Combining five criteria to identify relevant products measures for resource efficiency of an energy using product

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Abstract

Product recovery at end-of-life (EoL), initially focusing on the reduction of residual (hazardous) waste, is currently being enlarged and now link with emerging issues such as "resource efficiency" and "use and management of Critical Raw Materials". However, for many environmental aspects, product's measures considered by current policies and industry practices are not always consistent, nor optimized. It can be concluded that there is currently no systematic and consistent integration of EoL and resource efficiency measures in product design practices and in product policies and this should be improved. The paper proposes a new integrated method to assess the resource efficiency performances of products and to derive relevant product's measures for improvement. The assessment is based on five different criteria: reusability/recyclability/recoverability - RRR - (per mass and per environmental impacts); recycled content (per mass and per environmental impact); use and management of hazardous substances. The paper briefly describes the assessments methods proposed for each of these criteria. The methods are based on existing literature and technical documents, and have been adapted to this particular aim. The proposed method is presented and discussed on the basis of a Energy using Product (EuP) case-study: a LCD-TV.

Keywords:

Ecodesign, Energy using Products (EuP), Design for recycling, Recyclability, Recycled content, LCA, policy

1 INTRODUCTION

In 2011 the European Commission (EC) published its "Roadmap to a Resource Efficient Europe" indicating objective, strategies, milestones and actions to be undertaken in order to improve the resource efficiency of the European Union (EU) [1]. Among the others the EC will "*stimulate the secondary materials market and demand for recycled materials through economic incentives and developing end-of-waste criteria*" and "*assess the introduction of minimum recycled material rates, durability and reusability criteria and extensions of producer responsibility for key products*" [1].

Some principles of the EC roadmap have been already put into practice in several pieces of legislations as, for example, in the setting of minimum recycling and recovery rates (in mass) for Waste of Electrical and Electronic Equipment (WEEE) [2], limitation of use of hazardous substances [3], improvement of durability of Energy Using Products (EuP) [4] or in the setting of minimum thresholds for some Ecodesign criteria as reusability / recyclability / recoverability (RRR) in mandatory [5] or voluntary [6] policies. Analogously, ecodesign practises addressing some of these principles have been discussed by academics and are being applied by industries [7; 8]

However, for many environmental aspects, product criteria considered by these policies and practices are not always consistent. Furthermore, it has been evidenced the need to develop tools to help designers make better decisions while designing a product, following a multi-criteria approach [9; 10; 11]. This is in particular the case for EoL performances of products. It can be concluded that currently there is no systematic and consistent integration of EoL and resource efficiency criteria in product design practices and in product policies (e.g. EU Ecodesign Directive or Ecolabel) and this should be improved.

The paper introduces a new integrated method to assess the resource efficiency of EuP based on a multi-criteria analysis and to derive relevant product's measures for the improvement. Based on a review of the scientific literature (see for example, [8;12]) some relevant criteria have been identified. Among these the following five criteria have been considered currently as the most robust and applicable for the purpose of the analysis and have been embodied in the method: reusability / recyclability / recoverability - RRR (per mass and per environmental impacts); recycled content (per mass and per environmental impact); use and management of hazardous substances. Some other potentially relevant criteria for the analysis have been identified, including: durability, design for source reduction (dematerialisation) and design for the use of renewable materials. However, indexes to quantitatively assess these criteria are still to be developed. Therefore these criteria have been not considered in the method but could be potentially introduced in future developments.

Section 2 presents the general method while Section 3 introduces the indices used for the assessment. Section 4 illustrates the implementation of the method on an exemplary product, an LCD-TV, so that hot-spots of the product can be identified. Section 5 discusses, based on the results of the case study, the identification and assessment of product's measures, in particular for potential use in product policies.

2 METHOD FOR THE IDENTIFICATION AND ASSESSMENT OF PRODUCT'S MEASURES

We introduce a new method for the identification and assessment of measures, against a set of five selected criteria, to improve the resource efficiency of products at the EoL. The method is composed of the following steps (Figure 1):

Step 1. Selection and characterization of the product(s), including the collection of data (Bill of Materials, disassembly information) and the calculation of lifecycle impacts.

Step 2. Assessment of the product against a selected set of criteria. This is further subdivided in:

2.1 Definition of EoL scenario(s). EoL scenario(s) for the case-study product(s) are defined, representative of the current or future EoL treatments.

2.2. Calculations and assessment of qualitative and quantitative indices for the selected criteria.

Step 3. Identification of product's 'hot spots' for resources

Article submitted to the "20th CIRP International Conference on Life Cycle Engineering, Singapore, 2013"

efficiency, meaning product's components that are relevant for some criteria and for the considered EoL processes. This step is further subdivided in:

3.1.a Identification of key components (for hazardous substance).
3.1.b Identification of losses for the selected indices. 'Losses' occur when product's parts can grant high benefits at EoL (in terms of reused/recycled/recovered masses or in terms of environmental benefits) but this potential is only partially exploited due to the current EoL treatments.

3.2. Identification of hot spots. Results of the previous steps identified key components for some of the considered criteria. This new step combines these results to identify 'hot spots' at the product level.

Step 4. Identification of potentially relevant measures at the product level, which could contribute to the improvement of the product performances (e.g. contributing to the reduction of the losses) Measures are therefore tested to assess if and how they can produce, at the case-study level, some relevant lifecycle benefits.

Step 5. Assessment of policy measures at the 'product group' level. The last step consists in the extension of the analysis from the 'case-study' level to the 'product group' level. Performances of products representative of the considered product category are assessed over the considered EoL scenario(s).

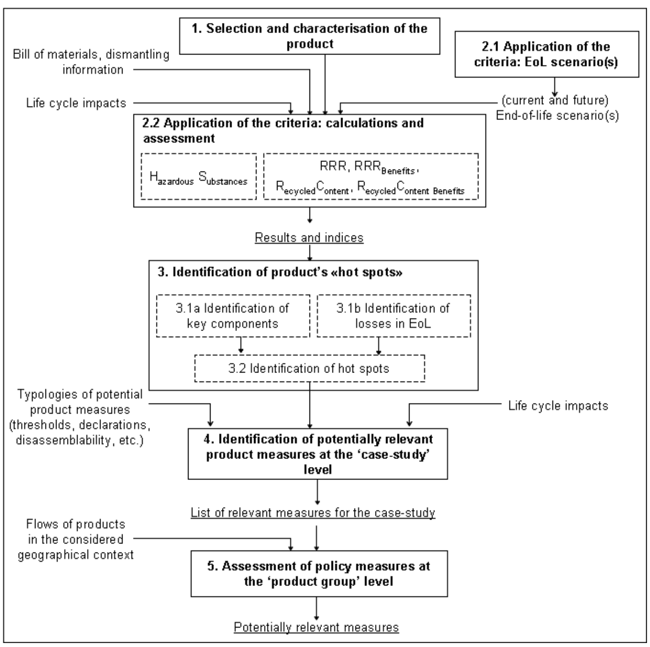

Figure 1: assessment of product's resource efficiency measures

3 INDICES FOR THE ASSESSMENT OF SELECTED CRITERIA

The present section presents a set of qualitative and/or qualitative indices for each criterion selected for the analysis of resource efficiency of products at the EoL (a more detailed description of the indices is illustrated in [13]).

- *Reusability/Recyclability/Recoverability (RRR) rates* (in mass)

The three Reusability/Recyclability/Recoverability (RRR) indexes in terms of mass rates can be calculated as:

$$RRR = \frac{\sum_{i=1}^{P} m_i \cdot X_{RRR,i}}{m} \cdot 100$$

where:

- RRR = Reusability / Recyclability / Recoverability rates [%];
- m_i = mass of the i^{th} part of the product [kg];
- $X_{RRR,i}$ = Rates of the i^{th} part of the product that is potentially reusable / recyclable / recoverable [%];
- P = number of parts of the product [dimensionless];
- m = total product's mass [kg].

This equation summarizes the structure of the three indices. Their structure is consistent with the formulas of the standard IEC/TR 62635 [14].

- *Reusability/Recyclability/Recoverability (RRR) rates (in terms of environmental impacts/benefits)*

The RRR rates (in terms of environmental impacts/benefits) are based on the RRR rates previously introduced with the inclusion of the lifecycle impacts about: production of virgin materials, manufacturing of the product, recycling and production of secondary materials, transport and disposal. These indexes have been named 'RRR Benefit Rates'. For example the rate for the Re

$$R_{cyc,n} = \frac{\sum_{i=1}^{P} \left(m_{recyc,i} \cdot X_{recyc,i} \cdot D_{n,i}\right) + \sum_{i=1}^{P} \left[m_{recyc,i} \cdot X_{recyc,i} \cdot \left(k_i \cdot V^*_{n,i} - R_{n,i}\right)\right]}{V_n + M_n + U_n + D_n} \cdot 100$$

where:

- $R_{cyc,n}$ = 'Recyclability benefit' rate (for the "n" impact category) [%];
- $m_{recyc,i}$ = mass of the i^{th} recyclable part of the product [kg];
- V_n, M_n, U_n, D_n = impacts (for the "n^{th}" impact category) due to the production of virgin materials, manufacturing, use and disposal of the product [unit][1];
- $V^*_{n,i}$ = impact (for the "n^{th}" impact category) due to the production (as virgin) of the material assumed to be substituted by the i^{th} recyclable material of the product [unit/kg];
- $R_{n,i}$ = impact (for the "n^{th}" impact category) due to the recycling of the i^{th} recyclable part [unit/kg];
- k_i = downcycling factor [dimensionless][2].

Similar equations can be developed for the 'Reusability benefit' and the 'Recoverability benefit' rates (for further details see [13]). These indexes are based on several scientific works (e.g. [8]).

- *Recycled content rate (in mass)*

The method for the calculation of the recycled content is substantially consolidated and standardised in the technical literature (e.g. by [15]). It accounts for the rate of recycled masses (overall or of certain materials) in the product's mass.

- *Recycled content rate (in terms of environmental impacts/benefits)*

The "Recycled content benefit" rate calculates, in a lifecycle perspective, the environmental benefits (for certain impact categories) that can be achieved by introducing some recycled materials during the manufacturing of the product:

$$RCB_n = \frac{\sum_{i=1}^{P} m_{r,i} \cdot \left(V_{n,i} - R^*_{n,i}\right)}{V_n + M_n + U_n + D_n} \cdot 100$$

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1 The unit of measure depends on the selected impact category.

2 The downcycling factor 'k' takes into account factors that "depreciate" the quality of the materials after their recycling (e.g. contamination among materials and loss of physical performances due to the treatments). For further details see [12].

Where symbols previously not introduced are:

- RCB_n = recycled content benefit rate of the product (for the "n^{th}" impact category) [%];
- $R^*_{n,i}$ = impact (for the "n^{th}" impact category) of the recycled material used for the i^{th} product's part [unit/kg];
- $m_{r,i}$ = mass of the i^{th} recycled material in the product [kg].

  - *Use of hazardous substances*

The use of hazardous substances (HS) can largely affect the EoL treatments of products. However this influence is related to several issues (including safety, environmental impacts and legislation in force) and cannot be translated into a simple formula. The use of HS can be assessed qualitatively, according to the following method:

Step 1. Definition of the set of substances to be considered for the analysis. The set shall include regulated substances and components and others substances and components as suggested by feedback from manufacturers and/or recyclers as potentially dangerous (as also suggested by the IEC 62635 [14]).

Step 2. Identification of parts of the product that contain the considered substances (quantities and typologies).

Step 3. Identification of current treatments for the EoL of these parts. It is necessary to identify the recovery treatments that the components will undergo at EoL and potential related impacts for workers and the environment.

Step 4. Identification of 'hot spots'. These are components that have a content of HS that is critical for the identified EoL treatments.

4 ANALYSIS OF A CASE-STUDY PRODUCT: LCD-TV

The objective of the analysis is the testing of the proposed method and indices to a EuP case-study: a LCD-TV (20.1 inches) with an integral Cold Cathode Fluorescent Lamp (CCFL) backlight system. Performances of the product have been analyzed in order to identify hot spots of the product and to identify potentially relevant policy measures to improve resource efficiency.

Data about the Bill of Materials (BOM) of the product have been collected in a WEEE recycling plant, while data concerning the dismantling and further recycling treatments have been collected from various recyclers. Product mass is largely composed by plastics (about 50%, mostly constituted by HI-PS frames and Polymethilmetacrylate – PMMA – board), metals (steel and aluminium, around 30%), electronic parts (around 15%, including LCD screen, Printed Circuit Boards – PCBs, capacitors), and other parts (CCFL, cables, fan, speakers).

A complete description of the product is provided in [16]. The EoL treatments that the product undergoes are based on two EoL scenarios (set in accordance to [14] and based on information collected from 4 representative European recycling plants):

- "Manual dismantling" scenario: the product is fully manually dismantled in order to separate potential hazardous components (e.g. CCFL, LCD screen, PCBs, capacitors) and other parts (mainly metals and plastics) for further treatments.
- "Mechanical Treatment" scenario: the product is mainly treated by special shredders (in a controlled environment). Shredded parts are subsequently mechanically sorted for recycling/recovery. Mercury is supposed to be sorted to avoid contamination of other parts and of the environment. Before the shredding, recyclers also implement some minor dismantling operations for a few key components, when economically viable or required by legislation.

Results of the indexes previously introduced are illustrated in Table 1, for the two EoL scenarios presented. The next step of the analysis consists in the interpretation of the results to identify product's 'hot spots'. Some identified 'hot spots' are discussed in the following sections and summarised in Table 2.

Indexes for resource efficiency			EoL scenarios	
			Dismantling	Mechanical treatment
Reusability	(in mass)	[%]	0%	0%
Recyclability	(in mass)	[%]	75.3%	34.5%
Recoverability	(in mass)	[%]	79.7%	49.0%
Reusability benefit	(for all impact categories)	[%]	0%	0%
Recyclability benefit	(Climate change)	[%]	6.6%	2.7%
	(Acidification)	[%]	19.5%	5.9%
	(Photochemical oxidant)	[%]	12.7%	4.2%
	(Ozone depletion)	[%]	1.2%	0.8%
	(Respiratory effects)	[%]	18.6%	6.2%
	(Eutrophication freshwater)	[%]	15.9%	5.5%
	(Eutrophication marine)	[%]	10.9%	3.5%
	(Human toxicity)	[%]	65.7%	32.1%
	(Aquatic Ecotoxicity)	[%]	47.9%	17.9%
	(Terrestric ecotoxicity)	[%]	50.4%	23.7%
	(Abiotic Depl. - element)	[%]	95.2%	24.8%
	(Abiotic Depl.-fossil)	[%]	8.3%	2.5%
Energy Recoverability benefit	(Abiotic Depl.-fossil)	[%]	2.8%	1.9%
Recycled content	(in mass)	[%]	0%	0%
Recycled content benefit	(Abiotic Depl.-fossil)	[%]	0%	0%
Use of hazardous substances			o CCFL (for the content of mercury) o LCD (for the content of heavy metals) o Capacitors (for the potential content of polychlorinated biphenyl) o PCBs (for the content of hazardous substances)	o CCFLs (for the content of mercury), which request a shredding treatments in a controlled environment o LCD (for the content of heavy metals), which requires preventive separation before shredding o Capacitors (for the potential content of polychlorinated biphenyl) which request 'hand picking' after shredding o PCBs (for the content of hazardous substances)

Table 1: Results of resource efficiency analysis.

Criteria	Hot spots
Reusability (in mass)	(none)
Recyclability (in mass)	LCD; large plastic parts (HI-PS frames; PMMA board)
Recoverability (in mass)	(none)
Reusability benefit (environmentally based)	(none)
Recyclability benefit (environmentally based)	PCB; PMMA board
Recoverability benefit (environmentally based)	(none)
Recycled content	large plastic parts (HI-PS frames;
Recycled content benefit (environmentally based)	(none)
Use of hazardous substances (HS)	CCFL; LCD; PCB

Table 2: LCD-TV's 'hot spots' for resource efficiency.

4.1 Hot spots for reusability

According to the interviewed recyclers, parts of LCD-TVs are currently not reused, both for economic and technical reasons. Although all the product's parts could be potentially reusable, current EoL treatments do not allow separation for reuse. Furthermore, special design alternative of the product would not have the effect of improving the reusability. For these reasons, it is assessed that the LCD-TV has no hot-spots for the reuse, both in terms of mass and environmental benefits.

4.2 Hot spots for recyclability (in mass)

The analysis of the recyclability (in mass) showed a large discrepancy between the two EoL scenarios. This is due to the performing processes (for the yield) in the "dismantling" scenario for the sorting of recyclable parts, mainly circuit boards and other electronics, large plastic fractions (HI-PS frames and the PMMA - board). On the other hand, the Recyclability rate in the "mechanical treatment" scenario is much lower. The shredding with mechanical sorting is, in fact, characterized by lower recycling percentages for common metals and, especially, for precious metals and plastic parts.

Hot spots for recyclability in mass therefore concern large plastic parts (HI-PS and PMMA board): they have been assumed as recyclable in the dismantling scenario while will be largely lost in the mechanical treatment, especially the PMMA that is not sorted by current mechanical treatments.

A large loss of mass during the EoL treatments is due to the LCD screen, which is also considered as a product hot spot. According to consulted recycling companies, LCDs are currently landfilled or, in some cases, temporary stored in prevision of the availability of future recycling technologies. In particular LCDs are relevant for their content of indium. Small amounts of indium are currently recycled due to lack of infrastructures and low prices of the metal [17]. However some exemplary recycling processes are currently under research and development (see for example [18]).

4.3 Hot spots for recyclability (environmentally based)

The analysis of the Recyclability benefit indexes confirmed the large discrepancy between the two considered scenarios. In particular, the analysis focused on losses of the potential environmental benefits due to different recycling rates of materials in the different EoL treatments.

It is observed that large losses of efficiency between the two scenarios occur for almost all the considered impact categories. In particular the most significant loss (over 70%) is related to the 'Abiotic Depletion – element' (ADP-Elements) category. Other relevant losses (from 20% to 30%) regard also the 'Human Toxicity', 'Freshwater Aquatic Ecotoxicity' and 'Terrestric ecotoxicity'.

The further analysis of the results shows that losses are mainly due to the lower recycling rates of metals in PCBs in Scenario 2, which are rich in precious metals (gold, silver, and platinum group metals). Manual dismantling allows to increase the recycling rates of precious metals, otherwise largely dispersed in the dusts during the shredding.

PCBs are therefore assessed as TV's hot spots for the environmentally based recyclability. Furthermore, the PMMA board, already identified as relevant for the recyclability in mass, is also here assessed as relevant in term of potential environmental benefits achieved by its recycling. The loss in the recyclability of the PMMA in the mechanical treatment scenario causes, in fact, a loss of benefits from 2% to 4% for various impact categories.

4.4 Hot spots for recoverability

Concerning the Recoverability (in mass), it is observed a similar behaviour as observed for recyclability in mass. Manual dismantling scenario is generally optimized for the additional energy recovery of not recyclable fractions. The mechanical treatments scenario is instead affected by larger losses of plastics in the shredding residuals, which are only partially recovered.

Concerning the Energy Recoverability benefit, the manual dismantling scenario has still higher performances, mostly due to the selective sorting of plastics. In terms of 'Abiotic Depletion – fossil' (ADP-Fossil) impact category, the energy recovery of plastics of the products allows a benefits of 2.8% of the lifecycle impact of the product. The loss of benefits during the treatments in the two scenarios is however limited (less than 0.9% for ADP-Fossil). It is further highlighted that product's measures would not have the effect of increasing product recoverability. Furthermore according to the European waste hierarchy [19], energy recovery of products has lower priority. Therefore, no product's hot spot is identified as relevant for the energy recoverability criteria.

4.5 Hot spots for recycled content (in mass and environmentally based)

According to the analysis of the scientific literature, the analysis of the recycled content focused to some specific materials (especially polymers). The present section analyzes if the introduction of recycled polymers in the manufacturing process could produce relevant benefits. First of all the attention was focused on large HIPS parts, heavier than 200g (back cover, front cover and support). According to studies in the literature [20], primary HI-PS used for the frames of EEEs can be substituted by recycled materials without interfering with its functionality. By changing the potential content of HI-PS large parts from 10% to 70%, the recycled content (in mass, formula) of the product varies from 2% to 16%. Large plastics parts are therefore considered as 'hot spots' for the recycled content in mass.

Subsequently, the potential environmental benefits associated to these percentages have been calculated. The calculation has been related to the "ADP-Fossil" impact categories (assumed as most relevant for the analysis of this criterion). The analysis demonstrates that, for example, a 20% recycled content of HI-PS can allow a 0.2% saving of the overall lifecycle 'ADP-fossil'. A percentage of 70% of recycled HIPS in the TV would allow a 1.5% benefit for the same impact category. Being these benefits much lower that benefits achievable through e.g. the reduction of the consumption in the use phase (see e.g. [21]), it is concluded that, for the moment, there are no product's hot spots relevant for the Recycled content benefit criterion.

4.6 Hot spots for the use of hazardous substances (HS)

According to communications from recyclers, the main criticality for HS in LCD-TV is represented by the mercury in CCFL potentially dangerous if spread during both the dismantling scenario [22] and the shredding scenario [23].

In particular in the dismantling scenario, the major risk is represented by the breakage of the lamps during the dismantling, with potential high impacts for the health of workers and releases in the environment. Risks could be minimized by a careful design of the lamps (and their casing) to facilitate their extraction. The mechanical treatment scenario allows minimizing the risks for the workers, but on the other hand, it is affected by larger risks of contaminating other recyclable parts. Special shredders in a controlled environment are requested [22]. CCFL are therefore assessed as 'hot spots'.

Other potentially relevant parts for the content of HS (especially heavy metals) are the LCD screens, PCBs and capacitors. According to current legislation [2; 3], these parts have to be removed from any separately collected WEEE. According to the EoL scenarios, this can be performed manually (by dismantling and sorting) or after the shredding by mechanical sorting or hand-picking. LCD screen and PCBs are therefore assessed as 'hot spots' for HS. Instead, according to communications from manufacturers, modern capacitors are nowadays free of polychlorinated biphenyl, and therefore these parts are not considered as relevant for the analysis.

5 PRODUCT'S MEASURES FOR THE IMPROVEMENT OF RESOURCE EFFICIENCY

5.1 Identification of product's measures

This step of the analysis focuses on the identification of product's measures that can contribute to improve the performances of the product at its EoL for each criterion. Selected measures could be applied as mandatory requirements (set by legislation the in force, as e.g. the achievement of minimum thresholds for performances [4] or by the declaration of information, see e.g. [24]), voluntary approaches based on mandatory requirements (as environmental labelling systems, e.g. [25]) or voluntary actions (as environmental claims and declarations [15]).

The starting point is the result of Table 2. It is observed that some recurrent components of the product are relevant for one or more studied resource efficiency criteria and, in particular:

- PCBs are 'hot spots' for Recyclability benefits and the content of HS. Manual dismantling of these parts should be improved (e.g. by thresholds for the time for dismantling). The proposed measure could in the future help both EoL scenarios: dismantling scenario will be more economically viable and the mechanical treatments scenario can implement pre-dismantling stages in order to reduce losses. This measure can regard both mandatory and voluntary tools.
- LCD is a hot spot for Recyclability (in mass) and the content of HS. According to current treatments, LCDs are landfilled, causing large environmental burdens [26] but, also, the loss of relevant materials (e.g. indium). According to communication from recyclers, the recycling of LCD could be fostered by measures to improve its dismantlability and by the communication of some key information [16].
- Large plastics parts (e.g. HI-PS frames in the case-study) are 'hot spots' for Recyclability (in mass) and Recycled content (in mass). Marking of some large plastic parts has been identified as a possible measure to support sorting during the manual dismantling by recyclers. Concerning the improvement of Recycled content, this could be fostered by measures to communicate the content of recycled materials in the product (e.g. via standardized self-claims [15]) or by the setting of minimum thresholds of recycled plastics.
- PMMA board represent a special case among large plastic parts. It is assessed as a hot-spot for Recyclability (in mass and environmental benefits). Analogously to LCD and PCBs, measures to support dismantlability of PMMA part should be developed to support manual and mechanical EoL treatments.
- Finally CCFL are 'hot spots' for the content of HS. The treatment of mercury in lamps represents one of the biggest difficulties faced in the treatment of LCD-TV. Measures should be set in order to improve the design for the disassembly of such a component containing HS, supporting the 'dismantling' scenario and minor dismantling operations before the 'mechanical treatments'. Due to the high relevance of this issue, measures should be preferably set via mandatory requirements.

According to previous considerations, one exemplary measure targeting these components could be formulated:

"*The time for the dismantling of product's key components (i.e. PCBs, LCD, PMMA and CCFLs) shall be less than 240 sec*[3]".

This measure could be set via mandatory requirements as proposed in [4]. The threshold should be derived from an analysis of products currently available in the market.

5.2 Assessment of product's measure for the case-study

According to communications from stakeholders (manufacturers, recyclers, NGOs) [16], the full dismantling scenario is currently economically viable and extensively applied in the EU for the treatments of LCD-TVs. However there is plenty of evidence of technological progresses moving towards mechanical systems for the EoL treatments of LCD-TV, including open air shredders or 'encapsulated units' (i.e. sealed shredders operating in a controlled environment) [27]. It is estimated that the mechanical treatment scenario will be improved and installed in the EU in the next future, mostly because of its higher economic efficiency and reduced risks for workers [16].

According to interviewed stakeholders, the dismantling scenario will become less competitive in the near future unless actions to support this scenario will be undertaken [28: 16]. The previously introduced measure is intended to contribute in this sense to the improvement of product's dismantlability.

The next step of the analysis consists in the calculation of potential environmental benefits related to the application of the selected measures to the case-study. In particular, the calculation aims at assessing the potential environmental benefits when the LCD-TV is treated in the dismantling scenario instead than in the mechanical treatment scenario.

The benefits have been calculated in terms of masses of additional recyclable materials by comparing the recycling yields of the two EoL scenarios. Successively, the related lifecycle environmental benefits have been estimated and compared to lifecycle impacts of the product for 12 impact categories (cf. Table 2).

Environmental impact category	Climate change kg $CO_{2\text{-eq.}}$	Acidification kg $SO_{2\text{-eq.}}$	Photochemical oxidant kg $NMVOC_{\text{-eq}}$	Ozone depletion kg $CFC_{11\text{-eq.}}$	Respiratory effects kg $PM_{10\text{-eq}}$	Eutroph. freshwater kg $P_{\text{-eq}}$
A. Estimated benefits	15.12	0.40	0.08	3.3E-07	0.08	0.011
B. Lifecycle impacts LCD-TV	397.4	3.5	1.0	8.8E-05	0.75	0.1
(A / B) [%]	3.8%	11.5%	7.8%	0.4%	10.5%	9.9%
Environmental impact category	Eutroph. marine kg $N_{\text{-eq}}$	Human toxicirty kg $DCB_{\text{-eq.}}$	Acquatic Ecotoxicity kg $DCB_{\text{-eq.}}$	Terrestric ecotoxicity kg $DCB_{\text{-eq.}}$	Abiotic Depl. - element kg $Sb_{\text{-eq.}}$	Abiotic Depl.- fossil MJ
A. Estimated benefits	0.022	26.43	0.87	0.26	0.009	241.92
B. Lifecycle impacts LCD-TV	0.3	116.8	3.1	1.2	0.0	4195.6
(A / B) [%]	7.3%	22.6%	28.2%	21.7%	71.6%	5.8%

Table 3: Environmental benefits (A_n) brought by the product's measure, compared to life cycle performances (B_n) of LCD-TV.

It is possible to observe that most relevant benefits concern the ADP-Elements. Relevant are also the benefits related to several other categories, including Human toxicity, Terretric Ecotoxicity and Acquatic Ecotoxicity.

5.3 Assessment of product's measures at the 'product group' level

The last step of the analysis is the assessment of the potential benefits brought by product's measures for the whole 'product group', so that the measure can be compared to other potential measures. Benefits can be also normalized (e.g. to the impacts of the product group or the overall impacts of some geographical context) in order to assess their relevance for the considered scope of the analysis.

For the LCD-TV case-study, the product-level benefits (see Table 3) have to be multiplied by the number of televisions currently

[3] This threshold is only exemplary, based on preliminary observations at the recycling plants. The threshold should be further discussed together with recyclers and manufacturers, and should be also adapted to LCD-TV with different dimensions and to automatic dismantling initiatives (when developed).

introduced in the market. The analysis should also determine how the measure would potentially affect their EoL of the LCD-TV flows (see [13]). For the case study, it is expected that the implementation of the proposed product's measure would have the effect of supporting the economical and technical convenience of the dismantling scenario, by diverting a portion of waste flow from the 'mechanical' to the 'dismantling' scenario and hence obtaining higher recycling yields. Due to large uncertainties for these assumptions concerning future scenarios, it is recommended the set of different scenarios for the assessment of the benefits.

6 CONCLUSIONS AND PERSPECTIVES

The paper discussed a new integrated method to assess the resource efficiency of products and to derive relevant product's measures for improvement. The assessment has been based on a multi-criteria approach focused on the following: reusability / recyclability / recoverability (per mass and per environmental impacts); recycled content (per mass and per environmental impact); use and management of hazardous substances. Indexes for each criteria have been derived by the scientific literature, and adapted to the scope of the method.

The method has been tested and illustrated on a EuP case-study: an LCD-TV. An exemplary product's measure has been discussed, including the related potential benefits achievable. The method reveals to be applicable and relevant, although some key robust input data (dismantling information of the product and lifecycle inventory data for some materials and processes) is needed.

In the future, it is planned to further investigate the potential applicability of the methodology for various EU mandatory and voluntary product policies, as well as exploring further additional resource efficiency criteria such as Durability and use of renewable resources.

7 ACKNOWLEDGMENTS

Results of the research have been financed by the European Commission - Directorate General Environment – within the project "Integration of resource efficiency and waste management criteria in European product policies - Second phase" (http://lct.jrc.ec.europa.eu/assessment/projects).

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