White paper

Quantitative environmental benefits of recycling and energy recovery

Purpose of this document

As defined in EN 45555, the **recyclability** & **recoverability** benefit rate of a product at its EoL can be calculated by combining mass based **recyclability** & **recoverability** information with Life Cycle Assessment (LCA) methodology and data, on the level of individual materials or substances that are recycled and energy carriers that are recovered. The environmental benefits of the avoided (primary production) burdens are to be credited to the product system that delivers the recycled material or recovered energy from its end-of-life treatment.

This White paper provides more guidance to develop reproducible provisions of the environmental benefit rate for their product group.

1 Recycling & Recovery Benefit Rate (RRBR)

The basis for the assessment builds on the system boundary identification between the original and subsequent product system that needs to be identified and explained, as already clarified for the quantitative recyclability and recoverability rate in EN 45555. This point of substitution is the point in the **recycling** chain where the recycled material is replacing primary material in a production step (e.g. injection moulding of recycled plastics granulate to plastics **parts**) and where recovered energy is replacing primary energy (e.g. feeding recovered electricity into the grid).

The Recycling & Recovery Benefit Rate (*RRBR*) represents then the share of theoretically avoidable environmental impacts of all the material(s) and energy that are physically contained in the end-of-life product (R_{contB}, expressed as avoidable primary production impacts,) that is actually recycled and recovered at the product's end-of-life under the assumed EoL scenario, as defined in EN 45555.

RRBR is hence the sum of the avoided primary production environmental impacts due to the obtained recycled materials (R_{cycB}) plus of the recovered energy (R_{covEnB}) minus the environmental impacts from **end-of-life treatment** *(Rr1* and *Rr2*), put in relation to the sum of avoided primary production environmental impacts of all the materials contained in the product before it undergoes **end-of-life treatment** (R_{contB}):

$$RRBR = ((R_{cycB} + R_{covEnB} - Rr1 - Rr2) \,/\, R_{contB})\; x\; 100\%$$

With:

$$\mathrm{R_{cycB}} = \sum m_{\mathrm{k}}\, x\, RCR_{\mathrm{k}}\, x\, \mathrm{P_k}\; x\; Qs_{\mathrm{k}} / Qp_{\mathrm{k}}$$

R_{cycB} is the gross environmental benefit of all recycled materials obtained at EoL from the **part** or product, considering their downcycling.

$$R_{\mathbf{covEnB}} = \sum m_k \, x \, e_k \, x \sum RVR_{EN,k,j} x \, P_j$$

R_{covEnB} is the gross environmental benefit of the sum of all recovered energy carriers j obtained at EoL from the **part**/material or product.

$$R_{\mathbf{contB}} = \sum m_k \quad \text{x } P_k \, x \, Qs_k/Qp_k$$

R_{contB} is the overall potential environmental benefit of all materials in the **part**/material or product prior to **end-of-life treatment**. R_{contB} is considering the possibly downcycled quality of recycled content via the downcycling factor Qs_k/Qp_k . Note: for the primary material share of material k, Qs_k/Qp_k is per definition equal 1.

Rr2 is the environmental impact of all **recycling** processes of the k materials plus that of the **energy recovery** processes of the j energy carriers in the product or **part**, i.e. after pre-treatment towards recycled material or recovered energy.

$$Rr_2 = \sum RCR_k \, x \, Rr_{2,k} + \sum RVR_{EN,k,j} \, x \, Rr_{2,j}$$

Note There is no separate energy term, as the energy that is contained in the EoL product prior to **end-of-life treatment** is contained in the materials of the product, hence already covered.

With:

Table 1: Symbols and Definitions

m_k	Mass of k^{th} **part**/material (both virgin and recycled content)
Rr_1	Environmental impact* of resources consumed/emissions in the pre-treatment of the EoL product, including separation, shredding and initial sorting, and the final depositing of unrecovered EoL product / fractions (i.e. landfilling)
$Rr_{2,k}$	Environmental impact* of resources consumed/emissions of the **recycling** processes for each **part**, fraction or material k obtained from the pre-treatment activities; this includes transport, further sorting, melting, refining, extruding, smelting etc. up to the point of substitution, and landfilling of remains
$Rr_{2,j}$	Environmental impact* of resources consumed/emissions of the waste-to-energy **recovery** processes for each **part**, fraction or material j obtained from the pretreatment activities; this includes transport, further processing and landfilling of slags, ashes, filter dust. Note that any possible recycled material from e.g. slag is to be counted either as **part** of the term R_{cycB} OR of the term $Rr_{2,j}$, not both.
e_k	Specific energy content per kg of the k^{th} material contained in the product at end-of-life
RCR_k	**Recycling rate** of the k^{th} **part**/material in the corresponding **end-of-life treatment scenario** (see section 4.4.2)
$RVR_{EN,k,j}$	**Energy recovery** rate of the j^{th} energy carrier for the k^{th} material/**part** in the corresponding **end-of-life treatment scenario**. (Considers exclusively the **parts**/materials that undergo **energy recovery**.)

P_k	Environmental impact* of resources consumed/emissions for the acquisition and pre-processing of virgin material equivalent to the recycled material.
P_j	Environmental impact* of resources consumed/emissions for the production of the primary energy carrier equivalent to the recoverable energy.
Qs_k/Qp_k	Ratio of any differences in quality between the secondary material from the EoL processes (e.g. down-cycling), where Qs is the quality of the secondary material at the point of substitution and Qp is the quality of the primary material[1].
* This can be a selected impact category such as Climate change impacts, or an aggregated value of several impacts, e.g. a normalised, weighted impact value, such as an Environmental footprint single score.	

The other variables are defined in EN 45555.

Note Benefit rates can be calculated either for the product as a whole or for its **parts**/materials after pre-treatment. If applied to the **parts**/materials obtained from pre-treatment, the terms of the formula have to be summed up first for all **parts**/materials before the product's overall *RRBR* is calculated.

Note Given limitations of availability of the complete composition of complex products, e.g. electronics, product TCs are advised to limit the materials to those that are known to be environmentally relevant for their product type, considering both their typical content ranges in those products and the material-specific avoidable primary production environmental impacts. Furthermore, some material variants could be grouped, e.g. different steel grades. The granularity of the materials and material groups should orient to the similarity of material variants in terms of environmental impact of their production (e.g. not merging different plastics such as PA, PE, ABS). Such a grouping of materials and a cut-off by environmental relevance can ensure practicality without overly negatively affecting the accuracy and credibility of the resulting indicator. In the same logic, also energy recovery may be excluded from the benefits calculation by setting exclusively the term ***RcovEnB*** to 0, i.e. obtaining the Recycling Benefit Rate, without considering energy recovery benefits.

The best possible *RRBR* value is 100%. Lower values indicate a progressively lower net environmental benefit. Values below 0% can occur, indicating that the environmental impacts of **recycling** and **recovery** are higher than the environmental value of the obtained recycled materials and **recovery** energy, leading to a negative environmental benefit, i.e. a net environmental burden from **end-of-life treatment**.

However, *RRBR* is not able to discern the efficiency of material use in the analysed product. E.g. adding an otherwise function-less, but easily recyclable big metal foot to a product would result in a better *RRBR* value, without any actual environmental benefit. In order to avoid this effect, the impacts can also be calculated in absolute terms rather than as a % rate. This can be done by calculating the absolute difference in environmental impact between the primary production impact of the product and the net avoided impact from recovery and recycling at end of life. The higher the value (difference), the greater the remaining net impact on the environment. The benefit rate and the absolute value can be used together as complimentary metrics.

The Recycling & Recovery Benefit Rate is to be calculated using the same end-of-life treatment scenario as used in EN 45555 for calculating the Recycling & Recovery Rate, to ensure a single

[1] This quality ratio can be approximated using an appropriate ratio such as the quantitative amount of primary material that is being replaced in subsequent uses, or the physical properties for the primary and secondary materials that reflect quality aspects, such as, strength, density, colour etc., or the long-term average relative market price ratio of the secondary material and the replaced primary material. The approach that would be selected by the product TC is to capture the loss of quality of the material in a way that it can suitably be combined / summed with quantitative losses. For example, where Qs_k/Qp_k would be e.g. 0.5 for a material, obtaining from end-of-life recycling 1 kg of this material at this downcycled quality 0.5 should be understood to be environmentally equivalent to losing 0.5 kg of the 1 kg to landfill plus recycling the other 0.5 kg to a quality level fully equivalent to the primary material.

and reproducible outcome. All relevant assumptions regarding **end-of-life treatment** should be based on best available information and based on current technology and average practice and should be documented in the report.

An informative example calculation for the Recycling & Recovery Benefit Rate is provided in chapter 3.

2 Potential data sources

General aspects

For most of the variables and terms in *RRBR*, default values and data should be provided in product-type specific standards, preferably consistently across the various product-type specific standards. For ensuring the necessary reproducibility and credibility, well-documented, high quality data sources, if possible with external, independent and qualified reviews of the data, should be selected. Primary data (e.g. production site specific) for any of the variables and data should be allowed only, if they are methodologically consistent with the default values and of high accuracy and quality.

In the simplest case, the producer would have to provide exclusively the material composition of the product-type specifically relevant materials (i.e. data that is already required for the recyclability and recoverability rate, as defined in EN 45555) as well as the energy content of the product prior to treatment (that can be calculated from the material composition by summing up the contained materials' calorific values), while all other data can be default values that are provided in the applicable product specific standard.

Life cycle data and impact values

Impact values (LCIA results) can be pre-calculated by combining LCI data with LCIA factors. Single score environmental indicator values combine these LCIA results with normalisation data and weighting factors. In both cases, tabular default values for all relevant materials, energy carriers, **recycling** processes etc. can be provided that express their environmental impact, or avoided primary production environmental impact.

Life Cycle Inventory (LCI) data sets are the basis to prepare default impact values for P_k and P_j for all relevant materials and energy carriers as well as for Rr_1 and Rr_2.

The combination of data from different sources of different LCI methodologies and/or background data is to be avoided, as leading to distortions. Only very few databases provide consistent LCI data sets across the needed wide range of materials, energy carriers and end-of-life processes. The following databases are listed in alphabetical order that could be checked for suitability (non-exhaustive):

- Base Impacts (http://www.base-impacts.ademe.fr/),
- CFP database of JEMAI (https://www.cfp-japan.jp/english/overview/index.html),
- ecoinvent (www.ecoinvent.ch),
- Environmental Footprint (EF) database (http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm#compliant , stepwise made accessible),
- EIME (http://www.codde.fr/page.php?rubrique=20),
- ELCD database (http://eplca.jrc.ec.europa.eu/ELCD3/),
- GaBi ts databases (http://www.gabi-software.com/international/databases/gabi-databases/),
- ÖKOBAUDAT (http://www.oekobaudat.de/en.html),
- US LCI database (https://www.nrel.gov/lci/).

If no LCI database can be identified that covers all relevant materials for the product group in question, this method might not be applicable.

For the Life Cycle Impact Assessment (LCIA) step, widely used methodologies include CML, EPS, ILCD2011/EF, Impact World+, Impact 2002+, LIME, ReCiPe, and TRACI.

Where a single score environmental indicator would be used as a normalised, weighted impact, normalisation data and weighting factors should stem form authoritative sources and have to be technically suitable to be combined with the LCI data sets and with the selected LCIA methods. Examples are the data and factors developed by CML, under the European Commission's Environmental Footprint initiative (ILCD/EF), and ReCiPe.

Recyclability, recoverability, downcycling factors

Where primary data is missing for the recycled content ($R_{content}$), the **recyclability** (RCR_k), the **recoverability** of energy ($RVR_{EN,k,j}$), and the downcycling factors Qs_k/Qp_k, default values are provided, among others under the Environmental Footprint (EF) initiative, in IEC/TR 62635, and by various research projects.

3 Example calculation of recyclability and recoverability benefit rates

An example calculation of the quantitative environmental benefits rate is provided as follows (**all numbers imaginative, for illustration purposes only**):

EoL of an electronic product, mass assumed as 187.3 g

The environmental impact of the contained materials, that forms the maximum, theoretical potential for recycling, and of the obtained recycled materials and recovered energy in this example is expressed as an overall (avoidable) environmental impact, a single number per kg of material or process. Instead, also specific impacts, such as e.g. the Climate change impact potential expressed in kg CO2-equivalents could be used.

Calculation of the variables R_{contB}, R_{cycB}, R_{covEnB} for assumed product-type specifically relevant materials (materials as selected by the product TC)

Material [k]	**Content in EoL product** [m_k]	**Down cycling factor recyc. cont.** [Qs_k/Qp_k]	**Env. impact primary mat. / g** [P_i]	**Recyc. env. benefit potential of product at EoL** [R_{contB} of material k]	Recycling rate [RCR_k]	Down cycling factor EoL [Qs_k/Qp_k]	**Avoided primary product env. impact due to rec. material** [R_{cycB} of material k]	**Specific energy content of material /part** [e_k]	**Recovered energy carrier** [$_j$]	**Energy recoverability rate** [$RVR_{EN,k,j}$]	**Env. impact primary energy / MJ** [P_j]	**Avoided primary product env. impact due to Energy recovery** [R_{covEnB} of energy carrier j]
ABS, secondary	40% = 75 g	0.8	2.5	149	10%	0.6	11.2	40 MJ/kg	Electricity, high voltage	5.1%	25	3.8
									Heat for district heating	13%	8.3	3.3
Glass	31% = 58 g	1	0.7	40.6	0%	1	0					
Stainless steel	15% = 28 g	1	1.5	42.1	70%	1	29.4					
Copper	7% = 13 g	1	8.6	112.75	85%	1	96					
Gold	0,1% = 0.19 g	1	6879	1288	80%	1	1030					

others	...	...	...	...	...	...	...	...	...	...	...	...
SUM				**1976**			**1229**					**7.1**
Data sources:	Mate-rial con-tent /BoM	Default values		Calcula-ted	Default values	Default values	Calcula-ted	Default values	Default types	Calculated	Default values	Calcula-ted

The environmental impacts for Rr_1 and Rr_2 of the analysed EoL scenario, i.e. the environmental impacts of the pre-treatment and of the recycling and energy recovery operations of the single piece of electronic equipment, may have been calculated, using default values from the product-specific standard or measured data as follows:

***Rr_1* = 8.5 (Environmental impact)**

***Rr_2* = 78.6 (Environmental impact)**

The indicator of the recycling and recovery benefit rate gives the following results:

***RRBR = $((R_{cycB}+R_{covEnB}-Rr_1-Rr_2) / R_{contB})$* x 100% = (1229+7.1-8.5-78.6) / 1976 x 100% = 58 %, i.e. we have a combined net environmental benefit rate of 58 %.**

For the material recycling & energy recovery loss of the maximum potentially avoidable primary production environmental impact we obtain:

loss (i.e. remaining net environmental impact) ***= $R_{contB}-(R_{cycB}+R_{covEnB}-Rr_1-Rr_2)$* = 1976 – (1229+7.1-8.5-78.6) = 827**, i.e. we have lost 827 Environmental footprint impact single score units (dimensionless) of the potentially avoidable primary production environmental impacts of the contained materials and energy due to incomplete recycling and energy recovery as well as the environmental impacts to run these recycling and recovery processes. (Note: If we would have used e.g. Climate change impacts instead of the single score, the result would be measured in kg CO_2-equivalents.)

Note that for this example, the amount of material recycled by mass of the whole product is below 20%, while the recycled environmental benefits in these materials is almost 60% of what could have been recycled theoretically.