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Method for the ranking of potential requirements, based on expected impacts and costs

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Contents

Abstract

The aim of this report is to contribute to the development of the methodology for setting ecodesign requirements for sustainable products for the implementation of the Ecodesign for Sustainable Products Regulation (ESPR). Starting from the analysis of the Methodology for the Ecodesign of Energy-related Products (MEErP), used under the Ecodesign Directive (on energy-related products), and considering the extended scope of the ESPR, this report proposes indications for the identification of improved design options (DOs), as well as a method to assess, define and rank paths of DOs, taking into account their interactions. These methods will be applied by the study team in the preparatory studies that proceed the publication of product-specific Delegated Acts setting the ecodesign requirements. A more systemic definition of DO than the one provided in the MEErP is proposed, since it is recognised in literature that, to achieve optimal product sustainability, the focus should expand from the product to the system level. The identification of the DOs should be a multi-disciplinary activity, which considers technological, environmental and market-related aspects. The creation and validation of DO paths is supported by the use of Life-cycle Assessment. Moreover, the optimal design configuration for each path is identified by using life-cycle costing (LCC). Finally, the DOs are ranked applying societal LCC: factors for the monetisation of environmental externalities are proposed. Eventually the result should be complemented with considerations on social aspects and policy objectives.

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Executive summary

Policy context

On 30 March 2022, the European Commission (EC) adopted a proposal for an **Ecodesign for Sustainable Products Regulation (hereafter ESPR)** with the aim of improving the environmental sustainability and the circularity of products on the European market. The proposal was finally approved and published in the Official Journal of the European Union on 28 June 2024[1]. It entered into force on 18 July 2024. The ESPR is based on the success of the Ecodesign Directive, whose main focus is to improve the energy efficiency of those products with a large energy consumption during the use phase.

The ESPR expands the scope of the Ecodesign Directive to cover almost all products on the European market, including both intermediate and final products, with the exception of food and feed, living plants, animals and microorganisms, products of human origin, and products of plants and animals relating directly to their future reproduction, medicinal products for human use, veterinary medicinal products, and vehicles as referred to in Article 2(1) of Regulation (EU) 2018/858, Regulation (EU) No 167/2013, Regulation (EU) No 168/2013, for those product requirements set for these vehicles under Union law[2]. The ESPR framework not only targets the energy consumption of products, but it expands the focus to cover the full environmental sustainability of products throughout their life-cycle, including products' circularity aspects. The ESPR envisages the possibility to set performance and information requirements. In particular, Article 5 of the ESPR lists the **product aspects** that should be addressed for ecodesign requirements:

(a) durability;

(b) reliability;

(c) reusability;

(d) upgradability;

(e) repairability;

(f) the possibility of maintenance and refurbishment;

(g) the presence of substances of concern;

(h) energy use and energy efficiency;

(i) water use and water efficiency;

(j) resource use and resource efficiency;

(k) recycled content;

(l) the possibility of remanufacturing;

(m) recyclability;

(n) the possibility of the recovery of materials;

(o) environmental impacts, including carbon footprint and environmental footprint;

(p) expected generation of waste.

Since the ESPR is a framework regulation, the aspects listed above should be analysed for individual product groups in so-called **Preparatory Studies**, with the aim of setting relevant ecodesign

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1781&qid=1719580391746

[2] E-bikes and e-scooters are not excluded of the ESPR scope.

requirements in product-specific **Delegated Acts (DAs)**. Under the current Ecodesign Directive (on energy-related products), Preparatory studies are carried out based on the **Methodology for the Ecodesign of Energy-related Products (hereafter MEErP)**. For carrying out preparatory studies under the ESPR, a new methodology needs to be developed. Ecodesign requirements are of utmost importance as products will have to comply with them to enter the European market or be put into service.

Key conclusions

Within this report, a new definition of design option (DO) is provided, in line with the extended scope of the ESPR compared to the previous Ecodesign Directive, and facilitating the integration between the preparatory study and the impact assessment. Improved design options (or "design options") are specific product service systems, with features which make them more advanced and/or more efficient when compared to the 'base case' in at least one of the product aspects listed in Article 5 of the ESPR. This extension of the definition requires that additional data are collected, in the first steps of the assessment. Compared to the MEErP, the ESPR methodology gives more importance to the analysis of the synergies and trade-offs between design options and to the creation of paths (i.e. clusters) of design options, because of the multi-objective approach of the ESPR (i.e. energy efficiency is no longer the ultimate goal). Moreover, the optimal configuration of each path might not correspond with the least life-cycle cost (LLCC) point. Indeed, while according to the legal text the affordability of products should be guaranteed (see Article 5.11.c "there shall be no significant negative impact on consumers in terms of the affordability of relevant products, also taking into account access to second hand products, durability and the life-cycle cost of products"), the ESPR does not claim that the analysis should aim to identify the LLCC point, in contrast to the Ecodesign Directive[3].

Main findings

The report proposes three different methods, one in each chapter of the report:

1. Indications for the identification of DOs.

2. Method to assess interactions between different DOs, and define and rank paths of DOs.

3. Method to assess DOs (base cases and alternative DOs), including consideration of non-quantifiable aspects and policy objectives.

For each step, an analysis of what was proposed in the MEErP is reported, followed by a proposal for the new ESPR methodology.

The first method identifies five dimensions that are relevant for the definition of DOs: product material, product architecture, product service, product business model and product ecosystem. The analysis of these dimensions contributes to the definition of improved design options. A new definition of DO is proposed: a 'design option' is a specific product service system, with features which make it more advanced and/or more efficient when compared to the 'base case' in at least one of the product aspects listed in Article 5 of the ESPR. The identification of the design options is a multi-disciplinary activity: the study team (i.e., the team performing the preparatory study) should consider technological, environmental and market-related aspects. Legislation and literature review, together with consultations with stakeholders, play a pivotal role in this process, as they are the basis for the identification of the environmental objectives to be achieved. Then, DOs to achieve

[3] As stated in Annex II to the Ecodesign Directive, "Concerning energy consumption in use, the level of energy efficiency or consumption must be set aiming at the life-cycle cost minimum to end-users for representative product models, taking into account the consequences on other environmental aspects."

each environmental objective should be identified. A preliminary check on functionality and affordability for the users (in economic terms) of each design option is recommended.

The aim of the second method is to create paths (clusters) of DOs, so that trade-offs between DOs are avoided as much as possible. After the definition of a preliminary priority list of DOs, paths of DOs are created based on the environmental and economic synergies and trade-offs. To guarantee an improvement in the environmental performance of the product group, LCA is used to validate the paths created (i.e. to confirm that they generate an environmental benefit), while life-cycle costing (LCC) is applied with the perspective of the user (conventional LCC) in order to identify the optimal configuration of each path. Finally, the societal LCC can be applied to rank the paths, coupled with an analysis of non-quantifiable aspects and policy objectives.

The third method clarifies how the base cases (in Task 5) and the improved DOs (in Task 6) should be assessed, taking into account the wider scope of the ESPR compared to the previous Ecodesign Directive. This section refers to scientific literature on environmental assessment and economic assessment, in particular on LCA and LCC. Both for intermediate and final products, the LCC analysis should be performed applying two different perspectives: first the perspective of the user (conventional LCC) and secondly the perspective of society (societal LCC). In the case of final products, the perspective of the manufacturer (conventional LCC) can also be assessed. For the monetary valuation of environmental impacts, three approaches are proposed: use of monetisation factors at impact category level, use of monetisation factors at elementary flow level, use of environmentally extended multi-regional input-output models. Finally, the assessment should be complemented with a qualitative analysis to identify which aspects of the EU Open Strategic Autonomy are most relevant to a given product, and to assess the potential impact of DOs in terms of either improving or worsening the current situation.

Related and future JRC work

The work presented in this report is part of the scientific support for the elaboration of a methodology for the prioritisation and evaluation of ecodesign requirements for a targeted product group in view of the ESPR (as state stated in Art. 5(3) of the ESPR, "*The Commission shall select or develop tools or methodologies, as necessary, for the setting of ecodesign requirements*"). It has been done in synergy with other tasks, collectively contributing to an ESPR methodology. As future work, all these will need to be combined and integrated to build the final Methodology for the evaluation of products and definition of ESPR requirements. The methodology presented in this report will be partially tested in the ongoing preparatory studies of steel and textiles, performed by the JRC, with the aim to be fully deployed for future ecodesign preparatory studies.

Extended executive summary

Background

The **Ecodesign for Sustainable Products Regulation (ESPR),** with the aim of improving the environmental sustainability and the circularity of products in the European market, entered into force in July 2024.

Since the ESPR is a framework regulation, relevant ecodesign requirements will be set in product-specific Delegated Acts. **Product aspects** will be analysed for individual product groups in so-called preparatory studies. Under the current Ecodesign Directive (on energy-related products), preparatory studies are carried out based on the **Methodology for the Ecodesign of Energy-related Products (MEErP)**. For carrying out new preparatory studies under the ESPR as well as review studies, new methods need to be developed, in order to identify and compare design options.

Task B4 methods within the revised MEErP

Taking the MEErP as a starting point, the present study focuses on the **development of a suggested set of generic and flexible methods** applicable to any kind of product group under the scope of the ESPR for the definition of product-specific ecodesign requirements:

- indications for the identification of improved design options;
- method to assess interactions between different DOs, and define and rank paths of DOs.;
- method to assess the impacts related to the base case and the improved design options, including consideration of non-quantifiable aspects and policy objectives.

In this section, a practical summary of the method will be provided for its integration with other tasks of the AA in the final joint report of the ESPR methodology. It follows the MEErP structure:

- **Task 0: Quickscan**

No additional steps.

- **Task 1: Scope**

No additional steps.

- **Task 2: Market**

Additional information (compared to that contained in the original MEErP) should be gathered within this task.

In the case of final products, information on the <u>most common business models</u> should be gathered, as well as information on the <u>market for remanufactured products</u>, on <u>reuse markets</u>. <u>Repair and refurbishment services</u> should also be investigated. Finally, <u>end-of-life costs (disposal tariffs/taxes)</u> should be analysed. The presence and diffusion of Extended Producer Responsibility schemes should be examined. Relevant information on the <u>market for secondary resources</u> should be taken into account: this is also valid in the case of intermediate products.

The best (in terms of environmental performance) available product service systems, product business models and product ecosystems should be selected and described. Moreover, the data needed to perform the LCC could already be gathered at this stage.

- **Task 3: Users**

The study team can investigate the impact of users' behaviour at different life-cycle stages, i.e. analyse pre-purchase aspects, post-purchase aspects and user behaviour related to disposal, taking into account that behaviours widely vary across cultures and socio-economic background.

The best (in terms of environmental performance related to user behaviour) available product service systems, product business models and product ecosystems should be selected and described, with a focus on their impacts on user behaviour.

The study team should look into:

- consumers' reasons for purchasing the product, attitudes towards second-hand products, refurbished/repaired products, attitudes towards products with recycled materials, attitudes towards potentially dangerous materials present in the products;
- consumers' habits in relation to the refusal of purchase the product (i.e. services instead of products), the extension of lifetime, the use, reuse and the disposal of the product and the related consumables;
- information offered to consumers, both in terms of energy efficiency and other product aspects;
- regarding circularity aspects, willingness to repair, reasons for disposal (and reason for return), willingness to use refurbished or second-hand products (or consumables), barriers to circularity, willingness to pay more for more durable products, willingness to pay for repair and other circularity strategies (e.g. as a percentage of the product price);
- best practices in sustainable product use;
- how the business model affects user behaviour and the circularity of products;
- how the local infrastructure affects user behaviour and the circularity of products (e.g. infrastructure to enable business models based on sharing, repair shops, take-back systems);
- how relevant design aspects influence consumers' purchase decisions (e.g. energy consumption, water consumption, lifetime, possibility of reuse).

- **Task 4: Technologies**

It is proposed to rename this task "Technologies, techniques and materials".

A distinction is introduced between technologies and techniques. The term "technology" refers to a product or to a component, while the term "technique" refers to an industrial process performed in an installation.

The following definition of best available technology (BATg) is proposed:

"best available technologies means the best performing product or component, in terms of environmental performance in (at least) one of the product aspects listed in Article 5 of the ESPR:

a) 'available technologies' means those available on the market;
b) 'best' means most effective in achieving a high general level of protection of the environment as a whole."

Considering the extended scope of the ESPR, in the definition of BATg at product and component level, the technical aspects which affect one or more product aspects should be evaluated, e.g. energy use, durability, reliability, repair and remanufacturing, use of consumables and other resources, recycled content. As specified in Annex II to the ESPR, the performance of products available on international markets and benchmarks set in other countries' law shall also be taken into consideration.

Best not yet available technologies (BNATg) at product and component level should be investigated: they are defined as emerging technologies that guarantee the improvements of the relevant product aspects.

As defined in Directive 2010/75/EU, "'best available techniques' means the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis for emission limit values and other permit conditions designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole:

a) 'techniques' includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;
b) 'available techniques' means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;
c) 'best' means most effective in achieving a high general level of protection of the environment as a whole." (Art. 3).

The study team should refer to the best available techniques (BATq) identified in the Commission Implementing Decisions under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions (if available for the sector under assessment) and to the so-called best available techniques reference documents (BREFs).

Moreover, BATq for remanufacturing processes should be investigated, if remanufacturing is a relevant product aspect for the selected product.

Finally, as for end of life and waste treatment, BATq for the treatment of the product in question should be investigated: particular attention should be devoted to the recycling process and recovery of materials, if these product aspects are relevant. It is understood that what is reported in Annex II to the ESPR should also be valid for the production process: therefore, the performance of production processes available on international markets and benchmarks set in other countries' law shall also be taken into consideration.

The study team should also investigate the best not yet available techniques (BNATq) for the production process, the remanufacturing, recycling and recovery of materials, if relevant for the product being analysed.

- **Task 5: Base case LCA and LCC**

Environmental and economic assessment of the base case are performed, as well as societal LCC to identify hotspots. The EcoReport tool may be used by the study team to perform the economic assessment; however, some limitations are highlighted in Section 4.4.5 (in **Table 15** and **Table 16**). The limitations are mainly related to the fact that the simplified version of the circular footprint formula (CFF) is used in the EcoReport tool to model the EoL of products. For the monetisation of environmental impacts in the societal LCC, three approaches are proposed: the first one is the use of monetisation factors at impact category level, like the one proposed in **Table 13** and **Table 14**; the second is the use of monetisation factors at elementary flow level (i.e., price for each environmental emission); and the third one is the use of environmentally extended multi-regional input-output models.

If the study team considers carbon footprint relevant, a methodology for its calculation is being developed, to be used for products within the scope of the EU Emissions Trading System (EU ETS) and Carbon Border Adjustment Mechanism (CBAM): it can be applied to the base case in Task 5 in order to define the benchmark for the later definition of requirements for this product aspect.

- **Task 6: Design options**
  - **Identification of DOs**

This step is investigated in Section 2.2 of this report. DOs are identified starting from environmental objectives; the number of DOs is limited thanks to a functionality and affordability check. DOs should be defined in a very specific way, so that they are close to ecodesign requirements. It represents a concrete measure (as in the preparatory study of smartphones), and improves the performance of the product in (at least) one of the product aspects listed in Article 5 of the ESPR. A DO can be performance-related (if it represents a performance requirement, for example in the case of a smartphone: provision of additional screen and glass back-cover protection) or information-related (if it represents an information requirement, for example in the case of a smartphone: information on the correct use of the battery).

A new definition of DO is proposed: 'design option' is a specific **product service system**, with features which make it more advanced and/or more efficient when compared to the 'base case' in at least one of the product aspects listed in Article 5 of the ESPR. A design option should represent a concrete measure.

A design option is not only described by a technology or a product configuration, but other product dimensions can be included, i.e. product material, product architecture, product service, product business model and product ecosystem. This broadens the definition provided by Polverini (2021), i.e. 'design option' is a specific product architecture, with technical features which make it more advanced and/or more efficient when compared to the 'base case'.

In the case of a performance DO with a quantitative value, it might be preferable to define only a range at this stage, and refine the value in a second stage, once the set of DOs (i.e. paths) to be implemented are defined: in this way, potential synergies and trade-offs among DOs can be taken into account. The quantitative value should represent the new average product on the market once the requirement is introduced and all the products are compliant. The definition of a quantitative value (or of a range) can come from the experts' judgement, consultation of stakeholders. In some cases, a numerical assessment can be performed, using LCA and LCC methodologies or other methodologies (e.g. Material Flow Analysis), for example to assess the impacts of different scenarios.

  - **Definition of paths**

This step is investigated in Section 3.2 of this report. The objective is to cluster DOs that (in principle) work in synergy. **Figure 12** summarises the steps to follow.

In the case of performance requirements, quantitative values (thresholds) for each product parameter in the path will need to be defined taking into account synergies with the rest of the parameters in the path and based on expert judgement and stakeholder consultation. In some cases, a numerical assessment can be performed, using LCA and LCC methodologies or other methodologies. The thresholds set represent the new average product, i.e. the average performance that can be achieved for that specific product parameter without conflicting with the other product parameters in the path, when all the products are compliant. This new average will be a point between the current average and the BATg.

In the case of information requirements, consumer surveys can inform on the response to the requirements on the market (in the case of consumer-oriented information requirements). In other cases, surveys targeted at specific stakeholders might be necessary (e.g. survey for professional repairers, in the case of instructions for repair, or survey for recyclers, in the case of information requirements aimed at them). This would result in an improved average performance that will be the one assessed in the cumulative LCA, as well as in costs of compliance covered by the manufacturers (and reflected in the product price), to be assessed in the cumulative LCC.

To validate the paths created, a cumulative LCA can be performed (adding one DO each time in the scope). The result should show a progressive improvement of the environmental performance. If all EF categories are assessed, the single score proposed under the EF method can be used, as it allows the aggregation of the environmental assessment in one single number.

To identify the optimal design configuration for each path, a cumulative LCC from the perspective of the user should be performed (see Section 4.4), to discard from the path those design options that are not cost-effective.

After this step, the quantitative values (thresholds) set for each product parameter can be revised, to take into account the final set of design options included in the path.

- **Ranking of the paths**

This step is investigated in Section 3.2.5 of this report.

To rank the different paths, a societal LCC can be performed (see Section 4.4). The societal LCC should include the monetisation of the environmental impacts. For the monetisation of environmental impacts, three approaches are proposed: the first one is the use of monetisation factors at impact category level, like the one proposed in **Table 13** and **Table 14**; the second is the use of monetisation factors at elementary flow level (i.e., price for each environmental emission); and the third one is the use of environmentally extended multi-regional input-output models.

In addition to that, in this step the non-quantifiable aspects can be investigated.

1 Introduction

This report is developed as part of the project to define a method for setting ecodesign requirements for sustainable products for the implementation of the Ecodesign for Sustainable Products Regulation (ESPR), which entered into force on 18 July 2024.

More specifically, this report includes the development of Task B4 of the ESPR Methodology entitled "Method for the ranking of potential requirements, based on expected impacts and costs" and is a deliverable under the Administrative Agreement (AA) JRC ref. Nr. 36532-2022 // ENV 09.0202/2022/888276/AA/ENV.B.4. Selected parts of this report will be part of the final report of Part B of the above-mentioned AA.

The ESPR, as part of the Circular Economy package adopted on 30 March 2022, is the cornerstone of the Commission's approach to more environmentally sustainable and circular products. It establishes the framework "for the setting of ecodesign requirements that products have to comply with to be placed on the market or put into service, with the aim of improving the environmental sustainability of products in order to make sustainable products the norm and to reduce the overall carbon footprint and environmental footprint of products over their life-cycle, and of ensuring the free movement of sustainable products within the internal market" (Art. 1). As defined in the ESPR text, an 'ecodesign requirement' means a performance requirement or an information requirement aimed at making a <u>product, including processes taking place throughout the product's value chain</u>, more environmentally sustainable. The value chain is defined as all activities and processes that are part of the life-cycle[4] of a product, as well as its possible remanufacturing.

According to the International Organization for Standardization (ISO) (2023), ecodesign is a broader concept than design for circularity: ecodesign means design and development based on life-cycle thinking aimed at supporting sustainable development, while design for circularity means design and development based on circular economy principles. This is in line with the definition of ecodesign provided by the ESPR, i.e. 'ecodesign' means the integration of environmental sustainability considerations into the characteristics of a product and the processes taking place throughout the product's value chain. Indeed, circular economy and sustainable development are not systematically synonyms, and some trade-offs might occur between circularity and sustainability (Saidani and Kim, 2022).

Within this context, the aim of this task is to design a method for the ranking of improved design options, based on expected impacts and costs. This ranking will enable the Commission to define policy options with different sets of requirements, typically with different ambition levels.

The aim is to develop a method flexible enough to be used for any product within the scope of the ESPR, including both Energy-related Products (ErPs) and other products, and both final and intermediate products. Indeed, the ESPR builds on the proven effectiveness of the Ecodesign Directive in relation to ErPs and will enable minimum ecodesign performance and information requirements to be set for almost all categories of physical goods placed on the EU market.

- **MEErP**

The MEErP, developed under the Ecodesign Directive 2009/125/EC, consists of a techno-economic-environmental assessment of a specific product group. It evaluates whether and to what extent

[4] According to the legal text, 'life-cycle' means the consecutive and interlinked stages of a product's life, consisting of raw material acquisition or generation from natural resources, preprocessing, manufacturing, storage, distribution, installation, use, maintenance, repair, upgrading, refurbishment and reuse, and end-of-life.

energy-related products fulfil certain criteria that make them eligible for ecodesign implementing measures and provides guidance for the identification and definition of the level of stringency of the (potential) requirements. The MEErP was originally published in 2011, as an adaptation of the previous Methodology for the Ecodesign of Energy-using Products (MEEuP) that supported the elaboration of implementing measures under the Ecodesign Directive 2005/32/EC. Since then, it has been revised in 2011, 2013 and 2024, and has been used in more than 40 preparatory studies for ecodesign of ErPs (BIO Intelligence Service, 2013).

The MEErP focuses primarily on the energy consumption of products during the use stage, and is structured in tasks as presented below and in **Figure 1**:

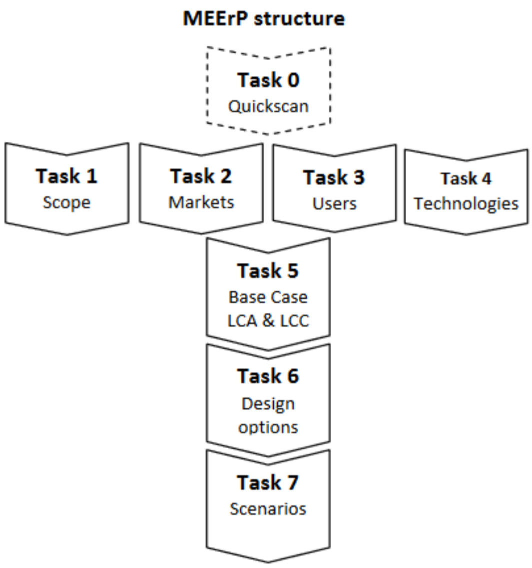
- Task 0: Quick scan
- Task 1: Scope
- Task 2: Markets
- Task 3: Users
- Task 4: Technologies
- Task 5: Environment & Economics (base case LCA & LCC)
- Task 6: Design options
- Task 7: Scenarios

- **Task 0 - Quick scan:** It is an optional task for the case of large or inhomogeneous product groups, where it is recommended to carry out a first product screening considering a preliminary assessment of the environmental impact and potential for improvement, with the purpose of regrouping or narrowing the product scope, as appropriate from an ecodesign point of view, for the subsequent analysis in Tasks 1-7.
- **Task 1 - Scope:** This task defines the methodology to identify the products to be included in the product group to which the ecodesign measures would apply.
- **Task 2 - Markets:** This task provides the market analysis of the product group under assessment, including the apparent product consumption in the EU, market and cost inputs for the assessment of the environmental impacts of the product group, and latest market trends in product design.
- **Task 3 - Users:** This task identifies barriers and restrictions to possible ecodesign measures due to social, cultural or infrastructural factors. This task also quantifies relevant user-specific parameters that can influence the product's environmental impacts during use.
- **Task 4 - Technologies:** This task entails a general technical analysis of products on the EU market, including a description of the existing products up to best available technology and best not yet available technology.
- **Task 5 - Environment & Economics (base case LCA & LCC):** This task requires one or more average EU product(s) to be defined as the "base case". This is subsequently used for the environmental and economic analyses that are also carried out within this task. For such assessments (LCA, LCC), the MEErP uses the EcoReport tool, which is a streamlined life-cycle-based tool that is openly available and simple to use whilst being sufficiently complex/complete to capture the main inputs and outputs at product-specific level.
- **Task 6 - Design options:** This task identifies possible design options, their monetary consequences in terms of life-cycle cost for consumers and their environmental costs and benefits using the EcoReport tool again. Design measures are addressed by the least life-cycle cost (LLCC) and the best available technology. In particular, the distance between the

LLCC and the best available technology indicates the remaining space for product differentiation (competition).

- **Task 7 – Scenarios:** This puts together the outcomes of all previous tasks. It looks at suitable policy measures to achieve the improvement potential for the product, e.g. implementing LLCC as a minimum mandatory requirement and best available technology as a target to be addressed via promotional measures, using legislation or voluntary agreements, labelling, benchmarks and possible incentives. It draws up scenarios quantifying the improvements that can be achieved with respect to a Business-as-Usual scenario and compares the outcomes with EU environmental targets. It makes an estimate of the impact on consumers (purchasing power) and industry (employment, profitability, competitiveness, investment level, etc.) and includes a sensitivity analysis of the main parameters to study the robustness of the outcome, amongst others, regarding energy prices and societal costs.

Figure 1. Structure of the Methodology for the Ecodesign of Energy-related Products (MEErP)



Source: COWI and VHK, 2011.

Tasks 1-4 can be performed in parallel and prepare the grounds for Tasks 5-7, which should be performed in series.

In 2013, the MEErP was supplemented by a module (BIO Intelligence Service, 2013) to assess the possibility of enhancing material efficiency aspects of products, in addition to their energy consumption. The module identifies four material efficiency parameters to be assessed within Task 2 of the MEErP: recyclability benefit rates, recycled content, lifetime and Critical Raw Material Index.

In addition, a new revision of the MEErP was completed in 2024 (Gama Caldas et al., 2024), in particular to update, when and where necessary, some of the data used in the analysis and to ensure that it is still fit for its purpose, in line with the policy developments of the last years. This revision includes the following:

1. The updating of the EcoReport tool.
2. A more systematic inclusion of material efficiency aspects and of environmental footprint/ecological profile aspects in the design options and in the least life-cycle cost (LLCC) curve.

3. A more systematic inclusion of societal life-cycle costs.
4. A more refined evaluation of the economic impacts in Task 7 of the MEErP.

1.1 Interaction between the MEErP and Task B4

The definition and ranking of design options will be performed within Task 6 of the MEErP, taking advantage of input from other tasks (e.g. Task B2, presented in Rodriguez Manotas et al., (2025)) of the ESPR methodology. However, in this report, some integration into other previous tasks of MEErP are also proposed (i.e. Tasks 2, 3 and 4). **Table 1** summarises the main steps of the task and the interaction with Tasks B1 (presented in Gonzalez Torres et al. (2025)) and B2 of the ESPR methodology.

Table 1. Main steps of Task B4 and interactions with Tasks B1 and B2

STEPS	METHODS/TOOLS	ESPR AA TASK
1. Choose the LCA method		Task B1
2. Define a baseline: LCA and LCC of the base case(s)	LCA with method selected in Task B1, conventional LCC, societal LCC	Task B1 and B4
3. Define a preliminary priority list (or more than one) of DOs	Expert judgement, optionally based on prioritisation of product aspects (outcome of Task B2)	Task B4, (Task B2)
4. Cluster DOs in paths, based on the environmental and economic synergies and trade-offs (starting from first DO in the list)	Expert judgement, optionally based on analysis of synergies and trade-offs among the different product aspects (outcome of Task B2)	Task B4, (Task B2)
5. Define specific thresholds for quantitative DOs	Expert judgement and stakeholder consultation. In some cases, LCA, LCC, Material Flow Analysis (MFA) etc.	Task B4
6. Validate the path with a cumulative LCA	LCA (optionally, single score proposed under EF can be used) with method selected in Task B1	Task B1 and Task B4
7. Identification of the optimal configuration for each path: cumulative LCC to discard DOs after the desired point (e.g. LLCC)	Conventional LCC, perspective of users	Task B4
8. Ranking of paths	Societal LCC, (optional) analysis of non-quantifiable aspects	Task B4

Source: JRC elaboration

1.2 Structure of report

The structure of the report is as follows:

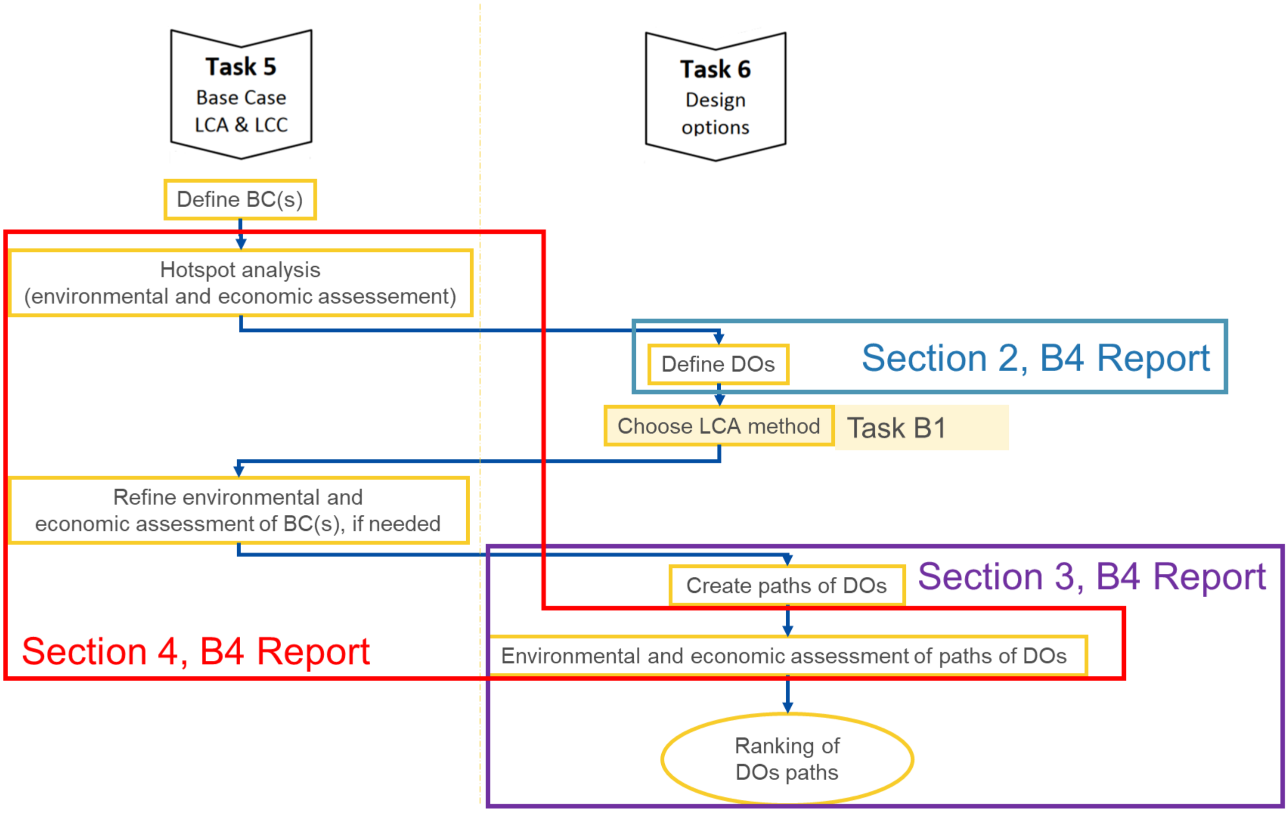
1. Indications for the identification of design options (DOs).

2. Method to assess interactions between different DOs, and define and rank paths of DOs.
3. Method to assess DOs (base cases and alternative DOs), including consideration of non-quantifiable aspects and policy objectives (OSA, social aspects).

For each step, an analysis of what was proposed in the MEErP is reported, followed by a proposal for the new ESPR methodology.

Figure 2 depicts how each section of this report is framed in Tasks 5 and 6 of the MEErP.

Figure 2. Structure of the report in the framework of Tasks 5 and 6 of the MEErP.



NB: BC = base case; DO = design option

Source: JRC elaboration

2 Indications for the identification of design options

In this section, some indications for the identification of design options (DOs) will be provided, starting from an analysis of the procedure followed in previous preparatory studies, when the MEErP was applied.

Design options should be defined for each representative product within the product group under analysis; they are the improved scenarios of the base case, to be assessed from an environmental and economic point of view. As written in Polverini (2021), “by ‘design option’ a specific product architecture is meant, with technical features which make it more advanced and/or more efficient when compared to the ‘base case’, which is the average EU product defined for analysis”. As an example, a performance-related design option can be a smartphone with pre-installed battery management software (which is not present in the base case). The effect of this is an extension of the lifetime of the smartphone, compared to the base case.

The DOs are preparatory to the definition of ecodesign requirements. According to Article 5 of the ESPR, “ecodesign requirements shall meet the following criteria:

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

(b) there shall be no adverse effect on the health and safety of persons;

(c) there shall be no significant negative impact on consumers in terms of the affordability of relevant products, also taking into account access to second hand products, durability and the life-cycle cost of products;

(d) there shall be no disproportionate negative impact on the competitiveness of economic operators and other actors in the value chain, including SMEs, in particular microenterprises;

(e) there shall be no proprietary technology imposed on manufacturers or other actors in the value chain;

(f) there shall be no disproportionate administrative burden on manufacturers or other actors in the value chain, including SMEs, in particular microenterprises.”

It is necessary to keep these criteria in mind even at the stage of identification of DOs.

Moreover, “the performance requirements shall be based on the relevant product parameters referred to in Annex I” (Article 6, ESPR).

After analysing the process for DO identification within the MEErP (Section 2.1), the process to be followed within the ESPR methodology is proposed and described in Section 2.2, where a new definition of DO is proposed, extending the definition reported in Polverini (2021).

2.1 Identification of design options in the MEErP

In Task 6 of the MEErP, the (aggregated paths of) design options to be taken into account are identified and described. In the MEErP 2011 report (Kemna et al., 2011), it is mentioned that design options should mainly come from Task 4, and that typically four to eight design options are manageable.

In previous preparatory studies, design options were developed based on a literature review (Aydemir et al., 2014), on the analyses of previous tasks (Rodríguez-Quintero et al., 2020) and on consultations with manufacturers or associations of manufacturers (Rodriguez Quintero et al., 2022).

In some cases (Bayramoglu et al., 2014; ICF Consulting Ltd, 2020), some principles for the identification of design options are mentioned:

- The functionality and quality of the products should not be significantly affected compared to the base cases, and the design options should not result in significant variations in the performance parameters.
- The design option should have significant potential for environmental performance improvement, i.e. significant potential for improvement of at least one ecodesign parameter without worsening others.
- The costs associated with implementing it should not be excessive and the impacts on manufacturers and the market should be investigated. However, in the case of the preparatory study on enterprise servers and data equipment, some options which might have been questioned from an economic point of view were kept and investigated, because the speed of technological change and associated falls in prices might make them more attractive (Bayramoglu et al., 2014).

In the cases of household dishwashers (Joint Research Centre (European Commission) et al., 2017) and household washing machines and household washer-dryers (Joint Research Centre (European Commission) et al., 2017), an initial long list of design options was subsequently shortened, according to the results of a questionnaire, where manufacturers were asked to provide specific technical and cost data of the design options and combinations thereof. To support the assessment of the design options, stakeholders were also asked to estimate the current and likely future market penetration of certain improvement options as well as to give an indication of which of the single options are compatible with other options. However, no information on the market penetration was provided by the stakeholders.

In the following two subsections, the cases of imaging equipment and mobile phones, smartphones and tablets are presented in detail, since the preparatory studies of these two product groups are recent, and they also consider many circularity aspects. The two studies were conducted in the framework of the Ecodesign Directive based on the MEErP. **Table 2** summarises the main findings. From these two examples, it can be noted that in the past the definition of design option was interpreted in different ways, and the identification of design options was not performed following a harmonised method and reasoning.

Table 2. Summary of the main differences between the approaches for the identification and comparison of DOs in the preparatory studies of imaging equipment and smartphones

	Imaging equipment	**Mobile phones, smartphones and tablets**
Task 4	Preliminary objectives of ecodesign measures are set (based on the results of the technical analysis).	Objectives are not analysed.
Task 6 – definition of DO	Environmental hotspots and potential areas of improvement, as well as the best available technologies, are used to propose design options, starting from the preliminary objectives identified in Task 4.	The individual design options are derived from prior work by the JRC, criteria already implemented in rating and labelling schemes, and further options identified in the analysis performed in Task 4 (at both component and product level).

Task 6 – setting the quantitative values related to a DO	The quantitative values are set based on the information collected in the previous tasks and on the feedback received from experts.	A lifetime model (for each base case) takes account of the identified reasons for products reaching their end of life and how this changes over time. Other quantitative values are estimated starting from the results of the previous tasks, from literature, stakeholder consultation and expert judgement.
Grouping of DOs	Not performed.	Performed.
Level of detail	The DO is more general.	The DO is already a specific measure (in some cases, with a quantitative value). It can be information-related or performance-related.

Source: JRC elaboration

2.1.1 Case of imaging equipment

In the recently published preparatory study on imaging equipment (European Commission, Joint Research Centre et al., 2024), design options for consumables (cartridges) are considered separately from design options for devices. Preliminary objectives of ecodesign measures are proposed at the end of Task 4. These objectives are the basis for defining the base cases and design options in Tasks 5 and 6, respectively. The identification of environmental hotspots and potential areas of improvement, as well as the best available technologies, is used in Task 6 to propose design options with the potential to improve the environmental performance of the base cases, both for devices and for consumables (i.e. cartridges). Regarding devices, the parameters used to define the base cases and the best available technologies are: energy and power consumption, lifetime, repairability, paper use; regarding cartridges, the parameters used to define the base cases and the best available technologies are: material efficiency, reusability, paper use, cartridge monitoring and traceability.

Table 3 reports the four design options identified for devices (printers). Based on the information collected in the previous tasks and on the feedback received from experts, the key parameters to be changed in design options (compared with the baseline) are estimated; for example, in the case of the first design option "Device with extended lifetime", the key parameters to be estimated are:

- average lifetime (years);
- average printed pages (in lifetime);
- refurbishing events (in lifetime);
- spare parts needed to refurbish the device (%);
- mass of device (kg);
- transport distance, from place of use to repair centre (km);

- end of life (% to recycling).

Then, in Task 7, some areas for measures are proposed, for each design option (**Table 3**), as well as the related requirements (information or performance requirements).

Table 3. Design options proposed in the preparatory study on imaging equipment: the case of devices

Objectives **(Task 4)**	**Design Options** **(Task 6)**	**Quantitative values linked with the Design Options** **(Task 6)**	**Areas for measures** **(Task 7)**
Ensure that devices last longer and are easier to repair, refurbish and recycle	Device with extended lifetime	Lifetime is extended by 50%	Repairability of devices Durability of devices Recyclability of devices
Explore untapped potential for improved energy savings in devices	Device with reduced energy consumption	Reduction of the overall energy consumption of devices by 20%	Reduction of energy consumption of devices
Optimise the consumption of paper	Device with reduced paper consumption	By including duplexing functionality in the inkjet device, the printing frequency on both sides of the paper increases from 20% (base case) to 58% (same printing frequency as laser devices with duplexing functionality)	Paper use optimisation in devices
Increase the amount of post-consumer recycled plastic in devices	Device with increased use of post-consumer recycled plastic	Post-consumer recycled plastic equal to 75%	Post-consumer recycled content of devices

Source: European Commission, Joint Research Centre et al. (2024)

2.1.2 Case of mobile phones, smartphones and tablets

In the preparatory study on mobile phones, smartphones and tablets (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (European Commission) et al., 2021), the individual design options are derived from prior work by the JRC (Tecchio et al., 2018; Cordella et al., 2020), implemented criteria in rating and labelling schemes, and further options identified in the technical analysis in Task 4. Indeed, in Task 4, best available technologies are analysed at both product and component level (i.e. battery, cover and backside glass, parts with recycled or bio-based materials, semiconductors).

Data on costs are integrated when defining design options to ease reflection on the interplay of design options, likely effects on environmental aspects and on costs. Some design options can already be dropped at this stage due to issues with associated costs. Options were grouped under 10 subsections:

1. Reliability.
2. Operating system, software and firmware.
3. Repairability.
4. Use of materials.
5. Readiness for second use and recycling.
6. Ability to recycle devices and parts.
7. Packaging.
8. Manufacturing.
9. Energy.
10. Other features.

The list of the 53 DOs developed is provided in **Figure 3**. It should be noted that the DOs included are both performance-related and information-related DOs.

In contrast to the DOs listed in the preparatory study for imaging equipment, here the DOs are specific measures, and in the case of performance-related ones, they include a quantitative value. For example, for design option 1 (DO1 – display robustness), the expected effect on affected devices is estimated, for each base case (15% increase in fracture toughness for base case 1, 10% increase in fracture toughness for base case 2, etc.), as well as the share of devices affected and the estimated effect on costs. These values are estimated starting from the results of the previous tasks, from literature, stakeholder consultation and expert judgement.

Moreover, a **lifetime model** (for each base case) was set up: it takes account of the identified reasons for products reaching their end of life and how this changes over time. Products leave the use stage due to hardware defects and non-hardware reasons. For the hardware-related defects, a yearly failure rate and yearly repair rate are calculated as percentages of the remaining stock based on assumptions from Task 5. Battery-related issues are treated differently with the failure rate of batteries increasing over time. The non-hardware reasons are then adjusted to meet the average lifetime of each base case.

The individual design options are plotted on these lifetime models to account for additional repairs and defects in later years when options extend the product lifetime for example. Thereby, the reduction of one failure rate (e.g. more resistant display) will reduce the number of products leaving the stock due to this specific defect, leading to an increase in absolute numbers of other defects and repairs in the following years as the number of products in the remaining stock changes and the percentage failure rates stay the same.

Depending on the design option, the failure rate and/or the repair rate is affected. Within the lifetime model, repair costs are calculated in parallel. Thereby, as for the failure rate, the repair regarding all defects changes with each option as the failure percentage and repair rate stay the same (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (European Commission) et al., 2021). As an example, the longer provision of operating system updates would lead to higher absolute hardware defects and higher repair costs as less products leave the stock early for software reasons. The costs per active use time however would decrease.

For the analysis of least life-cycle cost and best available technologies, clusters of design options are created, following two separate paths (**Figure 4**):

- a repairability-dominated path with ambitious repairability options (REP path); and
- a durability path, which also starts with some life-cycle cost-reducing repairability options, but then implementing enhanced water and dust ingress, which rules out some of the repairability options (DUR path).

However, most of the design options are shared by both paths.

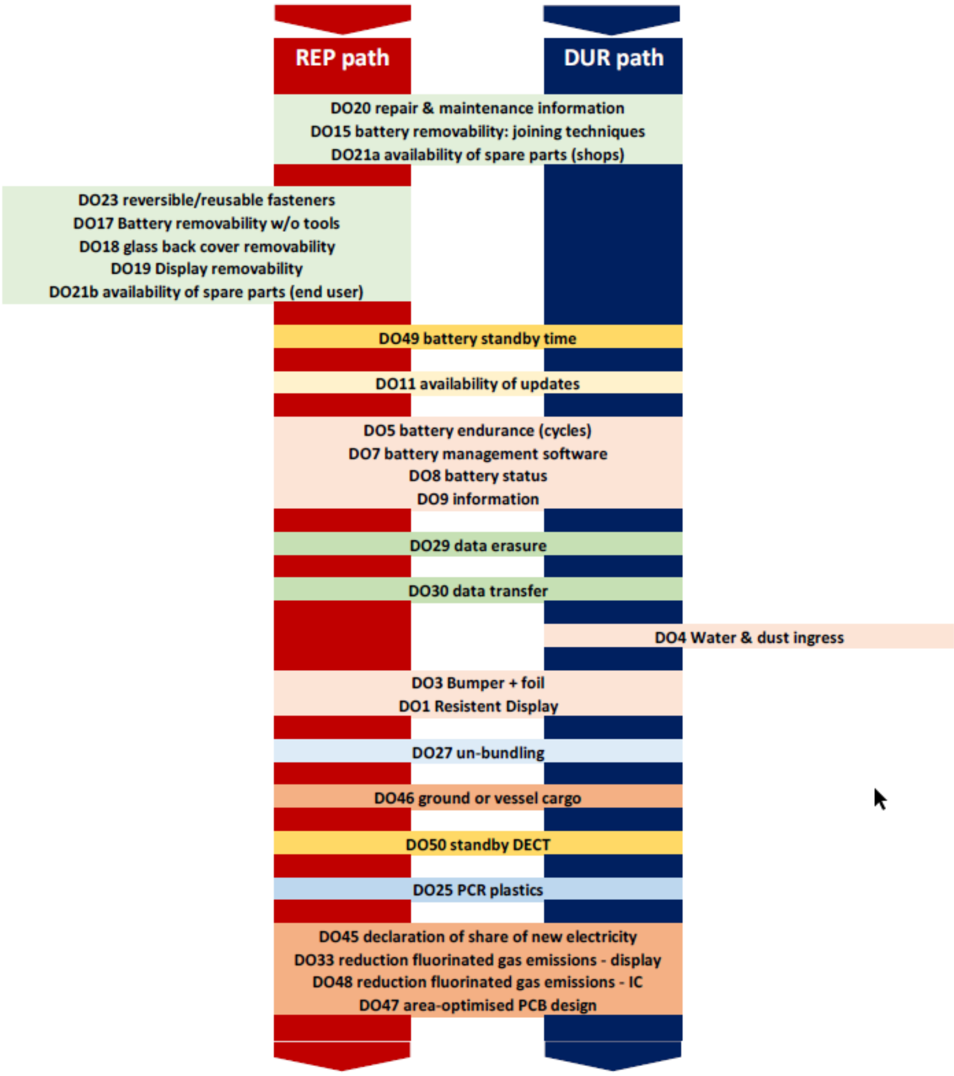
Figure 3. Design options proposed in the preparatory study on mobile phones, smartphones and tablets

DO1 Resistent Display
DO2 Scratch resistent display
DO3 Bumper + foil
DO4 Water & dust ingress
DO5 battery endurance
DO6 battery capacity
DO7 battery management software
DO8 battery status
DO9 information
DO10 most recent OS
DO11 availability of updates
DO12 open source OS
DO13 security patches
DO14 capacity for next OS
DO15 battery removability: joining techniques
DO16 battery removability: joining battery and display unit
DO17 Battery removability w/o tools
DO18 glass back cover removability
DO19 Display removability
DO20 repair & maintenance information
DO21a availability of spare parts (shops)
DO21b availability of spare parts (end user)
DO22 information on repair costs
DO23 reversible/reusable fasteners
DO24 recyclable materials
DO25 PCR plastics
DO26 bio-based plastics
DO27 un-bundling
DO28 standardized interfaces
DO29 data erasure
DO30 data transfer
DO38 take back schemes
DO39 Identification, access and removal of specific parts
DO40 provision of recycling information
DO45 declaration of share of new electricity
DO46 ground or vessel cargo
DO47 area-optimised PCB design
DO33 reduction fluorinated gas emissions - display
DO48 reduction fluorinated gas emissions - IC
DO49 battery standby time
DO50 standby DECT
DO51 Eco-DECT
DO52 Memory extension card option
DO53 Dual-SIM

NB The colours were used in the preparatory study to cluster Dos by category (Reliability; Operating system, software and firmware; Reparability; Use of materials; Readiness for second use and recycling; Ability to recycle smartphones / parts / materials; Packaging ; Manufacturing; Energy; Other features)

Source: Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (European Commission) et al. (2021)

Figure 4. Design options' implementation paths, in the preparatory study on mobile phones, smartphones and tablets



Source: Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (European Commission) et al. (2021)

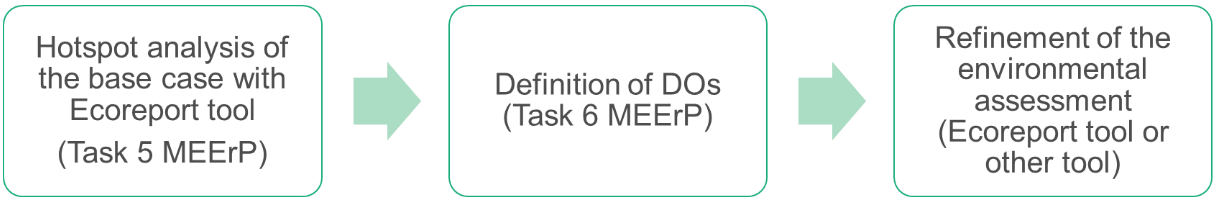
2.2 Proposal and indications for the identifications of DOs for the ESPR methodology

As mentioned in previous sections, in preparatory studies conducted in the past, the identification of design options was not performed following a harmonised method. For example, while in the case of smartphones DOs were already characterised as performance-related or information-related, in the case of imaging equipment this decision was made only in Task 7, when the measures were proposed.

After exchanges with the policy DGs and with the teams currently working on two pilot projects (i.e. textile project and steel project), it was concluded that DOs should be defined in a very specific way, so that they are close to ecodesign requirements. The advantage of this approach is that DOs can be modelled with a higher level of detail, as they represent a real case: this is essential for an effective and transparent stakeholder consultation. Moreover, it is easier to assess trade-offs and synergies between the different DOs, which are very likely under this new policy framework, also because of the introduction of circularity objectives. Finally, a better integration between the preparatory study and the respective impact assessment could be easily achieved.

This section proposes a definition of DO and discusses the identification of improved DOs, which should take place when Tasks 2, 3 and 4 of the MEErP are finalised, since input from them is required (see Section 2.2.2.3). Therefore, the identification of DOs should be performed at the beginning of Task 6. It should be noted that, since the selection of the most appropriate method for the environmental evaluation depends on the type of DOs to be assessed (refer to Gonzalez Torres et al. (2025[5]), Task 5 and Task 6 will be considered in parallel: the DOs will be defined after the hotspot analysis and then the assessment of the base cases in Task 5 will be refined according to the selected method (**Figure 5**).

Figure 5. Steps of the environmental assessment and its integration with the definition of DOs



Source: JRC elaboration

2.2.1 A new definition of DO: the product dimensions

In the original MEErP, since energy efficiency was the main focus, the analysis of technologies was sufficient to identify the best products and to create the improved design options. Indeed, in the MEErP 2011 report (Kemna et al., 2011), it is mentioned that design options should mainly come from Task 4. However, as recognised in literature, to design and create products that have a maximised environmental sustainability performance, i.e. that cause minimal negative environmental impacts over their life-cycle(s) or, optimally, contribute positively to sustainable development, product designers must expand their focus from the product to the system level (Ceschin and Gaziulusoy, 2016; Schöggl et al., 2024).

The transition to a circular economy entails more than mere technical modification, and circularity is not only determined by inherent product properties, but also depends on other factors such as influences during the use phase or the business models of the product supplier or third parties (Pruhs et al., 2024). This invites the adoption of a more holistic approach including reconsideration of entire product systems. According to Diaz et al. (2021), two tangible (material, architecture) and three intangible (service, business model, ecosystem) product dimensions can be considered.

The dimensions may be described as follows (Diaz et al. (2021), adapted to be consistent with the ESPR framework:

[5] By default, the simplified LCA in the EcoReport tool shall be the preferred method for the assessment of the environmental impacts of the base cases and design options. However, finer assessment shall be considered in the case of: (a) simplifications and shortcuts that may distort the results; (b) design options that cannot be modelled in the EcoReport tool; (c) construction products; (d) aspects beyond the resulting impact categories.

a) Product material: pertains to modification of one or more substances/materials embedded in the physical product and/or to substances/materials used in the production process. The processes to produce the substances/materials can also be included.

b) Product architecture: pertains to modification of one or more functional elements and physical components of products in terms of what they do and what their interfaces with the rest of the device are. The manufacturing processes can also be included.

c) Product service: pertains to modification of the intangible services combined with the physical product so that they are jointly capable of fulfilling specific customer needs (Tukker, 2004). As an example, in the case of product leasing, the consumer pays a regular fee for the use of the product, and in some cases the responsibility for maintenance and end-of-life processing stays with the manufacturer, encouraging design for longevity and recyclability. Other examples of services can be the availability of spare parts, the provision of software updates, or the availability of repair and maintenance instructions.

d) Product business model: pertains to modification of any of the elements determinant in a successful commercial transaction involving the product, such as the sources of revenue, the intended customer base or further financing details.

e) Product ecosystem: pertains to modification of the set of actors – producers, suppliers, service providers, end users, regulators, civil society organisations – that contribute to a collective outcome and the joint creation of value, through collaboration, experimentation or platformisation (Konietzko et al., 2020). Collaboration refers to how firms can interact with other organisations in their ecosystem to innovate towards circularity. Experimentation refers to how firms can organise a structured trial-and-error process to implement greater circularity. Finally, platformisation refers to how firms can organise social and economic interactions via online platforms to achieve greater circularity. The product ecosystem dimension should be the basis for promoting exchanges between manufacturers, suppliers, waste management companies, repairers, and consumers to create a closed-loop system.

So far, the identification of design options has focused on energy-related aspects and, in the most recent preparatory studies, on product material and architecture, within Task 4 of the MEErP. However, the definition of 'ecodesign requirement' provided in the legal text[6] invites an extension of the analysis to encompass the entire product value chain: all the dimensions should be considered by the study team to also tackle related aspects that can be addressed through ecodesign. In Annex 1, a table which links product dimensions to the product parameters listed in Annex I to the ESPR is provided to support the assessment of the study team. The table shows that product services, business models and ecosystems can be indirectly regulated under the ESPR: indeed, some of the parameters (e.g. conditions for access to product data, availability of guarantees specific to remanufactured or refurbished products, environmental footprint, carbon footprint, material footprint of the product, emissions to air, water or soil released in one or more life-cycle stages of the product) might be used by the policymakers to push the market towards more sustainable product service systems, business models and product ecosystems.

Therefore, a new definition of design option is proposed:

'Design option' is a specific **product service system**, with features which make it more advanced and/or more efficient when compared to the 'base case' in at least one of the product aspects listed in Article 5 of the ESPR.

[6] "Ecodesign requirement means a performance requirement or an information requirement aimed at making a product, including processes taking place throughout the product's value chain, more environmentally sustainable."

In many cases, a **“virtual” design option** will be used, since the same improvement can be achieved by different economic operators placing the product on the market (i.e. manufacturers, importers) through the adoption of **different product service system configurations**, i.e. with changes in one (or more) energy-related aspects and/or in one (or more) product dimensions (i.e. product material, product architecture, product service, product business model, product ecosystem). Each configuration will be weighted according to its estimated market share.

The best example is the product aspect “Environmental impacts, including carbon and environmental footprint”. The study team should make assumptions on the potential redesign paths that the economic operators might follow to be compliant with the future target. In a “virtual” DO, each product configuration (redesign path) is represented in a percentage equal to its estimated market share: the estimates should be based on the analyses done in the previous tasks. In most cases, it can be assumed that the economic operators will select the cheapest path. The study team should point out cases of potential burden shifting and suggest countermeasures.

The ecodesign requirements resulting from a design option will not directly regulate business models or product ecosystems, but they will regulate the product aspects listed in Article 5 of the ESPR (“the ecodesign requirements in the delegated acts (…) shall be such as to improve the following product aspects (‘product aspects’) where those product aspects are relevant to the product group concerned (…)”, Article 5, ESPR), with an indirect effect on business models and product ecosystems.

Finally, as presented in the case of imaging equipment (Section 2.1.1), design options can also be proposed for consumables.

More details on each product dimension are provided in the following subsections.

2.2.1.1 Product material and product architecture

At material level, the analysis should focus on the presence of substances, and in particular substances of concern (see definition (27) in Art. 2 of the ESPR and Task B5 of the ESPR methodology (Perez Camacho et al., 2025)), on the presence of strategic and critical raw materials (see Task B11 (Maury et al., 2025)), on the usage of renewable resources (e.g. materials with bio-based content), as well as on the release of nano- and microplastics (recital 24, ESPR). Both the quality and the quantity of materials used are relevant, as well as the content of recycled material. The analysis should consider the material embedded in the product, as well as the materials used in the production process (e.g. a process agent or a catalyst) and the consumables. The concept of material footprint introduced by the ESPR goes in this direction, because it refers to the total amount of raw materials extracted to meet final consumption demands (see Section 5.4 in Rodriguez Manotas et al. (2025)). Moreover, the processes to extract or produce the materials or substances should also be included.

Product architecture is a dimension that can be studied only for final products. The study team should focus the analysis on the most critical components, with respect to the product aspects listed in Article 5 of the ESPR, as well as the way the components are assembled. As an example, in the case of repair and/or upgrade operations, the methodology for the identification of priority parts presented in Joint Research Centre (European Commission) et al. (2019) can be used. Moreover, for products without components, other aspects can be considered (e.g. the arrangement of functional elements).

As a guide to define design options regarding the product material and architecture, the study team could use the framework proposed by Bocken et al. (2016) (**Figure 6**), where the following two fundamental strategies toward the cycling of resources are mentioned:

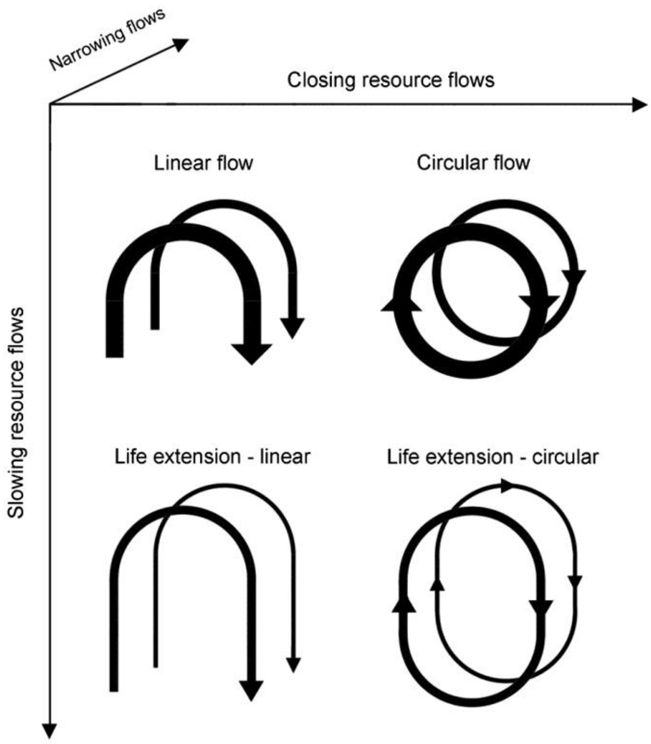
(1) Slowing resource loops: Through the design of long-life goods and product-life extension (i.e. service loops to extend a product's life, for instance through repair, remanufacturing), the utilisation period of products is extended and/or intensified, resulting in a slowdown of the flow of resources. As explained in Babbitt et al. (2021), this approach includes designing products that are durable and retain both their function and their appeal to users over an extended life span. A complementary strategy is creating products that are more easily disassembled and upgraded, both to allow the initial user to carry out maintenance and repair that extend the initial service life and to facilitate access to components requiring repair or replacement so that the critical material value can be extended over multiple life-cycles.

(2) Closing resource loops: Through recycling, the loop between post-use and production is closed, resulting in a circular flow of resources. This approach entails an interconnected suite of activities beginning with collection of manufacturing scrap or end-of-life products, followed by transportation and consolidation of similar components or materials, and finally the use of physical, chemical and thermal technologies to separate and purify individual elements or compounds (Babbitt et al., 2021).

These two approaches are distinct from a third approach aimed at reducing resource flows:

(3) Resource efficiency or narrowing resource flows, aimed at using fewer resources per product. Potential strategies include substituting non-renewable for renewable resources, dematerialising products through technological progress and multifunctionality, substituting digital alternatives for physical goods, and sharing or leasing products and services rather than individually owning goods (Babbitt et al., 2021).

Figure 6. Categorisation of linear and circular approaches for reducing resource use



Source: Bocken et al. (2016)

The analysis should consider not only material resources, but also energy resources. The same study by Bocken et al. (2016) discusses the potential business model strategies for a circular economy, creating a connection between business model and strategies toward the cycling of resources.

2.2.1.2 Product service

The concept of Product Service System (PSS) is widely used in literature. A PSS is an integrated combination of products and services: it is as a market proposition that extends the traditional functionality of a product by incorporating additional services (Baines et al., 2007). A more complete definition is given in Annarelli et al. (2016): a PSS is a business model focused on the provision of a marketable set of products and services, designed to be economically, socially and environmentally sustainable, with the final aim of fulfilling the customer's needs. As pointed out by Sassanelli et al. (2020), design for "X"[7] approaches have already been exploited to systematically support the PSS design process, given their re-known ability to allow better information-sharing between product designers and service managers.

A product can be supported through life-cycle services (e.g. maintenance, upgrade and take-back services) or offered as a service (e.g. through pay-per-service-unit). Products and services can be offered on a platform for customers to use (e.g. through subscriptions or short-term rentals).

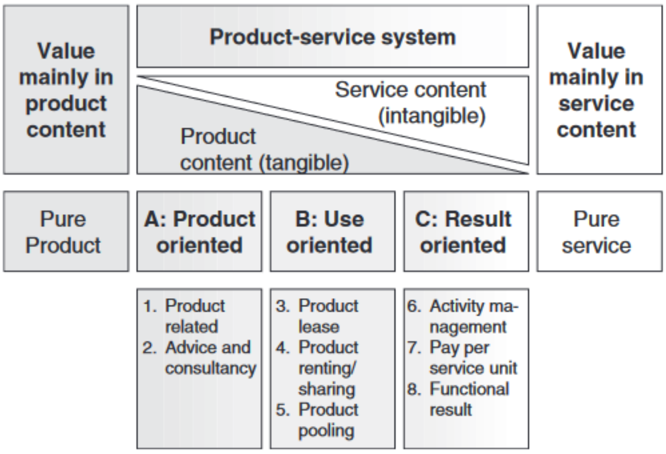
PSS are commonly understood as a means to achieve a circular economy. However, a PSS is not always circular (nor sustainable) (Fernandes et al., 2020). Guidelines for conducting LCA on PSS in six steps are presented by Kjaer et al. (2018).

As shown in **Figure 7**, three types of PSS are usually distinguished:

- PSS is product-oriented when it involves the traditional sale of a product, but additional services are offered to the customer to guarantee product functionality.
- In use-oriented PSS, the provider delivers the use or availability of a product. The product stays in the ownership of the provider, and is made available in a different form, and sometimes shared by a number of users.
- Lastly, the PSS is result-oriented when the provider and customer mutually agree on a solution to be delivered (Tukker, 2004).

[7] Design for "X" (DFX) refers to design methods that ensure that a particular characteristic, function, or quality criteria is reflected in the final design. Source: https://www.sciencedirect.com/topics/engineering/design-for-x

Figure 7. Subcategories of PSS



Source: Tukker (2004)

The inclusion of services that are integral to a product's use, maintenance and disposal is an important element in the definition of DOs for the subsequent environmental and economic assessment: excluding these services could lead to an incomplete or inaccurate assessment of the product's overall impact. Therefore, even if the services are outside the scope of the ESPR, their analysis should be taken into account to guarantee the accuracy of the environmental and economic assessment.

Moreover, as already pointed out in previous preparatory studies (Joint Research Centre (European Commission) et al., 2014; European Commission, Joint Research Centre et al., 2024), physical ownership of the appliances has a significant influence on many product aspects, e.g. reuse, repair, maintenance, remanufacturing, or on the interest of the owner in energy efficiency. As explained in the draft ISO standard 59004 (ISO, 2023), "performance-based actions and their associated business models are acknowledged as relevant to decouple revenues from the use of material resources and make organisations less dependent on the quantity of products delivered. Traditionally, a service is provided where products are sold. With the transition to a circular economy, ownership of products may be supplanted by the option to purchase services. Ownership of a product then remains with the supplier, but customers are loaned access to the product as part of delivering a service."

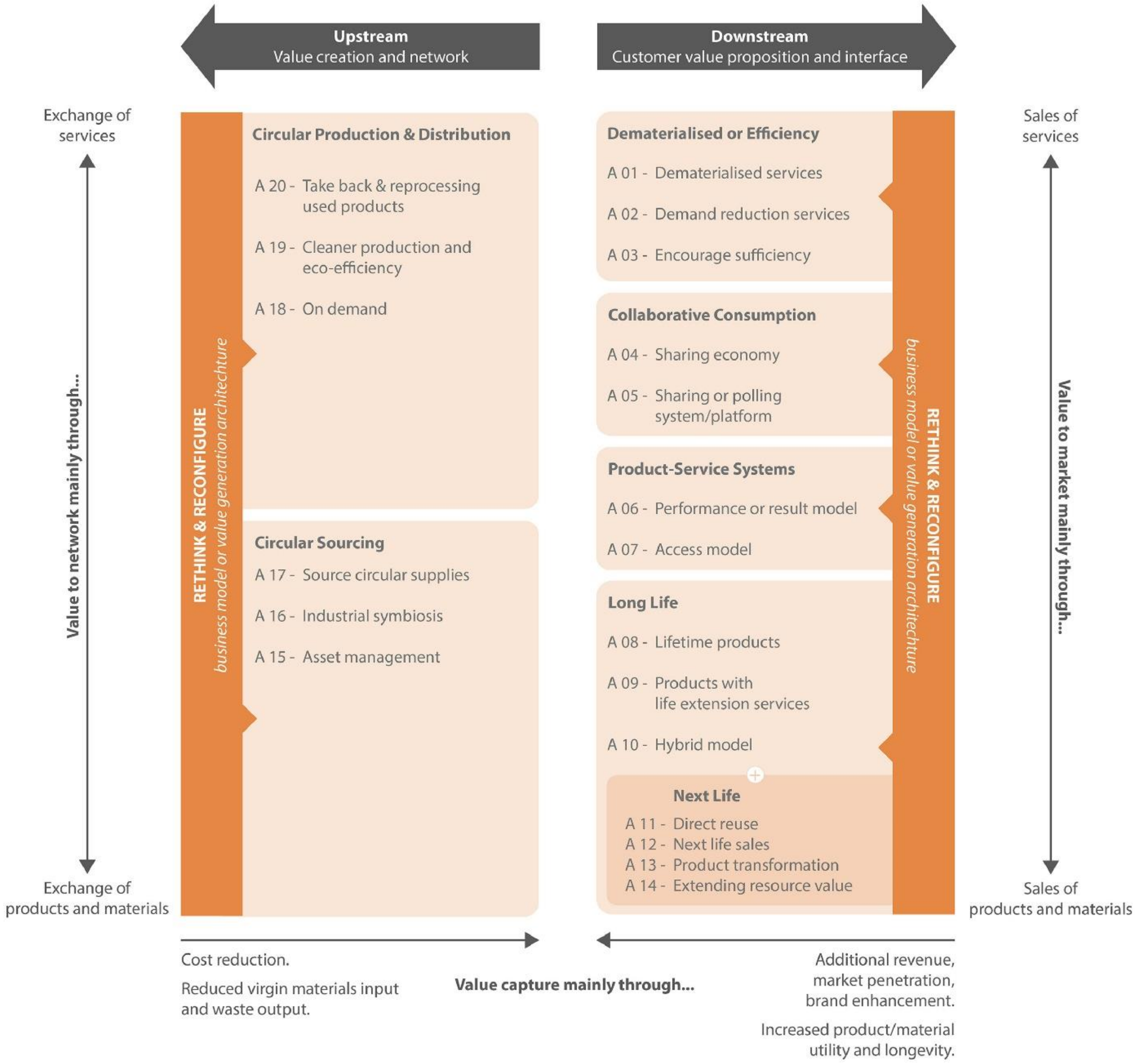
2.2.1.3 Product business model

As written in the ESPR, "common ecodesign requirements at Union level would enable the development, deployment and scaling-up of new circular economy business models throughout the internal market" (recital 3). Moreover, "the second-hand sector plays an important role in promoting sustainable production and consumption, including in the development of new circular business models, and contributes to prolonging the lifetime of a product and avoiding it becoming waste" (recital 17).

A circular business model can be defined as a business model in which the conceptual logic for value creation is based on utilising economic value retained in products after use in the production of new offerings. Thus, a circular business model implies a return flow to the producer from users, though there can be intermediaries between the two parties (Linder and Williander, 2017).

As noted by OECD (2019), the literature on circular business models is growing rapidly and contains a variety of different typologies. There are considerable differences in the level of granularity, as well as the classification approach that is taken. Some authors take a value chain perspective that structures business models into circular design, optimal use (by providing services or add-ons to extend the lifetime of a product or provide ways to use products more intensively or efficiently), and value recovery types (Achterberg et al., 2016). Others distinguish business models according to the material flows they address. IMSA (2015) focused on short loops, long loops, cascades, and pure cycles while Lewandowski (2016) focused on regeneration, sharing, optimisation, or looping. The activities implicit in all of these typologies overlap significantly, but are often given different names. A recent review by Pieroni et al. (2020) identified 20 different circular business model archetypes (**Figure 8**), and 63 subtypes.

Figure 8. Consolidated typology of business models of circular economy archetypes



Source: Pieroni et al. (2020)

However, not all circular business models have the same potential to reduce environmental impacts, and some circular business models can lead to unanticipated negative environmental impacts (Das et al., 2023).

Finally, it should be considered that, as stated in Regulation (EU) 2023/988[8], "online selling has grown consistently and steadily, creating new business models, new challenges regarding product safety and new actors in the market, such as providers of online marketplaces".

2.2.1.4 Product ecosystem

In literature, it is recognised that circularity is a property of a system, rather than of a single product (Konietzko et al., 2020). Circular economy ecosystems are defined as "communities of hierarchically independent, yet heterogeneous set of actors who collectively generate a sustainable ecosystem outcome" (Aarikka-Stenroos et al., 2021). Thus, value creation demands ecosystems where stakeholders at different levels (micro, meso, macro) collaborate to benefit customers (Tabas et al., 2024). As suggested by Aarikka-Stenroos et al. (2021), CE ecosystems can be grouped into three distinct categories based on their system interactions and flows as well as their system-level goals, namely: material flow-based industrial and urban ecosystems, knowledge flow-based entrepreneurial and knowledge ecosystems, and economic value flow-based innovation ecosystems which include platform and business ecosystems.

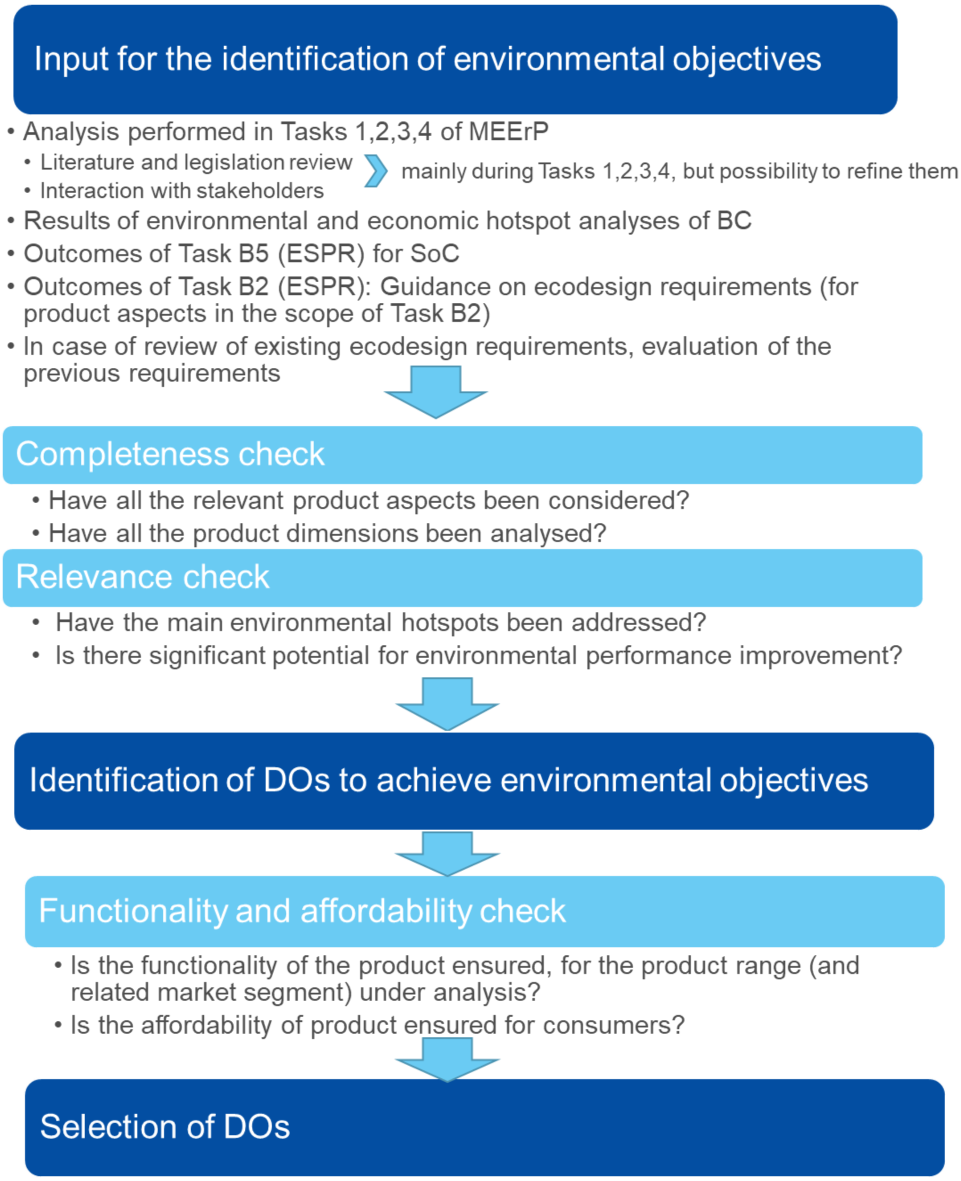
Therefore, the study team should analyse the whole value chain of the product group being analysed to identify potential room for improvements, including the activities performed by the users and the activities related to the end of life of the product. In this regard, the possibility to introduce a digital product passport and track information along the whole value chain should be considered.

2.2.2 Framework for the identification of DOs

The general framework proposed is depicted in **Figure 9**. The process should be iterative, and it should aim to select a limited number of design options, to streamline the study. The framework resulted from the analysis of MEErP and previous preparatory studies, as well as the integration of results from other tasks of the ESPR methodology.

[8] Regulation (EU) 2023/988 of the European Parliament and of the Council of 10 May 2023 on general product safety, amending Regulation (EU) No 1025/2012 of the European Parliament and of the Council and Directive (EU) 2020/1828 of the European Parliament and the Council, and repealing Directive 2001/95/EC of the European Parliament and of the Council and Council Directive 87/357/EEC

Figure 9. General framework for the identification of Design Options (DOs)



Source: JRC elaboration

The whole process can be divided into four main steps:

1. Identification of environmental objectives: The identification of design options should start with the identification of environmental objectives for the product being analysed (as was done in the case of imaging equipment, see Section 2.1.1). Like in previous preparatory studies, inputs from literature and legislation review and from stakeholder consultations should be considered, as well as input from other tasks of the ESPR methodology and MEErP. The environmental hotspots and the main barriers to circularity should be investigated (see output from Task B1, Gonzalez Torres et al. (2025)). The assessment of the base case (environmental and economic impacts, hotspots, areas of improvements) could provide inputs for the identification of alternative design options (see Section 4.4 for guidelines on the use of conventional and societal LCC). If the study team considers carbon footprint relevant, an updated methodology for its calculation is being developed, to be used

for materials within the scope of the ETS and CBAM and final products using such materials. Moreover, in the case of review of existing ecodesign requirements, the evaluation of the previous requirements can be used as an input (as was done for examples for household washing machines and household dishwashers).

2. Completeness and a relevance check: before identifying the DOs, the study team could perform a completeness and a relevance check:

    - Completeness check: the objective is to ensure that all the relevant product aspects (see **Table 4**) and product dimensions (product material, product architecture, product service, product business model and product ecosystem, see Section 2.2.1) have been considered, both for the product and for its consumables. As per Article 5 of the ESPR, "ecodesign requirements in the delegated acts adopted (…) shall be such as to improve the following product aspects ('product aspects') where those product aspects are relevant to the product group concerned". While all product aspects listed in Article 5.1 of the ESPR can be relevant for final products, it should be noted that not all of them can be applied to intermediate products (**Table 4**). The results of the assessment performed in Task B2 (Rodriguez Manotas et al., 2025) should be used to select the relevant circularity aspects.

Table 4. List of product aspects (Article 5.1) and their relevance for intermediate products

	Product aspects	**Applicable to intermediate products?**
a	Durability	Not applicable*
b	Reliability	Not applicable
c	Reusability	Not applicable
d	Upgradability	Not applicable
e	Repairability	Not applicable
f	Possibility of maintenance and refurbishment	Not applicable
g	Presence of substances of concern	Applicable
h	Energy use and energy efficiency	Applicable
i	Water use and water efficiency	Applicable
j	Resource use and resource efficiency	Applicable
k	Recycled content	Applicable
l	Possibility of remanufacturing	Not applicable
m	Recyclability	Not applicable*

n	Possibility of recovery of materials	Not applicable*
o	Environmental impacts, including carbon and environmental footprint	Applicable[9]
p	Expected generation of waste	Applicable

NB. Circularity aspects marked with an asterisk (*) refer to those that may also be applicable for the definition of ecodesign requirements. The study team will assess their applicability based on each specific product group in question and the considerations of the preparatory study (e.g. whether the study also considers the product's final application, where durability and/or recyclability could be relevant). In the case of information requirements, the non-applicable circularity aspects marked with an asterisk could also be considered. The study team will decide whether consumables should be included in the study of a final product or whether they should be the object of a separate study.

Source: JRC elaboration

- Relevance check: based on the results of the environmental assessment of the base case, the identified objectives should address the environmental hotspots identified and should aim at a substantial improvement of the life-cycle environmental performance of the product.

3. Identification of DOs. As in the case of imaging equipment, one DO can be linked to more than one product aspect (see **Table 3**). To facilitate the work of the study team in the identification of design options, **Table 5** could be used: it lists the product parameters (from Annex I to the ESPR) and links them to one or more product aspects. Indeed, the product parameters are an expression of the product aspects.

4. Selection of a limited number of DOs: the study team could perform a functionality and affordability check, in order to ensure that the selected DOs do not compromise the product functionality or its affordability.
    - The affordability check has to be understood as a preliminary assessment that will be further substantiated in Task 6 of the MEErP; the aim is the exclusion of those design options that clearly place a significant economic burden on manufacturers/consumers. This check is based on expert judgement and exchanges with stakeholders.
    - As regards the functionality check, it should be considered that functionality is here defined as the function provided by the product, the magnitude of the function and its duration. According to JRC (2011) and the Commission Recommendation on the use of the Environmental Footprint methods[10], the functionality can be defined by replying to four questions:

[9] Considering the results of the hotspot analysis, in the event that the impact category on Global Warming Potential is one of the hotspots, the study team may consider setting a requirement on carbon footprint, by referring to the specific methodology for the calculation of the carbon footprint currently under development (if the product is within the scope of the EU ETS or CBAM).

[10] Commission Recommendation (EU) 2021/2279 of 15 December 2021 on the use of the Environmental Footprint methods to measure and communicate the life-cycle environmental performance of products and organisations.

a) what function is provided;

b) in what quantity (how much);

c) for what duration (how long) and

d) in what quality (how well)?

The study team should refer to this definition of functionality and to these four questions, to check that the functionality of the product is ensured. For more details and for examples of application, Commission Recommendation (EU) 2021/2279[11] can be consulted.

The functionality can be checked for different product ranges: a product range refers to variations of a single product that are made in order to create similar yet distinctly different products. Each version of the product is designed to attract a different market segment.

Indeed, if we refer to a broader definition of functionality, including physical, economic, intangible and emotional functionality, as reported in ISO 14006 (ISO, 2020), "ecodesign can have a positive impact on functionality", thus modifying it, "as follows:

> a) energy consumption and material use are linked to physical functionality, e.g. smaller, lighter products;
>
> b) material and energy reduction, less packaging and transport and products designed for easier disassembly are related to economic functionality, e.g. lower transport cost, lower energy cost to user;
>
> c) material aesthetics and durability can be elements of emotional functionality".

Indeed, as reported by McDonagh-Philp and Lebbon (2000), products do not exist merely to perform tasks, they satisfy other functional requirements, including aspirations, cultural, social and emotional needs. There is currently interest in the emotional relationship between a product and its user.

[11] Commission Recommendation (EU) 2021/2279 of 15 December 2021 on the use of the Environmental Footprint methods to measure and communicate the life-cycle environmental performance of products and organisations.

Table 5. Product parameters and product aspects

	Product parameters (Annex I)	Examples (Annex I)	Related product aspects (Article 5.1)
a	Durability and reliability of the product or its components	Product's guaranteed lifetime	Durability, reliability
		Technical lifetime	
		Mean time between failures	
		Indication of real use information on the product	
		Resistance to stresses or ageing mechanisms	
b	Ease of repair and maintenance	Characteristics, availability, delivery time and affordability of spare parts	Repairability, possibility of maintenance and refurbishment
		Modularity	
		Compatibility with commonly available tools and spare parts	
		Availability of repair and maintenance instructions	
		Number of materials and components used	
		Use of standard components	
		Use of component and material coding standards for the identification of components and materials	
		Number and complexity of processes and whether specialised tools are needed	
		Ease of non-destructive disassembly and reassembly	

	Product parameters (Annex I)	Examples (Annex I)	Related product aspects (Article 5.1)
		Conditions for access to product data	
		Conditions for access to or use of hardware and software needed	
c	Ease of upgrading, reuse, remanufacturing and refurbishment	Number of materials and components used	Reusability, upgradability, possibility of maintenance and refurbishment, possibility of remanufacturing
		Use of standard components	
		Use of component and material coding standards for the identification of components and materials	
		Number and complexity of processes and tools needed	
		Ease of non-destructive disassembly and reassembly	
		Conditions for access to product data	
		Conditions for access to or use of hardware and software needed	
		Conditions of access to test protocols or not commonly available testing equipment	
		Availability of guarantees specific to remanufactured or refurbished products	
		Conditions for access to or use of technologies protected by intellectual property rights	
		Modularity	
d		Use of easily recyclable materials	

	Product parameters (Annex I)	Examples (Annex I)	Related product aspects (Article 5.1)
	Design for recycling, ease and quality of recycling	Safe, easy and non-destructive access to recyclable components and materials or components and materials containing hazardous substances and material composition and homogeneity	Recyclability, possibility of recovery of materials
		Possibility for high-purity sorting	
		Number of materials and components used	
		Use of standard components	
		Use of component and material coding standards for the identification of components and materials	
		Number and complexity of processes and tools needed	
		Ease of non-destructive disassembly and re-assembly	
		Conditions for access to product data	
		Conditions for access to or use of hardware and software needed	
e	Avoidance of technical solutions detrimental to reuse, upgrading, repair, maintenance, refurbishment, remanufacturing and recycling of products and components		Reusability, upgradability, repairability, possibility of maintenance and refurbishment, possibility of remanufacturing

	Product parameters (Annex I)	Examples (Annex I)	Related product aspects (Article 5.1)
f	Use of substances, and in particular the use of substances of concern, on their own, as constituents of substances or in mixtures, during the production process of products, or leading to their presence in products, including once these products become waste, and their impacts on human health and the environment		Presence of substances of concern
g	Use or consumption of energy, water and other resources in one or more life-cycle stages of the product, including the effect of physical factors or software and firmware updates on product efficiency and including the impact on deforestation		Energy use and energy efficiency, water use and water efficiency, resource use and resource efficiency
h	Use or content of recycled materials and recovery of materials, including critical raw materials		Recycled content, possibility of recovery of materials
i	Use or content of sustainable renewable materials		Resource use and resource efficiency

	Product parameters (Annex I)	Examples (Annex I)	Related product aspects (Article 5.1)
j	Weight and volume of the product and its packaging, and the product-to-packaging ratio	Weight and volume of the product and its packaging	Resource use and resource efficiency
		Product-to-packaging ratio	
k	Incorporation of used components		Resource use and resource efficiency
l	Quantity, characteristics and availability of consumables needed for proper use and maintenance	Yield	Reusability, repairability, possibility of maintenance and refurbishment, possibility of remanufacturing
		Technical lifetime	
		Ability to reuse, repair, and remanufacture	
		Mass-resource efficiency	
		Interoperability	
m	The environmental footprint of the product	Quantification, in accordance with the applicable delegated act, of a product's life-cycle environmental impacts, whether in relation to one or more environmental impact categories or an aggregated set of impact categories	Environmental impacts, including carbon and environmental footprint
n	The carbon footprint of the product		Environmental impacts, including carbon and environmental footprint
o	The material footprint of the product		Resource use and resource efficiency
p	Microplastic and nanoplastic release	The release during relevant product lifecycle stages including manufacturing, transport, use, and end of life stages	Environmental impacts, including carbon and environmental footprint, expected generation of waste

	Product parameters (Annex I)	Examples (Annex I)	Related product aspects (Article 5.1)
q	Emissions to air, water or soil released in one or more life-cycle stages of the product	Quantities and nature of emissions, including noise	Environmental impacts, including carbon and environmental footprint
r	Amounts of waste generated, including plastic waste and packaging waste and their ease of reuse, and amounts of hazardous waste generated		Expected generation of waste
s	Functional performance and conditions for use	Ability in performing its intended use	Resource use and resource efficiency, expected generation of waste, possibility of maintenance and refurbishment
		Precautions of use	
		Skills required	
		Compatibility with other products or systems	
t	Lightweight design	Reduction of material consumption	Resource use and resource efficiency, expected generation of waste
		Load- and stress-optimisation of structures	
		Integration of functions within the material or into a single product component	
		Use of lower density or high-strength materials and hybrid materials, with respect to material savings, recycling and other circularity aspects, and waste reduction	

Source: JRC elaboration, based on ESPR legal text

2.2.2.1 Input from literature and from other legislation

A review of the studies focused on the product under consideration could be performed by the study team, focusing on the main environmental hotspots and on the identification of barriers to circularity.

Note that a preliminary literature and legislation review should already be performed in Tasks 1, 2, 3 and 4 of the MEErP. However, at this stage the review can be more targeted and look for studies on specific product aspects or specific hotspots, possibly also looking for solutions/improved DOs already described in the literature. In this sense, the literature and legislation review can be seen as an iterative task.

A starting point for this targeted review can be the study performed by van Loon et al. (2021), who reported a review of publications on products that undergo circular processes (i.e. reuse, remanufacturing, lifetime extension), divided into three sections, considering what circular strategy (design or business model) is observed for the circular outcomes analysed: (1) products that exist with a design and business model that is not modified - it is made for a linear product (no circular strategy), (2) products that have a design that is 'intended' for circular use (circular product design) and (3) products that are offered within an alternative circular business model (see Table 1 in the study).

Moreover, criteria set by the EU Ecolabel and by other nationally or regionally officially recognised EN ISO 14024 type I ecolabels can be reviewed by the study team, as well as EU green public procurement criteria. The study "Improving material efficiency in the life-cycle of products: a review of EU Ecolabel criteria" by Cordella et al. (2020) could also be consulted, as it summarises the material efficiency aspects that are considered among the Ecolabel criteria for 26 different product groups.

2.2.2.2 Input from other tasks of the ESPR methodology

From **Task B1** (Gonzalez Torres et al., 2025), the results of the ad hoc hotspot analysis using the simplified LCA should be considered, to identify improved design options.

In this regard, scientific literature agrees on the fact that products usually cause significant environmental impacts in only one or a few of their life-cycle stages. The recent publication by Pruhs et al. (2024) defines raw-material-intensive products, manufacturing-intensive products, distribution-intensive products, use-intensive products and disposal-intensive products. For each of these categories, an ecodesign approach (based on Article 5 of the ESPR) is recommended in a decision matrix. Moreover, the authors proposed another matrix to link life-cycle-phase intensity to the types of circular business models that could be implemented. The two matrices are reported in Annex 2, and can be used together with the results from Task B1 (Gonzalez Torres et al., 2025).

From **Task B2** (Rodriguez Manotas et al., 2025), a list of relevant circularity product aspects will be provided. The circularity aspects considered within Task B2 are:

(a) durability;

(b) reliability;

(c) reusability;

(d) upgradability;

(e) repairability;

(f) the possibility of maintenance and refurbishment;

(i) water use and water efficiency;

(j) resource use and resource efficiency;

(k) recycled content;

(l) the possibility of remanufacturing;

(m) recyclability;

(n) the possibility of the recovery of materials;

(p) expected generation of waste

The study team can exclude the product aspects that are deemed irrelevant after the application of the method developed under Task B2 (Rodriguez Manotas et al., 2025). The proposal is that the ESPR methodology will enable the prioritisation of the design options related to one or more product aspects. As a complementarity analysis, Task B2 proposes a method to define whether the EU Open Strategic Autonomy (OSA) dimension is relevant for a specific product. While mitigation measures to ensure EU OSA can work in synergy with circularity-based DOs, the primary focus of DOs should remain on ecodesign. The potential impact of circularity strategies on the EU's OSA—such as the recovery of critical raw materials, incorporation of recycled content, and extension of product lifetimes—along with other strategies like substitution, should be analysed afterwards (see Section 4.5.1). This analysis of synergies and trade-offs should follow the selection of a limited number of DOs.

Task B5 resulted in a method that defines how to set information and performance requirements on the presence of substances, and in particular of substances of concern in the product value chain (Perez Camacho et al., 2025). This should be considered in the proposal of alternative design options.

Once the DOs are set up, the **Task B11** methodology will guide the study team to assess the potential consequences of specific ESPR product requirements on Open Strategic Autonomy. For each of the main aspects related to EU OSA[12], an assessment should be carried out to identify if potential benefits or a risk of hindering EU OSA are expected when selecting a DO (see Section 4.5.1 and (Maury et al., 2025)).

A summary of the inputs needed from other ESPR tasks is provided in **Table 6**.

Table 6. Summary of inputs from other ESPR tasks for the identification of DOs

Task	Input to this task
B1	Environmental hotspots
B2	List of circularity product aspects that are relevant for the product Relevance of OSA
B5	List of product-relevant substances of concern covered under Art. 2(27) a, b, c (to the extent possible), and d (obligatorily) and setting of performance requirements related to substances in the product value chain

[12] Four main EU OSA aspects are identified in Task B11: i) material composition, ii) energy demand, iii) EU market dynamics, and iv) innovative or critical production and recycling routes.

B11	Methodology to assess the potential consequences of specific ESPR product requirements on Open Strategic Autonomy aspects (e.g. mitigation of supply dependencies)

Source: JRC elaboration

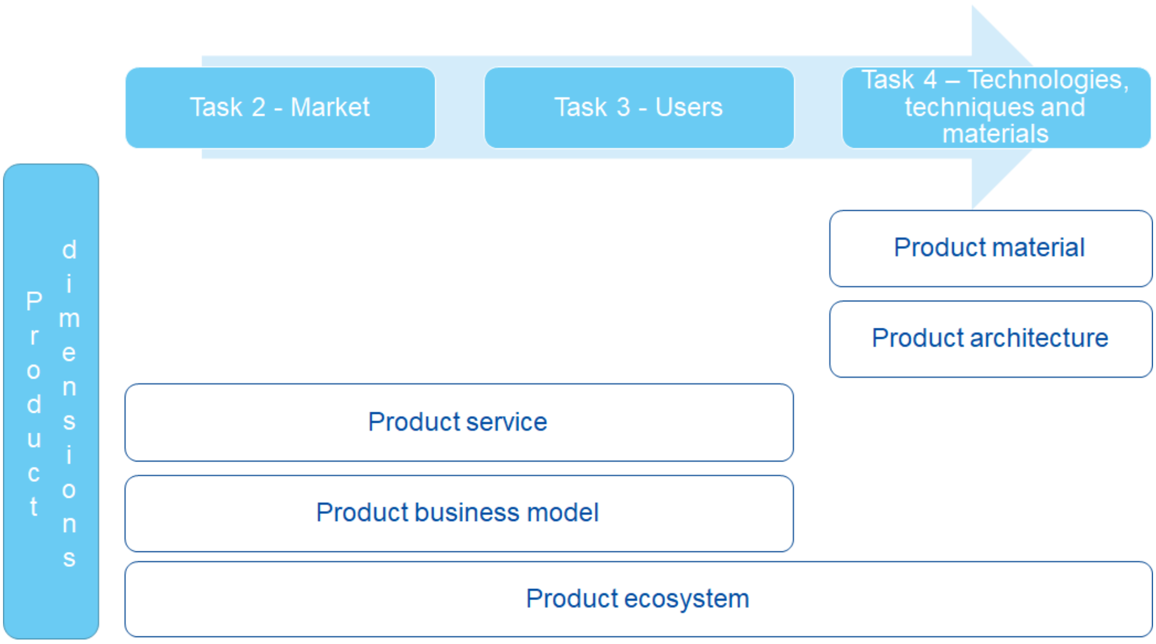
2.2.2.3 Input from previous tasks of the MEErP methodology

Considering the extension of the scope in the ESPR compared to the MEErP, information gathered in Tasks 2, 3 and 4 should also be extended to cover all the relevant product aspects. The product dimensions (product material, product architecture, product services, business models and ecosystem) should be investigated within Tasks 2, 3 and 4, as depicted in **Figure 10**. A literature review on each dimension for the product group being analysed should be performed by the study team.

Moreover, the analysis of best (in terms of environmental performance) available and best not yet available solutions, technologies and techniques should be performed, for each of the dimensions, as shown in **Table 7**. The term “technology” refers to product or to a component, while the term “technique” refers to an industrial process performed in an installation. The term “solution” is used to refer to services provided with the product, business models or ecosystems (for more complete definitions, see Section 2.2.2.3.3): indeed, product service, business model and ecosystem influence the environmental performance of a product. For the sake of simplicity, the study team will probably not describe the numerous business models, product services and product ecosystems present on the market, but will investigate some crucial parameters of the business models, services and product ecosystems that decrease the environmental and economic impacts.

Table 7 reports some examples of interactions between product dimensions and best (not yet) available solutions, technologies and techniques.

Figure 10. Interaction between tasks (from the MEErP) and product dimensions



Source: JRC elaboration

Table 7. Examples of interactions between product dimensions and best (not yet) available solutions, technologies and techniques

	Task(s)	**Best (not yet) available solutions**	**Best (not yet) available techniques**	**Best (not yet) available technologies**
Product material and energy-related aspects	4	-	e.g. production process	e.g. recycled content
Product architecture	4	-	e.g. production process	e.g. ease to disassembly and reassembly
Product service	2, 3	e.g. availability of spare parts	-	-
Product business model	2, 3	e.g. business model based on remanufacturing, business models based on sharing	-	-
Product ecosystem	2, 3, 4	e.g. industrial ecosystem, knowledge ecosystem, infrastructure for reuse	e.g. recycling process, repair process	-

Source: JRC elaboration

In the following subsections, some aspects to complement the ones already covered by the MEErP are proposed.

2.2.2.3.1 Task 2 - Markets

In this task, in the case of final products, information on the most common business models should be gathered, as well as information on the market for remanufactured products, and on reuse markets. Repair and refurbishment services should also be investigated. Finally, end-of-life costs (disposal tariffs/ taxes) should be analysed. The presence and diffusion of Extended Producer Responsibility schemes[13] should be examined. Relevant information on the secondary resources market should be taken into account: this is also valid in the case of intermediate products.

[13] As defined in Directive 851/2018, "extended producer responsibility scheme" means a set of measures taken by Member States to ensure that producers of products bear financial responsibility or financial and organisational responsibility for the management of the waste stage of a product's life-cycle.

The best (in terms of environmental performance) available product service systems, product business models and product ecosystems should be selected and described (see Sections 2.2.1.2, 2.2.1.3, 2.2.1.4).

Moreover, the data needed to perform the LCC could already be gathered at this stage (see Section 4.4.2 and Annex 5).

2.2.2.3.2 Task 3 - Users

User behaviour aspects should be investigated only in the case of final products. As summarised by Ravikumar et al. (2024), users can influence a circular economy by refusing a product, adopting services instead of purchasing products (i.e. rethink), extending the lifetime of a product (i.e. reduce), reusing a product, impacting the sorting and disposal of waste, purchasing refurbished and remanufactured products and waste materials.

The best (in terms of environmental performance related to user behaviour) available product service systems, product business models and product ecosystems should be selected and described (see Sections 2.2.1.2, 2.2.1.3, 2.2.1.4), with a focus on their impacts on user behaviour.

Following the example of textiles, the study team may investigate the impact of user behaviour in different life-cycle stages, i.e. analyse pre-purchase aspects (i.e. Reasons for purchasing, Criteria used when buying the product, User quality assessment of the product, Consumer behaviour towards information provided with the product, Attitudes towards second-hand products, Attitudes towards chemicals in the products, Attitudes towards the purchase of a product made with recycled materials), post-purchase aspects (i.e. User behaviour during use: laundering practices, Following apparel care label instructions, Repairability, Storage of apparel) and user behaviour related to the disposal of apparel (i.e. Reasons for the disposal of apparel, Disposal channels, Person-product attachment, Returns of apparel).

The study team should look into:

- consumers' reasons for purchasing the product, attitudes towards second-hand products, refurbished/repaired products, attitudes towards products with recycled materials, attitudes towards potentially dangerous materials present in the products;
- consumers' habits in relation to the refusal of purchase the product (i.e. services instead of products), the extension of lifetime, the use, reuse and the disposal of the product and the related consumables;
- information offered to consumers, both in terms of energy efficiency and other product aspects;
- regarding circularity aspects, willingness to repair, reasons for disposal (and reason for return), willingness to use refurbished or second-hand products (or consumables), barriers to circularity, willingness to pay more for more durable products, willingness to pay for repair and other circularity strategies (e.g. as a percentage of the product price);
- best practices in sustainable product use;
- how the business model affects user behaviour and circularity of products;
- how the local infrastructure affects user behaviour and circularity of products (e.g. infrastructure to enable business models based on sharing, repair shops, take-back systems);
- how relevant design aspects influence consumers' purchase decisions (e.g. energy consumption, water consumption, lifetime, possibility of reuse).

2.2.2.3.3 Task 4 – Technologies, techniques and materials

It is proposed to rename this task "Technologies, techniques and materials". Indeed, in this task, the definition of the base case is discussed, as well as the analysis of technologies, techniques and materials.

The best granularity in the definition of the base cases and in the analysis of technologies and techniques should be evaluated by the study team (see also section on Functional Unit 4.4.1.2).

As mentioned above, the term "technology" refers to a product or to a component, while the term "technique" refers to an industrial process performed in an installation.

As defined in Kemna et al. (2011), the best available technology point represents the best commercially available product with the lowest resources use and/or emissions.

As defined in Directive 2010/75/EU, "'best available techniques' means the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis for emission limit values and other permit conditions designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole:

a) 'techniques' includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;
b) 'available techniques' means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;
c) 'best' means most effective in achieving a high general level of protection of the environment as a whole." (Art. 3)

As reported by Deutsche Gesellschaft für and Internationale Zusammenarbeit (GIZ) GmbH (2019), it should be noted that the definition has an economic dimension in taking account of the economic viability of the implementation of the techniques. In 2006, the European Commission developed the document "Integrated Pollution Prevention and Control Reference Document on Economics and Cross-Media Effects"[14] to assist in the determination and selection of the most cost-effective best available techniques, including a methodology to estimate the costs and benefits that need to be taken into account when determining best available techniques. In implementing best available techniques, however, economic viability has not been interpreted as requiring a full cost-benefit analysis of the adoption of a technology.

Taking as a model the definition above, the following definition of best available technology is proposed:

"best available technologies means the best performing product or component, in terms of environmental performance in (at least) one of the product aspects listed in Article 5 of the ESPR:

a) 'available technologies' means those available on the market;
b) 'best' means most effective in achieving a high general level of protection of the environment as a whole."

[14] https://eippcb.jrc.ec.europa.eu/reference/economics-and-cross-media-effects

In the following sections, best available technologies will be abbreviated to BATg, while best available techniques will be abbreviated to BATq. Similarly, BNATg will be used to refer to best not yet available technologies, and BNATq to best not yet available techniques.

2.2.2.3.3.1 Base cases

The base case (BC) is the basis for all remaining tasks: it represents the average product on the market, and therefore it is the basis for the definition of the improved DOs.

In Task 4, the base cases are defined, taking into account that:

- "the use-phase impact of the BC, when multiplied with the total number of products in use, should result in the total impacts during the use phase;
- the production[15] and distribution impacts of the BC, when multiplied with the total number of products sold, should give the total production and distribution impact of those products;
- the end-of-life impacts of the BC, when multiplied with the total number of products discarded, should give the total end-of-life impact for that product" (Kemna et al., 2011).

In the event that the product group is subdivided into categories, the sum of the aggregated base cases (one per category) should meet these requirements. The impacts considered are not only environmental ones, but also economic impacts.

In the case of intermediate products, only the impacts from raw material extraction till the end of the manufacturing process (or the placing on the EU market, in the case of imported products) are taken into account.

Considering the definition of DO proposed in Section 2.2.1 (i.e. 'design option' is a specific **product service system**, with features which make it more advanced and/or more efficient when compared to the 'base case' in at least one of the product aspects listed in Article 5 of the ESPR), the definition of the base case should focus on product performance in terms of the product aspects listed under Article 5 of the ESPR. Moreover, the product dimensions (product material, product architecture, product service, product business model and product ecosystem, see Section 2.2.1) should be considered in the definition of the base case.

2.2.2.3.3.2 Best available technologies

The analysis and identification of the best available technologies (BATg) should help the study team to understand which the best performing products on the market are.

According to Kemna et al. (2011), the assessment of the BATg takes place on purely technical grounds, i.e. the product with the lowest environmental impact. In the analysis of BATg, the study team should also consider the best product material and product architecture, as described in Section 2.2.1.1.

Considering the extended scope of the ESPR, in the definition of BATg at product and component level, the technical aspects which affect one or more product aspects should be evaluated, e.g. energy use, durability, reliability, repair and remanufacturing, use of consumables and other resources, recycled content. As specified in Annex II to the ESPR, the performance of products

[15] Impacts of production include the impacts from the extraction of raw materials.

available on international markets and benchmarks set in other countries' law shall also be taken into consideration.

According to Kemna et al. (2011), it should be clear that, in terms of functional performance, quality and durability, the BATg should be a product that is at least equivalent to the base case. However, it should be considered that market segments are relevant, for example because a BATg in one market segment may be commonplace in a neighbouring segment, or may not yet be used commercially in a third segment (Bayramoglu et al., 2014). For example, low-end, medium-range and high-end products can be identified on the market (in particular in electronics, as was done in the preparatory study on smartphones). Some functionalities (e.g. a high-performing camera) are not relevant for those who purchase a low-end product. In this sense, the concept of sufficiency should be investigated: sufficiency's principle of satisfying human needs while reducing the demand for resources enables a profound re-evaluation of product and service design. For example, a sufficiency-based product design should be based on the assumption that not all consumers need high-end products, i.e. the products providing many functionalities and the best performance.

2.2.2.3.3.3 Best available techniques

In the case of intermediate and final products, the study team should investigate the best available techniques (BATq) for the production process. The study team should refer to the best available techniques identified in the Commission Implementing Decisions under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions (if available for the sector under assessment) and to the Best available techniques reference documents (BREFs). The BREFs provide a picture of the production in the EU (the performance of production processes occurring in third countries might be considerably different).

Moreover, best available techniques for remanufacturing processes should be investigated, if remanufacturing is a relevant product aspect for the selected product.

Finally, as concerns end of life and waste treatment, the best available techniques for the treatment of the product in question should be investigated: particular attention should be devoted to the recycling process and recovery of materials, if these product aspects are relevant.

It is understood that what is reported in Annex II to the ESPR should also be valid for the production process: therefore, the performance of production processes available on international markets and benchmarks set in other countries' law shall also be taken into consideration.

2.2.2.3.3.4 Best not yet available technologies

Best not yet available technologies (BNATg) at product and component level should be investigated. According to the ESPR, emerging technology improvements should also be investigated (see Annex II to the ESPR). The study team should focus the analysis on emerging technologies that guarantee the improvement of the relevant product aspects. Moreover, as highlighted by Campos-Carriedo et al. (2023), it should be considered that the objective of the requirements might shift from promoting replacement to preventing the penetration of alternatives that do not comply with certain sustainability standards.

2.2.2.3.3.5 Best not yet available techniques

In the revised version of the Industrial Emissions Directive[16], more focus is given to innovative techniques, including emerging techniques. In the case of intermediate products and final products, the study team should investigate the best not available techniques (BNATq) for the production process, and the remanufacturing, recycling and recovery of materials, if relevant for the product being analysed.

Table 8 summarises the main aspects to be analysed.

Table 8. BATg, BATq, BNATg, BNATq

	Technologies	**Techniques**
Definition	It refers to a product or to a component.	It refers to an industrial process performed in an installation.
Best available	Technical aspects which affect one or more product aspects, at product and component level, considering the performance of products available on international markets and benchmarks set in other countries' law.	BREFs for the production processes (if available), best techniques for remanufacturing processes and waste treatment processes, considering the performance of production processes available on international markets and benchmarks set in other countries' law.
Best not yet available	Emerging technologies that guarantee the improvements of the relevant product aspects, at product and component level.	Best not yet available techniques for the production process, the remanufacturing, recycling and recovery of materials, if relevant for the product in question.

Source: JRC elaboration

2.2.3 Definition of a quantitative target, in the case of performance-related DOs

In the case of a performance-related DO, the associated quantitative value should represent the new average product on the market once the requirement is introduced and all the products are compliant.

The definition of a quantitative DO (in the case of a performance requirement) could be supported by the guidelines provided by Task B2, as regards circularity aspects (Rodriguez Manotas et al., 2025). In the case of a requirement on carbon footprint, the calculation method under development should be followed. In the case of a requirement on environmental footprint, the most updated version of the Product Environmental Footprint (PEF) and the Organisation Environmental Footprint (OEF) method should be followed, taking into account the deviations mentioned in Gonzalez Torres et al. (2025). Moreover, the average value and the BATg/BATq value for a certain product parameter should be available from the analysis performed in the previous tasks of the methodology.

[16] Directive (EU) 2024/1785 of the European Parliament and of the Council of 24 April 2024 amending Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions (integrated pollution prevention and control) and Council Directive 1999/31/EC on the landfill of waste. http://data.europa.eu/eli/dir/2024/1785/oj

The definition of a quantitative value (or of a range) can come from the experts' judgement and consultation of stakeholders. The target should be achievable by the economic operators placing the product on the market: in the impact assessment (which follows the preparatory study) a timeline to be compliant with the requirement will be defined, considering technical and economic aspects, among others.

In some cases (e.g. in the case of a target on recycled content or one or more environmental footprint life-cycle indicators), a numerical assessment can be performed, using LCA and LCC methodologies or other methodologies (e.g. Material Flow Analysis), for example to assess the impacts of different scenarios. More particularly, it is recommended to include a quantification of mass flows when dealing with circularity measures. For instance, in the case of a recycled content target, the market-pull mechanism should be studied in the light of a supply/demand balance assessment, to ensure the increase of recyclate of sufficient quality produced will match the increased demand in the future.

Finally, it might be preferable to define only a range at this stage, and refine the value later on, once the paths (i.e. clusters) of DOs to be implemented are defined: in this way, potential synergies and trade-off among DOs can be taken into account (see Section 3.2.2).

2.2.4 Final considerations and summary

In this chapter, a new definition of DO is proposed: a 'design option' is a specific **product service system**, with features which make it more advanced and/or more efficient when compared to the 'base case' in at least one of the product aspects listed in Article 5 of the ESPR. A design option should represent a concrete measure (as was the case in the preparatory study of smartphones). A DO can be performance-related (if it represents a performance requirement, for example in the case of a smartphone: provision of additional screen and glass back-cover protection) or information-related (if it represents an information requirement, for example in the case of a smartphone: information on the correct use of the battery). In the case of a performance-related DO, the associated quantitative value should represent the new average product on the market once the requirement is introduced and all the products are compliant.

In many cases, a **"virtual" design option** will be used, since the same improvement can be achieved by adoption of different product service system configurations, i.e. with changes in one (or more) energy-related aspects and/or in one (or more) product dimensions (i.e. product material, product architecture, product service, product business model, product ecosystem). Each configuration will be weighted according to its estimated market share.

This means that an improvement of the product performance in one (or more) of the product aspects (or in one or more of the product parameters, which are an expression of the product aspects) can derive not only from the use of specific materials and/or a specific product architecture, but can also be the consequence of the provision of services with the product, of the adoption of a specific business model (or a set of business models, each one represented in the 'virtual' DO in a percentage equal to its market share), and of a certain product ecosystem. As a consequence, a design option is not only described by a technology or a product configuration, but other product dimensions can be included, i.e. product material, product architecture, product service, product business model and product ecosystem. This broadens the definition provided by Polverini (2021), i.e. 'design option' is a specific product architecture, with technical features which make it more advanced and/or more efficient when compared to the 'base case'.

Moreover, the proposed definition is in line with the definition of ecodesign requirement provided in the ESPR (i.e., "*an 'ecodesign requirement' means a performance requirement or an information requirement aimed at making a product, <u>including processes taking place throughout the product's value chain</u>, more environmentally sustainable.*")

The identification of design options is a multi-disciplinary activity: the study team should consider technological, environmental and market-related aspects. The product dimensions (product material, product architecture, product services, business models and ecosystem) should be investigated within Tasks 2, 3 and 4. Moreover, the analysis of best (in terms of environmental performance) available and best not yet available solutions, technologies and techniques should be performed, for each of the dimensions. The term “technology”[17] refers to a product or to a component, while the term “technique”[18] refers to an industrial process performed in an installation. The term “solution” is used to refer to services provided with the product, business models or ecosystems.

It is proposed to rename Task 4 “Technologies, techniques and materials”.

A framework depicting the procedure to follow for the identification of DOs is presented in **Figure 9**. The identification of design options should happen at the beginning of Task 6 of the MEErP. Inputs for the identification of the environmental objectives that should be pursued by the improved DOs can come from:

- Tasks 1, 2, 3 and 4 of the MEErP;
- Tasks B1, B2, B5 and B11 of the ESPR methodology (see **Table 6**);
- literature and legislation review on the product group being assessed;
- stakeholder consultations;
- assessment of the base case and identification of its environmental and economic hotspots (Task 5 of the MEErP);
- in the case of a review of existing ecodesign requirements, evaluation of the previous requirements.

Once the environmental objectives are identified, the study team should analyse them to ensure that they consider all the relevant product aspects (see Article 5 of the ESPR) and all the product dimensions (product material, product architecture, product service, product business model and product ecosystem, see Section 2.2.1). The objectives should address the main environmental hotspots and should potentially lead to a significant improvement of the life-cycle environmental performance. Then, the design options linked to each environmental objective should be identified. A preliminary check on functionality and affordability for the users (in economic terms) of each design option is recommended. Finally, a limited set of design options should be selected.

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[17] The following definition of best available technology is proposed in this report:
“best available technologies means the best performing product or component, in terms of environmental performance in (at least) one of the product aspects listed in Article 5 of the ESPR:
a) ‘available technologies’ means those available on the market;
b) ‘best’ means most effective in achieving a high general level of protection of the environment as a whole.”

[18] As defined in Directive 2010/75/EU, “‘best available techniques’ means the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis for emission limit values and other permit conditions designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole:
a) ‘techniques’ includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;
b) ‘available techniques’ means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;
c) ‘best’ means most effective in achieving a high general level of protection of the environment as a whole.”

3 Method to assess interactions between different DOs, and define and rank paths of DOs

After identifying the design options, the interactions between different DOs should be evaluated, both in terms of expected environmental improvement and expected economic impacts. The objective is to cluster the DOs and create paths of DOs. Then, the paths of DOs should be ranked.

3.1 Interaction between different design options and ranking of DOs in the current MEErP

As written in Annex II to the Ecodesign Directive 2009/125/EC, "*concerning energy consumption in use, the level of energy efficiency or consumption must be set aiming at the life-cycle cost minimum to end-users for representative product models, taking into account the consequences on other environmental aspects*". Therefore, in the MEErP, the environmental objective is energy efficiency, while the economic objective is the minimum life-cycle cost to end users. <u>The ranking of design options is based on the savings in energy consumption (and possibly other commodities) during the use stage, from a user perspective</u>. The LCC of the design options is calculated taking account of the extra investment in purchase price and of the reduction in annual operating expense (e.g. lower energy costs for the consumer).

This is then followed by the steps below:

1. Ranking of the individual design options by life-cycle cost (e.g. option 1, option 2, option 3), based on the savings in energy consumption (and possibly other commodities) during the use stage, from a user perspective.
2. Determination/estimation of possible positive or negative ('rebound') side-effects of the individual design measures. According to Kemna et al. (2011), when implementing multiple design options in the same product, the resulting environmental improvement is usually smaller than the sum of the environmental improvements per individual design option. In other words, if you have already improved a product with one design option, every consequent design option will only realise a part of its individual potential. How exactly this interaction works depends very much on the product technology, but it may well lead to a different ranking of accumulated options than the ranking of the individual options in terms of total effect and costs.
3. Estimation of the cumulative improvement and cost effect of implementing the ranked options simultaneously (e.g. option 1, options 1+2, options 1+2+3, etc.), also taking into account the above side-effects;
4. Ranking of the cumulative design options, drawing of a life-cycle cost-curve (Y-axis = LLCC, X-axis = options) and identifying the least life-cycle cost (LLCC) point and the point with the best available technology (BATg).

The individual design options usually have very different effects: some may generate huge savings on running costs at hardly any extra production costs, while others may be very expensive, deliver only small environmental improvements and give little reduction in terms of running costs. This phenomenon is the basis for ranking the individual design options in terms of life-cycle cost versus environmental benefits.

The quantitative basis for the ranking of options, in the event that the options result in monetary savings (e.g. lower energy costs for the consumer), is the payback period. This is the time period it takes for an investor to recuperate the extra investment in purchase price (dPP) through the reduction in annual operating expense (dOE). The operating expense should normally be corrected for discount rate and escalation rate, but if discount and escalation rate are equal, the Simple Payback Period (SPP) can be used. The equation for comparing two alternatives 'A' and 'B' is then:

Equation 1. Simple Payback Period

$$SPP_{AB} = \frac{dPP_{AB}}{dOE_{AB}}$$

(in years)

Note that the payback period approach –simple or more complex with discount and escalation rate for dOE– can only be used for economic evaluation if the product life of the design options is more or less the same.

In the event that this is not the case, economists would turn to the Equivalent Annual Cost (EAC) method or the 'chain' method.

1) In the EAC method, the basis is the Net Present Value (NPV) of the cost per year of owning and operating an asset over its entire life span. Simply put, without correction for NPV, the equation of EAC for a product 'A' (EAC_A) with purchase cost PP_A, lifetime N_A and annual operating expense OE_A is:

Equation 2. Equivalent Annual Cost

$$EAC_A = \frac{PP_A}{N_A} + OE_A$$

2) An alternative method with an identical result is the so-called chain method, which could be used more directly to assess how long it takes to recuperate the investment in years (comparable to SPP). In the chain method one could take the lifetime N_A (in years) of the design option 'A' with the highest purchase price PP_A and then compare it to the base case 'B' with a lower price PP_B and presumably a shorter life span N_B. The ratio between the life spans is then used to find the equivalent discounted purchase price for product A. In a simple equation without inflation correction the 'payback' PB_{AB} (in years) is then:

$$PB_{AB} = \frac{dPP_{AB}}{dOE_{AB}}$$

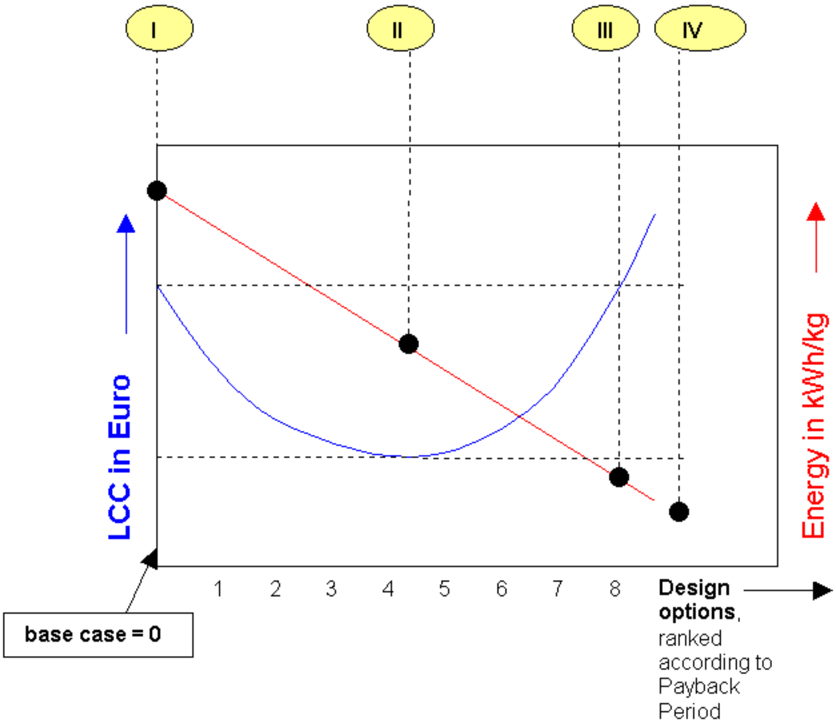
with

$$dPP_{AB} = PP_A - \frac{N_A}{N_B} PP_B$$

These methods, i.e. the EAC or chain method, are the ones to be used for ranking design options.

After the ranking process, the resulting graph will look like the one below (**Figure 11**) for parameters that have an impact on the running costs for the end user (energy, water, detergent, toner, paper, etc.).

Figure 11. Archetype life-cycle cost curve



NB. I = Base Case; II = Least life-cycle cost; III = No financial loss (break-even point); IV = BATg point

Source (Kemna et al., 2011)

Starting with the life-cycle cost (left y-axis) and environmental performance parameter (right y-axis) of the base case (design option "0" on the left of the x-axis), with the introduction of the first three design options the life-cycle cost curve will decrease due to savings on running costs. After design option 4, the environmental parameter will continue to improve, but the extra saving on the discounted running costs will be less than the increase of the purchase point and the life-cycle cost will go up. This lowest point on the life-cycle cost curve is called the point of the least life-cycle cost (LLCC) and the value of the environmental parameter (energy, water, etc.) at that point is proposed as the threshold value for minimum requirements (legislation or self-regulation). As stated by Polverini (2021), the way the LLCC approach has been applied so far within the MEErP is intrinsically 'user-centric', as it aims to minimise the total cost of ownership for the consumer, thus providing a strong rationale for identifying and formulating ecodesign requirements.

As clearly described in Kemna et al. (2011), further up the life-cycle cost curve, as more and more design options are being implemented there are still two interesting points: The 'break-even point' (III), where the total cost for the consumer remains equal to the current situation. Beyond this point any minimum requirement would usually become socially unacceptable, i.e. there would be a significant negative impact on consumers in particular as regards the affordability and the life-cycle cost of the product (see Art. 15.5. (c) of Directive 2009/125/EC, "*there shall be no significant negative impact on consumers in particular as regards the affordability and the life-cycle cost of the product*").

And finally there is the last point (IV) on the life-cycle cost curve, indicating the costs at the maximum technical potential, the best available technology (BATg). In the context of design options that have an effect on the running costs, this BATg point is not intended as a target level for legislation. It indicates what is technically feasible with the best-performing products and technologies available and, as such, it indicates whether - after the LLCC has been established as a minimum target - there is enough room for product differentiation in the short term.

From the point of view of socio-economic feasibility, the LLCC point is optimal: such a threshold value would not only result in an environmentally superior product, but even increase the purchasing power of the consumers as the total expenditure over the product life decreases. This message is also of interest to retailers, consumer associations and industry and others that have the best interests of all stakeholders in mind. Naturally, even at LLCC, the price increase must remain within the bounds of what is affordable for the end user; this will be an explicit task of the impact analysis.

It must be stressed that this life-cycle cost curve is typical for most direct ErPs, i.e. where the improvements lead to lower running costs for the end user (lower consumption of energy, water and auxiliary materials, etc.) at the expense of a higher product price. As the life-cycle cost consequences for each of the main environmental parameters per relevant product is analysed (a selection will have to be made), other types of trade-offs, e.g. between higher direct production costs and the costs of take-back obligations under the new WEEE Directive, will appear.

The distance between the LLCC and the BATg indicates - in the event that a LLCC solution is set as a minimum target - the remaining space for product differentiation (competition). The BATg indicates a medium-term target that would probably be subject more to promotion measures than restrictive action. The BNAT indicates long-term possibilities and helps to define the exact scope and definition of possible measures.

3.1.1 Examples from previous preparatory studies

As mentioned in Section 2.1, in some of the preparatory studies, via questionnaires manufacturers were asked to provide specific technical and cost data of the design options and combinations thereof, as well as indications of which of the single options are compatible with other options (Joint Research Centre (European Commission) et al., 2017; Joint Research Centre (European Commission) et al., 2017).

In the preparatory study on mobile phones, smartphones and tablets (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (European Commission) et al., 2021), first of all, life-cycle cost is calculated for each DO as individual “stand-alone” options, i.e. as if no other options have been implemented. Life-cycle cost is reported per year of use and as such already reflect the effect of an extended lifetime, where applicable (see Table 246 of the report (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (European Commission) et al., 2021)). Some of the DOs cause an increase in the product life-cycle cost (reported in red cells in Table 246).

However, “some options, implemented jointly, have a higher life-cycle cost savings potential than the addition of both individual life-cycle cost savings. In many other cases, combinations of options will yield lower effects than the addition of individual impacts.

This is because measures for lifetime extension will face limitations, as longer lifetime also means potentially more incidents that could terminate product life (e.g. accident induced defects). Further, the reuse market cannot absorb an infinite number of reusable devices: with more devices being available for reuse this market is likely to grow significantly as there are indications, that large remanufacturers rather face a supply shortage, and are currently not limited by market demand. (…)

Additionally, some aspects are in conflict with each other, such as enhanced protection against ingress of water and dust and enhanced repairability" (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (European Commission) et al., 2021).

Consequently, in addition to the assessment of the individual "stand-alone" options, as already presented and described in **Figure 4**, the LLCC methodology is adapted to consecutively implement clusters (paths) of design options and following two separate paths:

- a repairability-dominated path with ambitious repairability options (REP path); and
- a durability path, which also starts with some life-cycle cost-reducing repairability options, but then implementing enhanced water and dust ingress, which rules out some of the repairability options (DUR path).

In the case of the preparatory study for imaging equipment (European Commission, Joint Research Centre et al., 2024), synergies or trade-offs between the different design options are not assessed. Both environmental (CO_2 equivalent) and economic improvement potential (potential to reduce consumers' expenditure) are used to rank the design options.

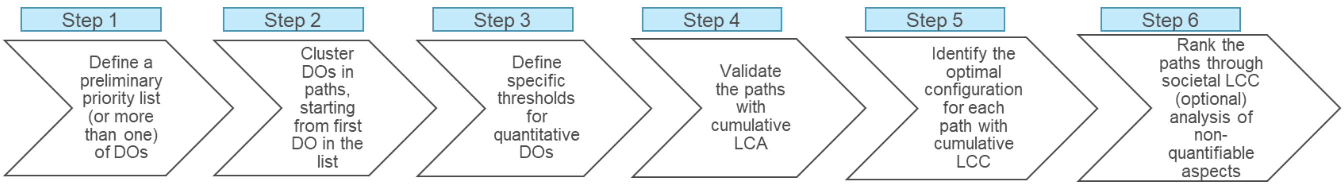
3.2 Proposal for the assessment of interaction between different design options, and the definition and ranking of paths for the ESPR methodology

The aim of this section is twofold: on the one hand, it provides indications on the assessment of the interaction between different DOs; on the other hand, it provides guidance on how to cluster the DOs to create paths and rank them.

Regarding the assessment of synergies or trade-offs between DOs, indications on modelling will not be provided, since this aspect is highly dependent on the product and will be managed by the study team. Compared to the MEErP, the analysis of synergies and trade-offs among DOs is more complex, because of the multi-objective approach of the ESPR in contrast to the sole environmental objective of energy efficiency. The depth of such an analysis should be proportionate to the actual existing trade-offs and synergies between DOs.

Figure 12 summarises the steps described in this section.

Figure 12. Summary of steps to assess interactions between DOs



Source: JRC elaboration

3.2.1 Definition of a priority list of DOs

First of all, the selected DOs should be ordered in a priority list, so that the DOs with the greatest environmental benefits are implemented first (the economic aspects will be considered at a later stage). The list can be defined based on the judgement of experts, eventually considering the results of the relevance assessment of circularity aspects performed under Task B2 (Rodriguez Manotas et al., 2025). As already mentioned in Section 3.1, it should be considered that if one has already improved a product with one design option, every consequent design option might only realise a part of its individual potential.

For the sake of completeness, more than one priority list can be defined. To order the DOs, the study team can follow many strategies. Four alternative strategies (or algorithms) for the definition of the priority lists could be as follows, for example:

- For each product aspect (in order of relevance), take the DO with the highest environmental improvement potential; go to the next product aspect, and do the same, until all DOs have been considered.
- For each product aspect (in order of relevance), take first the DO which contributes to the highest number of product aspects; go to the following product aspect, and do the same, until all DOs have been considered.
- Take first all the information-related DOs, then pass to the performance-related ones.
- For each environmental hotspot identified in the BC analysis, take the DO which can best improve that hotspot.

3.2.2 Definition of the paths

For each priority list defined, some paths (i.e. clusters of DOs) should be created, so that trade-offs between DOs are avoided.

Figure 13 presents a guidance process that the study team can follow to create “paths”, i.e. sets of DOs that can be grouped together. To answer the questions in the decision nodes, Task B2 of the ESPR methodology will provide guidance on the assessment of synergies and trade-offs among the different product aspects (Rodriguez Manotas et al., 2025). In general, the answers should be based on expert judgement. Moreover, the study team should take into account that one DO can be part of more than one path.

In the case of environmental (or economic) synergy between two DOs, when implementing the two design options in the same product, the resulting environmental improvement is greater than the sum of the environmental improvements per individual design option (or the resulting economic impact is lower than the sum of the economic impacts of the single DOs). A trade-off happens when the two DOs cannot be implemented together because the respective design configurations are not compatible or because the costs would be higher than the sum of the costs of the single DOs. It should be noted that synergy and trade-offs are considered mutually exclusive, i.e. there cannot be environmental (or economic) synergy and trade-offs between two DOs at the same time.

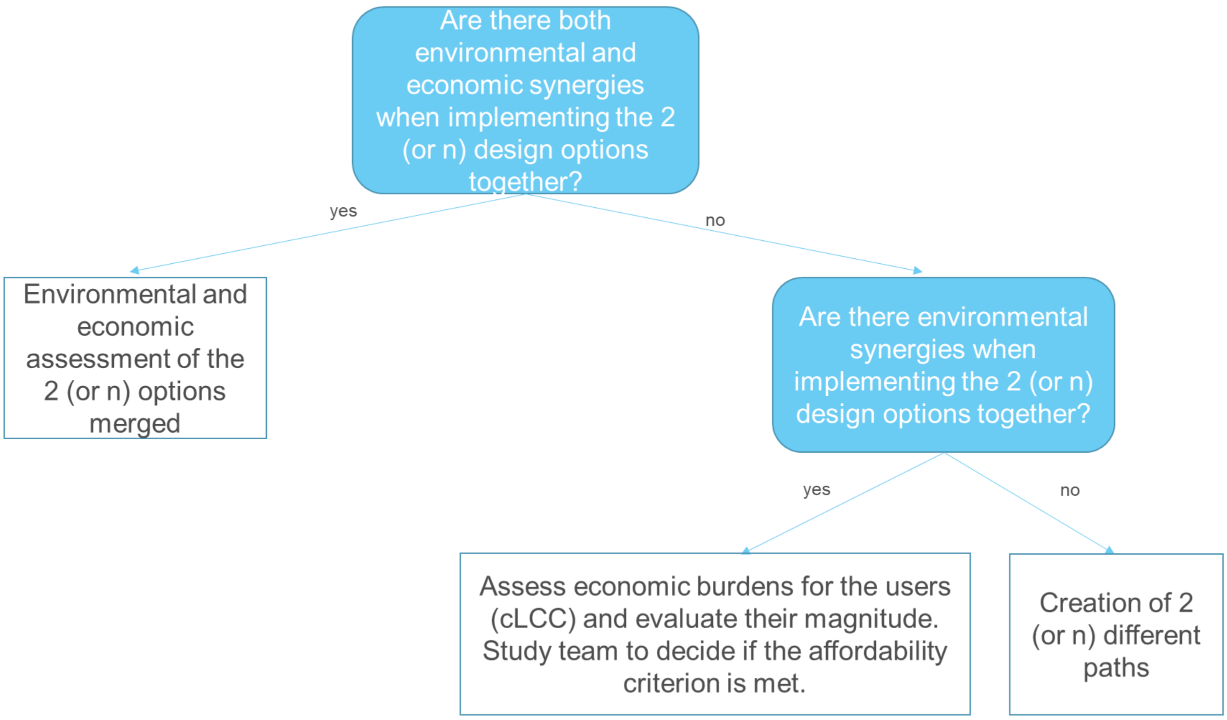
The procedure to follow for each priority list is described below.

- First of all, the study team should pick the first two DOs from the priority list.
  - In the case of synergies (i.e. positive effects) both from an environmental and economic point of view when implementing two (or any number of) DOs, these should be aligned under the same path and the assessment of their joint implementation should be performed.

- In the event that there are trade-offs from an environmental or economic point of view, the two DOs should be included in different paths. This implies that the assessment of their joint implementation should not be performed and that a new path needs to be defined starting from that DO and repeating the check of synergies and trade-offs with the ranked DOs.
- Finally, if there are no environmental trade-offs among the two (or n) DOs, or economic synergies, the study team should carefully evaluate the economic burdens for the users, by performing the LCC from the perspective of the user[19], to ensure that the affordability criterion is met (see Article 5.11.c of the ESPR "there shall be no significant negative impact on consumers in terms of the affordability of relevant products, also taking into account access to second hand products, durability and the life-cycle cost of products"). It should be noted that this is a preliminary affordability check, since the final one will be conducted when the paths are already set.

- Then, the study team should pick the third DO from the priority list and analyse the synergies with the path(s) already created.
- This should be repeated for each DO in the priority list. This will result in the creation of some subsets (or paths) of DOs.

Figure 13. Guidance process for the assessment of interactions between different DOs



Source: JRC elaboration

In the case of performance requirements, quantitative values (thresholds) for each product parameter addressed by the DOs included in the path will need to be defined taking into account

[19] In the case of intermediate products, the user is the actor buying the product when it leaves the manufacturing site or, in the case of imported products, when it is placed on the EU market (see Section 4.4.1.1).

synergies with the rest of the parameters in the path and based on expert judgement and stakeholder consultation. In some cases, a numerical assessment can be performed, using LCA and LCC methodologies or other methodologies (e.g. Material Flow Analysis (MFA)). The thresholds set represent the new average product, i.e. the average performance that can be achieved for that specific product parameter without conflicting with the other product parameters in the path, once all the products are compliant. This new average will be a point between the current average and the BATg/BATq.

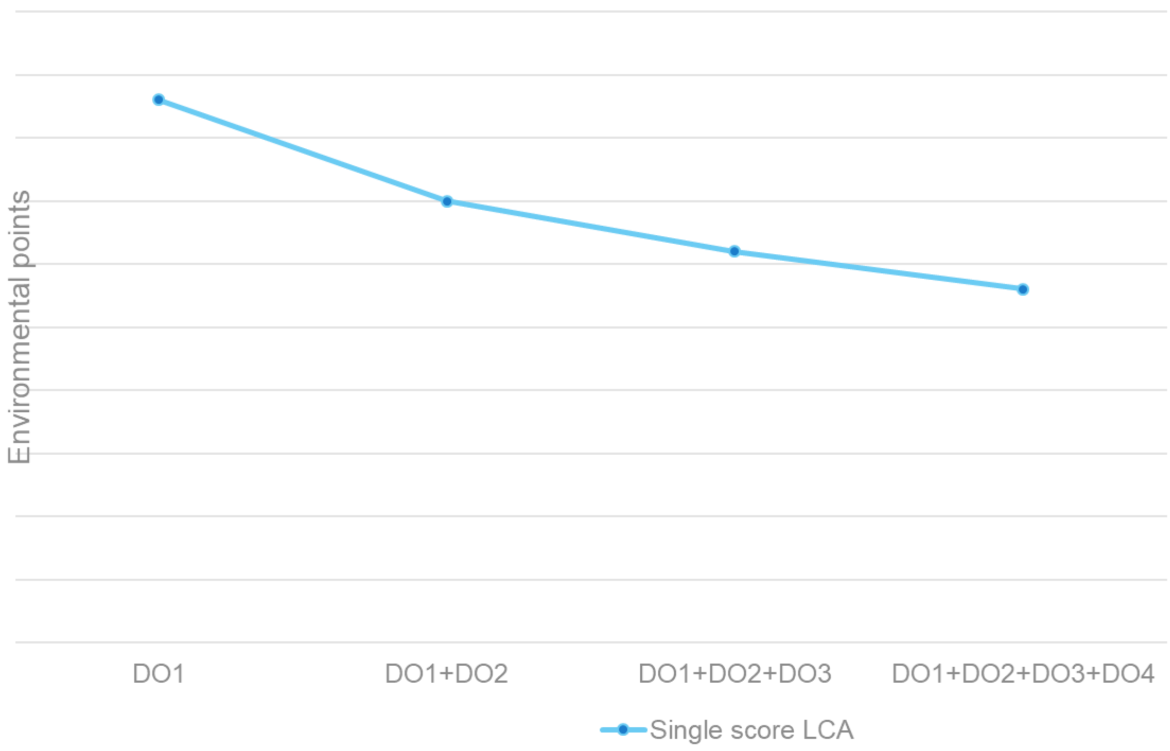
In the case of information requirements, consumer surveys can inform on the response of the requirements on the market (in the case of consumer-oriented information requirements, for example surveys on consumer behaviour). In other cases, surveys targeted at specific stakeholders might be necessary (e.g. survey for professional repairers, in the case of instructions for repair, or survey for recyclers, in the case of information requirements aimed at them). In the case of intermediate products, information requirements might be set on the following product aspects: presence of substances of concern, energy use and energy efficiency, water use and water efficiency, resource use and resource efficiency, recycled content, environmental impacts (including carbon and environmental footprint), expected generation of waste. Surveys addressing the main purchasers might be needed. The information requirements would result in an improved average performance that will be the one assessed in the cumulative LCA, as well as in costs of compliance covered by the manufacturers (and reflected in the product price), to be assessed in the cumulative LCC (as will be explained in the following chapter, the system boundaries considered for intermediate products are from cradle to placement on the EU market).

3.2.3 Validation of the paths created

To validate the paths created, a cumulative LCA can be performed (adding one DO each time in the scope). The result should show a progressive improvement of the environmental performance. In the event that all EF categories are assessed, the single score proposed under the EF method can be used, as it allows the aggregation of the environmental assessment in one single number. The resulting graph should be similar to the one depicted in **Figure 14**.

In the event that the addition of a DO to the cumulative LCA worsens the environmental performance, the priority order should be changed or that DO should be discarded from the path.

Figure 14. Cumulative LCA of a path of DOs



Source: JRC elaboration

3.2.4 Identification of the optimal design configuration for each path

In order to identify the optimal subset of DOs to be considered within each path, the results of an economic assessment should be taken into account.

The study team should perform a cumulative LCC from the perspective of the user. In the case of intermediate products, the user is the actor buying the intermediate product when it leaves the manufacturing site or, in the case of imported products, when it is placed on the EU market. The objective is to identify the optimal design configuration, which might not correspond with the least life-cycle cost. As highlighted by some stakeholders[20], in some cases the improvement of product performance in terms of circularity does not lead to savings for the end users. However, in particular for some product groups, consumers might be willing to pay a higher price for more sustainable products, as shown in the last Eurobarometer survey: 59% of Europeans said that they would pay a higher price (European Commission, 2024). The study team should investigate this aspect, on a product range[21] by product range basis, keeping in mind what is written in the ESPR regarding affordability *("there shall be no significant negative impact on consumers in terms of the affordability of relevant products, also taking into account access to second hand products, durability and the life-cycle cost of products*", Article 5). The study team should consider the effects of a price increase and of a life-cycle cost increase on affordability and on consumer behaviour. In

[20] "The future of the MEERP – reinforcement of circular economy aspects in the methodology position papers from stakeholders – in alphabetical order", available at: https://ec.europa.eu/docsroom/documents/37263?locale=en

[21] A product range refers to variations of a single product that are made in order to create similar yet distinctly different products. Each version of the product is designed to attract a different market segment.

some cases, a price (or life-cycle cost) increase might be acceptable only for a specific product range and market segment, while it may not be acceptable for another product range.

The underlying assumption is that if they are deemed affordable, then it means that the DO is not having a significant negative impact on the consumers of the final products.

After this step, the quantitative values (thresholds) set for each product parameter can be revised, to take into account the final set of design options included in the path.

3.2.5 Ranking of the different paths

To rank the different paths, a societal LCC[22] can be performed (see Section 4.4, where a definition of societal LCC is provided). Moreover, other non-quantifiable aspects can be taken into account (see Section 4.5).

3.2.6 Final considerations and summary

This section proposed a method to create paths (i.e. clusters of DOs), identify the optimal configuration for each path, and rank the different paths.

The steps to be taken are the following:

1. Define a preliminary priority list (or more than one) of DOs, so that the DOs with the highest environmental benefits are implemented first: this should be done according to expert judgement, optionally based on prioritisation of product aspects (outcome of Task B2, see Rodriguez Manotas et al. (2025)).
2. Cluster DOs in paths, based on the environmental and economic synergies and trade-offs (starting with the first DO on the list): this should be done according to experts' judgement, optionally based on analysis of synergies and trade-offs among the different product aspects (outcome of Task B2, see Rodriguez Manotas et al. (2025)).
3. Define specific thresholds (or ranges) for quantitative DOs taking into account synergies with the rest of the DOs in the path and based on expert judgement and stakeholder consultation: in some cases, LCA, LCC, MFA or other methods can be applied.
4. Validate the path with a cumulative LCA (optionally, a single score proposed under the EF can be used, though only in the event that all EF categories are assessed), with the method selected based on Task B1 (Gonzalez Torres et al., 2025). The result should show a progressive improvement of the environmental performance.
5. Identify the optimal configuration for each path, applying cumulative LCC (conventional LCC, perspective of users) to discard DOs after the desired point. Revise the thresholds set for quantitative DOs.
6. Rank the paths through a societal LCC and (optional) analysis of non-quantifiable aspects and policy objectives (see Section 4.5).

[22] Societal Life-Cycle Costing (sLCC) assesses all costs associated with the life-cycle of a product that are covered by anyone in society, whether today or in the distant future (see Section 4.2 for further details).

4 Method to assess base cases and DOs in preparatory studies

The method described in this section should be used in two tasks:

- In Task 5 of the MEErP, when environmental and economic assessment of the base case are performed, as well as societal LCC to identify hotspots. One has to take into account that the assessment can be very different for a product produced in the EU and outside the EU.
- After identifying the design options and creating the paths, when the assessment of their environmental and economic impacts should be performed (as described in Section 3), within Task 6 of the MEErP.

If the study team considers carbon footprint relevant, a methodology for its calculation is being developed, to be used for products under the scope of the EU ETS and CBAM. For all other environmental footprint indicators, the most updated version of the PEF/OEF methods shall be used, taking into account the deviations mentioned in Gonzalez Torres et al. (2025).

4.1 Environmental assessment

As stated by Harris et al. (2021), who reviewed the recent circular economy literature that focuses on assessing the environmental implications of the circularity of products and services, the most commonly used methodology for the environmental assessment at micro/product level is Life-cycle Assessment (LCA). The LCA papers assessed a wide range of products, involving a wide range of CE responses such as recycling, product life extension, reuse and remanufacturing, and product-as-service systems. The studies offer lessons on the consequences of circular-based design changes and the application of LCA (Harris et al., 2021).

The environmental assessment of design options is discussed within other tasks of the ESPR methodology (see mainly Task B1 (Gonzalez Torres et al., 2025)). A LCA of the product and its improvement options is performed in Tasks 5 and 6 of the MEErP; guidance to determine the LCA method to apply is provided as an outcome of Task B1 (Gonzalez Torres et al., 2025).

However, a lack of studies on products with so-called circular designs that are utilised within circular business models is apparent: the study performed by van Loon et al. (2021) presents the results of a systematic literature review of previous environmental assessments on circular products and circular business models, focusing on the tighter technical loops including reuse, refurbishment and remanufacturing. The authors find it remarkable that product design strategies for circular economy (e.g. design for remanufacturing, upgradability, modularity) and product-service systems or other types of circular business models are usually not considered in LCA studies. The study team should analyse and try to estimate the impact of the product service systems and business models on the environmental performance of the product.

For more guidance on environmental assessment, see Gonzalez Torres et al. (2025).

4.2 Economic assessment

4.2.1 Literature review on life-cycle costing (LCC)

The life-cycle cost is the cost throughout the life-cycle of a product system— from purchase, through use and maintenance, to its disposal. LCC is useful to compare the real financial costs of products rather than focusing solely on the purchase price.

LCC allows the evaluation of the economic consequences of a decision for the life-cycle of a product, in terms of costs, revenues and cash flows (Bierer et al., 2015). One of the first international standards adopted for LCC was ISO 15686-5 (ISO, 2017), published in 2008 and updated in 2017, the aim of which was to establish clear terminology and a common methodology for the economic impact evaluation in the building sector (civil construction).

LCC can be an appropriate tool to assess the economic sustainability of circular economy concepts across different product systems (Kambanou and Sakao, 2020). A LCC analysis can be used as an indirect indicator for product circularity, as it may reveal long-term savings made by using components that last longer and need less maintenance. For consumers, LCC analyses can deliver useful information on which to base procurement decisions because they provide a better estimate of the costs that are likely to occur in future. It makes both consumers and product providers more aware of the likely behaviour of a product over time and with maintenance, encouraging them to take into account design for disassembly, adaptability and upgradeability (EEA, 2017). Medina-Salgado et al. (2022) tried to verify, through a real-life case study, the effectiveness of the LCC in assessing circularity from an economic perspective: according to the authors, the LCC model was used to evaluate the role of circularity in the ceramic manufacturing context of reference.

As clearly summarised in Bianchi et al. (2021), within the LCM (Life-cycle Management) community, three types of LCC analyses are generally acknowledged: conventional LCC (cLCC), environmental LCC (eLCC) and societal LCC (sLCC) (Hunkeler et al., 2008)[23].

1. cLCC refers to the assessment of all costs associated with the life-cycle of a product that are directly covered by one or more actors in the product life-cycle (Rebitzer and Hunkeler, 2003; Swarr et al., 2011). In some cases, end-of-life costs are excluded. In contrast to eLCC and sLCC, cLCC only considers internal costs, i.e. real cash flows. It is also called business LCC or financial LCC.
2. eLCC builds upon cLCC and extends it by including (i) environmental externalities and (ii) a comprehensive multi-stakeholder perspective. Moreover, an eLCC is built upon the same product system as an environmental LCA (following ISO 14040/44 standards), thus making it relatively easy to align the two types of assessment, and all product life stages are considered. Whereas cLCC typically looks at cost implications from a manufacturer or consumer perspective, eLCC broadens the perspective by looking at one or several actors along the whole life-cycle of a product. Concerning the inclusion of externalities, some authors argue that only those projected to be internalised in the decision-relevant future should be considered (Hunkeler et al., 2008), while others extend the monetisation of externalities to all environmental impacts resulting from a LCA, then using the term full environmental LCC (feLCC) (Hoogmartens et al., 2014; Corona et al., 2016). The latter can also be interpreted as monetisation of environmental impacts as a kind of weighting in the frame of Life-cycle Impact Assessment (LCIA). First, the notion of “decision-relevant future” needs to be resolved: for a product, the technical product lifetime appears a reasonable default choice. Second, information is needed about which externalities are expected to be internalised through policies in the decision-relevant future. Another critical issue is the determination of the extent to which externalities are already internalised.
3. Concerning sLCC, it further extends eLCC by including additional externalities, associated with the life-cycle of a product (but, as opposed to feLCC, not necessarily linked to an

[23] In this report, we refer to the definitions provided by Bianchi et al. (2021) and Bachmann et al. (2024). Therefore, the term sLCC is used, even if only environmental externalities are monetised (as explained in Section 4.4.1. Many examples of publications applying the same logic can be find (e.g., Andreasi Bassi et al., 2021; Caro et al., 2024)

environmental LCA) (Bianchi et al., 2021). sLCC assesses all costs associated with the life-cycle of a product that are covered by anyone in society, whether today or in the distant future. It therefore extends the eLCC to also include all external costs (social and environmental, whether soon to be internalised or not), expressed in monetary terms. Therefore, it not only extends beyond the decision-relevant future, but also includes (societal) externalities that are not borne by any of the life-cycle actors during the relevant time period. For both eLCC and sLCC, environmental and societal impacts thus need to be converted into monetary units using some kind of valuation approach, posing certain methodological challenges. sLCC might be especially relevant for public authorities interested in knowing the overall societal burden (cost) of a product or a system, through the monetisation of societal and environmental impacts, as well as the computation of indirect costs incurred by actors not directly involved within the product life-cycle. In contrast to eLCC, transfer payments such as taxes and subsidies should not be included when taking a societal perspective, as these do not lead to a net cost effect for society as a whole (Hoogmartens et al., 2014), and should be subtracted (Magrini et al., 2022).

4.2.2 Steps of life-cycle cost assessment

According to the code of practice proposed by the SETAC working group (Swarr et al., 2010), LCC should include similar steps to the ones used in LCA, i.e.:

1. goal and scope definition;
2. information gathering, i.e. economic life-cycle inventory;
3. interpretation and identification of hotspots;
4. sensitivity analysis and discussion.

4.2.3 Life-cycle cost assessment and monetary evaluation of impacts

As pointed out by Bianchi et al. (2021), apart from purely private cost considerations, externalities (environmental and societal) are also relevant, especially for policymakers, and should be included at least for this stakeholder group. An externality is a positive or negative outcome of a given economic activity that affects a third party that is not directly related to that activity. The externality is not reflected in the cost of the activity.

There are two ISO standards that are relevant for monetary valuation in LCA: ISO 14007 (Environmental management — Guidelines for determining environmental costs and benefits) and 14008 (Monetary valuation of environmental impacts and related environmental aspects), and a technical specification ISO TS14074 (Environmental management — Life-cycle assessment — Principles, requirements and guidelines for normalization, weighting and interpretation).

For the monetary valuation of environmental impacts and related environmental aspects, as needed when carrying out eLCC and sLCC, several approaches can be followed (Pizzol et al., 2015; ISO, 2019; Arendt et al., 2020), each one with different data requirements (Bianchi et al., 2021):

- Combining environmental LCA midpoint or endpoint indicators with monetary valuation approaches for different areas of protection, e.g. human health, ecosystems or natural resources. This can be seen as an optional Life-cycle Impact Assessment (LCIA) weighting step; the amount of additional data needed (beyond the Life-cycle Inventory) is limited in this case.

- Combining life-cycle inventory data directly with unit damage cost factors per elementary flow, e.g. using the social cost of carbon (e.g. EUR per tonne of CO_2, i.e. not $CO_{2\text{-eq}}$) or monetary damage estimates of air pollution emissions (partly relying on the same data sources as the above-mentioned LCA-related approaches and thus involving monetary valuation of endpoint indicators).

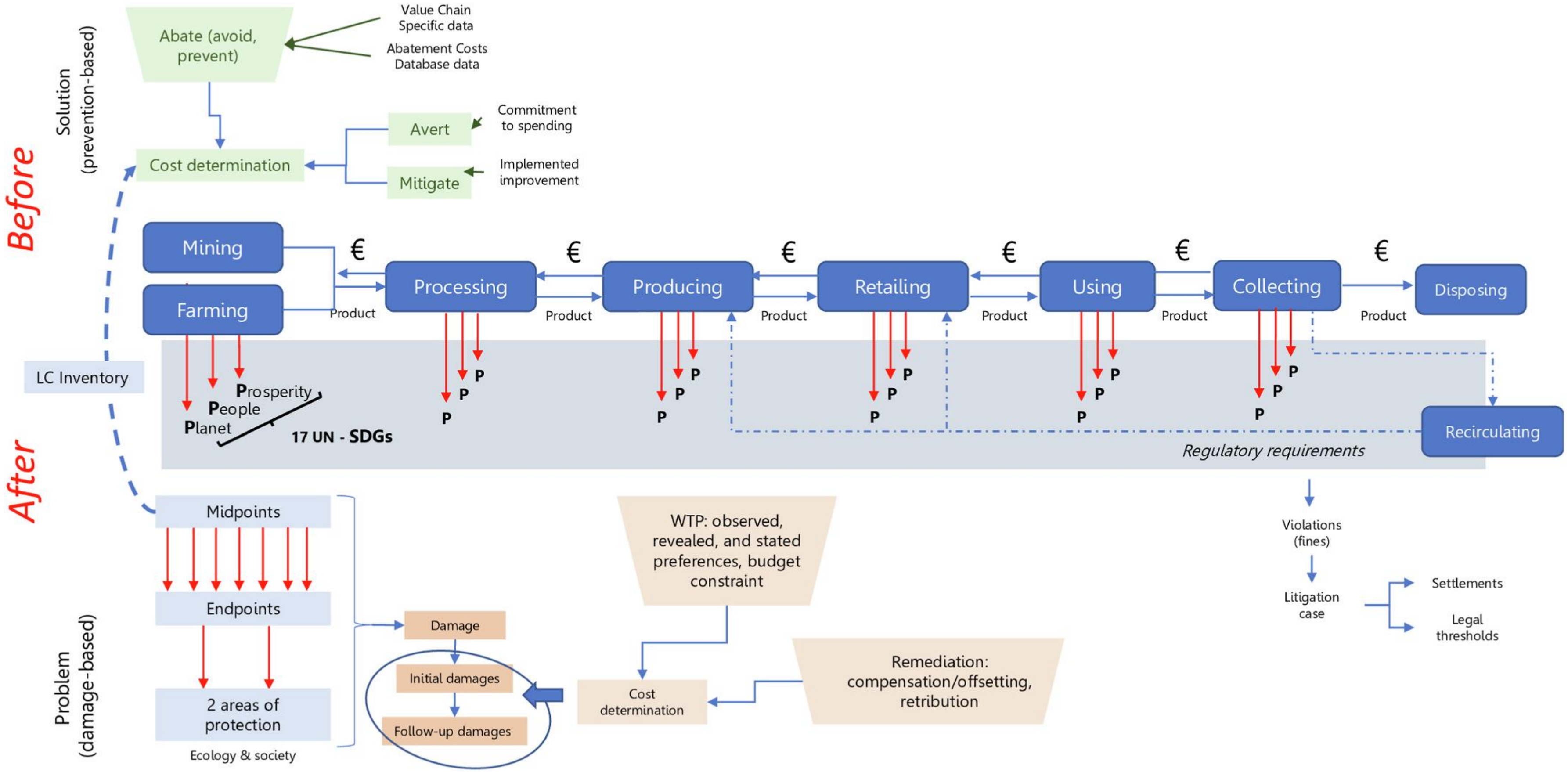
4.2.3.1 Valuation methods at midpoint level

As stated by Roos Lindgreen and Vermeulen (2023), the monetisation methods can be categorised into solution-oriented (prevention-based) and problem-related (damage-based) approaches, based on the time dimension.

The figure proposed by the authors (**Figure 15**) shows in blue a simplified value chain: from mining or farming of natural resources to processing them, producing the final product, retailing of the final product, to its use stage. Then, the product is collected and either disposed of or recirculated.

At each stage in the value chain, impacts or externalities occur. These are depicted by the red arrows and their impacts on the people, planet and prosperity domains. The activities and approaches before the creation of impacts are displayed above the value chain, while activities and approaches after the creation of impacts are displayed below it. Thus, the monetisation methods are categorised into **solution-related (prevention-based)** and **problem-related (damage-based) approaches**. Both are connected to the midpoint categories of impacts resulting from life-cycle methods.

Figure 15. Mapping of structured categorisation of monetary valuation methods to a value chain and time perspective



Source: Roos Lindgreen and Vermeulen (2023)

4.2.3.1.1 *Damage-based methods*

According to Roos Lindgreen and Vermeulen (2023), the bulk of monetary valuation methods focus on monetising environmental impacts from the perspective of damages. This holds both for those provided in the ISO 14008:2019 standard (ISO, 2019) for monetary valuation of environmental impacts and related environmental aspects, and for the recently updated CE Delft's Environmental Prices Handbook (only available in Dutch). As categorised in Pizzol et al. (2015), impacts or damages can be monetised using four primary monetary valuation approaches, with different degrees of 'directness':

1. observed preferences (market price);
2. revealed preferences (i.e. using a surrogate market: averting behaviour method[24], hedonic pricing method[25], travel cost method[26]);
3. stated preferences (i.e. creating a hypothetical market by way of a survey: contingent valuation[27], conjoint analysis[28]);
4. the budget constraint approach (i.e. determining willingness to pay for an additional Quality-Adjusted Life Year in a hypothetical situation without externalities).

These approaches have in common that they view the impacts from the perspective of the affected human population, and their preferences and perspectives (ISO, 2019).

As stated in Directorate-General for Energy (European Commission) et al., (2020), in the damage cost approaches, the costs are typically monetised using the willingness to pay (WTP) or willingness to accept (WTA) principles, i.e. the extent to which individuals are eager to pay to deal with the damage or to which individuals are willing to accept the damage. A further important aspect is that major costs may be incurred in the more distant future, and discounting them to the present year includes major uncertainties related to the discount rate to be used, which effectively determines how highly future damages are valued.

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[24] For example, expenditures on sound insulation can be used to indicate householders' valuations of noise reduction; and expenditure on liming might reflect the value of reduced water acidification. (source: https://www.fao.org/4/y5582e/y5582e08.htm)

[25] Taking housing as an example, hedonic pricing assumes that the expected stream of benefits of living in a property is capitalised into the market value of the property. For example, two properties in areas popular for water-based recreation that differ only in respect of water quality have different market values, owing to people's preferences for the difference in water quality. Hedonic pricing uses this difference in value as the implicit price of the difference in water quality. With adequate data and analytical skills, it is possible to determine the implicit price of environmental quality for properties that differ in not just one but a number of factors. (source: https://www.fao.org/4/y5582e/y5582e08.htm)

[26] Many natural resources, such as lakes and rivers, are used extensively for the purpose of recreation. It is often difficult to value these resources because no prices exist for them from which demand functions can be estimated. To enable valuation, the travel cost approach takes advantage of travel costs that are incurred by individuals in visits made to recreational sites. The travel costs (the costs of transport plus the value of time) are used as implicit prices to value the service provided and changes in its quality. Travel costs measure only the use value of sites and are usually limited to recreational use values; the option and existence value of the sites are measured using other techniques. (source: https://www.fao.org/4/y5582e/y5582e08.htm)

[27] In general, a survey is conducted in which people are asked questions regarding the amount of money they would be willing to pay for an improvement in an environmental good or service. This may be conducted through face-to-face interviews, telephone or mail surveys (source: https://www.fao.org/4/y5582e/y5582e08.htm)

[28] Individuals participate in a conjoint analysis experiment to undertake a large number of ranking tasks. Each ranking task involves a small number of alternative options. Based on the collected data, a type of utility index model is estimated for each individual. (source: https://www.fao.org/4/y5582e/y5582e08.htm)

As highlighted by Roos Lindgreen and Vermeulen (2023), another way to estimate the costs of environmental and social damages is to view them from the perspective of **remediation**, including elements such as restoration and compensation (True Price Foundation, 2023). While this is listed under ‘abatement’ by Pizzol et al. (2015), one could argue that this is a different perspective, focused on restoring a damaged situation/site to its original state, or compensating those affected for economic and/or non-economic damage caused by the social and environmental impacts. Remediation in the form of restoration or compensation thus takes place after the damage has already been done, while abatement (or prevention) aims to prevent it altogether before damage occurs (the cost of preventing a negative by-product for example, by avoiding or reducing impacts before or while products are being produced). An example can be the replacement cost approach, which values the costs of externalities based on the total costs required to repair or replace the adversely impacted aspects as a result of the externalities (Directorate-General for Energy (European Commission) et al., 2020).

As pointed out by Roos Lindgreen and Vermeulen (2023), different sources use different categorisations of this type of method: in True Price’s background documentation (True Price Foundation, 2023), ‘prevention of re-occurrence costs’ falls under ‘remediation’, while in ISO 14008:2019 (ISO, 2019), it is part of the revealed preference methods. Ahlroth (2014) groups avoidance/prevention costs and restoration costs together. However, Roos Lindgreen and Vermeulen (2023) argue that prevention-based monetisation methods can be seen as a different category entirely, since it is the only category that aims to prevent the impact altogether.

Finally, it should be taken into account that the damage costs might be very different depending on the geographical location where the damage occurs (Amadei et al., 2021a; Roos Lindgreen and Vermeulen, 2023).

4.2.3.1.2 Prevention/abatement-based methods

In different sources, varieties of prevention are mentioned, using the concept of prevention loosely. For instance, the ‘averting cost method’ comprises the actual preventive or offsetting expenses that are measured, i.e. those that have been spent before or after a commitment to spending has been made (ISO, 2019). An example given is clean-up costs for contaminated sites, which is not directly compatible with the prevention of damage: the damage has already occurred. Another frequently mentioned method is ‘mitigation’, which is associated with the expenditures to lower an impact, while not entirely preventing it. In practice, this can be a common method, since often it is impossible to achieve 100% abatement of impacts.

As reported in Directorate-General for Energy (European Commission) et al. (2020), the avoidance cost approach values the costs of externalities based on the total costs required to reach a certain (policy) target. This approach assumes that a certain policy target reflects collective preferences with respect to the externality and, as such, it is a proxy for the collective WTP to avoid damage caused by an externality. This is helpful in cases when damages are uncertain or difficult to measure, which is the case for climate change in particular with a number of impacts not fully understood, significant uncertainties in values and risks of repercussions or extreme events.

When choosing to calculate externalities as prevention-based costs, one should be aware that the magnitude of these prevention costs does not equal the magnitude of the (prevented) damages. For some aspects the prevention costs might be relatively higher and for others lower, if compared to the damage costs. Acknowledging the fundamental difference between damage-based and prevention-based approaches also creates an interesting challenge to analyse the difference between the cost of prevention and the damage costs in specific cases of products. A common-sense hypothesis would be that prevention is (far) cheaper than the costs of the damage. Remarkably, little research is available to showcase this (Roos Lindgreen and Vermeulen, 2023).

4.2.4 Life-cycle costing within the European Commission

The European Commission has developed a series of sector-specific life-cycle costing calculation tools which aim to facilitate the use of LCC among public procurers in line with Article 68 of Directive 2014/24/EU on public procurement and Article 83(2) of Directive 2014/25/EU on procurement by entities operating in the water, energy, transport and postal services sectors. Other LCC tools have been developed by other entities. The tools developed are for computers and monitors, imaging equipment, indoor lighting, outdoor lighting and vending machines[29].

Besides purchase price, operating costs and EoL costs, LCC may also include the cost of externalities (such as greenhouse gas emissions) under specific conditions laid out in the Directives. The current (2014) Directives require that, where LCC is used, the calculation method and the data to be provided by tenderers are set out in the procurement documents. Specific rules also apply regarding methods for assigning costs to environmental externalities, which aim to ensure that these methods are fair and transparent.

In the tools developed by the Commission, only externalities linked to energy consumption are taken into account (**Table 9**). Moreover, the user guides clarify that "at the EU level, Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles provided a range between 30-40 EUR/tonne CO_2eq (in 2007 prices). In a more recent report for DG Transport on the "Update of the Handbook on External Costs of Transport" by Ricardo-AEA from 2014, they propose a central value of 90 EUR/tonne (in 2010 prices) from a range between 48-168 EUR. In some countries, the Government might provide other figures. Therefore, practitioners will need to specify the costs for the climate change externality making sure that the figure they use is in line with the requirements defined in article 68.2 of Directive 2014/24/EU on public procurement. In the tool, it is proposed to use 90 EUR/tonne".

Table 9. Externalities considered in the tools developed by the Commission

Product	Externalities considered	Monetisation factors proposed
Computers and Monitors	$CO_{2\text{-eq}}$ emissions linked to energy consumption	In the tool, it is proposed to use 90 EUR/tonne.
Imaging Equipment	$CO_{2\text{-eq}}$ emissions linked to energy consumption	
Indoor Lighting	$CO_{2\text{-eq}}$ emissions linked to energy consumption	
Outdoor Lighting (Road lighting & Traffic signals)	$CO_{2\text{-eq}}$ emissions linked to energy consumption	
Vending Machines	$CO_{2\text{-eq}}$ emissions linked to energy consumption	

Source: JRC elaboration based on: https://green-business.ec.europa.eu/green-public-procurement/life-cycle-costing_en

[29] https://green-business.ec.europa.eu/green-public-procurement/life-cycle-costing_en

Moreover, according to the technical Support Document for Environmental Proofing of Investments funded under the InvestEU Programme (Directorate-General for Environment (European Commission) et al., 2021), the monetised estimates of impacts resulting from a monetary valuation exercise should be incorporated into the economic analysis and calculation of either the Economic Net Present Value[30] or the Economic Rate of Return[31].

As part of the assessment of impacts, environmental proofing should build on an understanding of the environmental impacts by including quantification and monetary valuation of significant environmental impacts, where proportionate and reasonable. It is likely to be of particular use for impacts:

- that are particularly significant and contentious (after mitigation measures); and
- for which the feasibility of undertaking monetary valuation is high because, for example, there are unit values that can be readily used, making value transfers possible.

4.3 Life-cycle costs and analysis of socio-economic impacts in the MEErP

The calculation of life-cycle cost is an explicit part of MEErP Task 5 (base case) and MEErP Task 6 (design options).

In the MEErP, based on the description in Annex II to the Ecodesign Directive 2009/125/EC, the LCC analysis from the perspective of the end users “uses a real discount rate on the basis of data provided from the European Central Bank and a realistic lifetime for the ErP”. Moreover, “it is based on the sum of the variation in purchase price (resulting from variations in industrial costs) and in operating expenses, which result from the different levels of technical improvement options, discounted over the lifetime of the representative ErP. The operating expenses cover primarily energy consumption and additional expenses in other resources (such as water or detergent).”

Task 5 determines the base-case life-cycle cost for consumers, i.e. the value of life-cycle cost for the average EU product defined for analysis from the perspective of end users. The base case is used as the reference for modelling the stock of products together with their environmental and economic impacts. Task 6 identifies design options, their monetary consequences in terms of life-cycle cost for the consumer, their environmental costs and benefits and pinpointing the solution with the least life-cycle cost (LLCC) and the best available technology (BATg).

The assessment of monetary life-cycle cost is relevant to indicate whether design options might negatively or positively impact the EU consumer’s total expenditure over the whole product life (purchase, running costs, etc.), while taking into account for the purchase price development the manufacturers' R&D and investment costs.

The Ecodesign Directive is very clear about the fact that the techno-economic analysis should aim to identify the least life-cycle cost point, which almost by definition would be beyond the ‘Business-as-Usual’ scenario (Kemna et al., 2011).

The LLCC is the designated target level for Ecodesign measures, as indicated in the Ecodesign Directive. Assessment of the LLCC involves not only an evaluation of the technical features, but also an evaluation of the economics, especially concerning how much the improved product should cost.

[30] The Economic Net Present Value is the difference between discounted total social benefit and social cost, valued at shadow prices and is expressed in monetary values.

[31] The Economic Rate of Return is the social discount rate producing a zero value of the Economic Net Present Value and is expressed in percentage points.

In the following section, the definition of functional unit in the MEErP will be discussed. Then, the two different perspectives assumed to perform the LCC in the MEErP (i.e. consumer LCC and societal LCC) will be presented, as well the modelling of the impact on employment. Finally, the role of the EcoReport tool in supporting the economic assessment within the MEErP will be described.

4.3.1 Functional unit

According to ISO 14040 (ISO, 2006, p.14), the functional unit is a quantified performance of a product system for use as a reference unit. LCA, such as LCC, is a relative approach, which is structured around a functional unit. This functional unit defines what is being studied. All subsequent analyses are then relative to that functional unit, as all inputs and outputs in the LCI and consequently the LCIA profile are related to the functional unit.

The definition of the functional unit is addressed in Task 1 of the MEErP, when product grouping is discussed and the scope of the study is defined. However, the definition is refined within Task 5.

The same functional unit is used both for the LCA and LCC.

When clustering products to define the functional unit, functionality should be the main criterion to be considered. As mentioned in ISO (2006), the overriding principle for life-cycle assessment should be a quantifiable "functional unit". Ideally this means that the function of, for example, a refrigerator is the preservation of perishable foodstuffs, a lamp should give light and a dishwasher should clean dishes. This should be the yardstick for clustering products in one preparatory study and applying specific ecodesign measures that are technology-neutral. However, as already mentioned in Kemna et al. (2011), in past ecodesign studies, products were clustered as indicated in EN test standards and/or PRODCOM categories[32], which are usually not technology-neutral. In fact, the functional performance has given rise to several complications, which are listed in Kemna et al. (2011). Three main issues are briefly summarised below:

- In the case of multiple functionality, the ecodesign measures should address and set minimum requirements for each functional parameter individually (Kemna et al., 2011).
- In the event that a product group offers models differing widely in terms of the capacity/size/intensity of the functional performance, the standard solution is to create appropriate (sub)categories. Another option, but less preferable, is to use the capacity or size itself as the functional unit, e.g. in the case of washing machines where the energy efficiency is measured in electricity use per kg of load capacity (in kWh/kg). Another example is domestic refrigeration where –despite the fact that categories based on the cooling temperature and freezing capacity are also used — the functional unit is in kWh electricity per unit of cabinet volume. In both cases there is a risk that this leads to larger appliances being more "efficient" (per capacity unit) than smaller ones, but with negative consequences for the environment because the absolute energy use increases. The remedy is in non-linear correction formulas, but the risk still remains (Kemna et al., 2011).
- If a substantial part of the functional unit is not quantifiable then it is very difficult to propose quantitative minimum ecodesign requirements. An example is the efficiency of domestic luminaires, which is certainly quantifiable (e.g. in lm/W), but where the legislator cannot propose a minimum without objections from citizens. Requirements should be

[32] PRODCOM is an annual survey for the collection and dissemination of statistics on the production of industrial (mainly manufactured) goods, both in value and quantity terms, in the EU. It is abbreviated from the French Production Communautaire. The PRODCOM survey is based on a list of products called the PRODCOM list which currently comprises about 4000 headings relating to industrial products and some industrial services. These products are detailed at an eight-digit level. The first four digits refer to the equivalent class within the Statistical classification of economic activities in the European Community (NACE), and the next two digits refer to subcategories within the Statistical classification of products by activity (CPA). Most PRODCOM headings correspond to one or more Combined nomenclature (CN) codes.

modest (if any) and mainly directed at product information requirements that can subsequently be used in other policy instruments.

4.3.2 Consumer life-cycle cost of a product in the MEErP

According to the MEErP (Kemna et al., 2011), the basic life-cycle cost formula is:

$$Life - cycle\ cost = PP + PWF * OE + EoL$$

where:

Life-cycle cost is life-cycle cost to end users in EUR,

PP is the purchase price (including installation costs) in EUR,

OE is the annual operating expense[33] in EUR,

PWF (Present Worth Factor) is

$$\mathrm{PWF} = \frac{1 - \frac{1}{(1+d)^N}}{\mathrm{d}} \quad (d \neq 0)$$

in which:

N is the product's life in years and

d is the discount rate in %,

and in case d=0 the value of PWF=N,

EoL is end-of-life costs (disposal cost, recycling charge) or benefit (resale).

Since the price increase of the operating expense might play an important role, the following formula (**Equation 3**) is proposed by:

Equation 3. Present Worth Factor

$$PWF = \begin{cases} \left(\frac{1+e}{d-e}\right)\left[1 - \left(\frac{1+e}{1+d}\right)^N\right] & e \neq d \\ N & e = d \end{cases}$$

where *e* is the aggregated annual growth rate of the operating expense (escalation rate, in EUR).

It should be noted that, as long as the discount rate and the growth ('escalation') rate are more or less balanced, the analyst can use the simplified result PWF=N which will help ease policymakers' understanding of the analysis (Kemna et al., 2011).

[33] According to Annex II to the Ecodesign Directive 2009/125/EC, "the operating expenses cover primarily energy consumption and additional expenses in other resources (such as water or detergent)".

For many products the disposal levy is included in the purchase price (PP) and the rest-value of most products at end of life is zero (i.e. the estimated value at the end of its useful life). In the event that the disposal costs are to be paid at the end of life, the discounted Net Present Value (NPV) of the disposal costs should be added to the PP. In the event that the product has a rest-value, then the discounted NPV of the rest-value should be deducted from the PP.

If the operating expense OE consists of several elements (e.g. energy, water, maintenance and repairs) with different annual growth rates, then the parameter e is a weighted average of these elements.

According to Kemna et al. (2011), in 2011 the three values (i.e. discount rate, escalation rate of external damages, inflation-corrected energy growth rate) were very close. The discount rate was 4%[34], the external damages escalation rate was around 4% and the inflation-corrected energy growth rate was also in the order of 3-4%. This means that, for cases where repair and maintenance costs are insignificant, the assumption of a case where r=p and thus PWF=1 would result in a negligible error.

As a result, the life-cycle cost formula for MEErP Tasks 5 and 6 the life-cycle cost can be simplified to:

$$Life - cycle\ cost = PP + N * OE + EoL$$

Note that this simplified formula cannot be applied if there is a significant (>1% point) difference between discount rate r and the aggregated growth rate of the operating expense.

4.3.3 Societal life-cycle cost of a product in the MEErP

The first version of the MEErP proposed an extension of the base-case life-cycle cost for the end user with the inclusion of societal cost for emissions, using the emissions in mass per product over product life and the monetary values per emission (in EUR/unit of mass), therefore combining life-cycle inventory data directly with unit damage cost factors per elementary flow, as described in Section 4.2.3. The monetary values proposed were the ones used by the EEA assessment (EEA, 2011) of the monetary costs of pollution from industrial and power plants in the European Pollutant Release and Transfer Register (E-PRTR) database. Apart from CO_2 and regional air pollutants (NOx, SO_2, NH_3, NMVOC, PM) the EEA included air pollution from heavy metals (As, Cd, Hg, Ni, Pb) and organic micro-pollutants (polycyclic aromatic hydrocarbons (PAHs), benzene, dioxins and furans). However, the uncertainties of the assessment were substantial.

As explained in Kemna et al. (2011), the accounting of the societal life-cycle cost entailed the following steps:

1. The environmental analysis in the MEErP provides the total mass of emissions of the indicators (GWP, AP, VOC, PM, HMa, PAHs, POPs) during production, distribution, use and end-of-life (recycling and disposal), separately counting HMa fractions for stainless steel, Cathode-Ray Tube, bitumen, electricity and copper.
2. The mass of an indicator in each life-cycle stage is multiplied with the ‘MEErP equivalent’ price (external marginal costs to society) to arrive at the external damages (in EUR).

[34] This discount rate is the required 4% discount rate of the impact assessment guidelines of the Commission. These guidelines are no longer in use, but can be accessed at: https://ec.europa.eu/smart-regulation/impact/commission_guidelines/docs/iag_2009_en.pdf

3. The external damages of production and distribution are added to the purchase price (PP).
4. The NPV end-of-life damages (i.e. after discounting over product life, using discount and escalation rate) are also added to the PP.
5. The annual damages during the use stage (total divided by product stock life) are added to the operating expense (OE).
6. The outcome, calculated with the life-cycle cost and PWF formulas, is the societal life-cycle cost of the product.

If the discount rate equals the escalation rate, the simplified equation can be used; in this case, the societal life-cycle cost is the sum of the external damages due to production and distribution PPext, the running costs OEext over a product service lifetime of N years and the costs of end-of-life EOLext. If this is not the case, then the equations with discount and escalation rate should be used to establish the Present Worth Factor (PWF).

Kemna et al. (2011) recommend that a preparatory study should calculate the implications of including the societal life-cycle cost for the outcome and recommendations of the study and work out the LLCC targets whereby the consumer life-cycle cost would be extended with the external monetary damages, i.e. to see whether the targets calculated with the 'normal' LCC calculations are robust.

According to Kemna et al. (2011), the societal LCC should be performed within Task 7, as part of a sensitivity analysis of the results previously calculated.

The recent revision of the MEErP proposed a different approach for the calculation of the societal LCC. Indeed, the monetary factors proposed relate to the impact categories and not to specific emissions (Gama Caldas et al., 2024). In this way, three types of external costs are taken into account: the external costs related to the production, the external costs due to lifetime operations and the external costs related to EoL.

The proposed monetary factors are reported in **Table 10**. The suggestion is to systematically incorporate the societal life-cycle cost - as given by the multiplication of the impacts by the pricing factors within the economic impacts estimated in Task 7 of the MEErP. Regarding the impact categories "Ionising radiation, human health", "Eutrophication, terrestrial", "Resource use, minerals and metals" and "Resource use, fossils", a methodological consensus was not reached, and therefore no value was proposed.

Table 10. Preliminary set of monetary valuation coefficients proposed in the recent MEErP revision

Impact category		Unit of measure	Value	Source
1	Climate change, total	$€_{2019}$/kg CO_2 eq.	$1.00*10^{-1}$	DG MOVE[35]
2	Ozone depletion	$€_{2019}$/kg CFC-11 eq.	$5.55*10^{+1}$	JRC[36]
3	Human toxicity, cancer	$€_{2019}$/CTUh	$1.66*10^{+5}$	JRC[36] based on Trinomics report[37]

[35] European Commission, Directorate-General for Mobility and Transport, Essen, H., El Beyrouty, K., Bieler, C., et al., Handbook on the external costs of transport: version 2019, Publications Office, 2019.

[36] Amadei, A., De Laurentiis, V., Sala, S, Monetary valuation of environmental impacts in life-cycle assessment: state of the art and challenges, European Commission, 2021, JRC125725.

4	Human toxicity, non-cancer	$€_{2019}$/CTUh	$9.19*10^{+5}$	JRC[36] based on Trinomics report[37]
5	Particulate matter	$€_{2019}$/disease incidence	$7.28*10^{+5}$	DG MOVE[35]
6	Ionising radiation, human health	$€_{2019}$/kBq U_{235} eq.	-	-
7	Photochemical ozone formation, human health	$€_{2019}$/kg NMVOC eq.	$1.20*10^{00}$	DG MOVE[35]
8	Acidification	$€_{2019}$/mol H^+ eq.	$3.50*10^{-1}$	JRC[36] based on Trinomics report[37]
9	Eutrophication, terrestrial	$€_{2019}$/mol N eq.	-	-
10	Eutrophication, freshwater	$€_{2019}$/kg P eq.	$1.95*10^{00}$	JRC[36] based on Trinomics report[37]
11	Eutrophication, marine	$€_{2019}$/kg N eq.	$3.27*10^{00}$	JRC[36] based on Trinomics report[37]
12	Ecotoxicity, freshwater	$€_{2019}$/CTUe	$3.89*10^{-5}$	JRC[36] based on Trinomics report[37]
13	Land use	$€_{2019}$/pt	$1.78*10^{-4}$	JRC[36] based on Trinomics report[37]
14	Water use	$€_{2019}/m^3$ water eq. of deprived water	$5.08*10^{-3}$	JRC[36] based on Trinomics report[37]
15	Resource use, minerals and metals	$€_{2019}$/kg Sb eq.	-	-
16	Resource use, fossils	$€_{2019}$/MJ	-	-

Source: Gama Caldas et al. (2024)

The main sources used for the selection of the monetary factors were:

1. the DG MOVE Handbook (CE Delft et al., 2020);
2. the Trinomics report (Directorate-General for Energy (European Commission) et al., 2020);
3. the JRC report (Amadei et al., 2021b).

The three reports will be described in the following subsections.

4.3.3.1 The DG MOVE Handbook (CE Delft et al., 2020)

[37] European Commission, Directorate-General for Energy, Smith, M., Moerenhout, J., Thuring, M., et al., External costs: energy costs, taxes and the impact of government interventions on investments: final report, Publications Office, 2020.

The Handbook covers the following four types of impacts caused by the emission of transport-related air pollutants:

— Health effects: The inhalation of air pollutants such as particles (PM_{10}, $PM_{2.5}$), nitrogen oxides (NOx) and others lead to a higher risk of respiratory diseases (e.g. bronchitis, asthma, lung cancer) and cardiovascular diseases. These negative health effects lead to medical treatment costs, production losses at work (due to illness) and in some cases even to death.

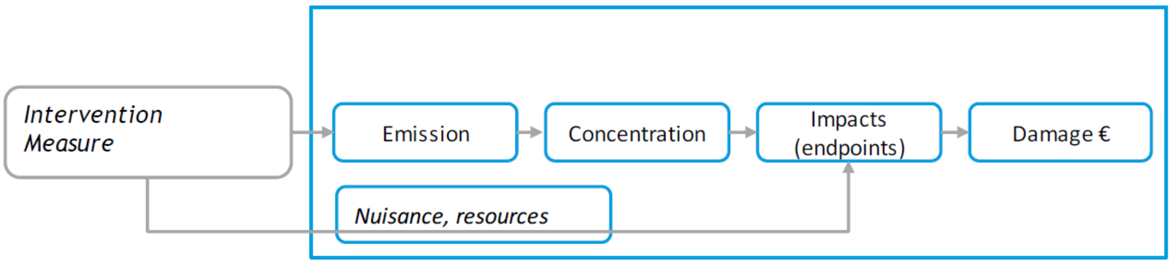
— Crop losses: Ozone as a secondary air pollutant (mainly caused by the emission of NOx and VOCs) and other acidic air pollutants (e.g. SO_2, NOx) can lead to damage of agricultural crops. As a consequence, an increased concentration of ozone and other substances can lead to lower crop yields (e.g. for wheat).

— Material and building damage: Air pollutants can mainly lead to two types of damage of buildings and other materials: a) pollution of building surfaces through particles and dust; b) damage of building facades and materials due to corrosion processes, caused by acidic substances (e.g. nitrogen oxides (NOx) or sulphur oxide (SO_2)).

— Biodiversity loss: Air pollutants can lead to damage of ecosystems. The most important damages are a) the acidification of soil, precipitation and water (e.g. by NOx, SO_2) and b) the eutrophication of ecosystems (e.g. by NOx, NH_3). Damage to ecosystems can lead to a decrease in biodiversity (fauna, flora).

The overall framework adopted for the estimation of the damage cost of pollutants is schematically summarised in **Figure 16**.

Figure 16. Framework adopted for the estimation of the damage cost of pollutants



Source: CE Delft et al. (2020)

A given activity leads to emissions. In the case of transport emissions, these emissions are primarily emissions to the air (a certain amount of tyre wear can end up as emissions to soils or water, but these have not been taken into account in the Handbook).

These emissions are subsequently transported through the atmosphere to other regions where they are added to existing emission concentrations. This concentration then leads to changes in ‘endpoints’ relevant to human welfare. These changes can be monetarily valued by quantifying the amount of damage caused at the endpoints.

4.3.3.2 Trinomics report (Directorate-General for Energy (European Commission) et al., 2020)

The Trinomics report (Directorate-General for Energy (European Commission) et al., 2020) identifies the external costs in the energy sector in power and heating and also makes a first estimate of the externalities of energy consumption. The external costs are disaggregated by the environmental impact and are presented at technology and country level.

4.3.3.3 The JRC report (Amadei et al., 2021b)

The JRC study resulted in the identification of monetisation factors for 12 impact categories, derived through different approaches.

4.3.4 Other social impacts in the MEErP: impact on employment

The methodology for the evaluation of impacts on employment was refined in the last update of the MEErP, to include the explicit modelling of the impact caused by changes in the lifetime of the products and redistribution effects between sectors and countries.

As described in Gama Caldas et al. (2024), changes in the amount of labour in the manufacturing sector are caused by the following:

1) A direct effect if the Ecodesign requirements change the amount of work necessary to produce one unit of the product (this will amount to a direct change in the employment factor). If present, this effect would be expected to be of a positive sign, thus increasing the total labour demand associated with the product group.

2) An indirect effect caused by possible changes in the production costs of the products that were induced by the ecodesign requirements. It is expected that firms respond to a change in production costs (including changes in the amount of labour required) and adjust the pricing of their products in order to keep their profits unchanged. In turn, this change in price might induce a change in the demand of the product. If present, this effect would be expected to be of a negative sign, thus decreasing the total labour demand associated with the product group.

3) Finally, and perhaps the most relevant effect, an indirect effect caused by changes in the longevity of the products that will affect yearly sales and thus the demand for the product. This change in demand induced by longevity changes can be estimated by the dynamic sales and stock model. This effect is expected to be of a negative sign, thus decreasing the total labour demand associated with the product group, i.e. increased longevity is expected to result in decreased demand.

In Gama Caldas et al. (2024), a detailed modelling is proposed to estimate all these effects. Then, the redistribution effects between the EU and the extra-EU space can be estimated just by checking what is the fraction of the total products sold that originates in each region and allocating the calculated changes in manufacturing labour accordingly.

Keeping in mind that the increased longevity of the products is in many cases due to an improvement in repairability and upgradability, it can be concluded that the expected decrease in demand for manufacturing labour will potentially be offset or overshadowed by an increase in demand for labour for the repair and upgrade sectors (Gama Caldas et al., 2024). This aspect would need further analysis, to understand whether the total effect on EU employment would be positive (considering not only the number of jobs, but also the skillset).

4.3.5 EcoReport tool to perform life-cycle costing (LCC) in the MEErP

As mentioned in Kemna et al. (2011), the EcoReport tool can be used to calculate the LCC of the average EU product –the so-called base case—but it can also be used to calculate the base case including one or more design options. With each design option, the environmental and the economic profile of the product will change. When opening several instances of the EcoReport in MS Excel and summarising the outcomes in a new spreadsheet, it is possible to experiment with the ranking of design options. The following subsections will discuss how the EcoReport tool can be used practically by the study team to perform a conventional LCC from the user's perspective and a societal LCC from society's perspective.

4.3.5.1 LCC from the user's perspective

As explained in Eynard et al. (2024), the EcoReport tool allows the automatic calculation of LCC. The EcoReport tool includes sections to facilitate the calculation of average life-cycle cost per product and the calculation of the total expenditure of EU consumers in the most recent year. The total expenditure relates to the production and distribution of new products plus the emissions and resources of the stock in that year. The total expenditure is given in direct costs to the end users in one year; running costs are not discounted and it is not a summation of individual life-cycle cost.

For such a calculation, input values should be inserted at the bottom of the Inputs spreadsheet, below the inputs for calculating the environmental impacts, where a dedicated section can be found (**Figure 17**).

Figure 17. EcoReport tool, Inputs for LCC

Inputs for EU-Totals & LCC

nr	INPUTS FOR EU-Totals & economic Life Cycle Costs Description		unit
A	Product expeted lifetime	**10.6**	years
B	Latest Annual sales	**100**	mln. Units/year
C	EU Stock	**1050**	mln. Units
D	Product price	**1000**	Euro/unit
E	Installation/acquisition costs (if any)	€ 0.00	Euro/ unit
F	Fuel rate (gas, oil, wood)	€ 0.00	Euro/GJ
G	Electricity rate	€ 0.60	Euro/kWh
H	Water rate	€ 1.00	Euro/m3
I	Auxiliary material 1	€ 0.00	Euro/kg
J	Auxiliary material 2	€ 0.00	Euro/kg
K	Auxiliary material 3	€ 0.00	Euro/kg
L	Auxiliary material 4	€ 0.00	Euro/kg
M	Auxiliary material 5	€ 0.00	Euro/kg
N	Repair & maintenance costs	€ 220.00	Euro/ unit
O	Discount rate (interest minus inflation)	3%	%
P	Escalation rate (project annual growth of running costs)	3%	%
Q	Present Worth Factor (PWF) (calculated automatically)	**10.6**	(years)
R	Ratio efficiency STOCK: efficiency NEW, in Use Phase	0.90	

Source: EcoReport tool

The product expected lifetime (in years, nr. A in **Figure 17**) is derived from the lifetime worksheet. Next, the total annual EU sales for the last 30 years should be estimated (in million units per year) together with the average lifetime of the products in the year of sale and should be inserted in the sales and stock dynamic model input box (**Figure 18**). These values, together with the Weibull shape parameter taken from the lifetime worksheet, allow for the calculation of the installed EU stock in million units (nr. C, in **Figure 17**).

Figure 18. EcoReport tool, stock calculation based on sales

Stock calculation based on sales

Weibull shape parameter (β)		1.5		Total EU Stock (mln. Units)	1050
Year	**Sales (mln. Units/year)**	**Expected lifetime (yrs)**	**Weibull location parameter (η)**	**Surv. factor**	**Surv.**
0	100.0	10.6	11.7	1.000	100.0
-1	100.0	10.6	11.7	0.975	97.5
-2	100.0	10.6	11.7	0.932	93.2
-3	100.0	10.6	11.7	0.878	87.8
-4	100.0	10.6	11.7	0.819	81.9
-5	100.0	10.6	11.7	0.757	75.7
-6	100.0	10.6	11.7	0.693	69.3
-7	100.0	10.6	11.7	0.630	63.0
-8	100.0	10.6	11.7	0.569	56.9
-9	100.0	10.6	11.7	0.510	51.0
-10	100.0	10.6	11.7	0.454	45.4
-11	100.0	10.6	11.7	0.402	40.2
-12	100.0	10.6	11.7	0.354	35.4
-13	100.0	10.6	11.7	0.310	31.0
-14	100.0	10.6	11.7	0.271	27.1
-15	100.0	10.6	11.7	0.235	23.5
-16	100.0	10.6	11.7	0.202	20.2
-17	100.0	10.6	11.7	0.174	17.4
-18	100.0	10.6	11.7	0.149	14.9
-19	100.0	10.6	11.7	0.127	12.7
-20	100.0	10.6	11.7	0.107	10.7
-21	100.0	10.6	11.7	0.091	9.1
-22	100.0	10.6	11.7	0.076	7.6
-23	100.0	10.6	11.7	0.064	6.4
-24	100.0	10.6	11.7	0.053	5.3
-25	100.0	10.6	11.7	0.044	4.4
-26	100.0	10.6	11.7	0.037	3.7
-27	100.0	10.6	11.7	0.030	3.0
-28	100.0	10.6	11.7	0.025	2.5
-29	100.0	10.6	11.7	0.020	2.0
-30	100.0	10.6	11.7	0.017	1.7

Source: EcoReport tool

Then comes a section that takes the product's average price from the lifetime worksheet and requests - if applicable - the installation (E) and maintenance costs (N) of the product to the consumer (including taxes). The consumer prices of fuel (F), electricity (G) and water (H) are required. For energy and water some default rates are given. Prices for other consumables (auxiliary materials, from I to M) can be filled in. All these prices and rates can be adjusted. The same goes for the discount rate (O). However, the Present Worth Factor (in years, Q) cannot be changed directly. This is calculated from the discount rate, the escalation rate and the product life (following **Equation 3**). The escalation rate, i.e. the annual growth rate of running costs (energy, water), allows the analyst to take into account energy price projections.

Finally, the last input in the LCC calculation is a rough indicator of the ratio between the energy consumption of the average new product and the energy consumption of the average product installed ('stock'). Generally, if there has been no dramatic growth or decrease in sales, the average product installed should equal the average new product a number of years ago, where the number of years equals half the product life. For instance, for white goods (refrigerators, dishwashers with a product life of ca. 15 years) this would be the average new product 7 to 8 years ago.

Figure 19. EcoReport tool, results of LCC from the user's perspective

Table . Life Cycle Costs per product and Total annual expenditure (2005) in the EU-27

	Products Item	LCC new product		total annual consumer expenditure in EU27	
140	**D** Product price	1,000	EUR	**100,000**	mln. EUR/year
141	**E** Installation/ acquisition costs (if any)	0	EUR	**0**	mln. EUR/year
142	**F** Fuel (gas, oil, wood)	0	EUR/year	**0**	mln. EUR/year
143	**F** Electricity	0	EUR/year	**0**	mln. EUR/year
144	**G** Water	0	EUR/year	**0**	mln. EUR/year
145	**H** Auxiliary material 1	0	EUR/year	**0**	mln. EUR/year
146	**I** Auxiliary material 2	0	EUR/year	**0**	mln. EUR/year
147	**J** Auxiliary material 3	0	EUR/year	**0**	mln. EUR/year
148	**K** Auxiliary material 4	0	EUR/year	**0**	mln. EUR/year
149	**L** Auxiliary material 5	0	EUR/year	**0**	mln. EUR/year
150	**M** Repair & maintenance costs	220	EUR	**22,000**	mln. EUR/year
151	**Total**	**115**	EUR/year	**122,000**	mln. EUR/year

Source: EcoReport tool

The table of the results worksheet (**Figure 19**) calculates two parameters that both relate to economic expenditure, but that are otherwise completely different.

- The first parameter is the life-cycle cost of one product for an end user, i.e. a (potential) buyer that calculates the economic rationale of their investment decision today and that looks into the future in terms of discounted running costs. This is important for the base case and the evaluation of an appropriate target.
- The second parameter calculates the EU total of all expenditure for end users in the most recent year, i.e. the running costs are not discounted and for the running costs in the use stage the calculation starts from the installed stock.

The formulas used to calculate these parameters are reported in Annex 3.

4.3.5.2 Societal LCC from the perspective of the society

As explained in Section 4.3.3, in the updated version of MEErP, a set of factors were proposed, which should adequately and, to the extent possible, accurately represent the societal costs, including externalities, associated with the life-cycle of products. The monetary factors shall relate to the output of the environmental assessment in the EcoReport tool (i.e. environmental impacts divided into EF impact categories), but it is not possible to accommodate monetisation factors related to specific emissions.

The table of the results worksheet (**Figure 20**) will report the same values in the cells with black text as in the cLCC described in the previous subsection, while adding the information on external costs in the cells in red text. The formulas used to calculate these parameters are reported in Annex 3.

Figure 20. EcoReport tool, results of societal LCC

Table . Societal Life Cycle Costs per product and Total annual expenditure (2005) in the EU-27

		Item	LCC new product		total annual consumer expenditure in EU27	
152	D	Product price	1,000	EUR	100,000	mln. EUR/year
153	E	Installation/ acquisition costs (if any)	0	EUR	0	mln. EUR/year
154	F	Fuel (gas, oil, wood)	0	EUR/year	0	mln. EUR/year
155	F	Electricity	0	EUR/year	0	mln. EUR/year
156	G	Water	0	EUR/year	0	mln. EUR/year
157	H	Auxiliary material 1	0	EUR/year	0	mln. EUR/year
158	I	Auxiliary material 2	0	EUR/year	0	mln. EUR/year
159	J	Auxiliary material 3	0	EUR/year	0	mln. EUR/year
160	K	Auxiliary material 4	0	EUR/year	0	mln. EUR/year
161	L	Auxiliary material 5	0	EUR/year	0	mln. EUR/year
162	M	Repair & maintenance costs	220	EUR	22,000	mln. EUR/year
163	N	**External damages total, of which**	**0.00**	EUR	**0.00**	mln. EUR/year
164		- production PPext	0.00	EUR	0.00	mln. EUR/year
165		- lifetime operating expense N*OEext	0.00	EUR	0.00	mln. EUR/year
166		- end-of-life OELext	0.00	EUR	0.00	mln. EUR/year
167		**Total**	**115**	EUR/year	**122,000**	mln. EUR/year

Source: EcoReport tool

4.3.5.3 Data needed

Task 2 of the MEErP aims to provide a practical data set of prices and rates to be used in a life-cycle cost calculation. As explained in the previous sections, in Task 2, the MEErP does not require that every preparatory study gives an overview of energy/water/etc. prices and escalation (growth) rates. MEErP rates and prices were given for 1 January 2011 and if the growth stays within a bandwidth of 4% per year, the analyst can use the default rates. Indeed, the Impact Assessment guidelines of the Commission[38] require that in economic analyses a discount rate of 4% be used (Kemna et al., 2011).

Regarding energy prices for private households, a boundary condition is that the real inflation-corrected energy prices' growth rates do not deviate more than 1 percentage point from the given 4%. If that happens, the differentiated life-cycle cost calculation with actual prices should be followed.

Apart from simplifying the calculations, the greatest advantage of this approach (i.e. the use of standardised rates and prices) is that the monetary outcomes of all studies will be comparable.

Data needed to perform a LCC in the EcoReport tool are as follows:

- Product expected lifetime: calculated with the Weibull function: four levels of reliability, repairability and upgradeability can be modelled.
- Latest annual sales.
- EU stock.
- Installation/acquisition costs (if any): Acquisition costs are the total of purchase price and - if appropriate - installation costs for the end customer. For business-to-business products this is the costs without value-added tax and for business-to-consumer products the value-added tax is included. In the LCC calculations of base case and design options (MEErP Tasks 5 and 6) as well as the scenario analysis (MEErP Task 7), it would be too complex to consider all installation options and thus here a single installation reference, preferably a sales-weighted average, should be used.
- Fuel price (gas, oil, wood).

[38] European Commission, Impact Assessment Guidelines, 15 January 2009, SEC(2009) 92.

- Electricity price.
- Water price.
- Costs of auxiliary materials.
- Repair and maintenance costs.
- Discount rate (interest minus inflation).
- Escalation rate (project annual growth of running costs).
- Tax rates: Rates for indirect energy taxes and value-added tax per country are given in Kemna et al. (2011). Other product levies, including levies relating to product disposal, should be assessed on a case-by-case basis.

Costs of third-party verification or certification are not taken into account.

4.4 Proposal for life-cycle costing within the ESPR methodology

This section aims to propose a LCC methodology, after assessing its applicability within the ESPR methodology, taking into account the wider scope of the ESPR compared to the previous Ecodesign Directive. The structure follows the four steps of LCC methodology (see Section 4.2.2), i.e. goal and scope definition, information gathering, interpretation and identification of hotspots, sensitivity analysis and discussion.

4.4.1 Goal and scope definition

4.4.1.1 LCC and ESPR scope: integration of non-ErPs and intermediate products

In literature, many examples of LCC applied to different categories of products can be found: steel (Janik, 2015), aluminium (Luthin et al., 2021), agri-food products (Degieter et al., 2022), buildings (Alasmari et al., 2024). LCC can be applied to any type of product: there are no particular limitations to using the method used so far for ErPs for non-ErPs as well. When it comes to the difference between intermediate and final products, the main difference is related to the system boundaries. In the case of final products, a cradle-to-grave assessment should be performed. In contrast, the system boundaries for intermediate products are from cradle to gate (plus the impacts of transport, until the placing on the EU market, in the case of imported products) to avoid double counting and because the use is unknown. Cradle-to-gate is an assessment of a partial product life-cycle from resource extraction (cradle) to the factory gate (i.e. before it is transported to the consumer).

Both for intermediate and final products, the LCC can be performed applying two different perspectives: the costs and savings for users and for society should be considered. In the case of final products, the perspective of manufacturers can also be assessed. When considering the perspective of users/manufacturers, a conventional LCC should be performed. When examining the perspective of the society, a societal LCC should be performed, including the monetisation of the environmental impacts. In the case of final products, the users are the end users[39] of the product,

[39] As defined in Regulation (EU) 2019/1020 of the European Parliament and of the Council of 20 June 2019 on market surveillance and compliance of products, 'end user' means any natural or legal person residing or established in the

while in the case of intermediate products the users of the intermediate products (the actor buying it when it leaves the manufacturing site or, in the case of imported products, when it is placed on the EU market) should be taken into account. It should be noticed that the analysis of the perspective of the end users also covers the perspective of the manufacturers, since the reasons for changes of the product price should be assessed.

The perspective of the user should be used when selecting the subset of DOs to be included in each path and when assessing the economic impacts of each path. On the other hand, the perspective of society should be taken when the study team wants to rank the different paths. The aim of the consideration of both perspectives is to ensure that, as written in the ESPR (Article 5.11), there is "no significant negative impact on consumers in terms of the affordability of relevant products, also taking into account access to second-hand products, durability and the life-cycle cost of products". At the same time, "there shall be no disproportionate negative impact on the competitiveness of economic operators and other actors in the value chain, including SMEs, in particular microenterprises".

4.4.1.2 Functional unit

The functional unit of a product system is a quantified description of the performance requirements that the product system fulfils. The selection of the functional unit is the first important choice to be made. It is proposed to address the definition of the functional unit in Task 1, as it was done in the MEErP, when product grouping is discussed and the scope of the study is defined, and in Tasks 5 and 6, when the base case and the design options are defined. The same functional unit should be used both for the LCA and LCC.

In order for products to be comparable in LCA, what they deliver needs to be the same, at least in terms of the main function of the product. A distinction is made between obligatory properties and positioning properties (Weidema et al., 2004). It is on the basis of sharing a set of obligatory properties, included in the functional unit definition, that alternative products can be considered functionally equivalent and, hence, substitutable. Positioning properties are non-obligatory properties which nonetheless are relevant for the market position of a product, for instance in terms of how products are evaluated or experienced by users (Weidema et al., 2004). For example, a beverage container must not leak, this being an obligatory property. A beverage container may be more or less easy to handle, this being a positioning property.

For final products, when possible, a functional unit that is not time-related can be used: for example, in the case of imaging equipment, the functional unit is the production of one printed page with each of the device base cases within the use stage. This also allows the comparison between different base cases (which is not necessary but can provide interesting insights to the study team). Indeed, if the functional unit was the production, use and EoL of a product, this would allow the simple direct comparison of different products, but the comparison would not be reliable. As explained by European Commission, Joint Research Centre et al. (2024) for the case of imaging equipment, this approach does not take into account, for instance, that a large A3 multi-function device will produce a significantly higher number of pages during its lifetime, compared to a household inkjet single-function printer. In other words, it can be expected that the overall environmental impact of the A3 multi-function device will be higher, but the performance and overall output will also be higher.

Union, to whom a product has been made available either as a consumer outside of any trade, business, craft or profession or as a professional end user in the course of its industrial or professional activities.

According to the Commission Recommendation on the use of the Environmental Footprint methods[40], "for intermediate products, the functional unit is more difficult to define as it may often fulfil multiple functions and the whole life-cycle of the product is not known. Therefore, a declared unit should be applied, for example, mass (kilograms) or volume (cubic meters). In this case, the reference flow may correspond to the FU." Moreover, "benchmarking may be excluded for intermediate products"[41].

Alignment with the PEF methodology is recommended. In the case of the ongoing preparatory study on steel, a material-based approach (mass or volume) is followed, in the definition of the declared unit. However, consideration of the final applications and performance parameters is required, in view of the definition of representative products. Indeed, in some cases knowing the final product for which the intermediate product will be used is pivotal.

Table 11 summarises the main differences between the scope elements for a final product and an intermediate product.

Table 11. Main differences in the LCC scope between final product and intermediate products

	Final products	**Intermediate products**
Functional unit	Functional unit (not time related)	Declared unit (material-based)
System boundaries	From cradle to grave	From cradle to placing on the EU market
Perspectives	Perspective of the end user (conventional LCC) Perspective of society (societal LCC)	Perspective of the manufacturer and of the user (conventional LCC) Perspective of society (societal LCC)

Source: JRC elaboration

4.4.1.3 Geographical scope

The geographical scope of the analysis should be the European Union market (EU-27): indeed, the ESPR applies to all products placed on the European market or put into service. However, in the event that some of the life-cycle stages are not performed in the European Union, they should be included in the environmental assessment (and indirectly in the sLCC, through the monetisation of environmental externalities).

4.4.1.4 Temporal scope

[40] Commission Recommendation (EU) 2021/2279 of 15 December 2021 on the use of the Environmental Footprint methods to measure and communicate the life-cycle environmental performance of products and organisations

[41] In the context of PEF, the term 'benchmark' refers to the average environmental performance of the representative product sold on the EU market.

The time horizon considered is the whole life-cycle of a product (or product service system). To compare the base case with the proposed design options, the impacts per FU should be calculated.

In Task 7 of the MEErP, the cumulative impacts (projections) should be calculated, including the impacts of all the products that will be sold until a selected date in the future, plus the impacts of the stock (for the stock, we should consider the use stage only; following the example of what is done in the EcoReport tool, we can include the impacts for the use over half a year, as if we were in the middle of year 0).

4.4.1.5 Technological scope

The technical dimension taken as the point of departure for data collection in the inventory analysis should match the geographical and temporal coverage of the study.

ISO 14044 states that technology coverage refers to specific technology or technology mix. Since the DOs should be technology-neutral, a weighted average of the actual technology mix should be used.

4.4.2 Information gathering: Life-cycle Inventory (LCI)

An Excel file with the list of relevant data to be collected to perform a LCC is available upon request (see Annex 5 to this report). The spreadsheet file contains two sheets: one for final products and the other for intermediate products. Note that the LCC does not have to be performed using the EcoReport tool. However, the spreadsheet file specifies the code used in the EcoReport tool for each data entry, to facilitate its use. Note also that the data on projections are gathered to perform the analysis of scenarios under Task 7.

Within the societal LCC, the environmental taxes already internalised in the price of the products (intermediate and final products) should be identified by the study team. Indeed, as explained in Section 4.2, transfer payments such as taxes and subsidies should not be included when taking a societal perspective, as these do not lead to a net cost effect for society as a whole, and should be subtracted. This avoids double counting of environmental externalities.

To simplify, the study team should consider only the taxes applied at European level. The following paragraphs provide some useful information on how to discount environmental taxes, when performing a LCC from the perspective of society.

4.4.2.1 Purchase price

The effects of a requirement on the availability of second-hand products should be considered. Therefore, the purchase price should reflect this change, in the long term.

4.4.2.2 Carbon pricing at EU level: ETS and CBAM

As written in the impact assessment of the ESPR (European Commission, 2022), in the EU there is a market distortion in the form of uncorrected externalities: environmental, health, social or other impacts generated by a product and not reflected in its price. Competitive market forces are not resulting in efficient prices, but instead are biased towards externality-generating products or activities. These externalities are only partially corrected through economic incentives, such as taxes, or fees, to "internalise" these products' externalities. For example, for air pollution, the degree of internalisation is estimated to be around 44% with unpriced externalities of around EUR 400 billion per annum[42]. The 'polluter pays' principle is not applied consistently across the EU, further aggravating the problem[43].

Within this context, the two main instruments of carbon pricing applied at European level are the EU Emissions Trading System (EU ETS) and CBAM. Carbon pricing is a policy tool used to internalise the cost of carbon: it aims to use free-market dynamics while imposing a strict limit on emissions. Indeed, the legislature controls the overall carbon budget available for the whole industry.

The EU ETS is a 'cap and trade' system, which started in 2005. It caps the total volume of GHG emissions from installations and aircraft operators responsible for around 40% of EU GHG emissions. The cap on emissions has been tightened to reduce emissions covered by the EU ETS by 62% by 2030, compared to 2005 levels. The cap is expressed in emission allowances, where one allowance gives the right to emit one tonne of CO_2 eq (carbon dioxide equivalent). For each year, companies must surrender enough allowances to fully account for their emissions[44]; otherwise, heavy fines are imposed. Within the cap, companies primarily buy allowances[45] on the EU carbon market, but they also receive some allowances for free[46]. For example, in sectors where there is considered to be a potential carbon leakage risk, meaning if they pay the full cost of all the emission allowances they need, that production (and pollution) could shift to countries with less costly emissions reduction policies in place. Companies can also trade allowances with each other as needed. If an installation or operator reduces their emissions, they can either keep the spare allowances to use in the future or sell them[47] (European Commission, 2017).

The EU ETS is a major tool of the European Union in its efforts to meet GHG emissions reduction targets now and into the future. The EU ETS covers power stations and manufacturing plants in all EU countries plus Iceland, Liechtenstein and Norway (European Economic Area-EFTA States). The EU ETS covers the following sectors and gases, focusing on emissions that can be measured, reported and verified with a high level of accuracy:

1. Carbon dioxide (CO_2) from:
    i. electricity and heat generation;
    ii. energy-intensive industry sectors, including oil refineries, steelworks, and production of iron, aluminium, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, acids and bulk organic chemicals;
    iii. aviation within the European Economic Area and departing flights to Switzerland and the United Kingdom;
    iv. maritime transport.
2. Nitrous oxide (N_2O) from production of nitric, adipic and glyoxylic acids and glyoxal.
3. Perfluorocarbons (PFCs) from the production of aluminium.

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[42] "Green Taxation and other economic instruments: Internalising environmental costs to make the polluter pay", IEEP et al, 2021

[43] ECA, Special report 12/2021: "The polluter pays principle: inconsistent application across EU environmental policies and actions".

[44] https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/monitoring-reporting-and-verification-eu-ets-emissions_en

[45] https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/auctioning-allowances_en

[46] https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/free-allocation_en

[47] https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/what-eu-ets_en

As part of the 2023 revisions of the ETS Directive[48], a new emissions trading system named ETS2 was created, separate to the existing EU ETS. This new system will cover and address CO_2 emissions from fuel combustion in buildings, road transport and additional sectors (mainly small industry not covered by the existing EU ETS)[49]. The ETS2 will become fully operational in 2027.

The EU's Carbon Border Adjustment Mechanism (CBAM) is the EU's tool to put a fair price on the carbon emitted during the production of carbon-intensive goods that enter the EU, and to encourage cleaner industrial production in non-EU countries.

By confirming that a price has been paid for the embedded carbon emissions generated in the production of certain goods imported into the EU, the CBAM will ensure the carbon price of imports is equivalent to the carbon price of domestic production, and that the EU's climate objectives are not undermined. The CBAM is designed to be compatible with World Trade Organization rules.

CBAM will apply in its definitive regime from 2026, while the current transitional phase lasts from 2023 to 2026. This gradual introduction of the CBAM is aligned with the phase-out of the allocation of free allowances under the EU ETS to support the decarbonisation of EU industry.

In its transitional phase (which started in October 2023), CBAM will only apply to imports of cement, iron and steel, aluminium, fertilisers, electricity and hydrogen. During this period, importers of goods in the scope of the new rules will only have to report GHG emissions embedded in their imports (direct and indirect emissions), without the need to buy and surrender certificates.

The Commission also published the default values for the transitional period of CBAM: declarants should use them when they do not have or are not able to report actual emissions (European Commission (Directorate-General taxation and customs Union), 2023). If we consider goods other than electricity, the default values represent a 'world' average, weighted by production volumes. They are based on estimations on embedded emissions in CBAM goods (i.e. iron and steel, cement, fertilisers and aluminium) as carried out by the Commission's Joint Research Centre. The emission intensities were estimated for different countries through a transparent methodology based on publicly available data. The JRC study (Vidovic et al., 2023) focused on the EU's main trading partners, covering around 15 to 20 countries for each sector in the CBAM scope. The default values for hydrogen are based on a separate JRC report (Dolci and Arrigoni, 2023), published in November 2023. As regards electricity, the default values represent the average emission factors of the electricity produced from fossil fuels in the country of origin, based on data from the International Energy Agency (IEA).

The transitional phase will serve as a learning period for all stakeholders (importers, producers and authorities). It will allow the European Commission to collect useful information on embedded emissions in order to refine the methodology for the definitive period, which starts in 2026. As of that date, importers will need to buy and surrender the number of "CBAM certificates" corresponding to the GHG emissions embedded in imported CBAM goods[50].

Therefore, the study team should not consider the environmental costs under CBAM, if the reference year of the study is before 2026. However, it can be included when future scenarios are modelled.

[48] https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/what-eu-ets_en

[49] https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/ets2-buildings-road-transport-and-additional-sectors_en

[50] https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en

4.4.2.2.1 Potential sources for the estimation of environmental taxes paid at product level

The biggest challenge of subtracting the ETS cost is that it is paid at installation level, and not at product level. In contrast to the Trinomics report[51] (Directorate-General for Energy (European Commission) et al., 2020), which identifies the external costs in the energy sector in power and heating, subtracting the value of the carbon cost (EUR/t CO_2 eq) is not easy in the LCC, since the scope of the EU ETS is limited to certain sectors/activities. Indeed, the approach of subtracting the value of the carbon cost was adopted in the Trinomics report (Directorate-General for Energy (European Commission) et al., 2020) because almost all major (fossil) power plants in the EU-27 are subject to the EU-ETS and therefore would face this cost.

Asking product manufacturers for data also has limitations (carbon costs might have been paid by their suppliers, and they might not be aware). Moreover, data would be aggregated at installation level.

Therefore, the study team should analyse the available information, with the objective of estimating the value of environmental externalities already internalised through taxes, to be discounted. To facilitate the work of the study team, two sources of information are proposed.

Using carbon intensity at product level: If the study team plans to investigate the possibility to use carbon intensity at product level, in the cases of preparatory studies on <u>iron and steel, fertilisers, aluminium and cement</u>, for which the taxes paid under CBAM should be subtracted, the default values for the transitional period of CBAM[52] can be used (reported by combined nomenclature[53] codes).

Once the study team has gathered the carbon intensity for the product under analysis, the total value of the carbon cost to be subtracted can be calculated as explained in the following formula:

$$LCC\ result - (price\ of\ CO2e_{CBAM} * default\ value\ (\frac{tonne\ CO2e}{tonne\ goods}) * weight\ of\ the\ product)$$

Using estimated CO_2 price coefficient: Another relevant report is “Ex-post investigation of cost pass-through in the EU ETS- An analysis for six sectors” by de Bruyn et al. (2015), and the related journal article (Cludius et al., 2020). The sectors analysed are <u>refineries, iron and steel, fertiliser, cement, petrochemicals, glass</u>. For this analysis, the relevant information is not the percentage of carbon costs that is passed on final product prices. However, the results also report the coefficient for CO_2, i.e. the percentage of the carbon cost internalised in the product price. This value should be

[51] European Commission, Directorate-General for Energy, Smith, M., Moerenhout, J., Thuring, M., et al., External costs: energy costs, taxes and the impact of government interventions on investments: final report, Publications Office, 2020.

[52] https://taxation-customs.ec.europa.eu/news/commission-publishes-default-values-determining-embedded-emissions-during-cbam-transitional-period-2023-12-22_en

[53] The Combined Nomenclature (CN) is a tool for classifying goods, set up to meet the requirements both of the Common Customs Tariff and of the EU's external trade statistics. The CN is also used in intra-EU trade statistics. It is a further development (with special EU-specific subdivisions) of the World Customs Organization's Harmonized System nomenclature. This is a systematic list of commodities applied by most trading nations (and also used for international trade negotiations). https://taxation-customs.ec.europa.eu/customs/calculation-customs-duties/customs-tariff/combined-nomenclature_en

subtracted from the product price, in order to discount the environmental cost. A summary of the results is reported in the following table (**Table 12**). The coefficient for CO_2 indicates that the price of diesel contains CO_2 costs in the order of 3%-5%.

$$Product\ price - (Product\ price * estimated\ CO_2\ price\ coefficient)$$

Table 12. Estimated CO_2 price coefficient for some products

Sector	Product	Estimated CO_2 price coefficient (average cost share, i.e. the share of the cost of CO_2 in the cost of production)
Refineries	Diesel	0.03 – 0.05
	Petrol	0.01 – 0.02
	Gasoil	0.02 – 0.07
Iron and Steel	Flat steel hot rolled coil	0.04 – 0.08
	Flat steel cold rolled coil	0.03 – 0.05
Fertilisers	Ammonia	NA
	Ammonium nitrate	0.12
	Calcium ammonium nitrate	0.13
	Urea ammonium nitrate	0.24
	Urea	0.09 – 0.10
Cement	Clinker	0.07 – 0.09
	Total cement	0.02 – 0.03
	Portland cement	0.07 – 0.11
Petrochemicals	Ethylene	0.03 – 0.12
	Mono ethylene glycol	0.18
	Propylene oxide	0.02
	Propylene glycol ether	0.06 – 0.07
	Methanol, Butadiene, Propylene	NA

Glass	Hollow glass	0.004 – 0.01
	Fibre glass	NA

Source: Cludius et al. (2020)

4.4.2.3 Monetary valuation of environmental impacts

For the monetisation of environmental impacts, different approaches can be followed, as mentioned in Section 4.2.3.

4.4.2.3.1 Use of monetisation factors at impact category level

The monetisation factors proposed in the revised version of MEErP (Gama Caldas et al., 2024) (based on the JRC report by Amadei et al. (2021b)) were analysed, to understand which evaluation method was used for each of them. The JRC activity resulted in the identification of monetisation factors for 12 impact categories. The results of the analysis are shown in **Table 13**.

Finnveden et al. (2006) concluded that, if LCA results are monetised, all impact categories should be monetised using the same cost perspective. Roos Lindgreen and Vermeulen (2023) support this idea. However, the use of different valuation methods is acceptable and was discussed during a meeting with experts from the ORIENTING project[54] on 20 November 2023 (see Annex 3).

To summarise, as a result of the analysis and discussion with experts and policy DGs, it is proposed to keep as valid the factors used in Gama Caldas et al. (2024) (see Table 18). However, they have to be updated to the reference year (2022). It should be noted that the study team should update the monetisation factors, following the same procedure, in the event that the reference year is not 2022 when data is available.

The values of the monetary valuation coefficients (MVCs) have been updated, using the following formula:

$$Final\ value_i = Present\ value_j * \frac{HICP_{final,i}}{HICP_{initial,j}}$$

where:

- Final value represents the monetary valuation coefficients (MVCs) for the year i adjusted for inflation;
- Present value represents the MVCs in the year j (this is the year set as the "Present year");
- $HICP_{final,i}$ represents the HICP value for the year i;
- $HICP_{final,j}$ represents the HICP value for the year j (this is the year set as the "Present year").

[54] ORIENTING is a research project to develop an operational methodology for product Life-cycle Sustainability Assessment. The main purpose of Orienting is to integrate a life-cycle approach that includes the analysis of environmental, social and economic impacts. See: https://cordis.europa.eu/project/id/958231, https://orienting.eu/

The source for the Harmonised Index of Consumer Prices (HICP) was Eurostat[55]. The values for 2022 were used, given that 2023 HICP data were not available yet.

Moreover, new monetisation factors for “Resource use” are proposed in **Table 14**.

For more details on the method used in the definition of each monetisation factor, see Annex 6.

[55] Eurostat, Harmonised Index of Consumer Prices (HICP) - annual data (average index).

Table 13. Valuation methods used for monetisation factors

Impact category		Unit of measure	Value	Source	Reference year	Updated value (2022)	Method
1	Climate change, total	€/kg CO_2 eq.	1.00 ´ 10^{-1}	DG MOVE[56]	2016	1.19 ´ 10^{-1}	Avoidance cost approach.
2	Ozone depletion	€/kg CFC-11 eq.	5.55 ´ 10^{+1}	JRC[57]	2019	6.28 ´ 10^{+1}	Damage cost, Average value (Min: Env. Prices Handbook EU28[58]; Max: Alberici et al., 2014[59]).
3	Human toxicity, cancer	€/CTUh	9.19 ´ 10^{+5}	JRC[57] based on Trinomics report[60]	Already updated to 2019 (in 2018: 902 616)	10.4 ´ 10^{+5}	Damage cost. Based on the values prepared for DG MOVE[56], which is based heavily on the Environmental Prices Handbook EU28[58]. DALY/CTUh values derived by 3 key studies in this area, namely: (1) Ponsioen & Goedkoop (2016) (2) Humbert (2015) (3) Vargas-Gonzalez et al. (2019).
4	Human toxicity, non-cancer	€/CTUh	1.66 ´ 10^{+5}	JRC[57] based on Trinomics report[60]	Already updated to 2019 (in 2018: 163 447)	1.88 ´ 10^{+5}	

[56] European Commission, Directorate-General for Mobility and Transport, Essen, H., El Beyrouty, K., Bieler, C., et al., Handbook on the external costs of transport: version 2019, Publications Office, 2019.

[57] Amadei, A., De Laurentiis, V., Sala, S, Monetary valuation of environmental impacts in life-cycle assessment: state of the art and challenges, European Commission, 2021, JRC125725.

[58] de Bruyn, S., Bijleveld, M., de Graaff, L., Schep, E., Schroten, A., Vergeer, R., Ahdour, S., 2018. Environmental Prices Handbook - EU28 version

[59] Alberici, S., Boeve, S., Van Breevoort, P., Deng, Y., Förster, S., Gardiner, A., van Gastel, V., Grave, K., Groenenber, H., de Jager, D., Klaassen, E., Pouwels, W., Smith, M., de Visser, E., Winkel, T., Wouters, K., 2014. Subsidies and costs of EU energy: final report. Ecofys, by order of: European Commission.

[60] European Commission, Directorate-General for Energy, Smith, M., Moerenhout, J., Thuring, M., et al., External costs: energy costs, taxes and the impact of government interventions on investments: final report, Publications Office, 2020.

5	Particulate matter	€/disease incidence	7.28 ´ 10^{+5}	DG MOVE[61]. See Annex IV of Gama Caldas et al. (2024) for a detailed conversion calculation.	2016	8.66 ´ 10^{+5}	Damage cost (multiplied by disease incidence from EF characterisation factors). The damage cost includes all effects: health effects, crop loss, biodiversity loss, material damage.
6	Ionising radiation, human health	€/kBq U_{235} eq.	-	-		-	
7	Photochemical ozone formation, human health	€/kg NMVOC eq.	1.20 ´ 10^{00}	DG MOVE[61]	2016	1.43*10^{00}	Average damage cost in the EU-28. The damage cost includes all effects: health effects, crop loss, biodiversity loss, material damage.
8	Acidification	€/mol H^+ eq.	3.50 ´ 10^{-1}	JRC[62] based on Trinomics report[63]	Already updated to 2019 (in 2018: 0.344)	3.96*10^{-1}	Damage and avoidance (restoration) cost (from OVAM[64]).

[61] European Commission, Directorate-General for Mobility and Transport, Essen, H., El Beyrouty, K., Bieler, C., et al., Handbook on the external costs of transport: version 2019, Publications Office, 2019.

[62] Amadei, A., De Laurentiis, V., Sala, S, Monetary valuation of environmental impacts in life-cycle assessment: state of the art and challenges, European Commission, 2021, JRC125725.

[63] European Commission, Directorate-General for Energy, Smith, M., Moerenhout, J., Thuring, M., et al., External costs: energy costs, taxes and the impact of government interventions on investments: final report, Publications Office, 2020.

[64] OVAM, 2017. Environmental profile building elements. Annex: Monetisation of the MMG method

9	Eutrophication, terrestrial	€/mol N eq.	-	-		-	
10	Eutrophication, freshwater	€/kg P eq.	1.95 ´ 10^{00}	JRC[65] based on Trinomics report[66]	Already updated to 2019 (in 2018: 1.92)	2.21*10^{00}	Mix of damage and abatement cost approaches for the different pollutants (from Env. Prices Handbook EU28[67]).
11	Eutrophication, marine	€/kg N eq.	3.27 ´ 10^{00}	JRC[65] based on Trinomics report[66]	Already updated to 2019 (in 2018: 3.21)	3.70*10^{00}	
12	Ecotoxicity, freshwater	€/CTUe	3.89 ´ 10^{-5}	JRC[65] based on Trinomics report[66]	Already updated to 2019 (in 2018: 3.82×10^{-5})	4.40*10^{-5}	Damage cost (from OVAM[68])
13	Land use	€/pt	1.78 ´ 10^{-4}	JRC[65] based on Trinomics report[66]	Already updated to 2019 (in 2018: 0.000175)	2.01*10^{-4}	Abatement cost

[65] Amadei, A., De Laurentiis, V., Sala, S, Monetary valuation of environmental impacts in life-cycle assessment: state of the art and challenges, European Commission, 2021, JRC125725.
[66] European Commission, Directorate-General for Energy, Smith, M., Moerenhout, J., Thuring, M., et al., External costs: energy costs, taxes and the impact of government interventions on investments: final report, Publications Office, 2020. (Directorate-General for Energy (European Commission) et al., 2020)
[67] de Bruyn, S., Bijleveld, M., de Graaff, L., Schep, E., Schroten, A., Vergeer, R., Ahdour, S., 2018. Environmental Prices Handbook - EU28 version
[68] OVAM, 2017. Environmental profile building elements. Annex: Monetisation of the MMG method

14	Water use	€/m^3 water eq. of deprived water	5.08×10^{-3}	JRC[65] based on Trinomics report[66]	Already updated to 2019 (in 2018: 0.00499)	$5.75*10^{-3}$	Resource depletion costs.

Source: JRC elaboration, adapted from Gama Caldas et al. (2024)

Table 14. Proposal of values for Resource use

Impact category		Unit of measure	Value	Source	Reference year	Updated value (2022)	Method
15	Resource use, minerals and metals	€/kg Sb eq.	- 1.67	JRC (Amadei et al., 2021b) based on Trinomics report (Directorate-General for Energy (European Commission) et al., 2020)	Already updated to 2019 (in 2018: 1.64)	1.89	Market price (from OVAM, 2017). The OVAM approach uses the ReCiPe Resource Depletion Costs and the market prices to calculate an average ratio between the two (of 83%).
16	Resource use, fossils	€/MJ	- 1.32 ´ 10^{-3}	JRC (Amadei et al., 2021b) based on Trinomics report	Already updated to 2019 (in 2018: 0.0013)	$1.49*10^{-3}$	Market price (from ReCiPe).

Source: JRC elaboration, adapted from Gama Caldas et al. (2024)

4.4.2.3.2 Use of monetisation factors at elementary flow level

Monetisation of impacts on the midpoint and endpoint levels introduces uncertainty as information disappears in aggregation. Therefore, a second strategy is to combine life-cycle inventory data directly with unit damage cost factors per elementary flow (e.g. EUR per tonne of CO_2). Prices for environmental emissions to air/water/soil reported by de Bruyn et al. (2018) can be used.

4.4.2.3.3 Use of environmentally extended multi-regional input-output (EE-MRIO) models

For linking monetisation factors with MRIO environmental accounts, global factors or (preferred) country/region-specific factors with global coverage are needed: Environmental Priority Strategies (EPS) weighting factors[69] can be used.

In parallel to this, the creation of the link between the EE-MRIO database EXIOBASE[70] and the new United Nations Environment Programme (UNEP)- Global Guidance on Environmental Life Cycle Impact Assessment Indicators (GLAM[71]) list (which in turn is also in line with the European Platform on LCA, https://eplca.jrc.ec.europa.eu/glam.html) is currently under development.

4.4.3 Interpretation and identification of economic hotspots

One of the limits of the method described is that the aggregate LCC model estimates the total monetary damage of the environmental impact of the process but fails to divide the damage between the actors in the supply chain, as pointed out by Medina-Salgado et al. (2022). Therefore, while in the conventional LCC the study team should consider only the impacts borne by the users, in the societal LCC the external impacts should be clearly linked to the actor generating them (i.e. externalities related to the manufacturing stage, the use stage and the EoL). This can help the effective definition of requirements.

4.4.4 Sensitivity analysis and discussion

The connections between uncertain parameters used in LCC and calculated outputs should be revealed by a sensitivity analysis. Many types of sensitivity analyses exist (e.g. partial sensitivity analysis, worst/best-case scenario, Monte Carlo). The study team should select the most appropriate method, considering the characteristics of the model. If robustness cannot be examined numerically, the study team should provide a qualitative discussion of the appropriateness to gage the reliability of results. As reported in the legal text, in the procedure for defining performance requirements, "a sensitivity analysis covering the relevant factors, such as the price of energy or other resources, the cost of raw materials and necessary technologies, production costs, discount rates, and, where

[69] https://www.lifecyclecenter.se/wp-content/uploads/2020_06_EPS-weighting-factors-version-2020d-2.pdf
[70] https://www.exiobase.eu/
[71] https://www.lifecycleinitiative.org/activities/life-cycle-assessment-data-and-methods/global-guidance-for-life-cycle-impact-assessment-indicators-and-methods-glam/

appropriate, external environmental costs, including avoided greenhouse gas emissions, shall be carried out" (ESPR, Annex II).

When the assessment of the base case is performed (in Task 5), the projection of this assessment to a future year can also be performed, to be used in Task 7 for the analysis of scenarios. Alternative baselines can also be developed (i.e. future scenario, assuming different evolution of the market, in the event that no measures are implemented).

4.4.5 Limitations of the EcoReport tool to perform the economic assessment

As already explained in Gonzalez Torres et al. (2025), the environmental impacts of some of the product aspects listed in Article 5 of the ESPR cannot be properly assessed through the EcoReport tool. Therefore, the assessment performed through the EcoReport tool shall be complemented by a more complete LCA using another tool. This has some implications for the societal LCC in the EcoReport tool, since the calculation of the environmental externalities is based on the results of the environmental assessment. A workaround to this problem can be to manually insert the results of the environmental assessment in the EcoReport tool (Results worksheet) as inputs, and use them as data for the sLCC.

As regards the economic assessment, in the EcoReport tool the following three important assumptions are made:

- the changes in manufacturing costs are reflected in the purchase price;
- EoL costs are included in the purchase price;
- costs of third-party verification or certification are not taken into account.

The possibility to use the EcoReport tool to economically assess the different product aspects was investigated, in the two cases:

- conventional LCC, from the user's perspective;
- societal LCC, from society's perspective.

4.4.5.1 User's perspective

In the case of the user's perspective, a conventional LCC is performed, so there is no monetisation of the environmental externalities. It is assumed that the economic burdens or benefits related to most of the product aspects are reflected in the purchase price, in the case of both final and intermediate products. **Table 15** reports whether the effect of each product aspect can be considered in the EcoReport tool and how. To summarise the results of the analysis, the EcoReport tool fully covers all the product aspects, except for reusability: the tool could be improved in a future revision to fully cover this product aspect.

Table 15. Economic benefits and burdens of the product aspects in the EcoReport tool – user's perspective.

Product aspect	Economic benefits	Economic burdens	Comments
Durability	Included in the extension of lifetime, and in the consequent reduction in the Latest annual sales. Product price and installation costs are potentially spread over a longer period.	Potential increase of the market price of the product (to be evaluated case by case).	
Reliability	Included in the extension of lifetime, and in the consequent reduction in the Latest annual sales. Product price and installation costs are potentially spread over a longer period.	Potential increase of the market price of the product (to be evaluated case by case). Given that reliability includes maintenance (see CEN-CENELEC, 2020), costs for the use stage could increase. In the Input sheet, "repair and maintenance costs" can be added.	
Reusability	The reusability of the product as a whole might be included in the extension of lifetime, and in the consequent reduction in the Latest annual sales. Product price and installation costs are potentially spread over a longer period. The reusability of a component might be simulated and included in the circular footprint formula (CFF), and it might contribute to a reduction of the product price.	Additional impacts of transport/shipping might be reflected in an increase of the product price (to be evaluated case by case).	The reusability of the product as a whole should be simulated through an extension of lifetime (Lt). This could be done by changing the value of the Lifetime ('Lifetime' sheet) directly or adding an additional factor to the formula to include the 'second life' ($1+\Delta L2$). For the latter, the EcoReport tool should be revised. The reuse of a component in a different product can be modelled

			with the EcoReport tool as part of the CFF (the parameter R2 should be used).
Upgradability	Included in the extension of lifetime, and in the consequent reduction in the Latest annual sales. Product price and installation costs are potentially spread over a longer period.	Potential increase of the market price of the product (to be evaluated case by case). In the Input sheet, “repair and maintenance costs” can be added.	The cell “repair and maintenance costs” is not linked to the table in the sheet Lifetime which contains the costs of repair and upgrade (labour cost + cost of spare parts) for the different levels.
Repairability	Included in the extension of lifetime, and in the consequent reduction in the Latest annual sales. Product price and installation costs are potentially spread over a longer period.	Increase in costs for the use stage. Potential increase of the market price of the product (to be evaluated case by case). In the Input sheet, “repair and maintenance costs” can be added.	The cell “repair and maintenance costs” is not linked to the table in the sheet Lifetime which contains the costs of repair and upgrade (labour cost + cost of spare parts) for the different levels.
Possibility of maintenance and refurbishment	Included in the extension of lifetime, and in the consequent reduction in the Latest annual sales. Product price and installation costs are potentially spread over a longer period	Increase in costs for the use stage. Potential increase of the market price of the product (to be evaluated case by case). In the Input sheet, “repair and maintenance costs” can be added.	Refurbishment should be simulated through an extension of lifetime (Lt). This could be done by changing the value of the Lifetime (‘Lifetime’ sheet) directly or adding an additional factor to the formula to include the ‘second life’ (1+ΔL2). For the latter, the EcoReport tool should be revised. The costs of refurbishment might be added in the same cell (“repair

			and maintenance costs"), which should be renamed for clarity.
Presence of substances of concern	Potential change in the product price (to be evaluated case by case).		
Energy use and energy efficiency	Potential change in the product price (to be evaluated case by case). Regarding efficiency in the use stage, it is modelled by the reduction in electricity or fuel use, and consequent reduction of related costs.		
Water use and water efficiency	Potential change in the product price (to be evaluated case by case). Regarding efficiency in the use stage, it is modelled by the reduction in water use, and consequent reduction of related costs.		
Resource use and resource efficiency	Potential change in the product price (to be evaluated case by case). Regarding efficiency in the use stage, it is modelled by the reduction in fuel and auxiliary material use, and consequent reduction of related costs. Potential change in EoL costs, which are assumed to be included in the product price.		
Recycled content	Potential change in the product price (to be evaluated case by case).		
Possibility of remanufacturing	Potential change in the product price (to be evaluated case by case). Potential change in EoL costs, which are assumed to be included in the product price. The benefits for the potential decrease of the price of the product resulting from remanufacturing should be evaluated case by case.		The modelling of remanufacturing would require an expansion of the system boundaries, in order to also include in the functional unit the product generated after the remanufacturing process (and the potential economic benefits for consumers arising from the availability of remanufactured

		products) or an allocation of the expected economic impacts.
Recyclability	Potential change in the product price (to be evaluated case by case). Potential change in EoL costs, which are assumed to be included in the product price.	The modelling of recycling would require an expansion of the system boundaries, in order to also include in the functional unit the product generated after the recycling process (and the potential economic benefits for consumers arising from the availability of recycled content) or an allocation of the expected economic impacts.
Possibility of recovery of materials	Potential change in the product price (to be evaluated case by case). Potential change in EoL costs, which are assumed to be included in the product price.	The modelling of recovery of materials would require an expansion of the system boundaries, in order to also include in the functional unit the product generated after the recovery process (and the potential economic benefits for consumers arising from the availability of recovered materials), or an allocation of the expected economic impacts.
Environmental impacts, including carbon footprint and environmental footprint		Not evaluated in a cLCC.

Expected generation of waste	Potential change in the product price (to be evaluated case by case). Potential change in EoL costs, which are assumed to be included in the product price.	

NB In green, aspects that are fully covered by EcoReport tool. In yellow, aspects that are partially covered.

Source: JRC elaboration

4.4.5.2 Society's perspective

With the perspective of society, a sLCC is to be performed to monetise environmental externalities. **Table 16** reports whether the effect of each product aspect can be considered in the EcoReport tool and how.

To summarise, the main issues are related to the limitations of the EoL model used in the EcoReport tool for the environmental assessment, which are reflected here in an inappropriate assessment of the environmental externalities generated in the EoL. Regarding remanufacturing, the challenge is that different system boundaries would be required to assess a DO based on this product aspect: this is an issue for the environmental as well as economic analysis, considering that it is not possible to compare design options if they are assessed with different system boundaries.

Table 16. Economic benefits and burdens of the product aspects in the EcoReport tool - society's perspective.

Product aspects	Economic benefits	Economic burdens	Comments
Durability	Included in the extension of lifetime, and in the consequent reduction in the Latest annual sales. Product price, installation costs and the environmental externalities are potentially spread over a longer period.	Potential increase of the market price of the product (to be evaluated case by case).	
Reliability	Included in the extension of lifetime, and in the consequent reduction in the Latest annual sales. Product price,	Potential increase of the market price of the	

	installation costs and the environmental externalities are potentially spread over a longer period.	product (to be evaluated case by case). Given that reliability includes maintenance (see CEN-CENELEC, 2020), costs for the use stage could increase. In the Input sheet, “costs of maintenance, repair and other circularity strategies” can be added. This cell It is not linked to the table in the sheet Lifetime which contains the costs of repair and upgrade (labour cost + cost of spare parts) for the different levels.	
Reusability	The reusability of the product as a whole might be included in the extension of lifetime, and in the consequent reduction in the Latest annual sales. Product price, installation costs and the environmental externalities are potentially spread over a longer period.	Additional impacts of transport/shipping might be added.	The reusability of the product as a whole should be simulated through an extension of lifetime (Lt). This could be done by adding an additional factor to the formula to include the ‘second life’ (1+ΔL2). In this case, the EcoReport tool should be revised.
Upgradability	Included in the extension of lifetime, and in the consequent reduction in the Latest annual sales. Product price, installation costs and the environmental externalities are potentially spread over a longer period.	Potential increase of the market price of the product (to be evaluated case by case). In the Input sheet, “costs of	

		maintenance, repair and other circularity strategies” can be added. This cell is not linked to the table in the sheet Lifetime which contains the costs of repair and upgrade (labour cost + cost of spare parts) for the different levels.	
Repairability	Included in the extension of lifetime, and in the consequent reduction in the Latest annual sales. Product price and installation costs are potentially spread over a longer period.	Increase in costs for the use stage. Potential increase of the market price of the product (to be evaluated case by case). In the Input sheet, “costs of maintenance, repair and other circularity strategies” can be added. This cell is not linked to the table in the sheet Lifetime which contains the costs of repair and upgrade (labour cost + cost of spare parts) for the different levels.	
Possibility of maintenance and refurbishment	Included in the extension of lifetime, and in the consequent reduction in the Latest annual sales. Product price and installation costs are potentially spread over a longer period	Increase in costs for the use stage. Potential increase of the market price of the product (to be evaluated case by case).	

		In the Input sheet, "costs of maintenance, repair and other circularity strategies" can be added. This cell is not linked to the table in the sheet Lifetime which contains the costs of repair and upgrade (labour cost + cost of spare parts) for the different levels.	
Presence of substances of concern	Potential change in the product price (to be evaluated case by case) and in the environmental externalities.		
Energy use and energy efficiency	Potential change in the product price (to be evaluated case by case). Regarding efficiency in the use stage, it is modelled by the reduction in electricity or fuel use, and consequent reduction of related costs and environmental externalities.		
Water use and water efficiency	Potential change in the product price (to be evaluated case by case). Regarding efficiency in the use stage, it is modelled by the reduction in water use, and consequent reduction of related costs and environmental externalities.		
Resource use and resource efficiency	Potential change in the product price (to be evaluated case by case). Regarding efficiency in the use stage, it is modelled by the reduction in fuel and auxiliary material use, and consequent reduction of related costs and environmental externalities. Potential change in EoL costs, which are assumed to be included in the product price.		
Recycled content	Potential change in the product price (to be evaluated case by case) and in the environmental externalities.		

Possibility of remanufacturing	Potential change in EoL costs, which are assumed to be included in the product price, and in the environmental externalities.	An extension of the system boundaries would be needed, hindering the comparison of the different DOs.
Recyclability	Potential change in EoL costs, which are assumed to be included in the product price, and in the environmental externalities.	The externalities from down-cycling cannot be modelled. Indeed, the simplified version of the CFF is used to model the EoL, so the impact of recycling can only be partially captured.
Possibility of recovery of materials	Potential change in EoL costs, which are assumed to be included in the product price, and in the environmental externalities.	The externalities from recovery operations (other than recycling) cannot be modelled. Indeed, the simplified version of the CFF is used to model the EoL, so the impact of recovery operations can only be partially captured.
Environmental impacts, including carbon and environmental footprint	The environmental impacts are reflected in the externalities.	The externalities from energy recovery, landfill, recovery operations (other than recycling) and down-cycling cannot be modelled. Indeed, the simplified version of the CFF is used to model the EoL, so the environmental impacts can only be partially captured.
Expected generation of waste	Potential change in EoL costs, which are assumed to be included in the product price, and in the environmental externalities.	The externalities from energy recovery and landfill cannot be modelled. Indeed, the simplified version of the CFF is used to model the EoL.

NB In green, aspects that are fully covered by EcoReport tool. In yellow, aspects that are partially covered.

Source: JRC elaboration

4.4.6 Final consideration and summary

To summarise, the study team should perform the LCC by following the four steps: goal and scope definition, information gathering, interpretation and identification of hotspots, sensitivity analysis and discussion.

Both for intermediate and final products, the LCC analysis should be performed applying two different perspectives: first the perspective of the user and secondly the perspective of society. In the case of final products, the perspective of manufacturers can also be assessed. When examining the perspective of the user/manufacturer, a conventional LCC should be performed. When considering the perspective of society, a societal LCC should be performed, including the monetisation of the environmental impacts.

For the monetisation of environmental impacts, three approaches are proposed: the first one is the use of monetisation factors at impact category level, like the one proposed in **Table 13** and **Table 14**; the second is the use of monetisation factors at elementary flow level; and the third is the use of environmentally extended multi-regional input-output models.

If the study team wants to use the EcoReport tool, some limitations have been highlighted in **Table 15** and **Table 16**. When the perspective of the user is taken, the EcoReport tool fully covers all the product aspects, except for reusability. When the perspective of society is taken, there are limitations, mainly related to the fact that the simplified version of the CFF is used in the EcoReport tool to model the EoL of products, and it does not take into account the impacts of energy recovery, disposal and down-cycling.

4.5 Proposal for considerations of non-quantifiable aspects and policy objectives

The Life-cycle Sustainability Assessment (LCSA) is a comprehensive approach for evaluating the sustainability of products, services or systems throughout their entire life-cycle. The analysis of sustainability encompasses three fundamental 'pillars', namely environmental, economic and social dimensions. The environmental dimension is commonly evaluated via LCA along the lines of the ISO standards[72]. The economic dimension is measured by instead leveraging LCC analysis, which is being applied by an increasing number of public authorities and therefore also supported by the European Commission[73], as described in the previous sections.

By contrast, properly assessing the sustainability of the social dimension has proved to be challenging due to the underlying nature of its related 'non-quantifiable' and 'quantifiable' aspects[74]. For the non-quantifiable aspects, the existing literature methods and approaches devoted to their analysis and integration in LCSA are explained in Annex 7. However, an assessment of quantifiable social aspects could be supported through the monetisation of societal and environmental impacts, adopting 'monetisation factors'. An overview of social impacts included in monetary valuation methodologies/approaches is described in **Table 17**, which reports the social impact aspects included in the monetisation factors proposed in this report. It is for instance evident from the table how the 'Damage cost' approach employed for the monetisation of toxicity-related

[72] In particular: ISO 14040 related to 'environmental management - life-cycle assessment - principles and framework' and ISO 14044 related to 'environmental management - life-cycle assessment - requirements and guidelines'.

[73] European Commission – Life-cycle Costing and Life-cycle Costing calculation tools.

[74] The term 'Quantifiable' refers to measurable indicators providing insights on product-related sustainability impacts. The term 'Non-quantifiable' or 'Qualitative' refers instead to attributes or properties possessed by a product that can be difficult to interpret and assess in quantitative terms due to their intrinsic complexity.

impact categories (i.e. ‘Human toxicity, cancer’ and ‘Human toxicity, non-cancer’), is developed including quantifiable social aspects related to human well-being. However, these costs are related to the impact on the human organism, but do not cover more abstract categories such as impacts related human rights.

Table 17. Social aspects included in the monetisation factors methods and approaches

Impact category	Unit	Method/Approach	Description of included Social Impacts
Ozone depletion	€/kg CFC-11 eq.	Damage cost.	In the 'Environmental Prices Handbook', estimates of human health impacts are based on the ReCiPe methodology (Goedkoop, et al., 2013). In said Handbook, the impacts related to **variations in Ultra-Violet Burn (UV-B) radiation on 'human health'** are calculated adopting the so-called AMOUR (Assessment MOdel for Ultraviolet radiation and Risks) model. This approach provides results for a 'damage factor' expressed in DALYs per unit change in the 'Effective Equivalent of Stratospheric Chlorine' (EESC). This 'damage factor' is then converted to a 'characterisation factor' expressed in 'DALYs/CFC-11-eq.' for each class of ozone-depleting substances. In Alberici et al. (2014), the monetisation factor for this impact category represents the damage on human health related to **increased exposure to UV radiation**, using the ReCiPe characterisation approach.
Human toxicity, cancer Human toxicity, non-cancer	€/CTUh	Damage cost.	These categories value the **adverse human health effects caused by the following:** **(1) For cancer impacts -** the **intake of toxic substances** through inhalation of air, food/water ingestion, skin penetration insofar as they are **related to cancer**. **(2) For non-cancer impacts** - **the intake of toxic substances** through inhalation of air, food/water ingestion, penetration through the skin insofar as they are **related to non-cancer effects** that are not caused by particulate matter/respiratory inorganics or ionising radiation. It mostly encompasses heavy metals and chemicals, small concentrations of which are released in fossil fuel combustion. It is measured in 'Comparative Toxic Units' for humans (CTUh), which describes the estimated increase in morbidity in the total human population per unit mass of a chemical emitted (i.e. cases per kilogram).
Particulate matter	€/disease incidence	Damage cost (multiplied by disease incidence from EF characterisation factors).	Health effects: The inhalation of air pollutants such as particles (PM_{10}, $PM_{2.5}$), nitrogen oxides (NOx) and others leads to a higher risk of respiratory diseases (e.g. bronchitis, asthma, lung cancer) and cardiovascular diseases.

		The damage cost includes all the following effects: health effects, crop loss, biodiversity loss, material damage.	
Photochemical ozone formation, human health	€/kg NMVOC eq.	Average damage cost in the EU-28. The damage cost includes all the following effects: health effects, crop loss, biodiversity loss, material damage.	Health effects: The inhalation of air pollutants such as particles (PM_{10}, $PM_{2.5}$), nitrogen oxides (NOx) and others leads to a higher risk of respiratory diseases (e.g. bronchitis, asthma, lung cancer) and cardiovascular diseases.

Source: JRC elaboration

4.5.1 Non-directly quantifiable EU OSA aspects

Ecodesign requirements often improve material and energy efficiency and speed up de-risking from supply dependencies. As further developed in Maury et al. (2025), it is not always straightforward to quantify the potential gain in terms of EU OSA regarding, for example, the supply risk of critical raw materials or import/export dynamics.

However, it is crucial to conduct a qualitative analysis (as developed in Rodriguez Manotas et al. (2025) and Maury et al. (2025)) to identify which aspects of the EU OSA are most relevant to a given product, and to assess the potential impact of DOs in terms of either improving or worsening the current situation.

While full quantification might not be possible because of a lack of information on the product, market dynamics and technological production routes, a semi-quantitative analysis as further developed in Maury et al. (2025) might confirm or strengthen the choice of some DOs.

5 Conclusions

According to the ESPR, 'ecodesign' means the integration of environmental sustainability considerations into the characteristics of a product and the processes taking place throughout the product's value chain. The aim of this report is to present a method for the ranking of improved design options, to enable the definition of policy options with different sets of ecodesign requirements, typically with different ambition levels.

The report proposes three different methods, one in each chapter of the report:

1. Indications for the identification of DOs.

2. Method to assess interactions between different DOs, and define and rank paths of DOs.

3. Method to assess DOs (base cases and alternative DOs), including consideration of non-quantifiable aspects and policy objectives (OSA, social aspects).

Each chapter starts with a review of methods and indications provided in the MEErP and in previous preparatory studies.

The proposed methods were shared with the teams currently working on two pilot projects (i.e. textile project and steel project) to take into account the challenges that they are facing. Some parts of the proposed methodology will be tested in the pilot projects.

The application of this methodology will support the work done during the impact assessment. Indeed:

- the objectives used to identify the DOs can be used in the impact assessment, when defining the objectives of the policy options and the intervention logic;
- the ranking of DOs will provide critical input to the impact assessment in terms of defining the intervention logic and the policy options;
- the areas with the highest improvement potential will be identified, as will areas of potential trade-offs between design options (helping to identify the real policy alternatives);
- the results of the LCA and LCC analysis should be used in evaluating environmental, societal and economic impacts.

The integration between the preparatory study and impact assessment is facilitated by the new definition of DO, provided by this report.

Indications for the identification of DOs

It was concluded that DOs should be defined in a very specific way, so that they are close to ecodesign requirements. To reflect the extended scope of the ESPR, it is proposed to define DOs considering the five product dimensions defined by Diaz et al. (2021): two tangible (material, architecture) and three intangible (service, business model, ecosystem). A new definition of DO is proposed: a 'design option' is a specific product service system, with features which make it more advanced and/or more efficient when compared to the 'base case' in at least one of the product aspects listed in Article 5 of the ESPR. The identification of DOs should use as input the results of previous tasks (both of the ESPR methodology and of the MEErP), including the results from the assessment of the base case, as well as input from literature review and stakeholder consultations. The identification of environmental objectives should be the starting point for the identification of improved DOs. One DO can be linked to more than one product aspect. In the case of a quantitative performance-related DO, the range of quantitative values is already defined at this stage. To select a limited number of DOs, an affordability check and a functionality check can be performed. This report includes a description of the additional aspects that should be investigated within Tasks 2, 3 and 4, due to the extension of the scope of the ESPR compared to the MEErP.

Method to assess interactions between different DOs, and define and rank paths of DOs

After prioritising the DOs, paths of DOs should be created and validated, using LCA and LCC methodologies. The interactions between different DOs should be evaluated, both in terms of expected environmental improvement and expected economic impacts. Finally, the different paths can be ranked by performing a societal LCC.

Method to assess DOs (base cases and alternative DOs), including consideration of non-quantifiable aspects and policy objectives (OSA)

This method should be applied in Task 5 of the MEErP, for the environmental and economic assessment of the base case, and in Task 6 of the MEErP, for the assessment of the paths of DOs.

Both for intermediate and final products, the LCC analysis can be performed applying two different perspectives: the costs and savings should be considered for users and for society. When examining the perspective of users/manufacturers, a conventional LCC should be performed. When considering the perspective of society, a societal LCC should be performed, including the monetisation of the environmental impacts. The updated monetisation factors are reported in **Table 13** and **Table 14**.

Limitations

The methodology has some limitations, mainly related to the fact that it must be generic because it can be applied to a large variety of products under the scope of the ESPR. Therefore, in some cases, it was considered more appropriate to leave some flexibility to the study team performing the preparatory study.

One limitation is that the methodology does not provide guidelines for the definition of the number of DOs that should be considered. Moreover, the methodology leaves some flexibility in the definition of the strategy to prioritise the DOs.

Other limitations are in the assessment of the paths of DOs. Indeed, a metric able to summarise all the environmental impacts is necessary. Therefore, the use of the EF single score is proposed, but the study team may prefer other metrics. Moreover, when the economic impacts of the paths are assessed, it does not provide guidelines on the affordability requirement. Indeed, in contrast to the Ecodesign Directive, the ESPR does not claim that the analysis should aim to identify the least life-cycle cost point[75]. The criterion of product affordability for the consumer should be met. However, "affordability" is not defined, and it is not clear if an increase of the product price for the sake of environmental sustainability is acceptable, at least in some cases, or if the price/life-cycle cost should never increase due to the implementation of the ecodesign requirements. Therefore, a product-by-product analysis is recommended; in some cases, the analysis should be performed at the level of product range and market segment.

The LCC assessment can be performed using the EcoReport tool. As already explained in Gonzalez Torres et al. (2025), the environmental impacts of some of the product aspects listed in Article 5 of the ESPR cannot be properly assessed through the EcoReport tool. Therefore, the assessment performed with the EcoReport tool shall be complemented by a more complete LCA using another

[75] As stated in Annex II to the Ecodesign Directive, "Concerning energy consumption in use, the level of energy efficiency or consumption must be set aiming at the life-cycle cost minimum to end-users for representative product models, taking into account the consequences on other environmental aspects."

tool. This also has some implications for the quality of the results of the societal LCC in the EcoReport tool, since the calculation of the environmental externalities is based on the results of the environmental assessment.

Moreover, in the EcoReport tool the following three important assumptions are made:

- the changes in manufacturing costs are reflected in the purchase price;
- EoL costs are included in the purchase price;
- costs of third-party verification or certification are not taken into account.

Next steps

As part of the update of the existing MEErP, the methods developed under this task and included in this report are planned to be integrated in a final report, alongside other methods developed in other tasks. The aim of this work and that of other tasks is to provide a useful guidance document that serves the study team for the development of ongoing and future preparatory studies in line with the mandate of the ESPR.

The methodology presented in this report will be partially tested in the ongoing preparatory studies on steel and textiles.

In the event of an update of the EcoReport tool, the limitations highlighted in this report should be taken into account.

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List of abbreviations and definitions

AA	Administrative Arrangement
AC	Acidification
AVE	Average
B2B	Business-to-Business
B2C	Business-to-Consumer
BATg	Best Available Technology
BATq	Best Available Technique
BC	Base case
BNATg	Best Not yet Available Technology
BNATq	Best Not yet Available Technique
BREF	Best Available Techniques reference document
CA	Circularity aspect
CC	Climate change
CF	Characterisation Factor
CFF	Circular Footprint Formula
cLCC	Conventional Life-cycle Costing
CN	Combined Nomenclature
CPI	Consumer Price Index
CTUe	Comparative Toxic Units for freshwater ecosystem
CTUh	Comparative Toxic Units for humans
DALY	Disability-Adjusted Life Year
DO	Design option
EAC	Equivalent Annual Cost
ECOTOX	Ecotoxicity, freshwater
EEA	European Environmental Agency
EE-MRIO	Environmentally extended multi-regional input-output
EF	Environmental Footprint
EFTA	European Free Trade Association
E-PRTR	European Pollutant Release and Transfer Register
EPS	Environmental Priority Strategies
eLCC	Environmental Life-Cycle Costing
feLCC	full environmental Life-Cycle Costing
EoL	End of Life
ErP	Energy-related product
ERT	EcoReport tool

ESPR	Ecodesign for Sustainable Products Regulation
EU	European Union
EUt	Eutrophication
FEU	Eutrophication, freshwater
FRD	Resource use, fossils
GHG	Greenhouse Gas
GLAM	Global Guidance on Environmental Life Cycle Impact Assessment Indicators (initiative under the United Nations Environmental Programme umbrella)
HICP	Harmonised Index of Consumer Prices
HTOX	Human toxicity
HTOX_nc	Human toxicity, non-cancer
HTOX_c	Human toxicity, cancer
IC	Impact Category
IP S-LCIA	Impact Pathway Assessment method
IR	Ionising Radiation
ISO	International Organization for Standardization
JRC	Joint Research Centre of the European Commission
LCA	Life-Cycle Assessment
LCC	Life-Cycle Costing
LLCC	Least Life-Cycle Cost
LCI	Life-cycle Inventory
LCIA	Life-cycle Impact Assessment
LCM	Life-cycle Management
LCSA	Life-cycle sustainability assessment
LU	Land use
MEErP	Methodology for Ecodesign of Energy-related Products (methodology for Directive 2009/125/EC)
MEEuP	Methodology for the Ecodesign of Energy-using Products
MEU	Eutrophication, marine
MF	Monetisation factor
MFA	Material Flow Analysis
MRD	Resource use, minerals and metals
MVC	Monetary valuation coefficient
NMVOC	Non-Methane Volatile Organic Compound
NPV	Net Present Value
OE	Annual operating expense
OEF	Organisation Environmental Footprint

OPD	Ozone depletion
OSA	Open Strategic Autonomy
PAF	Potentially affected fraction of species
PAH	Polycyclic Aromatic Hydrocarbons
PDF	Potentially Disappeared Fraction
PEF	Product Environmental Footprint
PM	Particulate matter
POF	Photochemical ozone formation
PP	Purchase price (including installation costs)
PSS	Product Service System(s)
PWF	Present Worth Factor
QALY	Quality Adjusted Life Years
RP	Representative product
RS S-LCIA	Reference Scale Assessment method
SETAC	Society of Environmental Toxicology and Chemistry
sLCC	Societal Life-cycle Costing
SPP	Simple Payback Period
TEU	Eutrophication, terrestrial
UNEP	United Nations Environment Programme
WP	Work package
WTA	Willingness to accept
WTP	Willingness to pay
WU	Water use

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Annexes

Annex 1. Product parameters in Annex I to the ESPR and link to dimensions

The product parameters listed in Annex I to the ESPR have been related to the five dimensions investigated (i.e. product material, product architecture, product service, product business model and product ecosystem), to facilitate the assessment of the study team (**Table A.1**).

Table A.1. Product parameters and five dimensions of products

Product parameters (Annex I)	**Examples (Annex I)**	**Dimensions**
Durability and reliability of the product or its components	Product's guaranteed lifetime	Product service, product material and product architecture
	Technical lifetime	Product material and product architecture
	Mean time between failures	Product material and product architecture
	Indication of real use information on the product	Product service and product ecosystem
	Resistance to stresses or ageing mechanisms	Product material and product architecture
Ease of repair and maintenance	Characteristics, availability, delivery time and affordability of spare parts	Product architecture, product service and product ecosystem
	Modularity	Product architecture
	Compatibility with commonly available tools and spare parts	Product architecture and product ecosystem
	Availability of repair and maintenance instructions	Product service and product ecosystem
	Number of materials and components used	Product material and product architecture
	Use of standard components	Product architecture
	Use of component and material coding standards for the identification of components and materials	Product material and product architecture
	Number and complexity of processes and whether specialised tools are needed	Product architecture and product ecosystem
	Ease of non-destructive disassembly and reassembly	Product architecture

	Conditions for access to product data	Product service and product ecosystem
	Conditions for access to or use of hardware and software needed	Product architecture and product ecosystem
Ease of upgrading, re-use, remanufacturing and refurbishment	Number of materials and components used	Product material and product architecture
	Use of standard components	Product architecture
	Use of component and material coding standards for the identification of components and materials	Product material and product architecture
	Number and complexity of processes and tools needed	Product architecture and product ecosystem
	Ease of non-destructive disassembly and reassembly	Product architecture
	Conditions for access to product data	Product service and product ecosystem
	Conditions for access to or use of hardware and software needed	Product architecture and product ecosystem
	Conditions of access to test protocols or not commonly available testing equipment	Product service and product ecosystem
	Availability of guarantees specific to remanufactured or refurbished products	Product service and product ecosystem
	Conditions for access to or use of technologies protected by intellectual property rights	Product architecture and product ecosystem
	Modularity	Product architecture
Design for recycling, ease and quality of recycling	Use of easily recyclable materials	Product material
	Safe, easy and non-destructive access to recyclable components and materials or components and materials containing hazardous substances and material composition and homogeneity	Product material and product architecture
	Possibility for high-purity sorting	Product material

	Number of materials and components used	Product material and product architecture
	Use of standard components	Product architecture
	Use of component and material coding standards for the identification of components and materials	Product material and product architecture
	Number and complexity of processes and tools needed	Product architecture
	Ease of non-destructive disassembly and re-assembly	Product architecture
	Conditions for access to product data	Product service and product ecosystem
	Conditions for access to or use of hardware and software needed	Product architecture and product ecosystem
Avoidance of technical solutions detrimental to re-use, upgrading, repair, maintenance, refurbishment, remanufacturing and recycling of products and components		Product architecture and product ecosystem
Use of substances, and in particular the use of substances of concern, on their own, as constituents of substances or in mixtures, during the production process of products, or leading to their presence in products, including once these products become waste, and their impacts on human health and the environment		Product material
Use or consumption of energy, water and other resources in one or more life-cycle stages of the product, including the effect of physical factors or software and firmware updates on product efficiency and including the impact on deforestation		Product material and product architecture

Use or content of recycled materials and recovery of materials, including critical raw materials		Product material
Use or content of sustainable renewable materials		Product material
Weight and volume of the product and its packaging, and the product-to-packaging ratio	Weight and volume of the product and its packaging	Product material and product architecture
	Product-to-packaging ratio	Product material and product architecture
Incorporation of used components		Product architecture
Quantity, characteristics and availability of consumables needed for proper use and maintenance	Yield	Product architecture
	Technical lifetime	Product architecture
	Ability to reuse, repair, and remanufacture	Product architecture
	Mass-resource efficiency	Product architecture
	Interoperability	Product architecture
Environmental footprint of the product	Quantification, in accordance with the applicable delegated act, of a product's life-cycle environmental impacts, whether in relation to one or more environmental impact categories or an aggregated set of impact categories	Product material, product architecture, product service, product business model and product ecosystem
Carbon footprint of the product		Product material, product architecture, product service, product business model and product ecosystem
Material footprint of the product		Product material, product architecture, product service, product business model and product ecosystem
Microplastic and nanoplastic release	The release during relevant product life-cycle stages including manufacturing, transport, use, and end of life stages	Product material
Emissions to air, water or soil released in one or more life-cycle stages of the product	Quantities and nature of emissions, including noise	Product material, product architecture, product service, product business model and product ecosystem

Amounts of waste generated, including plastic waste and packaging waste and their ease of re-use, and amounts of hazardous waste generated		Product material and product architecture
Functional performance and conditions for use	Ability to perform its intended use	Product ecosystem
	Precautions of use	Product ecosystem
	Skills required	Product ecosystem
	Compatibility with other products or systems	Product ecosystem
Lightweight design	Reduction of material consumption	Product material
	Load- and stress-optimisation of structures	Product material and product architecture
	Integration of functions within the material or into a single product component	Product material and product architecture
	Use of lower density or high-strength materials and hybrid materials, with respect to material savings, recycling and other circularity aspects, and waste reduction	Product material

Source: JRC elaboration

Annex 2. Decision matrices for the identification of dependencies of circular economy dimensions

Figure A.1. Decision matrices for the identification of dependencies of circular economy dimensions

	Ecodesign approaches (EDA)													
Life cycle phase intensity (LCI)	durability	reliability	reusability	upgradability	reparability	possibility of maintenance and refurbishment	presence of substances of concern	energy use or energy efficiency	resource use or resource efficiency	recycled content	possibility of remanufacturing and recycling	possibility of recovery of materials	environmental impacts, including carbon and environmental footprint	expected generation of waste materials
	Design a (more) ***durable*** *product.*	*Design a (more)* ***reliable*** *product.*	*Design a reusable product.*	*Design an* ***upgradable*** *product.*	*Design a* ***reparable*** *product.*	*Design your product with the possibility for* ***maintenance*** *and* ***refurbishment.***	*Avoid* ***substances of concern*** *in your product.*	*Design an* ***energy efficient*** *or low energy intensive product (use phase).*	*Design a* ***resource efficient*** *or low resource intensive product (use phase).*	*Design your product with a large amount of* ***recycled content.***	*Design your product with the possibility for* ***remanufacturing*** *and* ***recycling****.*	*Design your product with the* ***possibility to recover its materials at the end of its life.***	*Design your product with a low* ***environmental impact*** *throughout its entire lifecycle. (including carbon and environmental footprint).*	*Check the expected* ***generation of waste materials*** *in your product.*
raw material intensive products	1	1	2	1	1	1	1	0	2	2	2	1	1	1
manufacturing intensive products	2	2	2	1	1	2	1	1	1	0	2	0	1	1
distribution intensive products	2	0	0	1	1	0	1	1	2	0	0	0	1	1
use intensive products	1	2	0	2	1	2	1	2	2	0	2	0	1	1
disposal intensive products	1	1	2	1	1	1	2	0	1	0	2	2	1	2

according to Wimmer & Züst 2001.

Evaluation		
	2	High contribution to circularity and sustainability relative to all ED approaches within this life cycle phase intensity.
	1	Medium contribution to circularity and sustainability relative to all ED approaches within this life cycle phase intensity.
	0	Low contribution to circularity and sustainability relative to all ED approaches within this life cycle phase intensity.

	Circular business models (CBM)												
Life-cycle-phase intensity (LCI)	Intensification		Extension				Circulation						Dematerialisation
	sharing, P2P	PSS	repair & maintenance	gap exploiter	long lasting product design	upgrading	reuse & redistribution	remanufacturing & refurbish	recycling, upcycling (closed loop)	downcycling (open loop)	industrial symbiosis	circular supplies	digitalisation
raw material-intensive products	1	1	1	1	1	1	2	2	2	2	2	2	2
manufacturing-intensive products	1	1	1	1	1	1	2	2	0	0	0	0	2
distribution-intensive products	0	0	2	0	2	2	0	0	1	1	0	0	2
use-intensive products	2	2	2	2	1	2	0	2	0	0	0	0	2
disposal-intensive products	0	0	1	0	1	1	2	1	2	2	2	1	2

according to Wimmer & Züst 2001.

Evaluation		
	2	High contribution to circularity and sustainability relative to all circular business models within this life-cycle-phase intensity.
	1	Medium contribution to circularity and sustainability relative to all circular business models within this life-cycle -phase intensity.
	0	Low contribution to circularity and sustainability relative to all circular business models within this life-cycle-phase intensity.

Source: Pruhs et al. (2024)

Annex 3. ERT: Formulas of LCC results in the EcoReport tool

Table A.2. Formulas to calculate cLCC in the EcoReport tool

	LCC new product		**Total annual consumer expenditure in the EU-27**	
Product price	(D1) From Input sheet	EUR	(D1)* Latest Annual Sales [m units/year]	m EUR/ year
Installation/ acquisition costs (if any)	(D2) From Input sheet	EUR	(D2)* Latest Annual Sales [m units/year]	m EUR/ year
Fuel (gas, oil, wood)	(D3) PWF*unit price [€/GJ]*thermal energy consumption in the use stage [MJ] / product lifetime [years]	EUR/year	(D3)* EU stocks [m units]	m EUR/ year
Electricity	(D4) PWF*unit price [€/KWh]* in the use stage [kwh] / product lifetime [years]	EUR/year	(D4)* EU stocks [m units]	m EUR/ year
Water	(D5) PWF*unit price [€/m^3]* consumption [amount/year]	EUR/year	(D5)* EU stocks [m units]	m EUR/ year
Auxiliary material 1	(D6)	EUR/year	(D6)* EU stocks [m units]	m EUR/ year
Auxiliary material 2	(D7)	EUR/year	(D7)* EU stocks [m units]	m EUR/ year
Auxiliary material 3	(D8)	EUR/year	(D8)* EU stocks [m units]	m EUR/ year
Auxiliary material 4	(D9)	EUR/year	(D9)* EU stocks [m units]	m EUR/ year
Auxiliary material 5	(D10)	EUR/year	(D10)* EU stocks [m units]	m EUR/ year
Repair & maintenance costs	(D11) From Input sheet	EUR	(D11)* EU stock/ product expected lifetime [m units/year]	m EUR/ year
Total	**(D1+D2+D11) [€] / product expected lifetime [years] + D3+D4+D5…**	**EUR/year**	**SUM D1'+…+D11'**	

Source: EcoReport tool

Table A.3 Formulas to calculate external costs in the EcoReport tool

External damages total, of which:				
- production PPext	D12	EUR	(D12)* Latest Annual Sales[76] [m units/year]	m EUR/year
- lifetime operating expense N*OEext	D13	EUR	(D13)* EU stock [m units/year]	m EUR/year
- end-of-life OELext	D14	EUR	(D14)* Latest Annual Sales[77] [m units/year]	m EUR/year
Total		**EUR/year**	**SUM (D12':D14')**	**m EUR/year**

Source: EcoReport tool

Annex 4. Meeting with experts from the ORIENTING project

Attendees of the meeting on 20 November 2023:

- Till M. Bachmann, Jonathan van der Kamp (European Institute for Energy Research (EIFER) EDF-KIT EWIV, Karlsruhe, Germany)
- Marina Isasa Sarralde, Marco Bianchi (Tecnalia)
- Pihkola Hanna (VDD)
- Laura Zanchi (Ecoinnovazione)

Annex 5. Spreadsheet with data needs for LCC

Available upon request.

A screenshot is shown below.

[76] Only the impacts of the products manufactured in the reference year are included.

[77] The assumption is that the number of products that people have thrown away in the latest year is equal to the latest year sales.

1	from cradle to grave					
2	**Scenario**	**Code in ERT (The letters refer to column B, sheet Inputs of ERT)**	**Data**	**Calculated or input by study team? (if the cell is yellow, input from study team needed)**	**Time reference**	**Comments**
3						
4	for the Base Case and for each Design option	A	Product expected lifetime	Calculated with Weibul function: 4 levels of reliability, repairability and upgradeability can be modelled.	current year	
5	for the Base Case and for each Design option	Reliability	Average expected initial lifetime [yrs], level 1		current year	
6	for the Base Case and for each Design option		Average expected initial lifetime [yrs], level 2		current year	
7	for the Base Case and for each Design option		Average expected initial lifetime [yrs], level 3		current year	
8	for the Base Case and for each Design option		Average expected initial lifetime [yrs], level 4		current year	
9	for the Base Case and for each Design option	Reparability	% increase in lifetime (ΔLtR)			
10	for the Base Case and for each Design option		% increase in lifetime (ΔLtR)			
11	for the Base Case and for each Design option		% increase in lifetime (ΔLtR)			
12	for the Base Case and for each Design option		% increase in lifetime (ΔLtR)			
13	for the Base Case and for each Design option	Upgradability	% increase in lifetime (ΔLtU)			
14	for the Base Case and for each Design option		% increase in lifetime (ΔLtU)			
15	for the Base Case and for each Design option		% increase in lifetime (ΔLtU)			
16	for the Base Case and for each Design option		% increase in lifetime (ΔLtU)			
17	for the Base Case and for each Design option		Weibull shape parameter (beta)		current year	
18						
19	for the Base Case and for each Design option	B	Latest Annual sales		current year	
20	for the Base Case and for each Design option	C	EU Stock		current year	
21	for the Base Case and for each Design option	D	Product price		current year	It is assumed that variation in the manufacturing costs are reflected in variation of price.
22	for the Base Case and for each Design option		Environmental taxes already internalised in		current year	
23	for the Base Case and for each Design option		Projection of sales		from current year to?	The sales are influenced by the duration of the lifetime of a product
24	for the Base Case and for each Design option		Projection of stock	calculated considering expected lifetime and projection of sales	from current year to?	
25	for the Base Case and for each Design option		Projection of price		from current year to?	
26	for the Base Case and for each Design option		Projection of environmental taxes already internalised in product price		from current year to?	
27	for the Base Case and for each Design option	E	Installation/acquisition costs (if any)		from current year to?	
28	for the Base Case and for each Design option	F	Fuel rate (gas, oil, wood)		from current year to?	

intermediate products | final products

Annex 6. Details on the monetisation factors for each impact category

Impact category 1: Climate change

Numerous studies have advocated the use of avoidance costs rather than damage costs. The major weakness of the damage cost approach is the fact that all types of climate damage need to be fully understood and quantified. Although many of the types of climate damage are somewhat understood, there are certain feedback and potentially extreme events that are not yet fully understood. Furthermore, the spread of results from different studies assessing climate costs based on avoidance costs is significantly smaller than for studies using damage costs. This seems to suggest that there is more certainty around the avoidance costs estimates than the damage costs estimates.

The avoidance cost approach values the costs of externalities based on the total costs required to reach a certain (policy) target. This approach assumes that a certain policy target reflects collective preferences with respect to the externality and, as such, it is a proxy for the collective WTP to avoid damage caused by an externality. The method is based on a cost-effectiveness analysis, which determines the least-cost option to achieve a required level of GHG emission reduction.

The biggest argument for the use of avoidance costs rather than damage costs is the fact that countries have signed up to the Paris Agreement. The EU ratified the Paris Agreement on 5 October 2016, committing itself to limit the increase in global average temperatures to well below 2 degrees above pre-industrial levels (this can be roughly translated to 450 ppm CO_2 equivalents): this is a credible long-term reduction target, which is representative of the interests of society, and which we can use as a target to base the avoidance cost on.

The avoidance costs used in CE Delft et al. (2020) are based on an average of the values found in the literature, grouped according to the short and medium term (up to 2030) and the long term (2040-2060) (**Table A.4**). The values for both these time periods were reached by calculating the average of all central estimates, excluding the lowest and the highest one to eliminate outliers. This provides us with a central avoidance cost value of € 100 in the short and medium term. This process was repeated for the low and high estimates, which are € 60 and € 189 in the short and medium term respectively. In the long term, the climate costs were shown to have a central estimate of € 269/t CO_2 equivalent.

Table A.4. Climate change avoidance costs in t CO_2 equivalent (€ 2016)

	Low	**Central**	**High**
Short and medium run (up to 2030)	60	100	189
Long run (from 2040 to 2060)	156	269	498

Source: DG MOVE (CE Delft et al., 2020)

Impact category 2: Ozone depletion

The damage cost approach is used: the average value proposed by the JRC report (Amadei et al., 2021b) was taken. More details are reported in **Table A.5**.

Table A.5. ODP - minimum and maximum values, and sources

	Total number of analysed monetary valuation coefficients	Min.	Max.	Sources
ODP	5	3.20E+01	1.15E+02	4.61E+01 (De Bruyn et al., 2010) 1.15E+02 (Alberici et al., 2014) 3.20E+01 (de Bruyn et al., 2018) 5.20E+01 (OVAM, 2017) 3.20E+01 (Directorate-General for Energy (European Commission) et al., 2020)

Source: Amadei et al. (2021b)

Impact categories 3 and 4: Human toxicity – cancer and non-cancer

The costs approach used is damage costs.

This category values the adverse human health effects caused by '(1 – cancer) the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to cancer; and (2 – non-cancer) the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to non-cancer effects that are not caused by particulate matter/respiratory inorganics or ionising radiation.' It mostly encompasses heavy metals and chemicals, small concentrations of which are released in fossil fuel combustion. It is measured in units of Comparative Toxic Units for humans (CTUh); this unit describes the estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kilogram).

The valuation approach is based on the values prepared for the DG MOVE Handbook (CE Delft et al., 2020) on the external costs of transport and its derivation of €/DALY values. Note that a DALY (Disability-Adjusted Life Year) can be defined as one lost year of 'healthy' life. The sum of DALYs across a population is the burden of disease, and can be thought of as a measure of the gap between the current health status and the ideal health status of the population.

The DG MOVE Handbook is based heavily on the Environmental Prices Handbook EU28 (de Bruyn et al., 2018).

The €/DALY values can be converted to €/CTUh values based on assumptions on the DALY/CTUh ratio. On the advice of the JRC, Trinomics (Directorate-General for Energy (European Commission) et al., 2020) took as the central value for both human toxicity impacts the value derived from the average of the DALY/CTUh values derived from 3 key studies in this area. The formula used is:

$$Average\ of\ damage\ factors\left(\frac{DALY}{CTUh}\right) * Economic\ value\,\frac{€}{DALY} = Monetary\ value$$

This results in the following values being used, which are comparable to values derived in other studies such as the OVAM (Public Waste Agency in the region of Flanders, Belgium) work (OVAM, 2017):

Non-cancer:

- Low: €30 211/CTUh;
- Central: €163 447/CTUh;
- High: €755 270/CTUh.

Cancer:

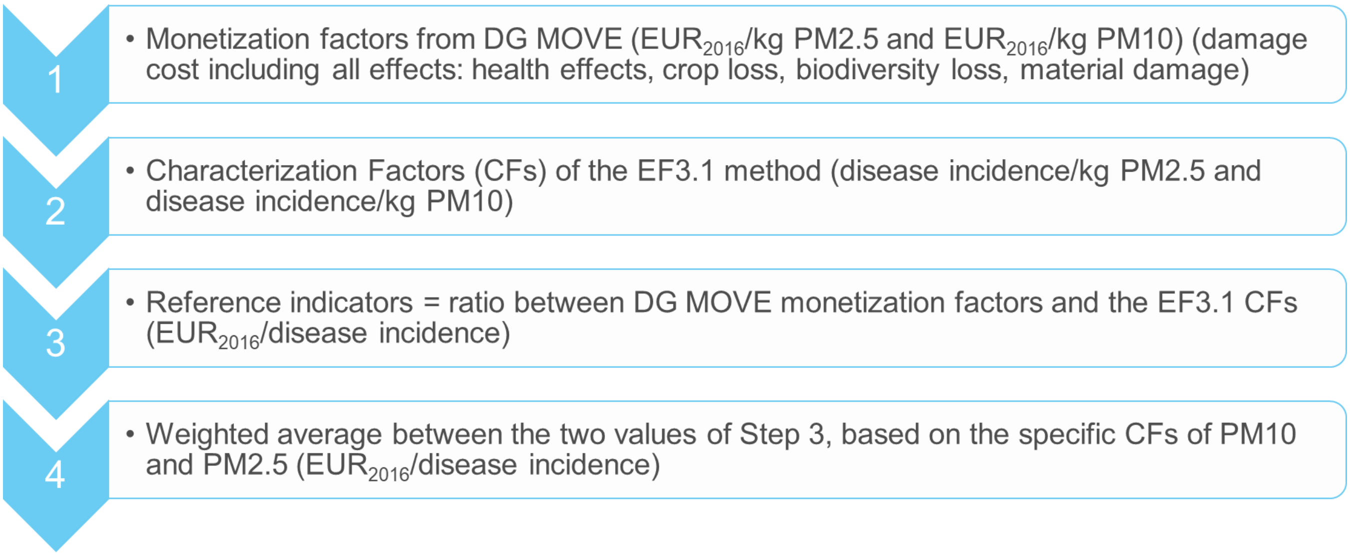
- Low: €174 324/CTUh;
- Central: €902 616/CTUh;
- High: €2 789 181/CTUh.

Low and high values for both indicators are based on OVAM (OVAM, 2017).

Impact category 5: Particulate matter

The approach followed for particulate matter is summarised in **Figure A.2**, in line with what was reported by the DG MOVE Handbook (CE Delft et al., 2020).

Figure A.2 Particulate matter: the approach



Source: adapted from CE Delft et al. (2020)

Impact category 7: Photochemical ozone formation

The average damage cost of NMVOC (Non-Methane Volatile Organic Compounds) in Europe proposed by the DG MOVE Handbook (CE Delft et al., 2020) is used. The damage cost includes all effects: health effects, crop loss, biodiversity loss, material damage.

Impact category 8: Acidification

The approach used to value acidification is based on OVAM (OVAM, 2017). This is based on damage cost and avoidance (restoration) cost approaches.

It includes:

- damage costs for impacts on building materials and ecosystems, assessed based on the Ecosense model (ExternE-Needs); and
- impacts on ecosystems (Potentially Disappeared Fraction - PDF) valued based on restoration costs (Ott et al., 2006).

Values from the OVAM report were converted from kg SO_2 eq. to Mol H+ eq. using the characterisation factors from the EF 3.0, with an approximate conversion of 1.31 Mol H+ eq. per kg SO_2 eq.

The authors of this report validated that EF 3.0 uses the same values as EF 2.0.

Impact categories 10 and 11: Eutrophication, freshwater and marine

In Directorate-General for Energy (European Commission) et al. (2020), the values for eutrophication are derived from the Environmental Prices Handbook EU28 (de Bruyn et al., 2018) which are based on a mix of damage and abatement cost approaches for the different pollutants.

ReCiPe distinguishes eutrophication of freshwaters and marine waters. For the former, kg P (phosphorus) is taken as the midpoint indicator unit, for the latter kg N (nitrogen).

The price of P is derived directly from the ReCiPe[78] characterisation factors (based on average European values) and the value reported in species.yr, with a conversion being made from the number of species to PDF/m^2/yr. Use of this method leads to an environmental price for phosphate from animal manure of € 0.62 per kilogram phosphate as central value.

ReCiPe provides no endpoint characterisation for nitrogenous eutrophication of freshwater (abatement-cost method), using the charge paid for discharges to Dutch surface waters: € 37.28 per pollution unit VeO (1 kg N = (4.57/54.8) VeO. Multiplying this ratio by the wastewater levy yields a charge of € 3.11 per kg N).

Impact category 12: Ecotoxicity, freshwater

A damage cost is calculated. The OVAM work (OVAM, 2017) uses valuation of the PDF of terrestrial species (corresponds to the value attached to protection of terrestrial biodiversity, and is based on the costs citizens say they are willing to pay to protect biodiversity. The underlying assumption is that all terrestrial species are valued equally).

Conversions to both the freshwater environment and PAF are used to estimate a value per CTUe (**Table A.6**).

Table A.6. Ecotoxicity freshwater

Indicators	Correction factor	Value
Economic value of terrestrial biodiversity in PDF m^2.year/kg		0.46
From PDF m^2 terrestrial to PDF m^3 freshwater	0.053	0.025
From PDF to PAF	0.55	0.013
From PAF year to PAF day	0.00273973	0.0000370
Value ecotoxicity, €/CTUe (in PAF.m^3.day/kg)		3.70E-05

Source: OVAM (2017)

Impact category 13: Land use

The land use impact category is measured in terms of a soil quality index by a dimensionless unit called "pt" (points).

The pt unit is a composite indicator of 4 indicators produced by the associated LCIA approach based on the LANCA model (Bos et al., 2016). These include:

1. biotic production (kg);
2. erosion resistance (kg soil);
3. mechanical filtration (m^3 water); and
4. groundwater replenishment (m^3 groundwater).

[78] ReCiPe is a method for the life-cycle impact assessment (LCIA). It was first developed in 2008 through cooperation between RIVM, Radboud University Nijmegen, Leiden University and PRé Sustainability. The primary objective of the ReCiPe method is to transform the long list of life-cycle inventory results into a limited number of indicator scores.

The value was derived according to the method suggested in the study from Cao et al. (2015). It represents the potential additional economic costs that society must bear to compensate for the change in the ecosystem service, i.e. the reduction of a given ecosystem service due to land use. The method was adapted to be used in combination with the land use impact assessment model from the EF presented in De Laurentiis et al. (2019). It is noted that the value only characterises the impacts caused by land occupation, not transformation.

Impact category 14: Water use

The costs approach used is resource depletion costs. As reported by Directorate-General for Energy (European Commission) et al. (2020), this impact category addresses water use with an indicator on 'user deprivation potential (deprivation-weighted water consumption)', which is measured in m^3 water (world) equivalents. It is based on an LCIA method called Available Water Remaining (AWARE) by Boulay et al. (2015). The formula shown below is used, with values from Fazio et al. (2018) and Alberici et al. (2014).

$$Monetary\ value_{water\ use} =$$

$$Economic\ value\left[\frac{€_{2019}}{m^3}\right] / \ Characterization\ factor\left[\frac{m^3\ water\ eq.deprived\ water}{m^3}\right]$$

2.00E-01 $€_{2012}/m^3$ from Alberici et al. (2014)

4.30E+01 m^3 water eq. deprived water/m^3 (Fazio et al., 2018)

Impact categories 15 and 16: Resource use

External costs associated with resource depletion can be controversial as there is a case to be made that markets for the resources will already price in the scarcity and therefore that there is no externality cost.

This is particularly relevant for fossil, mineral and metal resources for which there are relatively open global markets and prices.

Despite these concerns, Trinomics (Directorate-General for Energy (European Commission) et al., 2020) included values, considering that the private markets for resources do not adequately price in the additional marginal cost of present consumption on prices of and scarcity to future generations, i.e. implicitly the needs of future generations are more heavily discounted by private markets than may be optimal from a societal perspective.

As there are effectively no other non-commercial uses for the resources, it is then most appropriate to use the commercial market values as having effectively internalised the relevant scarcity costs.

An important note relates to the uncertainties for valuing resources, in that their economic availability varies considerably over time with changes in supply and demand, new discoveries, depletion of quality of existing reserves and improvements in technology (which can reduce extraction costs) all being reflected in prices.

The use of market prices (without taxes) was selected: this approach was validated by experts (ORIENTING project).

- Resource use, minerals and metals

Table A.7. Resource use, minerals and metals - Monetary indicator for abiotic depletion of non-fossil resources

Depletion of non-fossil resources		Value €/kg Sb (antimonium) equivalent		
Indicator	Region	Central	Low	High
Full life-cycle	Western Europe	1.56	0	6.23
	Flanders/Belgium	1.56	0	6.23
	Rest of world	1.56	0	6.23

Source: OVAM (2017)

According to OVAM (OVAM, 2017 and **Table A.7**), the low value is null, and reflects the point of view that resource depletion costs are internalised in prices.

The high estimate is based on the additional costs for future generations for extraction of raw materials. It is based on ReCiPe and the additional costs of energy required for extraction that can be interpreted as a 'resource depletion cost'. The resource depletion costs differ between resources, depending on the current grade of metals or minerals in the ore for example.

According to OVAM (2017), the methods and data to monetise abiotic depletion of non-fossil resources are based on ReCiPe. However, as in ReCiPe the indicator is based on $/kg Fe eq., and as there is no conversion factor given for Sb, an additional step was added to express the costs in terms of €/kg Sb eq.

In ReCiPe, the resource depletion costs are calculated for 20 substances: the resource depletion costs for Sb are estimated based on the average value for the ratio between resource depletion costs - as estimated in ReCiPe - and the market price. On average, this ratio is 82.9 %.

To estimate the central value, OVAM applies the general approach, based on the standard deviation (σg = 5), using a bandwidth of 16 between the low and high estimates.

The approach proposed by Directorate-General for Energy (European Commission) et al. (2020) is based on the one described by OVAM.

The following values were used:

- Low: €0 /kg Sb eq;
- Central: €1.64 /kg Sb eq;
- High: €6.53 /kg Sb eq.

The report by JRC (Amadei et al., 2021b) uses the following formula:

$$Monetary\ value_{resource\ use, minerals\ and\ metals} = Economic\ value\ \left[\frac{€_{2019}}{kg\ Fe\ eq}\right] / \ Characterization\ factor\ \left[\frac{kg\ Sb\ eq.}{kg\ Fe}\right]$$

Regarding the characterisation factor, the value of 5.24E-08 kg Sb eq./kg Fe was derived by Van Oers et al. (2002) and refers to the ultimate reserve (non-country-specific EF CF for emissions of kg Sb eq. due to resource depletion). The "ultimate reserve" takes into account the resources in the earth's crust. On the other hand, the "reserve base" takes into account the resources that have a reasonable chance of becoming economically and technically available, while the "reserve" takes into account the part of the reserve base which could be economically extracted or produced at the time of determination.

In the end, the value selected is the one reported by Directorate-General for Energy (European Commission) et al. (2020).

- Resource use, fossils

According to OVAM (OVAM, 2017), the low value and the central value are null. This reflects the point of view that resource depletion costs are internalised in market prices. In addition, OVAM already in 2014 uses a valuation of greenhouse gas emissions based on prevention costs, which assumes that we limit emissions of greenhouse gases to limit global warming to a maximum of 2 °C, in line with the UN objective. This emission path limits the use of fossil fuels, irrespective of their availability.

The high value is based on the Eco-indicator 99 method and costs of military action to secure energy supply.

Table A.8. Monetary indicator for abiotic depletion of fossil resources

Depletion of fossil resources		Value €/MJ, net caloric value		
Indicator	Region	Central	Low	High
Full life-cycle	Western Europe	0	0	0.0065
	Flanders/Belgium	0	0	0.0065
	Rest of world	0	0	0.0065

Source: OVAM (2017)

The factors proposed by Directorate-General for Energy (European Commission) et al. (2020) are based on two LCIA methods from 2002, namely CML 2002 (Guinée et al., 2002) and Van Oers et al. (2002). The high value is based on OVAM (2017).

— Low: €0/MJ;

— Central: €0.0013/MJ;

— High: €0.0068/MJ.

One of the limitations of the approach for the central value is that the valuation of scarcity is based on the scarcity of oil, with values then adjusted relative to energy content for the other fuels. This therefore does not account for differing reserves for different energy carriers, which in reality would see lower scarcity values for coal and uranium as these energy carriers are much more abundant than oil. The central value therefore likely overestimates the external costs of this impact for the coal, lignite and nuclear technologies.

Annex 7. Non-quantifiable social aspects

The relevance of non-quantifiable aspects cannot be overstated. Despite their crucial role in the holistic evaluation of a product's sustainability, the measurement of these aspects can be challenging, especially regarding social, ethical and cultural impacts.

The integration of non-quantifiable factors in the analysis of products' life-cycle sustainability has been a subject of interest in the scientific community in recent years. Several literature references provide methods and guidelines to achieve this integration, in view of providing a more comprehensive understanding of the broader implications on products, communities and ecosystems (e.g. the 'Reference Scale Assessment' approach (UNEP, 2020); the 'Impact Pathway Assessment' approach (UNEP, 2020); the 'Product Social Impact Assessment' (Goedkoop, et al., 2020); Integrating reporting framework (IRFS Foundation, 2021)). This ensures that assessments are not solely driven by numerical data, but also by the well-being of affected citizens/stakeholders, which may not be easily quantified.

A recent attempt to map available knowledge on the topic of LCSA[79] and to enhance its methodologies and tools has been undertaken within the ORIENTING project (ORIENTING, 2021), funded by the European Union's Horizon 2020[80]. This study was carefully analysed in the context of the present report, as it not only provides a summary of literature information about sustainability assessment and non-quantifiable aspects integration, but also aims at creating guidelines and best practices for practitioners in LCSA implementation. The information retrieved from the ORIENTING project was processed with a view to unveiling its potential added value for non-quantifiable (social) aspects and for the products' Design Options (DOs) and DOs ranking discussed in the present report.

The ORIENTING project is divided into seven work packages (WP), which cover data collection, model development, integration of the findings and management and communication of the project. In particular, WP1 is structured in six deliverables that describe the concept and specifications of LCSA, while WP2 explains the LCSA methodology. A thorough analysis of the work packages was conducted to identify the most pertinent information for this report. Upon examining the work packages, a few key deliverables were identified. These include WP1 deliverables 1.2 related to the 'Critical evaluation of social approaches' (Harmens and Goedkoop, 2021) and 1.5 related to the 'Critical evaluation of sustainability integration approaches' (Huysveld et al., 2021); as well as WP2 deliverable 2.3 related to the 'Development of a robust methodology for LCSA of products' (Hackenhaar et al., 2021).

According to the ORIENTING project, qualitative aspects describe the attributes or proprieties possessed by a product that can be difficult to interpret and assess in quantitative terms due to their intrinsic complexity, despite their potential influence on the overall sustainability of a product design. As social aspects are recognised as the main driver of non-quantifiable aspects, a thorough assessment of their relevance is performed in the ORIENTING project. In fact, social aspects are often difficult to quantify because they are largely based on behavioural elements, such as how companies behave towards their employees or stakeholders. These behavioural elements can be challenging to express in numerical terms. For instance, it is not straightforward to assign a numerical value to concepts like respect for human rights, fair working conditions, or cultural heritage. Behavioural aspects could be potentially evaluated via different approaches, depending on the type of result that is required. Quantifying social impacts in Social Life-cycle Assessment (sLCA) could be challenging, due to the need to establish a connection between the behaviour of companies in the supply chain and the product to which social impacts should be related

[79] LCSA is a life-cycle-based assessment of products that considers all sustainability domains. In the framework of the ORIENTING project, LCSA covers relevant life-cycle impacts and benefits related to all assessed sustainability domains (environmental, economic and social) including circularity and criticality of materials.

[80] European Union's Horizon 2020.

(ORIENTING, 2021). In addition, the aggregation of various social impacts could be challenging because they do not affect all stakeholders in the same way. For example, positive or negative impacts might be experienced by different stakeholders when evaluating the same product, depending on the assessment specific perspective (e.g. an increase in production capacity for a given company could generate revenue and improve employees' salaries, although such an increase could potentially also lead to additional resource depletion and potential pressures on local communities), similarly to LCC. Consequently, such aggregations are either neglected (e.g. to avoid the justification of negative practices such as child labour with an additional added value generated elsewhere) or assessed typically via 'normalisation' and 'weighting' (like the ones suggested as optional steps in ISO 14044 (ISO, 2006) and further better formalised and standardised in other methods and approaches such as the PEF[81]).

Upon conducting a comprehensive and varied examination of literature studies within the sLCA field, the retrieved sources were categorised by the ORIENTING project into the following groups:

- **The UNEP (United Nations Environment Programme) Guidelines** (UNEP, 2020), detailing two main families of impact assessment methods, namely, the (i) 'Reference Scale Assessment' method - formerly 'RS S-LCIA' methods - and the (ii) 'Impact Pathway Assessment' method - formerly 'IP S-LCIA' methods.
    - The RS S-LCIA[82] methods assess the social performance or risk of products and organisations and its performance indicators are typically either qualitative or semi-qualitative.
    - The IP S-LCIA[83] methods characterise the cause-effect chain of a product or service. The impacts are quantified in terms of QALY[84] or DALY[85] indicators. This impact assessment family is predominantly quantitative and therefore necessitates quantified life-cycle data as input.
- **Several literature papers** related to and further developing the two main impact assessment methods families identified by the UNEP Guidelines. Among these papers, recent comprehensive literature reviews were selected and prioritised for further examination.
- **Industry initiatives** focused on social metrics, offering practical strategies related to the assessment of social impacts (e.g. Handbook of Product Social Impact Assessment, PSIA - (Goedkoop, et al., 2020)).
- **Other relevant social assessment approaches** available from literature which are not part of one of the above identified groups (e.g. the Life-cycle Working Environment (LCWE) method, developed by Ko et al., 2018), the Social Footprint approach, developed by Weidema (2018)).

The various sources collected for the above-mentioned four groups, were screened by the ORIENTING team according to a dedicated set of criteria[86]. Based on his procedure, three main

[81] Commission Recommendation (EU) 2021/2279 of 15 December 2021

[82] 'Reference Scale Assessment' method. Additional details are provided in Section 5.2.1 of the UNEP Guidelines (UNEP, 2020).

[83] 'Impact Pathway Assessment' method. Additional details are provided in Section 5.2.4 of the UNEP Guidelines (UNEP, 2020).

[84] 'Quality Adjusted Life Years' (QALY) is an indicator used to estimate years of healthy life (UNEP, 2020).

[85] 'Disability Adjusted Life Years' (DALY) is an indicator used to estimate the years of life lost/disabled (UNEP, 2020).

[86] Such as credibility, transparency, scientific robustness.

potentially useful approaches to assess qualitative social aspects were identified (classifiable as 'scale approaches'[87]):

- The 'Literature Reference Scale Assessment' approach, as described by a group of similar literature papers selected considering recent studies providing further elaboration/development compared to the UNEP Guidelines for the 'Reference Scale Assessment'. Such papers were mapped and evaluated collectively (especially via key literature reviews provided by Russo Garrido et al. (2018) and Ramos Huarachi et al. (2020).
    - The selected papers focus on methods aimed at assessing the impacts related to products, technologies or processes. These methods are mainly semi-quantitative, despite including quantitative elements in certain cases (such as the 'hours worked' by employees).
- The approach described in the 'Handbook for Product Social Impact Assessment' (Goedkoop, et al., 2020).
- The 'UNEP Guidelines for sLCA Reference Scale Assessment' (UNEP, 2020), as indicated in the Guidelines for Social Life-cycle Assessment of Products and Organizations (UNEP, 2020) without further elaborations.

Among the above-mentioned approaches, the Product Social Impact Assessment - PSIA Handbook (Goedkoop, et al., 2020) is identified as the most suitable for including social life-cycle assessment in a LCSA context, due to its high score regarding the 'RACER (Relevance, Accessibility, Clarity, Easiness, Robustness) methodology'[88] (Lutter and Giljum, 2008).

The social aspects assessed in the PSIA approach are divided into stakeholder groups, as reported in **Figure A.3**, enabling a more accurate and relevant evaluation of social impacts. This division grants an alignment with the stakeholder engagement[89], which highlights the importance of addressing the interests and concerns of different stakeholder groups.

Figure A.3. Social aspects identified in the PSIA method, divided by stakeholder group

Social topics for workers	Social topics for local communities
1.1 Occupational health and safety 1.2 Remuneration 1.3 Child labour 1.4 Forced labour 1.5 Discrimination 1.6 Freedom of association and collective bargaining 1.7 Work-life balance	3.1 Health and safety 3.2 Access to material and immaterial resources 3.3 Community engagement 3.4 Skill development 3.5 Contribution to economic development
Social topics for users	**Social topics for small-scale entrepreneurs**
2.1 Health and safety 2.2 Responsible communication 2.3 Privacy 2.4 Affordability 2.5 Accessability 2.6 Effectiveness and comfort	4.1 Meeting basic needs 4.2 Access to services and inputs 4.3 Women's empowerment 4.4 Child labour 4.5 Health and safety 4.6 Land rights 4.7 Fair trading relationships

Source: PSIA Handbook (Goedkoop, et al., 2020).

[87] 'Scale approaches' are intended as methods used in sLCA to evaluate social performances or social risks in the life-cycle of a product or service. In a 'scale approach', indicators are often qualitative or semi-quantitative.

[88] A set of criteria (such as credibility, transparency, scientific robustness) are employed to evaluate the relevant social assessment method.

[89] The 'stakeholder engagement' refers to the commitment to include, directly or indirectly, all relevant parties affected by a decision or action.

Specific thresholds are then established to classify the relative importance of the PSIA social aspects. These thresholds are derived via expert judgement, assessing the importance of each social aspect compared to the interests of the intended audience/stakeholders (engaged indirectly or directly with the assessed product or service). Aspects classified above a certain threshold are considered relevant and should be prioritised in a PSIA study.

The most important social aspects identified according to the above-mentioned analysis are then further examined. This examination leverages performance indicators[90] provided within the PSIA methodology for each social aspect. Practitioners can collect case-specific values of these performance indicators from various available sources[91]. The case-specific collected data are then assessed via a five-point scale[92] and compared to the 'reference scale' to determine the social performance level for each social aspect (**Figure A.4**).

Figure A.4. Definitions of each 'reference scale' to assess the social performance of products and services

+2	best in class, continuous improvement
+1	beyond generally acceptable situation, continuous improvement
0	generally acceptable situation,
-1	unacceptable situation but improving
-2	unacceptable situation, no improvement

Note: The PSIA methodology also suggests underpinning sources/documents for better context and details on each point of the scale.

Source: PSIA Handbook (Goedkoop, et al., 2020).

Table A.9 presents an overview of the product aspects for the definition of design options (illustrated in Section 2.2) and their potentially associated social aspects (engaged indirectly or directly according to the list provided by the PSIA method). The table lists the most relevant social aspects that could potentially directly/indirectly relate to 'categories of product aspects'. 'Categories of products aspects' were established by grouping 'Ecodesign product aspects'[93] as described in Article 5 of the ESPR, and associated with examples of DOs. The mapped social aspects proposed in Table A.9 are not intended as product-specific examples, but rather to be applicable/generalised to many different products. It is also worth mentioning that the associations proposed in Table A.9 are

[90] Performance indicators estimate the potential social impacts associated with organisations in a product system. Performance indicators could include for instance: an indicator on the implementation of the health and safety standards or local laws, and indicator related to the number of accidents or incidents, and indicator covering the percentage of workers who have received health and safety training, etc.

[91] Such as company documents (e.g. audits and surveys), industry benchmarks (e.g. data from industry associations, research reports, consulting firms), stakeholders' inputs (e.g. engaging with employees), external standards and certification or government requirements.

[92] Each position on the scale representing a performance reference point assigned a score ranging from -2 to +2. A score of -2 indicates unacceptable performance, while +2 indicates ideal performance.

[93] In particular, 'Second life' includes durability, reliability, reusability, upgradability, reparability, possibility of maintenance and refurbishment; 'Resource use and efficiency' includes energy use or energy efficiency, recycled content and resource use or resource efficiency; 'End of life management' includes possibility of remanufacturing and recycling, possibility of recovery of materials and expected generation of waste materials; 'Emission and pollution' includes environmental impacts, including carbon and environmental footprint; and 'Information and communication' includes presence of substances of concern.

based on expert judgment/dedicated assumptions and serve the sole purpose of visualising potential links between DOs and social aspects. For example, the DO related to ‘increased use of post-consumer recycled plastics’ (under the category of product aspect ‘End of life management and second life’) could be examined from the user perspective of the ‘health and safety’ social aspect, which focuses on the well-being of consumers.

Table A.9. Example of mapping of potentially relevant direct/indirect social aspects according to ‘categories of product aspects’ for the Design Options (DOs)

Category of product aspects	**Examples of related DOs**	**Mapped social aspects by stakeholder group**			
		Workers	**Users**	**Local communities**	**Small-scale entrepreneurs**
Second life	Extended lifetime	Remuneration (indirectly)	Responsible communication (directly)	Contribution to economic development (directly)	Meeting basic needs (indirectly)
Resource use and efficiency	Reduced energy consumption	Child labour, forced labour, discrimination (indirectly)	Affordability (directly) Accessibility (directly)	Access to material and immaterial resources (directly)	Meeting basic needs (indirectly) Access to services and input (indirectly)
End of life management	Increased use of post-consumer recycled plastic	Occupational health and safety (directly)	Health and safety (directly)	Health and safety (directly)	Health and safety (directly)
Emission and pollution	Reduction fluorinated gas emissions	Occupational health and safety (directly)	Health and safety (directly)	Health and safety (directly) Community engagement (indirectly)	Access to services and input (indirectly)
Information and communication	Battery endurance	Occupational health and safety (directly)	Responsible communication (directly)	Health and safety (directly)	Fair trading relationships (indirectly)

Note: Categories of products aspects were established by grouping ‘Ecodesign product aspects’ as described in Article 5 of the Ecodesign for Sustainable Products Regulation.

Source: own assumptions.

As previously mentioned, the qualitative aspects are primary related to social issues. With that in mind, from a sustainability perspective, social themes are an important aspect to include in the evaluation of the DOs. Therefore, qualitative aspects could influence the evaluation of the DOs, yielding a more comprehensive and accurate ranking.

An example could be a DO related to an extended lifetime (for example a pair of shoes that lasts longer). In the context of the user, an extended lifetime could mean less wear and tear, and thus less frequent need for repairs (e.g. change of soles or heels). If consumers typically bring in their shoes for repairs every year, and suddenly they last longer without needing such services, the shoe repairers could see a decline in their orders for repair and this could directly impact their remuneration, as they get paid per job. However, it is worth noting that these are potential scenarios and the actual impact on a shoe repairer's remuneration would depend on various factors, including their specific customer base and the range of services they offer. Therefore, even if the primary aim of such a DO is to extend lifetime and minimise the environmental impact, non-quantifiable aspects could influence the sustainability. For example, regarding the social equity aspect, this could lead to remuneration/job losses that have to be considered properly to avoid the development of social inequality. This explains how qualitative factors can significantly impact the sustainability assessment and then influence the ranking of DOs.

Incorporating non quantifiable social aspects into decision-making processes could be essential to a complete evaluation of the social impact assessment of a product. The ORIENTING project recommends the use of the PSIA method (as it provides specific reference scale indicators), although the UNEP Guidelines for Reference Scale Assessment should not be neglected (due to their completeness regarding definitions and theoretical assumptions). However, attention must be devoted to the results' aggregation as well, because this could lead to their misinterpretation and loss of valuable contextual information. Future research in this field should also focus on the harmonisation of terminologies to avoid confusion and help practitioners (e.g. stakeholder category/ stakeholder group).

Nowadays, integrating non-quantifiable social aspects over the entire life-cycle assessment of a product remains a challenge. To address this and integrate non-quantifiable social aspects more effectively, practitioners are encouraged to explore Multiple-Criteria Decision Analysis (MCDA[94]) methods[95]. These methods can support the integration of social impacts (maintaining a clear distinction between negative and positive aspects) with environmental and economic impacts (Cinelli, 2023).

In terms of consistency and practicality, employing the PSIA methodology in product social metrics assessments may yield uncertain results due to data limitations and challenges. Although the PSIA method can be applied to assess a specific product because data on the associated processes of the specific supply chain can be collected, it is not the same for a representative product (RP). RPs are used to represent the average products placed on the EU market and this poses several limitations. The primary issue could be that they are not realistic products but a fictitious weighted average of the products consumed (i.e. produced and imported, excluding the exports), making it difficult to gather accurate data and conduct a precise assessment. Furthermore, average products often involve a broader array of countries and suppliers, which complicates the assessment of criteria affected by country-specific conditions and regulations. For instance, issues like child and forced labour (aspects in social topics for workers) are regulated within the EU, but the same cannot be said for other countries in Africa or Asia. So, for a product such as a T-shirt manufactured and sold in the EU, child and forced labour should not be an issue but the equivalent RP may have to deal with this issue because of the imports from non-EU countries. Moreover, average products involve a broad range of users, influenced by different cultural factors, which could have an impact on the way the product is used or disposed. Finally, the application of a 'five-point scale' may oversimplify the complexities of real-life situations. Despite these limitations, the PSIA method could help to identify the relevant social aspects of alternative DOs by offering a multi-criteria

[94] Multi-Criteria Decision Analysis (MCDA) methods. MCDA methods employ evaluation criteria, elicited via stakeholders' preferences, to construct a model able to assess alternatives.

[95] SOCRATES tool (the EU commission's tool for MCDA) can be used. In enables to integrate qualitative and quantitative variables, and making a ranking out of it. https://web.jrc.ec.europa.eu/socrates/screen/home

framework to qualitatively evaluate the social performance. This could allow for a wider and comprehensive understanding of the non-quantifiable aspects and their impact on overall sustainability. The sLCA scales are for information only and at present cannot affect the ranking.

In conclusion, the findings of this section could assist policy makers and practitioners in unveiling and mapping non-quantifiable aspects in a product life-cycle. Furthermore, a proper understanding of social impacts could represent a key added value for the ranking of DOs of products in the future. Future development should focus on reinforcing the knowledge base on social impacts in products' life-cycles and in providing operational guidelines for a smooth integration in current life-cycle analysis of products. Such improvement could represent the foundation for future research aimed at accurately reflecting the multitude and interactions of impacts related to 'real-world' products' value chains.

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