered, based on actual practices [IEC/TR 62635, 2012].
- *Recoverability Rate*: Index for the calculation of the recoverability of the product.

Method:

$$R_{\mathrm{cov}} = \frac{\sum_{i=1}^{Q}\left(RVR_i \cdot m_{re\,\mathrm{cov},i}\right)}{m} \cdot 100 \qquad [\%]$$

- R_{cov} = Recoverability rate [%];
- m = total product mass [kg];
- RVR_i = Recovery rate of the ith recoverable part [%];
- $m_{recov,i}$ = mass of the ith recoverable part [kg].
- Q= number of recoverable parts.

The analyst performing the calculation shall define an EoL scenario of the product, by identifying:

1. Parts for selective treatments (accomplishing to legislative prescriptions);
2. Parts for selective recovery. These include parts with one or more recyclable materials that can be easily dismantled and addressed to specific recovery channels.
3. Parts difficult to process.
4. Other parts for materials separation.

Analyst should assess the corresponding recovery rate (RVR$_i$) for each part previously identified, Data from IEC/TR 62635 relatively to the European context shall be used. When not available, analyst should refer to other available references and/or to information from recyclers.

Verification:

The verification of the "*recoverability rate*" is based on the declaration of the analyst performing the calculation (calculated according to data-sheet provided in Section1.3.3), supported by technical documentation, including:

- Bill of material of the product (evidencing mass, composition and disassembly information of parts for selective treatments, selective recovery, difficult to process and parts for material separation);

- Recovery rate (RVR) for each considered part (including the reference) related to the considered EoL scenario (developed according to procedure set in the method section).

Guidance document on Reusability Benefit rate

Definitions:

- *Reuse:* Operation by which a product, or a part thereof, having reached the end of one use-stage is used again for the same purpose for which it was conceived. It does not include second-hand sales. [IEC/TR 62635, 2012]
- *Reusable part*: Part of the product that has been specifically designed to be potentially reused.
- *Reusability:* Ability of a waste product to be reused.
- *Reusability Benefit rate*: Index for the prioritisation of product's parts based on the potential benefits that can be achieved from their potential reuse.

Method:

$$R'_{use,n} = \frac{\sum_{j=1}^{K} m_{reuse,j} \cdot \left(V_{reuse,n,j} + M_{reuse,n,j} + D_{reuse,n,j} - T_{reuse,n,j}\right)}{\sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot V_{n,i,j} + M_n + U_n + \sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot D_{n,i,j}} \cdot 100$$

- $R'_{use,n}$ = Reusability Benefit rate for the nth impact category [%]
- $m_{reuse,j}$ = mass of the jth reusable part [kg]
- $V_{reuse,n,j}$ = impact related to the nth impact category for the production of virgin materials constituting the jth reusable part [unit/kg];
- $M_{reuse,n,j}$ = impact related to the nth impact category for the manufacturing of the jth reusable part [unit];
- $D_{reuse,n,j}$ = impact related to the nth impact category for the disposal of the jth reusable part [unit/kg];
- $T_{reuse,n,j}$ = impact related to the nth impact category for the treatments for reuse of the jth reusable part [unit/kg];
- $m_{i,j}$ = mass of the ith material of the jth part of the product [kg]
- $V_{n,i,j}$ = impact related to the nth impact category for the production (as virgin) of the ith material of the jth part of the product [unit/kg];
- M_n = impact related to the nth impact category for the manufacturing of the whole product [unit];
- U_n = impact related to the nth impact category for the use of the product [unit];
- $D_{n,i,j}$ = impact related to the nth impact category for the disposal of the ith material of the jth part of the product [unit/kg];
- K = number of reusable parts;
- P = number of parts of the product;
- N = number of materials in the jth part of the product

Verification:

The verification of the "Reusability Benefit rate" is based on the declaration of the analyst performing the calculation supported by technical documentation, including:

- Bill of material of the product (evidencing parts that are potentially reusable);
- (in cases where the product is not reusable as whole) Disassembly information, proving that binding systems are reversible and the reusable parts can be accessed and disassembled without damaging;
- Provision of evidences that a commercial reuse and refurbishment system has been established. "This can take the form of contracts with commercial partners, availability of refurbished parts in the marketplace, or other evidence that there is an established system" [IEC/TR 62635, 2012].
- References used for the impacts of production (V) of virgin materials and disposal (D);

- Assumption and references used to calculate impacts due to treatments for the reuse (T);
- Assumption and references used to calculate impacts due to the manufacturing of the product (M);
- Assumption and references used to calculate impacts due to the use phase of the product (U).

Guidance document on Recyclability Benefit rate

Definitions:

- *Recycling:* Means the reprocessing in a production process of the waste materials for the original purpose or for other purposes, but excluding energy recovery [EU, 2009b].
- *Recyclable material:* Material of the product that is potentially suitable for recycling.
- *Recyclability:* Ability of waste product to be recycled, based on actual practices [IEC/TR 62635, 2012]
- *Recyclability Benefit rate*: Index for the prioritisation of resources based on the potential benefits that can be achieved from their recycling.

Method:

$$R'_{cyc,n} = \frac{\sum_{j=1}^{P}\sum_{i=1}^{N} m_{recyc,i,j} \cdot RCR_{i,j} \cdot D_{n,i,j} + \sum_{j=1}^{P}\sum_{i=1}^{N} m_{recyc,i,j} \cdot RCR_{i,j} \cdot \left(V_{n,i,j} - R_{n,i,j}\right)}{\sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot V_{n,i,j} + M_n + U_n + \sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot D_{n,i,j}} \cdot 100$$

- $R'_{cyc,n}$ = Recyclability Benefit rate for the nth impact category [%];
- $m_{i,j}$ = mass of the ith material of the jth part [kg];
- $m_{recyc,i,j}$ = mass of the ith recyclable material of the jth part [kg];
- $RCR_{i,j}$ = Recycling rate of the material ith of the jth part (see guidance document of Recyclability Rate) [%].
- $D_{n,i,j}$ = impact related to the nth impact category for the disposal of the material ith of the jth part [unit/kg];
- $V_{n,i,j}$ = impact related to the nth impact category for the production of the virgin material ith of the jth part [unit/kg];
- $R_{n,i,j}$ = impact related to the nth impact category for the recycling of the material ith of the jth part [unit/kg];
- Mn = impact related to the nth impact category for the manufacturing of the product [unit];
- Un = impact related to the nth impact category for the use of the product [unit];
- P = number of parts of the product;
- N = number of materials in the jth part of the product.

Verification:

The verification of the Recyclability Benefit rate is based on the declaration of the analyst performing the calculation supported by technical documentation, to be provided on request by the market surveillance authority, including:

- Bill of material of the product (evidencing parts that are potentially recyclable);
- Recycling rate (RCR) for each considered recyclable material (including reference) estimated on the basis of the adopted EoL scenario (developed according to procedure set in the guidance document on the Recyclability Rate);
- References for the adopted values of $D_{n,i}$, $V_{n,i}$ and $R_{n,I}$ for each considered material;
- Assumptions and references used for the calculation of the terms (Mn) and (Un).

Guidance document on Energy Recoverability Benefit rate

Definitions:

- *Recovery:* Means any of the applicable operations provided for in Annex II B to Directive 2006/12/EC of the European Parliament and of the Council of 5 April 2006 on waste [EU, 2009b].
- *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 [EU, 2009b].
- *Energy recoverable material:* Material of the product that is potentially suitable for energy recovery.
- *Energy Recoverability Benefit rate:* Index for the prioritisation of resources based on the potential benefits that can be achieved from their energy recovery

Method:

$$ER_{\mathrm{cov},n} = \frac{\left(\eta_{el} \cdot \sum_{i=1}^{Q} RVR_i \cdot m_{re\mathrm{cov},i} \cdot HV_i\right) \cdot El_n + \left(\eta_{heat} \cdot \sum_{i=1}^{Q} RVR_i \cdot m_{re\mathrm{cov},i} \cdot HV_i\right) \cdot Heat_n - \sum_{i=1}^{Q} m_{re\mathrm{cov},i} \cdot I_{i,n}}{\sum_{j=1}^{M} \sum_{i=1}^{N} m_{i,j} \cdot V_{n,i,j} + M_n + U_n + \sum_{j=1}^{M} \sum_{i=1}^{N} m_{i,j} \cdot D_{n,i,j}} \cdot 100$$

- $ER_{cov,n}$ = Energy Recoverability Benefit rate for the n^th impact category [%];
- η_{el} = energy efficiency for the production of electricity in the incineration plant (default value assumed 0.3) [%];
- *RVRi* = Recovery rate of the i^th energy recoverable material (see guidance document of Recoverability Rate) [%];
- $m_{recov,i}$ = mass of the i^th energy recoverable material [kg];
- *HVi* = High heating value of the i^th energy recoverable material [MJ/kg];
- η_{heat} = energy efficiency for the production of heat in the incineration plant (default value assumed 0.6) [%];
- El_n = Average impact for the production of electricity in the EU27 for the n^th impact category (calculated on life cycle inventory data from ELCD database[118]) [unit/MJ];
- $Heat_n$ = Average impact for the production of heat in the EU27 for the n^th impact category (calculated on life cycle inventory data from ELCD database[119]) [unit/MJ];
- $I_{i,n}$ = Impact of the incineration of material i^th for the n^th impact category [unit/kg];
- $V_{n,i,j}$ = impact related to the n^th impact category for the production (as virgin) of the i^th material of the j^th part [unit/kg];
- $D_{n,i,j}$ = impact related to the n^th impact category for the disposal of the i^th material of the j^th part [unit/kg];
- *Mn* = impact related to the n^th impact category for the manufacturing of the product [unit];
- *Un* = impact related to the n^th impact category for the use of the product [unit];
- *Q* = number of energy recoverable materials.

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[118] Average European data can be referred to the module ‘Electricity Mix AC; consumption mix, at consumer; 1kV - 60kV’ of ELCD database [ELCD, 2012].

[119] Average European data can be referred to the module ‘Heat; residential heating systems from natural gas, condensing boiler, max. heat output 14,9 kW; consumption mix, at consumer; at a temperature level of 55°C’ of ELCD database [ELCD, 2012].

Verification:

The verification of the Energy Recoverability Benefit rate is based on the declaration of the analyst performing the calculation supported by technical documentation, to be provided on request by the market surveillance authority, including:

- Bill of material of the product (evidencing parts that are potentially energy recoverable);
- Recovery rate (RVR) for each considered energy recoverable material (including reference) estimated on the basis of the adopted EoL scenario (developed according to procedure set in the guidance document on the Recoverability Rate);
- References for the adopted values of high heating value HV_i for each considered energy recoverable material;
- References for the adopted values of $D_{n,i}$ and $V_{n,i}$ for each considered energy recoverable material;
- Assumption and references used for the calculation of the terms (Mn) and (Un).

Annex 3 – Guidance Document on ‘Recycled content’

Guidance document on Recycled content

Definitions:

- *Recycled content*: Proportion, by mass, of recycled material in a product or packaging [ISO 14021, 1999][120].
- *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 [ISO 14021, 1999].
- *Traceability*: the ability to trace materials and/or products sequentially throughout a manufacturing process and/or value chain in a way that is verifiable through objective evidence [SCS, 2011].

Method:

$$R_{Content} = \frac{\sum_{i=1}^{K} m_i \cdot r_{Cont,i.}}{m} \cdot 100 \quad [\%]$$

- $R_{Content}$ = Post-consumers recycled content of the product [%];
- $m_{.}$ = overall mass of the product [kg].
- $m_{i.}$ = mass of the ith part of the product having a post-consumer recycled content [kg];
- K = Number of parts of the product having a post-consumer recycled content;
- $r_{Cont,i}$ = post-consumers recycled content of the ith part of the product, calculated as:

$$r_{Cont} = \frac{Mass\ of\ \ post-consumer\ recycled\ material\ in\ the\ part}{Mass\ of\ \ the\ part} \cdot 100 \qquad [\%]$$

Verification:

The analyst performing the calculation shall provide a declaration of the recycled content of post-consumer materials in the products. The declaration shall be supported by the technical documentation (to be provided on request by the market surveillance authority) including:

- documented practises that assure the traceability of the product and its constituting materials and components (according to the standard EN 15343 [CEN15343, 2007]);
- records of the amount and types of recycled materials used in the product for the previous four consecutive quarters preceding the declaration.
- a diagram and description of the flows of post-consumer recycled materials in the manufacturing process;
- declarations from each supplier of post-consumers recycled materials (or of components embodying post-consumers recycled materials).;
- records that demonstrate an active business relationship with each supplier of recycled post-consumers materials.

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[120] Recycling content may make sense only to recycling markets which are neither profitable nor mature as, for example, plastics or technical glass.

Guidance document on Recycled Content benefit

Definitions:

- *Recycled content*: Proportion, by mass, of recycled material in a product or packaging [ISO 14021, 1999][121]
- *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 [ISO 14021, 1999].
- *Traceability*: the ability to trace materials and/or products sequentially throughout a manufacturing process and/or value chain in a way that is verifiable through objective evidence [SCS, 2011].

Method:

$$RCB_n = \frac{\sum_{i=1}^{K} m_i \cdot r_{cont,i} \cdot \left(V_{n,i} - R_{n,i}\right)}{\sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot V_{n,i,j} + M_n + U_n + \sum_{j=1}^{P}\sum_{i=1}^{N} m_{i,j} \cdot D_{n,i,j}}$$

- RCB_n = Recycled Content Benefits index of the product related to the nth impact category [unit];
- m_i = mass of the i^{th} part of the product having a post-consumer recycled content [kg];
- $r_{cont,i}$ = post-consumers recycled content of the ith part (calculated according to the "Guidance document on Recycled content") [%];
- $V_{n,i}$ = Environmental impact for the n^{th} impact category for the production as virgin of the i^{th} material [unit/kg];
- $R_{n,i}$ = Environmental impact for the n^{th} impact category for the recycling of the i^{th} material [unit/kg];
- $m_{i,j}$ = mass of the ith material of the jth part [kg];
- $V_{n,i,j}$ = impact related to the nth impact category for the production of the virgin material ith of the jth part [unit/kg];
- M_n = impact related to the nth impact category for the manufacturing of the product [unit];
- U_n = impact related to the nth impact category for the use of the product [unit];
- $D_{n,i,j}$ = impact related to the nth impact category for the disposal of the material ith of the jth part [unit/kg];
- K = Number of parts of the product having a post-consumer recycled content.
- P = number of parts of the product;
- N = number of materials in the jth part of the product.

Verification:

The analyst performing the calculation shall provide a declaration of the recycled content of post-consumer materials in the products. The declaration shall to be supported by the technical documentation foreseen in the "Guidance document on Recycled content" (to be provided on request by the market surveillance authority).

In addition, the analyst shall provide

- References for the adopted values of $D_{n,i}$, $V_{n,i}$ and $R_{n,I}$ for each considered material;
- Assumptions and references used for the calculation of the terms (*Mn*) and (*Un*).

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[121] Recycling content may make sense only to recycling markets which are neither profitable nor mature as, for example, plastics or technical glass.

Annex 4 – Guidance Document on the ‘Use of hazardous substances’

Guidance document on the Use of hazardous substances

Definitions:

- *Hazardous substance:* substance identified as hazardous to human health and/or the environment according to current legislation or other criteria.
- *Key component:* component containing hazardous substances.
- *Disassemblability:* degree of easy disassembly (Mok et al., 1997).

Method:

The method for the assessment of components using hazardous substances includes[122]:

Step 1. Definition of the set of substances to be considered.

Step 2. Identification of components embodying the considered substances.

Step 3. Identification of treatments for the EoL of the component and potential risks.

Step 4. Identification of key components.

Verification:

The above method for the assessment of components using hazardous substances aims at identifying key substances and components of the product. This method could be run when analysis of product groups are performed[123]. This method therefore does not foresee a verification process.

Verification is instead needed when specific measures are set to improve the EoL of key components as, for examples, concerning measures to improve the ‘disassembly of the key components’.

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[122] Details of the method’s steps are provided in Section 4.5.

[123] For example, during the development of preparatory studies.

Annex 5 – Guidance Document on Durability

Guidance document on Durability

Definitions:

- *Durability:* the ability of products to maintain their functions and performances over their life-cycle.
- *Operating time*: Average time frame during which the product is supposed to be used.
- *Extension of operating time*: Estimated time frame extension of the operating time that can be achieved due to specific design and maintenance actions

Method:

$$D'_n = \frac{\frac{P_n}{T} \cdot X + \frac{D_n}{T} \cdot X - (1-\delta) \cdot U_n \cdot X - R_n}{P_n + U_n \cdot T + D_n}$$

- D'_n = Simplified Durability index of the considered product for the impact category “n” [%];
- P_n = Environmental impact for category “n” for the production of the considered product (including the production of raw materials and manufacturing) [unit];
- T = Operating time of the considered product [year];
- D_n = Environmental impact for category “n” for the disposal of the considered product [unit];
- X = Extension of operating time of the considered product [year];
- U_n = Environmental impact per unit of time for category “n” for the use of the considered product [unit/year];
- R_n = Environmental impacts for category “n” for additional treatments (e.g. repairing, refurbish) necessary for the extension of operating time T of the considered product [unit].
- δ = Percentage representing the lower impacts of a new product that could substitute the considered product [%].

Note 1: negative values of the durability index imply that there is not an environmental convenience into extending the operating time of the product

Note 2: value of X should be based on the expert judgment upon the considered product. Whenever large uncertainties rise, it is recommended a sensitivity analysis of the parameter.

Note 3: value of δ should be based on the analysis of the product category. Whenever large uncertainties rise, it is recommended a sensitivity analysis of the parameter.

Annex 6 – Market surveillance

The previous guidance documents illustrated the methods for the assessment of project parameters (RRR, use of priority resources, use of hazardous substances, durability). Guidance documents also introduced the verification procedures. Verifications should be carried out by market surveillance authorities. The present Annex illustrates some key issues concerning the conformity assessment of products and the market surveillance according to the current European legislation.

The Regulation (EC) No 765/2008 provides a framework for the market surveillance of products to ensure that those products fulfil requirements concerning, among the other, the protection of consumers and of the environment [EU, 2008c]. According to the Regulation 765/2008, it is defined that:

- ‘market surveillance authority’ means “an authority of a Member State responsible for carrying out market surveillance on its territory”;
- ‘market surveillance’ means “the activities carried out and measures taken by public authorities to ensure that products comply with the requirements set out in the relevant Community harmonisation legislation and do not endanger health, safety or any other aspect of public interest protection”.
- ‘conformity assessment’ means “the process demonstrating whether specified requirements relating to a product, process, service, system, person or body have been fulfilled”;
- ‘harmonised standard’ means “a standard adopted by one of the European standardisation bodies […] laying down a procedure for the provision of information in the field of technical standards and regulations […]”

Member States shall appoint the national accreditation bodies and shall organise and carry out the market surveillance.

On such purpose “market surveillance authorities shall perform appropriate checks on the characteristics of products on an adequate scale, by means of documentary checks and, where appropriate, physical and laboratory checks on the basis of adequate samples […]. Where economic operators present test reports or certificates attesting conformity issued by an accredited conformity assessment body, market surveillance authorities shall take due account of such reports or certificates” [EU, 2008c].

Market surveillance shall ensure that “products covered by Community harmonisation legislation which […] do not conform to applicable requirements set out in Community harmonisation legislation are withdrawn or their being made available on the market is prohibited or restricted and that the public, the Commission and the other Member States are informed accordingly” [EU, 2008c].

Annex 7 – Summary of comments on reports produced during Phase I of the project

Author of comment (Type)	**Item**	**Comment**	**How comment was / is addressed in the two phases of the project**	
			Phase I[124]	**Phase II**[125]
WRAP (Environmental organization)	1	How economic viability of re-use is addressed?	Out of the scope	The re-usability assessment method will contain a condition on the technical and economic viability of re-use
	2	How the sociological / psychological of re-use is addressed	Out of the scope	Out of the scope: the study focuses on the assessment of re-usability of product / components
	3	Did you consider the WRAP studies?	Not considered	WRAP studies available in the website concerning the recycled content have been cited. Studies related to recyclability have been not cited because not found (links suggested do not work)
	4	Glass recycling	The text was referring to loss of quality of technical glass due to recycling. However the comment is not relevant for the development of the method	Not considered
	5	Correlation GWP – Energy consumption	GWP was only an example. The project underlined the relevance of multi-criteria approach	Multi-criteria analysis is proposed
	6	Reuse and displacement of products	It is considered that the reuse of components for remanufacturing of product (and not the re-use as whole). It is assumed that the reused components (after minor treatment) substitute the manufacturing of the new component.	Same as for Phase 1.
Hewlett-Packard (Industry / Trade association)	1	It is not supported the Risk-phrase philosophy used in most eco labels and GPP criteria	The project performed a survey of ecodesign criteria already applied by environmental labelling schemes (including those based on risk phrases)	Method for the use of hazardous substances has been refined, focusing more on EoL treatments of components containing haz. sub. Requirements based on the risk phrases have been omitted.
	2	What assessment method and which endpoints should be included in a hazard assessment?	Assessment of hazard is out of the scope of the project	Out of the scope :the hazard is supposed to be known
	3	Which information is available and will not be available via REACH?	REACH Directive was part of the survey of current legislation on hazardous substances. However, a deep analysis of the REACH Directive and potential interaction with product policies was out of the scope.	Out of the scope
	4	Suggestion to consider the 'Green Screen assessment method'	Not considered	The suitability of the method for the project's purposes has been investigated in Phase II (Report n° 3)
Federal Environment Agency Germany (Member State)	1	the method should be checked for more complex products,	Not considered	Practicability of the refined methods has been tested on three new more complex case-studies
	2	other methods have been assessed for their usability, like Environmental Impact Index (Atlee et. al. 2006) or "Quotes for environmentally Weighted Recyclability and Eco-Efficiency" (QWERTY/EE), (Huisman et. al. 2006)	QWERTY method has been considered in the survey of available methods, and it was at the basis of the development of method for RRR benefits indices.	Study of Atlee and Kirchain considered for the revision of the methods

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[124] Ardente, F., Wolf,M.A., Mathieux,F., Pennington,D., Reports of the project : "Integration of resource efficiency and waste management criteria in the implementing measures under the Ecodesign Directive": Case study. 2011, European Commission - Joint Research Centre: Ispra (Italy). http://lct.jrc.ec.europa.eu/assessment/projects#d (access on 30/07/2012).

[125] Ardente, F., Mathieux,F., Reports of the Project "Integration of resource efficiency and waste management criteria in European product policies – Second phase": Revised methodologies and guidance documents. 2012, European Commission - Joint Research Centre: Ispra (Italy)

	3	The indices for mechanical disassembly need to be rechecked. […] According to Chancerel the values are for silver below 20 %, gold and palladium about 20 % and copper about 60 %.	Not considered	The method for the assessment of disassemblability has been revised, to be in line also with IEC/TR 62635 method. Studies and data from Chancerel have been considered
	4	In case, that a company needs to calculate indicators, the affordability for manufacturers, especially for small and medium sized companies should be assessed.	Not considered	Not all indices are recommended for direct calculation by companies (but more for high level assessment or preparatory studies). Potential efforts for analysts have been qualitatively estimated
	5	it would be interesting to compare several models of one product type	Not considered	It has been considered in the analysis of the washing machine product group, where two largely different products have been considered
	6	The use of indicators like reusability and recyclability also need to be assessed in correlation of the reality of electronic waste collection and treatment.	Not considered	The collection is out of scope of the project. The reality of the treatment of electr(on)ic waste has been considered through interactions with several representative recyclers and a professional association.
GDF Suez (Recycler)	1	- A broader initial question might also have been addressed, whether resource efficiency (RE) requirements could be applied at points of intervention upstream of the product itself. - to create a coherent set of resource RE indicators at national and regional level (DMI, DMC, TMR, TMC, final energy input, etc)	Not considered	Methods developed focused on the ecodesign of the product. The relevance of raw materials has been partially assessed in the "high level" assessment, and afterwards at the product's life-cycle level. Other set of high level resource efficiency indicators were out of the scope.
	2	To translate the present model into a workable regulatory system is likely to prove extremely challenging	Not considered	Methods have been revised (also according to standards under development as e.g. IEC/TR 62635) to be simplified and more workable.
	3	A model that articulates RE indicators at a site or sectoral level allows indicators such as DMI and TMC to be defined at national level, to be cascaded down to individual sectors depending on their material use, and then applied at site level via a BOM	Not considered	Out of scope (see similar comment on point 1)
	4	We recommend that the project revisits the issue of reuse, its relationship to disassembly	Not considered	Methods have been revised (also according to standards under development as e.g. IEC/TR 62635) especially concerning the assessment of disassemblability.
	5	An extension of the project could usefully explore the linkages between the ecodesign of a product, and claims made for the product. For example, Ecolabel Regulation asks that criteria be developed to assess "the potential to reduce environmental impacts due to durability and reusability of products".	Not considered	Method for reusability was revised, while method for durability has been introduced.
	6	Implications for new value chain relationships	Not considered	This comment is valuable (also in line with considerations from Phase 1). However suggestions refer to policy actions that are out of the scope of the project
	7	Transferability of existing directives	Not considered	This comment is valuable. However suggestions refer to policy actions that are out of the scope of the project
European Environmental Bureau (Federation of environmental organisations)	1	The RRR benefit ratios are not crystal clear	Not considered	The three RRR benefits ratios have been revised and clarified, based on the modifies of the RRR ratios and the life cycle impacts of the product
	2	The part on hazardous substances is clear, but potentially overlapping for some substances already regulated by REACH/RoHS/CLP	Not considered	The assessment of the use of hazardous substances has been revised, focusing on the EoL of the product and potential impacts for the humans and the environment that could arise during the EoL treatments.
	3	Evaluating contamination risk from the BOM may be limited as different products are mixed together in shredding process	Not considered	Methods have been revised. According to the IEC/TR 62635, contamination issues are considered for the calculation of the actual recycling/recovery rates.

European Commission
EUR 25461 EN – Joint Research Centre – Institute for Environment and Sustainability

Refined methods and Guidance documents for the calculation of indices concerning Reusability/Recyclability/Recoverability, Recycled content, Use of Priority Resources, Use of Hazardous substances, Durability. European Commission. Joint Research Centre. Institute for Environment and Sustainability. Report n° 3 of the project “Integration of resource efficiency and waste management criteria in European product policies – Second phase”. September 2012

Ardente Fulvio, Fabrice Mathieux

Luxembourg: Publications Office of the European Union

2012 – 105 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424

ISBN 978-92-79-25931-9

doi: 10.2788/42590

Abstract:
The present Report refines the methods for the assessment of the following parameters: reusability/recyclability/recoverability-RRR, use of relevant resources, recycled content, use of hazardous substances, durability. These methods are derived from those developed during the first phase of the project (Ecodesign Phase 1), refined according to comments received from stakeholders and according to the application to new product groups (see Report n° 2) and the alignment to new published studies and/or studies currently under development. The report is structured in 5 chapters, one for each method. Each chapter is then subdivided into:

- Introductory part, which analyzes additional relevant references for the revision of the method;
- Developed method, including the description of main indices and potential variants;
- Procedure for the verification of the calculation of indices
- Guidance documents (in the Annexes) summarizing the developed methods and main indices

LB-NA-25461-EN-N

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ISBN 978-92-79-25931-9

Publications Office