The Integration of the PEF Method in the Ecodesign Directive

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THE INTEGRATION OF THE PEF METHOD IN THE ECODESIGN DIRECTIVE

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PREFACE

The following report presents the main findings of the research project: *How the PEF method can be integrated into the Ecodesign Directive*. The project was conducted from October 2020 until December 2021 and was financed by the Danish Environmental Protection Agency. The content of this publication reflects the position of the authors and does not necessarily represent the official views of the Danish Environmental Protection Agency.

The authors would like to thank all interviewees for their valuable insights. Please note that the conclusions reflect the position of the authors and not necessarily the views of the interviewees.

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ABSTRACT

The Ecodesign Directive is assigned a prominent role in the sustainable product policy framework as a policy instrument prompting sustainable product design. Consequently, the Ecodesign Directive is under revision as within the upcoming Sustainable Products Initiative (SPI), to expand its scope and ensure that is delivers on circular design.

Concurrently, the Product Environmental Footprint (PEF) method finalised its pilot phase and entered the transition phase. In the transition phase its policy application is to be specified. The PEF method is a standardised lifecycle assessment (LCA) method, which should improve the comparability of LCAs by decreasing the flexibility in the methodological choices. Beside the PEF method, product specific category rules called (PEFCR) are developed for several product groups. The Ecodesign Directive also takes a lifecycle perspective and uses a simplified LCA method. Consequently, the PEF method could potentially play a role in the Ecodesign Directive. Therefore, the purpose of this study is to examine:

- Which aspects of the Product Environmental Footprint (PEF) can be expected to be implemented into the MEErP methodology in the future e.g., short, medium, and long term and how can this support material efficiency aspects?

The study is conducted based on a literature review and expert interviews. Furthermore, two case studies were conducted of the PEFCRs and preparatory studies for batteries and photovoltaic modules, inverters, and systems along with the Regulation concerning Batteries and Waste Batteries.

The study showed that on the short-term, elements from the PEF method will be implemented into MEErP, specifically in the EcoReport Tool, as part of the ongoing MEErP revision. The elements are the impact categories, a simplified version of the Circular Footprint Formular (CFF) and the Environmental Footprint (EF) datasets. However, the current MEErP revision will in principle not further align the ecodesign preparatory studies and the PEFCR.

In the medium term, the PEF method and PEFCRs can be used as the methodological basis for the information requirements on the GER and GWP product declaration for PV modules, inverters, and systems and carbon footprint in the Battery Regulation. On the longer term, these information requirements could extend to performances classes and threshold requirements. Furthermore, the impact categories may be expanded from energy and CO2 emissions to also cover resources and water consumption. Finally, other product groups may also be coved by information, threshold and performance class requirements to the environmental footprint or ecological profile of the product. Thus, it will be based on a specific evaluation of the product or product group in question.

There are some limitations to the use of the PEF method in MEErP and its use as a methodological basis for a more systematic inclusion of environmental footprint or ecological profile in the design option. These are:

- Limited overlap between the product groups covered by PEFCRs and the Ecodesign Directive
- No guideline on how to use the impact categories from the PEF method in the ecodesign process

- Potentially high cost associated with conducting LCA studies
- Intellectual property rights of the EF datasets
- The PEF method and PEFCRs are not developed for this specific policy application.

The introduction of the simplified CFF and the recycling data into the EcoReport Tool will improve its ability to model recycling and the potential offsetting for recycling. Furthermore, the introduction of the PEF impact categories on “resource use” could also strengthen the focus on material efficiency aspects in the EcoReport Tool and MEErP. However, the introduction of elements from the PEF methods will not directly support other circular economy aspects, such as repairability, durability and upgradability. The current MEErP revision will introduce a new method to calculate and model durability including also upgrade and repair options. However, this method stems from the 4555x series of standards, and the repair index report developed by Joint Research Centre.

DANSK RESUME

Ecodesign Direktivet er betroet en prominent rolle i EU's bæredygtige produktpolitik som et redskab der kan fremme bæredygtigt produktdesign. Derfor er direktivet p.t. under revision, for at udvide anvendelsesområdet og sikre at det kan levere på cirkulært design. Direktivet vil blive revideret som en del af initiativet vedrørende bæredygtige produkter (Sustainable Products Initiative (SPI)).

Sideløbende med revisionen af Ecodesign Direktivet er pilotfasen for metodeudviklingen for produkters miljømæssige fodaftryk (PEF) afsluttet og nu undersøges anvendelsesmulighederne for PEF i en reguleringsmæssig kontekst. PEF-metoden er en standardiseret livscyklusvurderingsmetode (LCA), som har til hensigt at forbedre sammenligningsgrundlaget for LCA'er ved at reducere fleksibiliteten i de metodiske valg i udførelsen af LCA'en. Foruden PEF-metoden, er der udviklet produktspecifikke kategoriregler for forskellige produktgrupper, de såkaldte PEFCR. Ecodesign Direktivet tager også et livscyklusorienteret perspektiv og anvender en simplificeret LCA-metode. Det er således muligt at PEF også kan spille en rolle i Ecodesign Direktivet. Formålet med dette projekt er derfor at undersøge:

- Hvilke aspekter af produkters miljømæssige fodaftryk (PEF) kan forventes at blive implementeret i MEErP metoden i fremtiden, f.eks. på kort, mellem og lang sigt, og hvordan kan dette understøtte materiale effektivitetsaspekter?

Dette undersøges gennem litteraturstudier og ekspertinterviews. Derudover gennemføres casestudier af PEFCR og de forberedende studier for batterier og solcellemoduler, invertere og systemer, samt af Forordningen om batterier og udtjente batterier.

Undersøgelserne viste at på kort sigt, og som en del af den igangværende revision af MEErP, vil elementer fra PEF-metoden blive implementeret i MEErP, helt konkret i EcoReport Tool. Disse elementer er belastningskategorierne, en simplificeret udgave af Circular Footprint Formular (CFF), og PEF datasættene. Dog vil den igangværende MEErP revision ikke yderligere samstemme de forberedende studier til Ecodesign Direktivet og PEFCR'erne.

På mellemlang sigt kan PEF-metoden og PEFCR'erne bruges som det metodiske grundlag til at sætte informationskrav til GER og GWP i miljøvaredeklarationer for solcellemoduler, invertere og systemer, samt til klimaaftrykket (carbon footprint) i Batteriforordningen. På længere sigt kan disse informationskrav udvides til virkningsgrad-klassificering og grænseværdikrav. Derudover kan belastningskategorierne blive udvidet fra energi og CO2 emissioner til også at inkludere ressourcer og vandforbrug. Slutteligt kan yderligere produktgrupper også blive omfattet af informationskrav, grænseværdikrav og virkningsgrad-klassificering i forhold til det miljømæssige fodaftryk eller produktets miljømæssige profil. Det vil derfor være baseret på en specifik evaluering af det pågældende produkt eller produktgruppe.

Der er dog begrænsninger i brugen af PEF-metoden i MEErP i brugen af PEF-metoden som metodisk grundlag for en mere systematisk inklusion af det miljømæssige fodaftryk eller produktets miljømæssige profil i designløsningerne. Disse er:

- Begrænset overlap mellem produktgrupper omfattet af PEFCR og Ecodesign Direktivet
- Ingen vejledning til hvordan belastningskategorierne fra PEF-metoden bør benyttes i ecodesignprocessen

- Potentielt høje omkostninger tilknyttet udarbejdelsen af LCA-studier
- Immaterielle rettigheder knyttet til EF datasættene
- PEF-metoden og PEFCR er ikke udviklet med henblik på denne specifikke anvendelse

Lanceringen af det simplificerede CFF og genanvendelsesdata i EcoReport Tool vil forbedre værktøjets muligheder for at modellere genanvendelse og den potentielle offsetting i forhold til genanvendelse. Derudover kunne introduktionen af PEF belastningskategorierne vedrørende ressourceforbrug styrke fokusset på materialeeffektivitetsaspekter i EcoReport Tool og MEErP. Dog vil introduktionen af elementer fra PEF-metoden ikke understøtte andre cirkulærøkonomiske aspekter som reparationsevne, holdbarhed og opgraderbarhed direkte. Den igangværende MEErP revision lancerer en ny metode til at beregne og modellere holdbarhed, herunder også opgraderings- og reparationsmuligheder. Denne metode stammer dog fra 4555x-standardserien og reparationsindeksrapporten fra Joint Research Centre.

ABBREVIATIONS

BAT:	Best Available Technology
BoM:	Bill of Material
CFF:	Circular Footprint Formular
EF:	Environmental Footprint
EV:	Electrical Vehicle
GER:	Gross Energy Requirements
GPP:	Green Public Procurement
GWP:	Global Warming Potential
LCA:	Life Cycle Assessment
LCI:	Life Cycle Inventory
LLCC:	Least Life Cycle Costs
MEErP:	Methodology for ecodesign of energy-related Products
OEF:	Organisational Environmental Footprint
SPI:	Sustainable Products Initiative
PEF:	Product Environmental Footprint
PEFCR:	Product Environmental Footprint Category Rules

1 INTRODUCTION AND OBJECTIVES

In the sustainable product policy framework, described in the European Circular Economy Action Plan from 2020, the Ecodesign Directive is assigned an important role in designing more sustainable products and delivering on sustainability (European Commission 2020b). By end of March 2022, the new the Sustainable Products Initiative will be published, also affecting the Ecodesign Directive. Furthermore, it is the intention that the Ecodesign Directive in the future should cover the broadest possible range of products (European Commission 2020b). As a starting point, priority has been given to product groups such as electronics, ICT, textiles, furniture, and high impact intermediary products (European Commission 2020b). Until the revised Ecodesign Directive steps into force, there will be a transitional period covered by the Ecodesign working plan 2020-2024. This research project primarily takes outset in the Ecodesign Directive and the transitional period.

PEF was initiated in 2008 and up until now focus has been to develop and test the methods. However, with the finalisation of the pilot phase in 2018 and transition phase in 2021, the tool has entered a new phase, where its policy role is to be defined. One of the ideas for the PEFs role in the product policy mix is described in Figure 1. Where, PEF can work as a tool to identify benchmarks or average performance on the market. As part of the sustainable product policy framework, the Commission also wants to empower consumers an¬¬¬¬d public buyers by ensuring that they have trustworthy and relevant information on products at the point of sale (European Commission 2020b). Here, the Commission wants the Product and Organisation Environmental Footprint methods to play a role in ensuring trustworthy and relevant information (European Commission 2020b). More specifically, the integration of the PEF will be tested in relation to the EU Ecolabel and to substantiate environmental claims (European Commission 2020b).

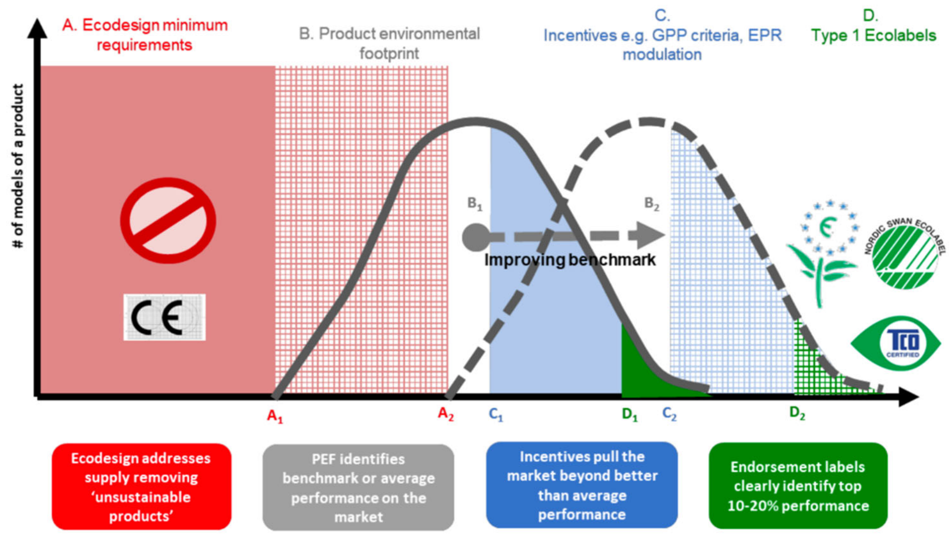

Figure 1: Illustration of the envisioned synergies between in the Sustainable Product Initiatives (EEB 2020: 6)

Like PEF, the Ecodesign Directive takes a life cycle approach and includes life cycle assessment methods in its preparatory study. Therefore, there is a specific potential to further integrate the PEF methodology in the Ecodesign Directive especially in relation the Methodology for ecodesign of energy-related products (MEErP) and the EcoReport Tool. The MEErP methodology is also currently under revision and one of the aspects examined is how PEF can be integrated into MEErP and more specifically the EcoReport Tool. This research project therefore examines:

- Which aspects of the Product Environmental Footprint (PEF) can be expected to be implemented into the MEErP methodology in the future e.g., short, medium, and long term and how can this support material efficiency aspects?

Sub-questions:

- Considerations regarding definition of the base case – is there information in the PEF which can be used directly to define the base case?
- Which alteration to the EcoReport Tool can be expected?

2 METHODOLOGY

This research project was conducted as a desktop study including literature reviews and several expert interviews. The details of the applied methods are elaborated in the following.

2.1 LITERATURE REVIEW

To introduce the PEF methodology (Chapter 3), an overall review of the process of developing the PEF method and the appertaining documents was carried out. This review primarily included official documents and webpages from the European Commission as well as peer reviewed articles on the challenges related to PEF method.

In Chapter 4, we introduce the Ecodesign Directive, the MEErP and the EcoReport Tool. The primary literature reviewed are official European Commission documents, the reports on the update of the MEErP and the EcoReport Tool, and an in-depth review is conducted on two reports analysing improvement potentials of the EcoReport Tool concerning including aspects of circular economy and Implementing elements from the PEF Method.

To analyse the overlap between the product scope in the ecodesign regulations and the Product Environmental Footprint Category Rules (PEFCRs) in Chapter 5, a detailed literature review is conducted on the PEFCRs developed in the pilot and transition phase, the Ecodesign Directive, working plans and preparatory studies of the Ecodesign Directive, and finally the Sustainable Products Initiative concerning the possible expansion of the scope of the Ecodesign Directive. Based on this analysis, two product groups were identified as overlapping in scope. Hence, a case study of the batteries and photovoltaic panels was conducted (Chapter 6). Furthermore, two previous Danish studies were reviewed looking into the role of PEF in MEErP and the EcoReport Tool (Wesnæs and Hansen 2021; Wesnæs, Hansen, and Gydesen 2019).

2.2 INTERVIEWS

To qualify the literature reviews and especially for the analysis of the opportunities and barriers of applying the PEF method in the Ecodesign Directive and MEErP and the analysis of whether the implementation of PEF elements into MEErP can support material efficiency aspects, interviews with five key experts involved in the current revision of the MEErP was conducted. The details concerning the interviews are listed in Table 1.

Table 1: Overview of interviews conducted for this research project.

Interviewee	**Organisation**	**Date**	**Duration**	**Themes**
Ecodesign representative	DG GROW, circular Economy Team	28 May 2021	60 minutes	Introductory interview discussing the MEErP revision and the potential role of PEF
Three representatives from the MEErP revision team	Joint Research Centre	30 November 2021	60 minutes	Revision of the MEErP Revision of the EcoReport Tool The Role of PEF in the Ecodesign Directive, MEErP and the EcoReport Tool Barriers and opportunities of using PEF as part of MEErP Possible interactions of the MEErP and PEF with other product policies
PEF Representative	DG GROW, policy officer	16 December 2021	60 minutes	Same as above plus: The role of PEF in SPI Circular economy and material efficiency aspects in the PEF method Environmental Footprint (EF) datasets

3 INTRODUCTION TO THE PRODUCT ENVIRONMENTAL FOOTPRINT METHODOLOGY

3.1 THE DEVELOPMENT OF THE ENVIRONMENTAL FOOTPRINT INITIATIVE

The tentative beginning of PEF was in 2008, when the Council invited the European Commission to examine how to introduce carbon footprinting of products in existing legislation such as the Ecolabel and Energy Label (Council of the European Union 2008). Since, the objective of the environmental footprint was specified in the Single Market act as being (European Commission 2010, 16):

Proposal No 10: Before 2012, the Commission will look into the feasibility of an initiative on the Ecological Footprint of Products to address the issue of the environmental impact of products, including carbon emissions. The initiative will explore possibilities for establishing a common European methodology to assess and label them.

In the Council's conclusions on sustainable materials management and sustainable production and consumption, the European Council invited the Commission to (Union 2010, 4):

"develop a common methodology on the quantitative assessment of environmental impacts of products, throughout their life-cycle, in order to support the assessment and labelling of products"

In the Resource Efficiency Roadmap from 2011, the future role of the environmental footprint is further strengthened and explained (European Commission 2011). The roadmap specifies that a common methodological approach should be established enabling the private sector and Member States to assess, display, and benchmark a product, service, or company's environmental performance (European Commission 2011). The methodology should be based on a comprehensive assessment of the environmental impacts covering the entire life cycle of the product (European Commission 2011). The methodology should ensure a better understanding of consumer behaviour and better information on the environmental footprint of products. Thereby, preventing misleading claims and refining the ecolabelling schemes (European Commission 2011).

3.1.1 THE FIRST PEF RECOMMENDATION AND GUIDELINES

From 2011 to 2013, the PEF method was developed in parallel with the Organisation Environmental Footprint (OEF). In 2013, The European Commission published the communication *Building the Single Market for Green Products* (European Commission 2013b) along with the recommendation *on the use of common methods to measure and communicate the life cycle environmental performances of products and organisations* (European Commission 2013a). These two documents further specified the PEF and OEF method. One of the main goals of PEF was to increase the comparability of the PEF result between products within the same product groups (Bach et al. 2018a). This increased comparability would be achieved by reducing the flexibility of the methodological choices taken when conducting the PEF (Bach et al. 2018a). This is also different from the approach in the ISO14040/44 standard, which offers a higher degree of flexibility (Bach et al. 2018a). Besides providing a less flexible LCA approach in the PEF guide, the PEF method provides additional specification in the Product Environmental Footprint Category Rules (PEFCRs) increasing comparability by decreasing flexibility (Bach et al. 2018a).

The recommendations also specified potential fields of application of the PEF and OEF in Annex 1 (Table 2) (European Commission 2013a). As documented in Table 2, the use of the PEF method in connection with the Ecodesign Directive was not included in the first ideas for the potential application of the PEF methods or results (European Commission 2013a). Instead, focus was on voluntary schemes such as ecolabels and environmental claims (European Commission 2013a). Annex 2 of the recommendation contains the PEF guide. The PEF guide provides the technical guidance on how to conduct a PEF study, covering aspects such as the role of the PEFCRs, the goal and scope of the PEF study, resource use and emissions profiles, the impact assessment, interpretation of the results and the reporting of the results (European Commission 2013a).

Table 2: Overview of the potential application of the PEF method and its result (European Commission 2013a: Annex 1)

Potential application of PEF and its results
Optimisation of the processes in the product life cycle
Supporting a design that can minimise the environmental impact of a product in a life cycle perspective
Communication of the environmental performance of the products in a life cycle perspective through voluntary schemes or individual companies
Ensure robustness and completeness of environmental claims
Identification of the significant environmental impact when setting ecolabel criteria
Providing incentive based on life cycle performance

3.1.2 THE PEF PILOT PHASE

In the period from 2013 to 2018, the PEF pilot phase was conducted. The purpose of the pilot phase was to test the PEF method and develop PEFCRs for a selection of product (European Commission 2021b). Furthermore, different verification approaches and communication vehicles should be tested (European Commission 2021b). During this period, 24 product categories were selected for the development of PEFCRs. They were selected based on diversity of the product categories and the availability of secondary life cycle data of a good quality (Bach et al. 2018a). By the end of 2021, 19 of the selected product categories had finalised PEFCRs. The PEFCRs are developed based on the PEFCR guide, which has also been updated several times.

During the pilot phase, several technical aspects concerning the environmental footprint method were updated, such as:

- The application of the materiality principle (to act where it matters) was implemented (European Commission 2021a).
- The representative product was defined corresponding to the environmental footprint profile of the average product on the market (European Commission 2021a).

- Agreement on how to model climate change, electricity, transport, infrastructure and equipment, packaging, end-of-life, and agriculture (European Commission 2021a).
- The introduction of normalisation and weighting (European Commission 2021a).
- A guideline on how biodiversity should be included as additional information (European Commission 2021a).
- Improvement of certain impact assessment methods (European Commission 2021a).
- Characterisation factors based on REACH (European Commission 2021a).
- Development of a guide on Environmental compliant datasets (European Commission 2021a).

3.1.3 THE TRANSITIONAL PHASE

From the completion of the pilot phase and until the possible adoption of policies implementing the PEF method, a transition phase was planned (European Commission 2021c). This phase ran from 2018 until 2021 (European Commission 2021c). The purpose of the transitional phase was to monitor the implementation of the finalised PEFCRs from the pilot phase and to develop new PEFCRs (European Commission 2021c). The new product categories covered are apparel, cut flowers and potted plants, flexible packaging, synthetic turf and marine fish (European Commission 2021c). Furthermore, selected methodological aspects related to the PEF method and the PEFCR guide should be updated during this period (European Commission 2021c). During the transitional phase, the European Commission are of course also exploring how the potential policy implementation of the PEF method could look.

3.1.4 THE SECOND ENVIRONMENTAL FOOTPRINT RECOMMENDATION FROM 2021

In December 2021, the second environmental footprint recommendation was published (European Commission 2021a). The purpose of the update was to integrate the technical developments achieved during the pilot phase (European Commission 2021a). Especially, in relation to the development of the PEFCRs (European Commission 2021a). The recommendation specifies how the PEF and OEF method should be used in member states policies, by companies and other private organisations and the financial community (European Commission 2021a). Furthermore, the communication specifies three specific uses of the Environmental footprint method in EU policies and legislation namely the Taxonomy Regulation, the Sustainable Batteries Initiative, and the Green Consumption Pledge (European Commission 2021a). The second communication also includes four annexes. Annex 1 and annex 2 comprise the updated the PEF an PEFCR guidelines. Whereas annex 3 and 4 comprise the updated OEF and the OEFCRs guidelines.

3.2 CHALLENGES RELATED TO THE PEF METHOD

Several challenges have been highlighted related to the PEF method by the scientific community. This section provides a short overview of a selection of these challenges.

3.2.1 THE GOALS AND POLICY APPLICATION OF PEF

An early critique of the PEF initiative was the missing goals and intended policy implementation (Lehmann, Bach, and Finkbeiner 2016). However, The European Commission kept this question deliberately open and stressed that it could only be specified after the pilot phase was completed (Lehmann, Bach, and Finkbeiner 2016). However, especially for the PEFCRs it is difficult to clearly define specific rules before a specific purpose is established (Lehmann, Bach, and Finkbeiner 2016). It is also different from the current LCA practice, where the scope of an LCA study is determined based on the goal of the study and its application (Lehmann, Bach, and Finkbeiner 2016). These missing goals provide significant risks in terms of the applicability and meaningfulness of the final PEFCRs (Lehmann, Bach, and Finkbeiner 2016). The missing aim and application also make the choice of communication vehicle unclear for the results of the PEFCRs.

With the finalisation of the pilot phase and the publications of amongst other *the Roadmap Towards an EU Product Policy Framework contributing to the Circular Economy* and the second circular economy action plan, the policy purpose of the PEF Initiative has been further defined. The question then remains if all developed PEFCRs are fit for this purpose or revisions are needed in the nearest future.

3.2.2 DEFINITION OF FUNCTIONAL UNIT

A point of critique of the PEFCRs is the definition of the scope and functional unit, as not all functional units defined in the PEFCRs follow the recommendations specified in the PEF guideline (Pedersen and Remmen 2022; Lehmann, Bach, and Finkbeiner 2016; Bach et al. 2018b). The PEF guideline requires that the functional unit should be defined by asking the four following questions: what, how much, how well and how long (Pedersen and Remmen 2022). However, several of the PEFCRs do not include the performance and quality of the products in their functional units (Pedersen and Remmen 2022; Bach et al. 2018b). Hence, they are not answering the two questions “how well” and “how long”. These questions are important, when comparing different products, that performance and quality is covered by the functional unit (Pedersen and Remmen 2022).

3.2.3 DATA REQUIREMENTS

Another potential challenge is the requirements in the PEF guideline to the data quality (Golsteijn et al. 2018). Here, the PEF guidelines requests that all known inputs and outputs from the processes (energy, water, land, products, co-products and waste) is based on company specific data (Pedersen and Remmen 2022). Previously, no cut-off criteria were allowed, which significantly increased the workload for collecting data (Pedersen and Remmen 2022). This has however changed and in the updated PEF guideline a cut-off of 3% or less is allowed (Pedersen and Remmen 2022). Still, a considerable workload is expected for data collection (Pedersen and Remmen 2022). The use of secondary data is allowed for processes outside the control of the company (Pedersen and Remmen 2022).

3.2.4 END-OF-LIFE MODELLING

The end-of-life modelling in the PEF guidelines has also been a point of criticism in the scientific literature throughout the years resulting in different calculations models (Wade et al. 2018; Mengarelli et al. 2016; Lehmann, Bach, and Finkbeiner 2016; Schrijvers, Loubet, and Sonnemann 2016; Allacker et al. 2017; Hohenthal et al. 2019).

The PEF-method from 2013, introduced a standardised method for allocation of burdens and benefits in the end-of-life stage - the so call End-of-Life Recycling formular. The standardised method should help increase comparability of different product systems. However, the End-of-Life formular was criticised for leading to inadequate results and not being in alignment with the waste framework directive as the formular did not consider that materials could be recycled more than once (Lehmann, Bach, and Finkbeiner 2016). Furthermore, the formular favoured incineration over reuse and recycling as reuse and recycling of materials are credited with 50% and incineration is credited with 100% (Lehmann, Bach, and Finkbeiner 2016).

Consequently, the end-of-life formular was replaced within the Circular Footprint Formular (CFF) towards the end of the pilot phase (Bach et al. 2018a). Figure 2 provides an overview of the elements included in the CFF. The CFF defines the rules for allocating the environmental burdens and benefits of recycling (part/product reuse), recycled content, energy recovery and disposal. Furthermore, the CFF takes into consideration the quality degradation associated with recycling. However, as you can see from Figure 2, the term Circular Footprint Formular is a bit misleading as the formular merely covers aspects related to recycling (or part/ product reuse), recycled content, energy recovery and disposal. Hence, aspects such as maintenance, repair, durability, refurbishment, and remanufacturing, traditionally related to circularity, are not directly covered by the formular.

The new formular has solved some of the former problems such as the priority to incineration over recycling and it enables a more realistic modelling of the end-of-life (Pedersen and Remmen 2022). Still, the CFF provides some challenges (Pedersen and Remmen 2022). For instance, the CFF does not take into consideration that some materials are recycled multiple times whereas others are only recycled once (Pedersen and Remmen 2022; Bach et al. 2018b). Hence, the materials get the same credit no matter how many times they are recycled (Pedersen and Remmen 2022; Bach et al. 2018b). Furthermore, the default data provided for the quality of the recycled materials is not accurate enough to truly reflect the differences in the materials' ability to be recycled (Pedersen and Remmen 2022; Bach et al. 2018b). The CFF also only allows to credit 80% of the recycled material to go to the production system, whereas the ISO 14044 allows to credit 100% (Pedersen and Remmen 2022; Bach et al. 2018b).

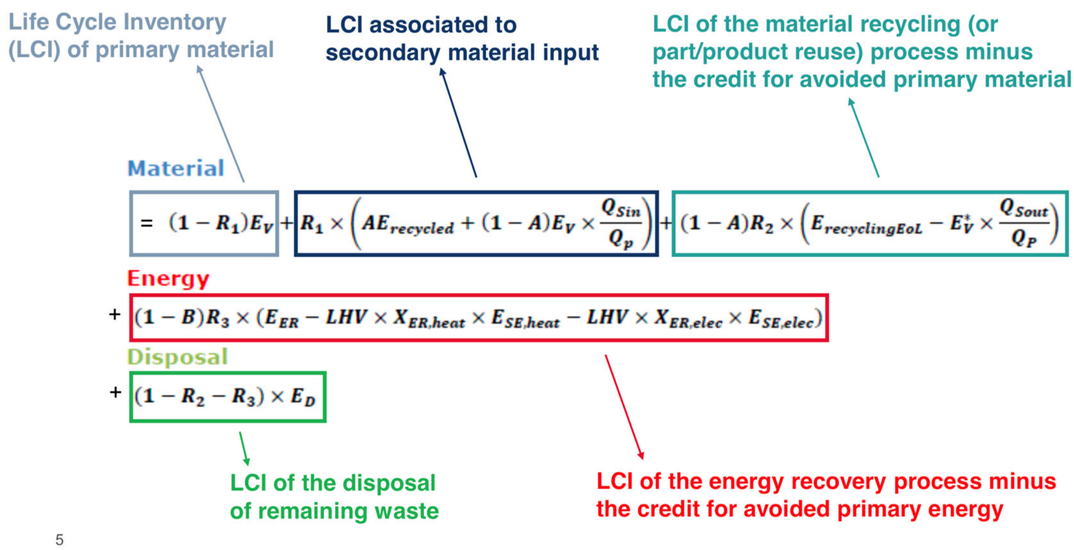

Figure 2: Overview of the elements in the Circular Footprint Formular. The parameters are described in Figure 3. (Wolf et al. 2019: 5)

A: allocation factor of burdens and credits between supplier and user of recycled materials.
B: allocation factor of energy recovery processes: it applies both to burdens and credits.
Q_{sin}: quality of the ingoing secondary material, i.e. the quality of the recycled material at the point of substitution.
Q_{sout}: quality of the outgoing secondary material, i.e. the quality of the recyclable material at the point of substitution.
Q_p: quality of the primary material, i.e. quality of the virgin material.
R_1: it is the proportion of material in the input to the production that has been recycled from a previous system.
R_2: it is the proportion of the material in the product that will be recycled (or reused) in a subsequent R2 shall therefore take into account the inefficiencies in the collection and recycling (or reuse) processes. R2 shall be measured at the output of the recycling plant.
R_3: it is the proportion of the material in the product that is used for energy recovery at EoL.
$E_{recycled}$ (E_{rec}): specific emissions and resources consumed (per functional unit) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process.
$E_{recyclingEoL}$ (E_{recEoL}): specific emissions and resources consumed (per functional unit) arising from the recycling process at EoL, including collection, sorting and transportation process.
E_v: specific emissions and resources consumed (per functional unit) arising from the acquisition and preprocessing of virgin material.
E^*_v: specific emissions and resources consumed (per functional unit) arising from the acquisition and preprocessing of virgin material assumed to be substituted by recyclable materials.
E_{ER}: specific emissions and resources consumed (per functional unit) arising from the energy recovery process (e.g. incineration with energy recovery, landfill with energy recovery, ...).
$E_{SE,heat}$ and $E_{SE,elec}$: specific emissions and resources consumed (per functional unit) that would have arisen from the specific substituted energy source, heat and electricity respectively.
E_D: specific emissions and resources consumed (per functional unit) arising from disposal of waste material at the EoL of the analysed product, without energy recovery.
$X_{ER,heat}$ and $X_{ER,elec}$: the efficiency of the energy recovery process for both heat and electricity.
LHV: Lower Heating Value of the material in the product that is used for energy recovery.

Figure 3: The parameters describing the calculations in Figure 2. (European Commission 2018c, 113)

3.2.5 THE IMPACT ASSESSMENT

The PEF Guideline specifies a set of impact assessment methods which should be used. In total, 16 impact categories are now included in the most recent PEF method, covering (European Commission 2021a):

- Climate change, ozone depletion, human toxicity (cancer), human toxicity (non-cancer), particulate matter, ionising radiation (human health), photochemical formation (human health), acidification, eutrophication (terrestrial), eutrophication (freshwater), eutrophication (marine), ecotoxicity (freshwater), land use, water use, resource use (minerals and metals) and resource use (fossils).

Providing requirements to the specific impact assessment methods to apply for the PEF studies will increase the consistency across different PEF studies. However, a critique in the scientific publications is that the impact assessment methods have been selected without proper consideration for their maturity level embedding (Finkbeiner 2013a) a uncertainty in the result for some impact categories (Six et al. 2017). Thus, the impact assessment method's maturity levels are considered in the weighting system and are also under update.

3.2.6 NORMALISATION AND WEIGHTING

Normalisation is a means to ease the comparison of the result by dividing the result into something that is relatable, which is called a normalisation factor (Kørnøv et al. 2007). In the PEF method, normalisation is mandatory, and global impact per person is used as the normalisation factor (European Commission 2021a). The normalisation method provides some challenges, and it has been suggested that the method is not sufficiently mature (Pedersen and Remmen 2022; Ojala et al. 2016). One of the challenges is that the results are normalised to the global impact per person (Pedersen and Remmen 2022). Hence, if the local emissions are relatively low compared to the global emission; the impact is less relevant after normalisation (Pedersen and Remmen 2022; Bach et al. 2018b). This implies that the specific emission of a product system is considered more relevant when the overall emissions in the reference region is low and less important in a region where the background emissions are already high (Bach et al. 2018b). The challenge is that it is not necessarily always true (Pedersen and Remmen 2022; Bach et al. 2018b).

Weighting is an evaluation of the relative importance or seriousness of each impact category (Kørnøv et al. 2007, 231). During this step, the normalised results are multiplied with a set of weighting factors making it possible to aggregate the results of the impact categories into one single score (European Commission 2021a). These weighting factors reflect the relative importance of the impact categories considered in the PEF method (European Commission 2021a) and the robustness of the indicators. An overview of the weighting factors is provided in Table 3. Weighting is also a mandatory step in a PEF study (European Commission 2021a). However, in the ISO 14044, both normalisation and weighting are optional. The idea of the weighting is that it should support the interpretation and the communication of the results (European Commission 2021a). However, the weighting steps also give rise to several challenges. Previously, weighting has been considered more a political issue than a scientific issue (though it also covers scientific aspects such as robustness), and consequently, it should not be part of a scientific assessment method (Pedersen and Remmen 2022; Bach et al. 2018b). Furthermore, there is a risk that weighting could result in burden shifting, as focus will be on those impact categories with the highest weighting factor at the expense of the others (Pedersen and Remmen 2022; Lehmann, Bach, and Finkbeiner 2016). Finally, there is also an implicit weighting of the impact categories, as some impact categories are represented with more than one indicator like for instance eutrophication, which is represented by three indicators (Pedersen and Remmen 2022; Bach et al. 2018b), thus this is also considered in the weighting factors.

Table 3: Overview of weighting factors from the PEF method (Sala, Cerutti, and Pant 2018, 5)

Impact category	**Weighting factors (incl.) robustness**
	Scale to 100
Climate change	21.06
Ozone depletion	6.31
Human toxicity, cancer effects	2.13
Human toxicity, non-cancer effects	1.84
Particulate matter	8.96
Ionizing radiation, human health	5.01
Photochemical ozone formation, human health	4.78
Acidification	6.20
Eutrophication, terrestrial	3.71
Eutrophication, freshwater	2.80
Eutrophication, marine	2.96
Ecotoxicity freshwater	1.92
Land use	7.94
Water use	8.51
Resource use - minerals and metals	7.55
Resource use, fossils	8.32

3.2.7 THE COST OF MAKING A PEF STUDY

Another challenge is the cost associated with conducting a PEF study. Generally, the cost of conducting an LCA can be high (up to 50.000 $ per product) depending on the complexity (Businessenergy.com 2022a). Here, the largest costs are often linked to the data collection and the calculations (Businessenergy.com 2022b). A study has suggested that PEF can reduce the cost associated with an LCA with 30-50% (Galatola and Pant 2014), whereas another study have suggested that the cost will double (Finkbeiner 2013b). Hence, currently there is no consensus in the scientific community on whether or not the PEF method will decrease or increase the cost of LCAs. However, high cost can be especially problematic for SMEs, where the resources for this type of work are limited.

4 INTRODUCTION TO THE ECODESIGN DIRECTIVE AND MEERP

4.1 ECODESIGN DIRECTIVE

The Ecodesign Directive adopted in 2005 sets up a framework for establishing ecodesign requirements for energy-using products. In 2009, the directive was revised, and the scope was expanded to include energy-related products. The aim of the Directive is to ensure the free movement of such products within the internal market (European Commission 2009a), and it contributes to sustainable development by increasing energy efficiency and the level of protection of the environment, while at the same time increasing the security of the energy supply (European Commission 2009a).

The product specific ecodesign requirements are setup in regulations, the so-called implementing measures, or in voluntary agreements. The product groups covered by the implementing measures are laid down in the working plans. Article 15(2) of the Ecodesign Directive 2009/125/EC prescribes the criteria, which the products must fulfil to be eligible to be covered by ecodesign requirements. The criteria are (European Commission 2009a):

a) *the product shall represent a significant volume of sales and trade, indicatively more than 200 000 units a year within the Community according to the most recently available figures;*
b) *the product shall, considering the quantities placed on the market and/or put into service, have a significant environmental impact within the Community, as specified in the Community strategic priorities as set out in Decision No 1600/2002/EC; and*
c) *the product shall present significant potential for improvement in terms of its environmental impact without entailing excessive costs, taking into account in particular:*
    i. *the absence of other relevant Community legislation or failure of market forces to address the issue properly; and*
    ii. *a wide disparity in the environmental performance of products available on the market with equivalent functionality.*

To support the analysis of whether a product group is eligible for ecodesign requirements, an underlying methodology for the Ecodesign of Energy-using Products (MEEuP) was developed. This method was, with the expansion of the scope of the Ecodesign Directive, revised to an underlying methodology for the Ecodesign of Energy-related Products (MEErP). It is based on this methodology that the working plans and later preparatory studies are prepared.

4.2 MEERP AND THE ECOREPORT TOOL

This section will provide a short introduction to the MEErP and the appertaining EcoReport Tool. This is followed by a review of two existing studies examining the role of PEF in relation to MEErP and the Ecodesign Directive. Finally, an overview is provided of the ongoing revision of MEErP covering the tasks finalised by December 2021.

The preparatory studies are typically conducted by a consultant. The ecodesign preparatory studies provide analyses and information on the product group under consideration for ecodesign requirements. The study covers economic, environmental, consumer and technical aspects relevant for the selected product group and consists of seven tasks (for more details see Table 4).

Table 4: Overview of the seven tasks in MEErP

Task 1: Scope	Definitions, standards and legislation test and calculation methods
Task 2: Markets	Volumes, prices, market trends
Task 3 User	Product demand side – consumer behaviour and its link to product design
Task 4 Technologies	Product supply side, (includes both BAT and BNAT) technical analysis of current products on the EU-market
Task 5 Base case	Defines the base case and the LCA and LCC
Task 6 Design options	Identifies design options, their monetary consequences using Life Cycle Cost for the consumer, their environmental costs and benefits and pinpointing the solution with the Least Life Cycle Costs (LLCC) and the Best Available Technology (BAT).
Task 7: Scenarios	Scenarios including policy, scenarios, impacts and sensitivity analysis. Based on the previous six tasks recommendations for ecodesign regulation is made.

To assess the environmental aspects, MEErP has its own LCA tool called the EcoReport Tool. The EcoReport Tool is a simplified excel LCA tool. However, the EcoReport Tool and the data used in the EcoReport Tool are outdated and in need of a revision (Wesnæs, Hansen, and Gydesen 2019). Especially, in relation to the assessment of aspects central to circular economy, such as resource use, recyclability, recycled content, the EcoReport Tool has deficiencies (Wesnæs, Hansen, and Gydesen 2019). Furthermore, the EcoReport Tool has previously been criticised for favouring energy consumption in the use phase, and thereby resulting in a focus on energy efficiency requirements in existing implementing measures (Bundgaard, Mosgaard, and Remmen 2017).

The outcome of the preparatory study is a working paper. The working paper consists of a set of recommendations for the ecodesign requirements, which is sent to the Consultation Forum for discussion.

In 2013, MEErP and the EcoReport Tool were updated (BIO Intelligence Service 2013b; 2013a). The purpose of this update was to improve the tool's ability to include material efficiency aspects (BIO Intelligence Service 2013b; 2013a). The update resulted, amongst other things, in the implementation of a recyclability benefit ratio, data on recycled content, lifetime modelling and a critical raw materials index into the EcoReport Tool (BIO Intelligence Service 2013b; 2013a). Due to data constraints, only data for plastic was included for the recyclability benefit ratio and only data on paper, PVC, PET, and HDPE was included for the recycled content (BIO Intelligence Service 2013b; 2013a). Lifetime was already coved by the EcoReport Tool before the update. However, the update made it possible to calculate per year of use and not only for the whole lifespan (BIO Intelligence Service 2013b; 2013a). Generally, the 2013 update did not make any significant changes to MEErP, and it can be questioned if alterations were enough to fully support the material efficiency agenda (Bundgaard, Remmen, and Zacho 2015).

4.3 PREVIOUS STUDIES ON THE USE OF PEF IN THE MEERP

Two recent Danish studies have examined the potential use of PEF in MEErP, namely Wesnæs et al. (2019; 2021). The first study from 2019 is an initial analysis of the EcoReport Tool. The study provides suggestions on how to improve the EcoReport Tool and an analysis of the advantages and disadvantages of implementing elements from the PEF method into the EcoReport Tool (Wesnæs, Hansen, and Gydesen 2019).The second study from 2021 analyses the possibilities for implementing circular economy aspects into the EcoReport Tool focusing on reuse, recycling, repair, and lifetime extension (Wesnæs and Hansen 2021) .The study provides an analysis of circular economy aspects included in the current EcoReport Tool and selected circular economy aspects from the PEF method. Calculations are made for household refrigerators using the EcoReport Tool and the PEF method to identify significant differences. The two studies provide several conclusions and recommendations for the update of MEErP and the EcoReport Tool and a short review is provided here.

4.3.1 PARALLEL STRUCTURE BETWEEN PEFCR AND THE PREPARATORY STUDY

The study from 2019 provides an analysis of the overlaps between the ecodesign regulations and the PEFCR (Wesnæs, Hansen, and Gydesen 2019). At the time of the study, there were only two product groups with a clear overlap, namely rechargeable batteries and photovoltaic (Wesnæs, Hansen, and Gydesen 2019). Furthermore, it is unclear if a better overlap between PEFCRs and the ecodesign regulations can be expected in the future (Wesnæs, Hansen, and Gydesen 2019).

The study also points out that it would be ideal if the methods and results used in the PEF method, the PEFCRs and the ecodesign regulations could be coordinated to some extent (Wesnæs, Hansen, and Gydesen 2019). It would increase the credibility of the PEF initiative and the ecodesign regulations if the results and requirements are not diverging (Wesnæs, Hansen, and Gydesen 2019). However, the study also points out that it might be difficult to fully coordinate the two initiatives, due to the complexity of the two processes (Wesnæs, Hansen, and Gydesen 2019). A parallel structure is therefore suggested, where the PEFCR and the ecodesign preparatory study is running within the same timeframe and involving the same stakeholders and consultants (Wesnæs, Hansen, and Gydesen 2019).

4.3.2 ALIGNMENT OF THE PRODUCT CATEGORY AND THE FUNCTIONAL UNIT IN PEFCR AND THE BASE CASE IN MEERP

The study from (2019) also provides a comparison of the definitions of the product categories in PEFCRs and the base cases in MEErP for the two product groups rechargeable batteries and photovoltaic modules. The study concludes that the definitions of the product categories in the PEFCRs and the base cases in the ecodesign preparatory studies are related. Therefore, the coordination of the product categories and the base cases would not constitute a significant barrier for the coordination of the two schemes.

The study from 2019 also concludes that the EcoReport Tool could benefit from applying a more systematic use of the concept functional unit like in the PEFCRs (Wesnæs, Hansen, and Gydesen 2019). Furthermore, the functional unit of the PEFCRs and the preparatory studies could also be coordinated (Wesnæs, Hansen, and Gydesen 2019). Still, there are some challenges when it comes to a full coordination of the functional units in the PEFCRs and the preparatory studies (Wesnæs, Hansen, and Gydesen 2019). One of these challenges relates to the need to differentiate between different technologies within the framework of the Ecodesign Directive. Two very different products can provide the same function (and thereby same functional unit) but be based on very different technologies (Wesnæs, Hansen, and Gydesen 2019). It provides some challenges within the Ecodesign Directive, as it is specified that (European Commission 2009, Article 15 paragraph 4(d-e)):

"(d): there shall be no significant negative impact on industry's competitiveness and (e) in principle, the setting of an ecodesign requirement shall not have the consequence of imposing proprietary technology on manufacturers".

This implies that the functional unit cannot always be used in all tasks of the preparatory studies, as it is necessary to differentiate between different technologies (Wesnæs, Hansen, and Gydesen 2019).

4.3.3 UPDATE OF ASPECTS RELATED TO CIRCULAR ECONOMY IN THE ECOREPORT TOOL

The study from 2021 concludes that for the ecodesign regulations to move towards a wider integration of circular economy aspects, the EcoReport Tool needs to focus on aspects such as recycled content, reuse, repair, maintenance, extended lifetime, production of spare parts, dismantling and recovery of waste (Wesnæs and Hansen 2021). The study suggests that the EcoReport Tool should include guidance on aspects related to circular economy (Wesnæs and Hansen 2021). It could be in the form of a list of question and calculations covering aspects such as: (1) the future expected improvement in energy consumption, (2) the expected lifetime, (3) if the expected lifetime is decreasing, (4) the expected development of CO2 emissions and (5) economic considerations of the parts (Wesnæs and Hansen 2021).

Modelling of Primary and Secondary Materials as Input for Production
In the current version of the EcoReport Tool, the share of primary and secondary materials in the input for production for each material is not clearly described (Wesnæs and Hansen 2021). It is therefore recommended that a clear description of the method for the applied share of primary and secondary materials is provided in the EcoReport Tool (Wesnæs and Hansen 2021). Furthermore, it is recommended that the data for the share of the use of primary and secondary materials is examined and updated where needed (Wesnæs and Hansen 2021).

Modelling of Recycling and Incineration
The number of recycled materials in the current EcoReport Tool is also limited, and it is not possible to apply the actual share of primary and secondary materials (Wesnæs and Hansen 2021). Both studies therefore recommend that, the PEF method for recycling should be incorporated into the EcoReport Tool (Wesnæs, Hansen, and Gydesen 2019; Wesnæs and Hansen 2021). More specifically, the study from 2021 recommends, that the EcoReport Tool applies the same approach for calculating credits for recycling as the PEF method to ensure alignment of the results (Wesnæs and Hansen 2021). Therefore, the CFF and default data for recycling should be incorporated into the EcoReport Tool (Wesnæs and Hansen 2021). However, to reduce complexity, it is recommended not to use the quality factors (Q) and the downcycling factors (k) from the CFF (Wesnæs and Hansen 2021). The study also recommends using the allocation factor (A) from the CFF to assign the burdens and credits between the user and supplier of recycled materials (Wesnæs and Hansen 2021). The study from 2021 concludes that the recycling rates in the EcoReport Tool are not updated and are unrealistically high (Wesnæs and Hansen 2021). The study therefore recommends using the

recycling rates from the PEF method and the data from the background reports from the EU list of Critical Raw Materials (Wesnæs and Hansen 2021). Furthermore, it should be easier for the practitioners to make changes to the recycling rates in the EcoReport Tool (Wesnæs and Hansen 2021). The study from 2021 also recommends that the data for waste incineration and avoided heat and electricity productions from the PEF method is incorporated into the EcoReport Tool (Wesnæs and Hansen 2021).

Modelling of Lifetime and Lifetime Extensions

The study from 2021 concludes that there is a lack of data covering aspects such as lifetime, lifetime extension, repair, spare parts, maintenance, reuse and the impact of maintenance and repair on product lifetime (Wesnæs and Hansen 2021). The report therefore recommends that more studies are issued on these topics (Wesnæs and Hansen 2021). The lifetime in the EcoReport Tool is based on an average lifetime of the production not varying over the years (Wesnæs and Hansen 2021). It is therefore recommended that the EcoReport Tool includes the possibility to model different lifetimes (Wesnæs and Hansen 2021). Hereunder, also the possibility to model potentially decreasing lifetimes of energy-related products (Wesnæs and Hansen 2021). Furthermore, it should be possible in the EcoReport Tool to model different scenarios with dynamic sales, stock, and efficiency improvements (Wesnæs and Hansen 2021).

The study from 2021 also recommends that the EcoReport Tool should be able to calculate if lifetime extension will result in an environmental improvement taking into consideration the trade-off between increasing energy efficiency of a new product and the benefits of prolonging the lifetime (Wesnæs and Hansen 2021). The calculation should include aspects such as the future improvement in energy efficiency, the CO2 intensity of the electricity supply, the expected lifetime of the product (currently and in the future) and the effects on sales and stock (Wesnæs and Hansen 2021).

Modelling of Maintenance, Repair and Spare Parts

The study from 2021 recommends that is should be possible to better model maintenance by including chemicals and auxiliary products used for maintenance during the use phase (Wesnæs and Hansen 2021). In the current version of the EcoReport Tool, there are two ways to model impacts related to repair and the use of spare part (Wesnæs and Hansen 2021). It can be modelled either as a default factor set to 1% of the bill of materials or as an increased recycling rate (Wesnæs and Hansen 2021). Currently, there is a lack of data when it comes to the modelling of repair and spare parts. This is also the case for the PEF method (Wesnæs and Hansen 2021). Therefore, the study from 2021 recommends keeping the modelling option of 1% of the bill of materials, as it might be sufficient in most cases (Wesnæs and Hansen 2021). However, it should also be possible to adjust the repair factor in the EcoReport Tool and insert specific materials used for repair along with and adjustable lifetime due to the repair actions (Wesnæs and Hansen 2021).

Modelling of Resource Consumption

In the current version of the EcoReport Tool, resource consumption is reported as an amount of each material in grams and data for recycled material is based on an average recycling rate (Wesnæs and Hansen 2021). This approach does not create any incentive for using recycled materials in the production of new product (Wesnæs and Hansen 2021). Furthermore, the criticality of these materials is not considered (Wesnæs and Hansen 2021). As resource consumption is challenging to assess, it is recommended to follow the development of the PEF method, when it comes to resource consumption (Wesnæs and Hansen 2021).

4.3.4 ENVIRONMENTAL FOOTPRINT (EF) DATASETS IN THE ECOREPORT TOOL

The study from 2021 concludes that the data in the EcoReport Tool is rather robust, when it comes to energy and climate (Wesnæs and Hansen 2021). However, when it comes to circular economy and material efficiency, the EcoReport Tool needs to be further developed (Wesnæs and Hansen 2021). Especially, more data for recycled materials is needed as only plastic is covered (Wesnæs, Hansen, and Gydesen 2019). Both studies therefore recommend updating the datasets in the EcoReport Tools and base it on the EF datasets (Wesnæs, Hansen, and Gydesen 2019; Wesnæs and Hansen 2021). The reason for using the EF dataset is that it is newer, more updated and of a higher quality. Furthermore, it will increase consistency of the results from the two initiatives (Wesnæs and Hansen 2021).

4.3.5 IMPACT CATEGORIES FROM THE PEF METHOD IN THE ECOREPORT TOOL

Both studies conclude that the impact categories and methods in the current version of the EcoReport Tool are outdated and need updating (Wesnæs and Hansen 2021; Wesnæs, Hansen, and Gydesen 2019). The studies recommend using the impact categories from the PEF method in the EcoReport Tool (Wesnæs, Hansen, and Gydesen 2019; Wesnæs and Hansen 2021). The study from 2021 recommends the possible use of all impact categories with the exceptions of those related to toxicity. Toxicity is excluded as it is too complex to include in a simplified tool such as the EcoReport Tool. The study especially stresses climate change and resource use (minerals and metals) and land-use as important impact categories to include from the PEF method.

4.3.6 ADDITIONAL RECOMMENDATIONS

The study from 2019 recommends that the EcoReport Tool is updated to implement the normalisation factors and weighting factors from the PEF method (Wesnæs, Hansen, and Gydesen 2019). Furthermore, a more detailed guide should be developed on how to understand the normalised and weighted results from the EcoReport Tool (Wesnæs, Hansen, and Gydesen 2019). The study from 2019 also recommends that it should be possible for the practitioner to include user specific inputs on manufacturing processes and transport in the EcoReport Tool (Wesnæs, Hansen, and Gydesen 2019). Both studies recommend that the EcoReport Tool in the future should be able to model different scenarios directly and not only be used as a hotspot analysis (Wesnæs, Hansen, and Gydesen 2019; Wesnæs and Hansen 2021). The study from 2021 also recommends that the EcoReport Tool should include a dynamic model for CO2 emissions considering the decreasing CO2 from electricity consumption (Wesnæs and Hansen 2021). Due to the complexity and the immaturity of the impact methods for toxicity, the study from 2021 does not recommend extending the EcoReport Tool to cover chemicals or impact categories related to toxicity (Wesnæs and Hansen 2021).

4.4 CURRENT MEERP REVISION PROCESS

4.4.1 INTRODUCTION

In 2020, a MEErP revision was initiated by the Commission and the revision process should be completed in Q2 2022. The main aim of the revision process is (Caldas et al. 2021):

- To update assessment methods and data used in the different MEErP tasks.
- To improve MEErP’s capabilities to tackle material efficiency aspects.
- To suggest changes to MEErP, so it can tackle broader environmental aspects by using e.g. environmental footprint and/ or ecological profile.

The update consists of five tasks (Caldas et al. 2021):

- Task 1 is an update of the EcoReport Tool.
- Task 2 is to include more systematic the environmental footprint/ ecological profile aspects and the material efficiency aspects both in the design options and in the LLCC curve.
- Task 3 is to include more systematic societal life cycle costs in MEErP
- Task 4 is an update of task 7 of MEErP to include more refined evaluations of the economic impacts.
- Task 5 covers other updates such as energy prices, escalations rate etc. and integrations of a standard for future review studies and how specific product groups can build on EU Ecolabel and the EU GPP criteria.

Only task 1 and task 2 of the MEErP revision study is relevant for the scope of this research project, and therefore the following section will mainly focus on these two tasks, based on the current level of advancement of the MEErP revision study.

4.4.2 TASK 1: PROPOSED CHANGES TO THE ECOREPORT TOOL

Impact Categories

The impact categories in the current EcoReport Tool are comprised of a combination of inventory flows and more complex impact assessments categories (as indicated in Table 5) (Caldas et al. 2021). This is not in line with most LCA approaches, where a characterisation factor typically is used to go from the life cycle inventory to the impact potential (Caldas et al. 2021). To align the EcoReport Tool with the LCA methodology, it is proposed to replace the impact categories in the current EcoReport Tool with the impact categories from the PEF method (Caldas et al. 2021).

Table 5: Overview of the impact categories covered in the existing EcoReport Tool and the proposed impact categories in the MEErP revision (Caldas et al. 2021).

Current impact categories covered by the EcoReport Tool	**Unit**	**New proposed impact categories in the MEErP revision**	**Unit**
Total Energy (GER) (MJ)	MJ	Climate change total	Kg CO2 eq
Of which is electricity	MJ	Ozone depletion	Kg CFC-11 eq
Process water	ltr	Human toxicity (cancer)	CTUh
Water for cooling	ltr	Human toxicity (non-cancer)	CTUh
Non-hazardous waste/ landfill	g	Particulate matter	Disease incidence
Hazardous waste/ incinerated	g	Ionising radiation	kBq U235 eq
Greenhouse gases in GWP100	Kg CO2 eq.	Photochemical ozone	Kg NMVOC eq
Acidification	Kg SO2 eq.	Acidification	Mol H+eq
Volatile Organic Compounds (VOC)	g	Eutrophication terrest	Mol N eq

Persistent Organic Compounds (VOC)	Ng i-Teq	Eutrophication freshwater kg P eq	Kg P eq
Heavy Metals	Mg Ni eq.	Eutrophication marine	Kg N eq
PAHs	Mg Ni eq.	Land use	points
Particulate Matter (PM, dust)	g	Water use	M^3 water eq of deprived water
		Resource use mineral	Kg Sb eq
		Resource use fossils	MJ

End-of-life Modelling and the Circular Footprint Formula (CFF)
The MEErP revision also includes an update of the EcoReport Tool to improve its ability to model end-of-life scenarios (Caldas et al. 2021). A similar update was made in 2013 introducing the CRM calculator, recyclability benefit rates for plastic, new datasets for recycled material and credits for end-of-life recycling (Fraunhofer IZM 2014). However, there is a need to calculate recyclability benefits rates for other materials beside plastic and the datasets in the current EcoReport Tool need more detailed and consistent data on recyclability (Caldas et al. 2021).

To create consistency in the calculation of the recyclability of material, it is suggested to implement a simplified version of the CFF from the PEF method in the EcoReport Tool (Caldas et al. 2021). Furthermore, the CFF default factors are introduced in the EcoReport Tool on national recyclability rates and allocation factors. The simplified CFF suggested for the EcoReport Tool is (Caldas et al. 2021: 9):

$$(1 - R_1)E_v + R_1 \times \left(AE_{recycled} + (1 - A)E_v\right) + (1 - A)R_2 \times \left(E_{recycled} - E_v\right)$$

Where, R1 is the proportion of material in the input to the production that has been recycled from a previous system (Zampori and Pant 2019). Ev is the specific emissions and resources consumed from the acquisition and pre-processing of virgin material (Zampori and Pant 2019). A is an allocation factor shifting the burdens and credits between the supplier and user of the recycled material (Zampori and Pant 2019). Erecycled is the specific emission and resources consumed from the recycling process of the recycled material (Zampori and Pant 2019). R_2 is the proportion of the material in the product that will be recycled in a subsequent system (Zampori and Pant 2019).

The main simplification of the CFF lies in the assumption that the quality ratio between the quality of the ingoing secondary material (Qs_{in}) and the quality of the primary material (Q_p) is 1, and that the quality ratio of the outgoing secondary material (Qs_{out}) and the quality of the primary material is 1. Furthermore, only the material part of the CFF is included.

Update of the Datasets
Several challenges are emphasised in previous studies on the difficulties and limitations of the life cycle inventory data available in the EcoReport Tool, such as discrepancy between emissions data from the various database sources and lacking documentation of the database sources (Caldas et al. 2021). Furthermore, most of the datasets are outdated (Caldas et al. 2021). It is therefore suggested to replace the previous datasets with EF 3.0 datasets (Caldas et al. 2021). This will ensure consistency, robustness, and representativeness of the data, as

all datasets are developed according to the same rules and are representative for the European Union (Caldas et al. 2021).

Further Improvements of the Modelling

The transparency and the level of detail of the EcoReport Tool will also be improved in the current revision of MEErP (Caldas et al. 2021). The idea is to make it possible to emphasise a specific life cycle stage, which might be relevant for that specific product groups (Caldas et al. 2021). More specifically, it will be possible to make more user-specific changes to the calculation of manufacturing/assembly, packaging, distribution, use phase and maintenance and repair (Caldas et al. 2021).

Material Efficiency

It is one of the objectives of the MEErP-update to ensure that the EcoReport Tool becomes an effective instrument to identify environmental hotspots in relation to material efficiency aspects (Caldas et al. 2021). In the MEErP revision from 2013, material efficiency aspects were partly addressed introducing a recyclability benefit rate for plastic and the Critical Raw Materials Index (Caldas et al. 2021).

The MEErP revision suggests that durability is modelled as part of task 2: the economic and market analysis (Caldas et al. 2021). In task 2, an initial lifetime of the product is estimated based on the specific characteristic of the product (Caldas et al. 2021). This initial lifetime can also be referred to as reliability and runs until the occurrence of the first limiting event (Technical Committee CEN-CENELEC/JTC 10 2020). Subsequently, a final value for durability of the product is estimated by assessing lifetime extensions due to repairability and upgradability (Caldas et al. 2021). The calculations are based on a discrete scoring system and the specific values for the scoring levels are calculated using a Weibull longevity mode (Caldas et al. 2021). The results will be linked back to the EcoReport Tool (Caldas et al. 2021). However, the details on how durability and reliability is implemented in the EcoReport Tool is not yet available (Caldas et al. 2021). It will also be possible to model repairability in the updated EcoReport Tool (Caldas et al. 2021). Here, it will be possible for the user to tailor the model according to the energy and material inputs needed for repairability (Caldas et al. 2021). Recycled content and recyclability are modelled by using the CFF as described in section 5.2.2 (Caldas et al. 2021).

Modelling of Annual Sales

In the current revision of MEErP, it is recommended to exchange the constant sales figures from year to year with a dynamic stock model for annual sales in the EcoReport Tool (Caldas et al. 2021). A dynamic stock model will make it possible to estimate the economic impact of the ecodesign requirements, by also including the potential impact on sales, to estimate the total stock of products and the environmental impact from production and use (Caldas et al. 2021). In the modelling of the annual sales the lifetime is modelled through the 3 parameter Weibull distribution (Caldas et al. 2021).

Critical Raw Materials

As mentioned, the MEErP revisions from 2011 and 2013 introduced a Critical Raw Material Index into the EcoReport Tool. However, the Critical Raw Material Index has only been used in very few preparatory studies to date. Consequently, the Critical Raw Material Index has not had a real impact or resulted in specific ecodesign requirements since its introduction in 2011-2013. The current revision of MEErP therefore suggests replacing the Critical Raw Material Index with a new step-by-step approach. The step-by-step approach should be based on a sequential screening of Critical Raw Material in the product under study and take outset in the 2020 criticality assessment and the future 3-yearly update. The approach includes three steps:

(1) Shortlist the Critical Raw Material potentially in the products
(2) Collect, when possible, data on Bill of Material (BoM) of the shortlisted Critical Raw Materials
(3) Select a possible strategy (declaration of Critical Raw Materials, extend product lifetime or improve recyclability and/ or the use of recycled materials)

4.4.3 TASK 2: MORE SYSTEMATIC INCLUSION OF MATERIAL EFFICIENCY ASPECTS AND OF ENVIRONMENTAL FOOTPRINT/ ECOLOGICAL PROFILE ASPECTS IN THE DESIGN OPTIONS AND IN THE LLCC CURVE

In the MEErP revision, a more systematic inclusion of material efficiency aspects covers a new method to calculate the expected lifetime (durability), the introduction of CFF and a new approach to assess critical raw materials. The following section will elaborate on the new approach to model durability and the adoption of the CFF in the EcoReport Tool. Task 2 also covers a more systematic inclusion of environmental footprint or ecological profile in the design options. However, this inclusion was not coved in the draft rapport available by the time this research project finished.

Estimation of the Expected Lifetime or Durability

The MEErP revision includes a new calculation method for the expected lifetime (or durability) of the product. The calculation of the expected lifetime (L_t) includes the initial lifetime expectation (L0) (reliability) plus the lifetime increase due to repairability (ΔL_R) and upgradability (ΔL_U):

$$L_t = L_0(1 + \Delta L_R)(1 + \Delta L_U)$$

The calculation of L_0, ΔL_R and ΔL_U relays on the methods outline in the EN 4555x family of standards (Caldas et al. 2021). When following this procedure, the product is modelled as an assembly of critical components that can be repaired and upgraded (Caldas et al. 2021). If any of these critical components fail, it will result in the failure of the product (Caldas et al. 2021). For simplification, it is assumed that each critical component will only be repaired or upgraded once (Caldas et al. 2021). When, determining the lifetime extension due to repair and upgrade, a four-level scoring system for repairability and upgradability is used (Caldas et al. 2021). The scoring system sets four discrete levels for reliability, repairability and upgradability and links it to specific design options (Table 6) (Caldas et al. 2021). The scoring system is further explained in Cordella et al. (2019). The expected lifetime should be used to calculate both the Life Cycle Costs (LCC) and the lifetime normalised environmental impacts (Caldas et al. 2021).

Table 6: Overview of design features for the four levels (Caldas et al. 2021, 21)

Level 1	Potentially easy and quick disassembly (no special tools needed) Availability of spare parts Comprehensible repair info to consumers Diagnostics comprehensible to consumers Public availability of software updates Data transfer and deletion function Password reset Settings restoration function
Level 2	Possibility of disassembly with professional tools Availability of spare parts Repair info and diagnostic tools to independent repairers Software updates Data transfer and deletion function Password reset Settings restoration function
Level 3	Possibility of disassembly with proprietary tools Availability of spare parts Repair info and diagnostic tools only to authorised/official repairers Software updates, Data transfer and deletion function Password reset Settings restoration function
Level 4	The product cannot be repaired and must be replaced in case of failure

Other Material Efficiency Parameters
Beside durability, a new method to model recyclability and recycled content is proposed in the current MEErP revision (Caldas et al. 2021). Namely, a simplified version of the CFF from the PEF method (Caldas et al. 2021). The CFF is implemented through the EcoReport Tool (Caldas et al. 2021). Default parameters will be defined in the database for each material and introduced in the Bill of Material (Caldas et al. 2021). The default CFF parameters are based on average values from the PEF method (Caldas et al. 2021). However, it will also be possible to apply user specific values and a discrete step scoring system for recyclability is also introduced (Caldas et al. 2021).

4.5 SUB-CONCLUSIONS

The review in section 4.3 of the two studies Wesnæs et al. (2019) and Wesnæs and Hansen (2021) provided several recommendations for the update of MEErP more generally and the EcoReport Tool specifically. An overview of these recommendations is provided in Table 7 along with an indication of whether the recommendations are considered in the current MEErP revision.

As indicated in Table 7, Wesnæs et al. (2019) provides some recommendations on more coordination of the ecodesign preparatory study and the PEFCRs. It includes the proposal about a parallel structure between the preparatory study and the PEFCRs, and an alignment of product categories and functional units in PEFCRs with the base cases in MEErP. However, this broader coordination is not considered in the current revision of MEErP. Wesnæs and

Hansen (2021) also suggest that further studies on lifetime, lifetime extension, repair, spare parts, maintenance, reuse and the impact of maintenance and repair on product lifetime is needed. However, the current revision relies on existing studies covering these topics such the EN4555x series of standards and the scoring system for repair and upgrade developed by JRC (Cordella, Alfieri, and Sanfelix 2019).

Many of the recommendations from Wesnæs et al. (2019) and Wesnæs and Hansen (2021) on the update of the EcoReport Tool are considered in the current MEErP revision such as: the use of PEF datasets, the PEF impact categories, the PEF method for calculating recycling and benefits from recycling (the CFF) along with the possibility to better model maintenance, repair and spare parts, manufacturing processes and transport in the EcoReport Tool.

Thus, there are some differences in the recommendations made in the two studies and the current revision of MEErP. Wesnæs and Hansen suggested to also include incineration in the CFF. However, waste incineration and landfill has been removed from the CFF in the current MEErP update. Furthermore, all impact categories from the PEF method will be implemented into EcoReport Tool in the current MEErP revision. However, Wesnæs and Hansen (2021) recommended to not include the impact categories related to toxicity. Furthermore, it is still unclear how durability will be modelled in the EcoReport Tool. Finally, normalisation and weighting will not be included from the PEF method.

Table 7: Overview of recommendations provided in Wesnæs et al. (2019) *and Wesnæs and Hansen* (2021) *and the changes in the current MEErP revision. Red indicates that it is not covered in the MEErP update, yellow indicates that it is partly covered in the MEErP update and green indicates that it is covered in the MEErP update.*

Recommendations from two previous studies	**MEErP update 2020-2022[1]**
Recommendations to MEErP tasks	
Parallel structure between PS and PEFCR	Not covered
Alignment of product categories and functional units in PEFCR with base cases in MEErP	Not covered
More studies on lifetime, lifetime extension, repair, spare parts, maintenance, reuse and the impact of maintenance and repair on product lifetime	Not covered in the current revision. However, a new model for calculating durability (covering maintenance, reuse and repair) is implement based on existing studies and standards.
Recommendations to the EcoReport Tool	
Use the EF datasets in the EcoReport Tool	Covered
Use the Impact categories from PEF (excluding toxicity)	Covered (however all 16 impact categories have been included)
A clearer description of the method applied for the share of primary and secondary material used in the production in the EcoReport Tool along with an examination and update of data	Covered: As the data will be replaced by the PEF data

1 To be confirmed (MEErP review study still on-going).

Incorporate the PEF modelling of recycling and waste incineration (the CFF) including allocation factors and default data but excluding the quality factors and downcycling factors	Partly covered: A simplified version of the CFF is incorporated into the EcoReport Tool with the allocation factors and default data (but energy recovery and disposal in landfill will not be included
Include recycling rates from PEF and data from the background reports from EUs list of critical materials	Covered as data from PEF will be incorporated into the EcoReport Tool and critical materials will be handled according to the new critical material approach including a step-by-step approach taking outset in EUs list of critical materials
Possibility to make changes to the recycling rates in the EcoReport Tool	Covered
The possibility to better model different lifetimes in the EcoReport Tool	Partly covered: A new model for calculating the durability of the products is introduced including upgrade and repair. However, the actual implementation of durability in the EcoReport Tool is not decided yet.
The possibility to model different scenarios in the EcoReport Tool with dynamic sales, stock, and efficiency improvements	Partly covered: A dynamic model for sales and stock will be included.
The possibility to better model maintenance, repair and spare parts, manufacturing processes, and transport in the EcoReport Tool	Covered: It will be possible to model it separately and consistently and to add energy and materials consumed during the processes
Normalisations factors and weighting from the PEF method	Not covered
Detailed guide for how to interpret the normalised and weighted results	Not covered
Include the opportunity to create scenarios directly in the EcoReport Tool	Partly covered. Feasible to some extent (as modeling different scenarios is possible with different spreadsheets). The tool is however too simplified to model different scenarios in parallel.
Include a dynamic modelling for CO2 emissions considering the decreasing CO2 from electricity consumption	Covered as PEF data is now used

5 OVERLAP BETWEEN THE PRODUCT SCOPE IN THE ECODESIGN REGULATIONS AND THE PEFCRS

A precondition for using product specific elements from the PEF method in MEErP and in the ecodesign regulations more specifically is that the product groups covered by the ecodesign regulations and the PEFCRs are overlapping.

By the end of 2021, there are no overlaps between adopted implementing measures under the Ecodesign Directive and finalised PEFCRs. Currently, 19 PEFCRs are finalised as part of the pilot phase and five new PEFCRs are to be developed during the transition phase. Out of the 19 finalised PEFCRs, six were covered by the current scope of the Ecodesign Directive (covering energy-related products) including rechargeable batteries, hot and cold-water supply pipes within the building, IT-equipment (storage), photovoltaic electricity production, thermal insultation and uninterruptible power supply (see Table 8). None of the new PEFCRs to be developed during the transition phase are within the current scope of the Ecodesign Directive.

For the six PEFCRs, within the scope of the Ecodesign Directive, only four were included in the working plan of the Ecodesign Directive resulting in the development of preparatory studies. The product categories covered are rechargeable batteries, photovoltaic electricity production, thermal insultation and uninterruptible power supply. For thermal insulation it was decided not to proceed with specific ecodesign regulation in 2014. Mainly, because the energy saving potential in the use phase outweighs the energy consumption in the production phase, and because it would overlap with existing regulation. It was also decided not to go with ecodesign regulation for rechargeable batteries. Instead, rechargeable batteries will be covered by the Battery Regulation. One of the arguments for not going forward with ecodesign regulation on batteries was that transport is not covered by the Ecodesign Directive. Thereby, it was not possible to cover batteries for e-mobility within the scope of the Ecodesign Directive. For uninterruptible power supply ecodesign regulations has likewise been abandoned. However, ecodesign regulation for photovoltaic electricity production is still ongoing.

With the EU's Sustainable Products Initiative from the second action plan on circular economy, a possible expansion of the scope of the Ecodesign Directive is proposed to also cover products such as textiles, furniture and high impact intermediary products (such as steel, cement and chemicals) (European Commission 2020a). Depending on how the more precise definition will be of textiles, furniture, and high impact intermediary products, there is a potentially larger number of PEFCRs which will now be within the scope of the Ecodesign Directive as illustrated in table 8.

Table 8: Overlap between the PEFCR and the Ecodesign Directive (European Commission 2021c; 2021b). Green indicates that there is an overlap, yellow indicated that there might be an overlap and red indicated that there is no overlap.

	PEF product groups	**Within the scope of the Ecodesign Directive (energy-related products)**	**Covered by the working plans and/ or preparatory study**	**Covered by the potential extension of the Ecodesign Directive**
PEFCR developed under the pilot phase	Rechargeable Batteries	Covered	Ecodesign regulation under development	
	Decorative paints			
	Hot and cold-water supply pipes within the building		Covers only showerheads and taps	
	Household liquid laundry detergents			
	Intermediate paper product			
	IT equipment – storage			
	Leather			
	Metal sheets			
	Photovoltaic electricity production		Ecodesign regulation under development	
	Thermal insultation		Ecodesign regulation rejected/ postponed	
	T-shirts			
	Uninterruptible power supply		PS completed in 2014 no regulation developed	
	Beer			
	Dairy			
	Feed for food-producing animals			
	Packed water			
	Pasta			
	Pet food (cats & dogs)			
	Wine			
PEFCR under development during the	Apparel			
	Cut flowers and potted plants			
	Flexible packaging			

transition phase	Synthetic turf			
	Marine fish			

5.1 SUB-CONCLUSIONS

It can therefore be concluded that the possibility to use product-specific data and rules from the PEFCRs in MEErP and the ecodesign process in general is limited on the short and medium timeframe due to the very limited overlaps in the product groups covered. Two exceptions are photovoltaic electricity production, and then there are also a potential overlap between the Battery Regulation and the PEF method. The following chapter will therefore look more specifically on how PEFCR has been used for these two product categories. Furthermore, for the already overlapping product groups, the scopes, and definitions in the PEFCR and the preparatory studies still differ, making it more difficult to fully take advantage of the data and rules developed in the PEFCR in the MEErP studies and Ecodesign Regulation.

Based on the initial conclusions two recommendations can be made to better utilise PEF and the PEFCR in MEErP and the Ecodesign Regulations:

- Create a larger overlap between the product groups covered by the ecodesign regulation and the PEFCRs. Though it is important to underline that the process and criteria for selecting products for PEFCRs and for Ecodesign Regulation differ.
- To unify the scope and product definitions applied by the PEFCRs and the ecodesign regulations.

6 CASE STUDY OF PHOTOVOLTAICS AND BATTERIES

In Chapter 5, two product groups were identified as overlapping between the PEFCRs and ecodesign preparatory studies. In this chapter, we investigate the specifics of the preparatory studies to identify if and how the PEFCR have been applied in the preparatory studies. Furthermore, we will investigate the proposal for regulation concerning batteries and waste batteries, as it has replaced the proposed ecodesign regulation.

6.1 PHOTOVOLTAIC MODULES, INVERTERS AND SYSTEMS

Solar panels and inverters are included in the 2016-2019 working plan of the Ecodesign Directive. The preparatory study was conducted by the Joint Research Centre in the period 2017-2020 (Dodd et al. 2020). The pilot phase for the PEF method took place from 2014 to 2017, also covering the study on photovoltaic electricity generation. This study could serve as input to the preparatory study of the photovoltaic modules, inverters, and systems according to the Ecodesign Directive (DG Environment - European Commission n.d.). In the following, we will focus on this preparatory study and the aspects here, which relate to the PEF method.

The preparatory study on photovoltaic modules, inverters and systems includes analyses of seven different policy options (Dodd et al. 2020):

(1) Business as usual scenario
(2) Ecodesign requirements on modules and inverters
(3) Energy labelling requirements for residential PV systems
(4) Ecolabel criteria set
(5) Green public procurement criteria
(6) Combined policy options
(7) Policy options using other EU policy instruments

In policy scenario 2, the preparatory study suggests setting efficiency and yield requirements as well as performance requirements on quality, durability, and circularity for modules (Dodd et al. 2020). For inverters, the preparatory study suggests setting performance requirements on efficiency as well as quality, durability, and circularity (Dodd et al. 2020). In addition to these ecodesign requirements, the preparatory study suggests a provision of life cycle data that *would establish a standardised basis for the collection, analysis and presentation of module and inverter life cycle data and Life Cycle Assessment (LCA) results in the EU* (Dodd et al. 2020). Two impact categories are recommended as focus, namely primary energy (GER) and Global Warming Potential (GWP) (Dodd et al. 2020). Table 9 depicts the suggested ecodesign requirements.

Table 9: Suggested ecodesign requirement with relation to PEF. (Dodd et al. 2020)

Performance aspect	**Detailed proposed requirement**
Information requirement	
2.5.1 Life cycle GER and GWP product declaration	At the latest by [delayed year of introduction] and for a representative product from each module series placed on the market, an Environmental Product Declaration (EPD) for, as a minimum, life cycle primary energy (GER) and Global Warming Potential (GWP) shall be developed and provided. For further discussion: options are for the EPD to be in conformity with EN 15804 or the PEFCR and to have been registered with a Type III Product Category Rule operator.

As evident from Table 9, the preparatory study specifically notes that the LCA should be in conformance with the standard for EPD (EN 15804) for construction products and service, which is deemed relevant given most photovoltaic applications are building attached (Dodd et al. 2020). Another option is for the LCA to follow the PEFCRs for photovoltaic modules (Dodd et al. 2020).

To assess the feasibility and formulation of these ecodesign requirements and to include the feedback from stakeholders, a technical and legal analysis was conducted by the Joint Research Centre of the European Commission (Joint Research Centre 2021). This is especially important, as the discussion paper notes, due to the novelty of the proposed requirements, as an aspect that has not yet been enacted within Ecodesign measures is information regarding the "ecological profile" or environmental footprint, as established in Article 14(b) and Annex I of the Ecodesign Directive 2009/125/EC (Joint Research Centre 2021). Regarding the requirement on the life cycle GER and GWP product declaration, the discussion paper only includes an analysis of the PV modules, whereas an analysis of inverters is missing. The following therefore only regards PV modules.

The discussion paper concludes that the Ecodesign Directive 2009/125/EC does provide the legal framework for setting the proposed requirements on calculation and publication of environmental performance information via Annex I Part 3 (Joint Research Centre 2021).

The discussion paper, Annex B: Ecological profile of PV modules, presents a preliminary sketch of how the calculations of the ecological profile could be organised. Hence, the proposed method is subject to further revisions and elaborations. Annex B of the discussion paper clearly states that *The harmonized calculation rules shall build on the latest version of the Commission Product Environmental Footprint (PEF) method and relevant Product Environmental Footprint Category Rules (PEFCRs) and reflect the international agreements and technical/scientific progress in the area of the life cycle assessment* (Joint Research Centre 2021). However, some differences between the method described in Annex B and the PEFCR for PV modules have been identified. These differences are presented in Table 10.

Table 10: Identified differences between the methods for the calculations of the ecological profile of PV modules proposed in Annex B of the discussion paper and the PEFCR for PV modules.

	Proposed method in Annex B (Joint Research Centre 2021)	**PEFCR PV modules** (European Commission 2019)
Functional unit (FU)	The functional unit is further defined as one kWh (kilowatt-hour) of the total energy provided over the service life by the PV modules, measured in kWh DC. The total energy is obtained from the yield calculated according to Annex X.	The FU is 1 kWh (kilowatt hour) of DC electricity generated by a photovoltaic module. The key aspects of the FU being: *What:* DC electrical energy measured in kWh (provided power times unit of time) at the outlet of the DC connector attached to the junction box of the PV module *How much:* 1 kWh of DC electrical energy *How well:* DC electrical energy at the photovoltaic module at a given voltage level *How long:* amount of DC electrical energy produced with the photovoltaic module of a given maximum power output during the service life of 30 years.
Reference flow	The reference flow is the amount of product needed to fulfil the defined function and shall be measured in m2 of PV module per kWh of the total energy required by the application over its service life.	The reference flow is the amount of product (i.e., photovoltaic module) needed to fulfil the defined function and shall be expressed in the maximum power output measured in kWp (kilowatt peak) under standard conditions.
System boundary	The following life cycle stages of the PV modules shall be included in the system boundary: • Raw material acquisition and pre-processing • Main product production The following processes shall be excluded: Manufacturing of equipment for modules assembly and recycling, as there is evidence that their impacts can be considered as negligible. All other processes belonging to the subsequent life cycle stages, such as transport to the place of installation, assembly of the system, use and disposal, dismantling and recycling in its case, of the PV modules, shall be excluded from the life cycle ecological profile calculations.	The life cycle stages that shall be included in the system boundary are: • raw material acquisition and pre-processing • product distribution and storage • production of the main product • use stage • end of life stage

PEF profile	The results shall be provided as characterised results (without normalisation and weighting)	The following information shall be included in the PEF report: • full life cycle inventory • characterised results in absolute values, for all impact categories (including toxicity; as a table) • normalised and weighted result in absolute values, for all impact categories (including toxicity; as a table) • the aggregated single score in absolute values.

The difference in the description of the functional unit is primarily that the description is more detailed for the PEFCR, which may be because the methods described in Annex B is only a preliminary sketch for now, and the mentioned Annex X is not yet specified. Specifically, the PEFCR specify the service lifetime to 30 years and that the functional unit is 1 kWh of DC electricity generated by a photovoltaic module *at a given voltage level*.

Another difference is the definition of the reference flow, where Annex B specifies that the reference flow is measured in m2 of PV module per kWh of the total energy required by the application over its service life, whereas the PEFCR specifies it to be expressed in the maximum power output measured in kWp (kilowatt peak) under standard conditions.

The perhaps largest difference between the two methods is that Annex B specifies that the only two life cycle phases that should be included in the calculations are the raw material acquisition and pre-processing as well as the main product production, whereas the PEFCR includes all life cycle phases. The reason for the selection of two life cycle phases in Annex B is that these two phases by far are responsible for the largest impact on energy consumption and greenhouse gas emissions, which are the two impact categories in focus (Joint Research Centre 2021)

The final difference listed in Table 10 is that Annex B recommends that the results are provided as characterised results (without normalisation and weighting), whereas the PEFCR recommends that the results are presented both as characterised results in absolute values, as normalised and weighted results in absolute values and as aggregated single score in absolute values. Hence, the PEFCR recommends to also include the normalised and weighted results whereas Annex B does not. The normalised and weighted results represents a further aggregation of the characterised results. However, they also makes the results easier to communicate to non LCA experts.

6.2 BATTERIES

6.2.1 PREPARATORY STUDY ON RECHARGEABLE ELECTROCHEMICAL BATTERIES WITH INTERNAL STORAGE

In the period September 2018 to September 2019, a preparatory study was prepared by VITO, The Flemish Institute for Technological research, The Fraunhofer Institute for Systems and Innovation Research and Viegand Maagøe focusing on rechargeable electrochemical batteries with internal storage (European Commission n.d.). The scope of the preparatory study is high energy rechargeable batteries of high specific energy with solid lithium cathode chemistries of e-mobility and stationary energy storage. In March 2020, a follow up study was published, focusing among other things on the feasibility of extending the scope to Electric Scooter, Bicycles, Mopeds and Motorcycles (European Commission n.d.).

The preparatory study on rechargeable batteries is not based in the working plans of the Ecodesign Directive, as other preparatory studies, instead it is rooted in the Strategic Action Plan for Batteries from May 2018 (European Commission 2018a). The aim of the Action Plan is *to make Europe a global leader in sustainable battery production and use, in the context of the circular economy* (European Commission 2018b). This includes among other things to (European Commission 2018b):

- *launch a study on the key determining factors for the production of safe and sustainable ('green') batteries.*
- *put forward battery sustainability 'design and use' requirements for all batteries to comply with when placed on the EU market (this comprises an assessment and suitability of different regulatory instruments such as the Ecodesign Directive and the Energy Labelling Regulation and the EU Batteries Directive).*

Since the preparatory study on rechargeable batteries was finished, no work seems to have been conducted in establishing ecodesign requirements in implementing measures. Instead, the preparatory study has served as background document for the proposal for a Regulation concerning batteries and waste batteries (European Commission 2020d). Table 11 features the policy measures related to the PEF methodology, which are proposed in the preparatory study of rechargeable batteries.

Table 11: Proposed policy measures related to PEF in the preparatory study of rechargeable batteries (Van Tichelen et al. 2019)

Proposed policy measures - Requirement on carbon footprint information	Carbon footprint calculated according to the Product Environmental Footprint Category Rules (PEFCR) for high specific energy rechargeable batteries for mobile applications. The carbon footprint is therefore part of a life cycle approach, and the PEF, among other impact categories, defines how to calculate the GWP. The PEFCR has also defined a representative product (the average product sold in EU), for different types of batteries, including EV. It provides the calculations of the corresponding benchmark, including the Global Warming Potential (GWP). It also includes LCI data for lithium batteries. Also, to be provided are the calculated Primary Energy (MJ) and the share of electricity (MJ) according to the PEFCR and compatible with the MEErP. When the PEFCR carbon footprint calculation is not based on the local electricity mix, a warranty should be provided that the low carbon electricity (if any) has been supplied based on hourly net metering. Country specific residual electricity grid mix could be considered for the production this would encourage battery manufacturers to seek clean (provided it is additional) electricity supply, thus putting pressure on member states to increase their investment in renewable power generation. This can be for done by installing a battery ESS on the production plant itself to cope with variable supply of renewables and preferably second life EV batteries that return to plant before remanufacturing. Also, information could be provided more specific on the share of renewable energy used in the electricity mix.

	Carbon footprint (gCO2eq/kWh) should be calculated; relative to the minimum functional unit based on the product warranty and relative to the specified average lifetime based on laboratory tests and the applicable test cycles from EN standards.
Scope	High energy rechargeable batteries of high specific energy with solid lithium cathode chemistries of e-mobility and stationary energy storage.
Timing	Carbon footprint information requirements for all lithium cells should start from 2021. Carbon footprint information for packs and systems should start from 2022.
Threshold	It is not recommended to put a minimum carbon footprint threshold in the short term, because there are several challenges to be addressed for the carbon footprint information first. It is recommended to reconsider the option to set a minimum threshold on carbon footprint 2 years after that this information is made available based on the information provided by the manufacturers.

First, it appears from Table 11 that the proposed carbon footprint should follow the PEFCR. Furthermore, in line with the approach applied in previous implementing measures a two-tier approach is recommended. This implies that in the short term the requirement should focus on providing carbon footprint information, while setting minimum thresholds is recommended to be applied two years after the information requirement is in force, and the threshold should be based on the information provided by the manufacturers.

6.2.2 PROPOSAL FOR REGULATION CONCERNING BATTERIES AND WASTE BATTERIES

Currently, batteries are regulated through Directive 2006/66/EC (European Commission 2006). In accordance with Article 23 of this Directive, an evaluation report on the implementation and the impact on the environment and the functioning of the internal market of Directive 2006/66/EC was published in April 2019 (European Commission 2019a). The evaluation of the Directive focused primarily on the collection and recycling of waste batteries and the management of hazardous substances in batteries (European Commission 2019b). While, it is concluded that the directive has delivered positive results, limitations are also highlighted, such as (European Commission 2019b):

- *The current targets for collecting waste portable batteries do not promote a high level of collection.*
- *[...] the general objective of achieving a high level of material recovery has not been achieved. Recycling efficiencies are defined for only two substances: lead and cadmium, ignoring other valuable components such as cobalt and lithium. In addition, these definitions are not oriented towards increasing material recovery. Therefore, current recycling requirements are not considered appropriate to promote a high level of recycling and recovery from waste batteries and accumulators.*
- *Extended producer responsibility obligations for industrial batteries are not well-defined. There are no detailed provisions for collection, setting up national schemes and financing aspects for industrial batteries*
- *While the Directive encourages developing batteries with smaller quantities of dangerous substances, it does not specify any criteria for identifying the substances concerned or the type of management measures that could be adopted.*
- *Reporting obligations are only established when targets are set. The absence of quantified targets makes it very difficult to assess Member States' performance on these particular aspects.*

In December 2020, the Commission proposed a Regulation concerning batteries and waste batteries, which will repeal Directive 2006/66/EC (on batteries) and amend Regulation (EU) No 2019/1020 (on market surveillance and compliance of products) (European Commission 2020d). All batteries are in scope of the Regulation, except for batteries applied in equipment that is sent into space and equipment connected with the protection of Member States' essential security interests (European Commission 2020d). The proposal was accompanied by an impact assessment report, in which 13 policy measures are evaluated (European Commission 2020c). Table 12 features the policy measures related to the PEF methodology, which are proposed in the Regulation on batteries and waste batteries.

Table 12: Proposed policy measures related to PEF in the Regulation on batteries and waste batteries (European Commission 2020d). The highlights are added to emphasise the topics regulated.

Article 7:

Carbon footprint of electric vehicle batteries and rechargeable industrial batteries

1. Electric vehicle batteries and rechargeable industrial batteries with internal storage and a capacity above 2 kWh shall be accompanied by **technical documentation** that includes, for each battery model and batch per manufacturing plant, a carbon footprint declaration drawn up in accordance with the delegated act referred to in the second sub-paragraph and containing, at least, the following information:
   a) administrative information about the producer;
   b) information about the battery for which the declaration applies;
   c) information about the geographic location of the battery manufacturing facility;
   d) the total carbon footprint of the battery, calculated as kg of carbon dioxide equivalent;
   e) the carbon footprint of the battery differentiated per life cycle stage as described in point 4 of Annex II;
   f) the independent third-party verification statement;
   g) a web link to get access to a public version of the study supporting the carbon footprint declaration results.

   The carbon footprint declaration requirement in the first subparagraph shall apply as of 1 July 2024 to electric vehicle batteries and to rechargeable industrial batteries.

   The Commission shall, no later than 1 July 2023, adopt:
   a) a delegated act in accordance with Article 73 to supplement this Regulation by establishing the methodology to calculate the total carbon footprint of the battery referred to in point (d), in accordance with the essential elements set out in Annex II;
   b) an implementing act establishing the format for the carbon footprint declaration referred to in the first subparagraph. That implementing act shall be adopted in accordance with the examination procedure referred to in Article 74(3).

   The Commission shall be empowered to adopt delegated acts in accordance with Article 73 to amend the information requirements set out in the first subparagraph.

2. Electric vehicle batteries and rechargeable industrial batteries with internal storage and a capacity above 2 kWh shall bear a conspicuous, clearly legible, and indelible **label indicating the carbon footprint performance class** that the individual battery corresponds to.

   In addition to the information set out in paragraph 1, the technical documentation shall demonstrate that the carbon footprint declared and the related classification into a carbon footprint performance class have been calculated in accordance with the methodology set out in the delegated act adopted by the Commission pursuant to the fourth subparagraph.

> The carbon footprint performance class requirements in the first subparagraph shall apply as of 1 January 2026 for electric vehicle batteries and for rechargeable industrial batteries.
>
> The Commission shall, no later than 31 December 2024, adopt
>
> a) a delegated act in accordance with Article 73 to supplement this Regulation by establishing the carbon footprint performance classes referred to in the first subparagraph. In preparing that delegated act, the Commission shall take into account the relevant essential elements set out in Annex II;
> b) an implementing act establishing the formats for the labelling referred to in the first subparagraph and the format for the declaration on the carbon footprint performance class referred to in the second subparagraph. That implementing act shall be adopted in accordance with the examination procedure referred to in Article 74(3).
>
> 3. Electric vehicle batteries and rechargeable industrial batteries with internal storage and a capacity above 2 kWh shall, for each battery model and batch per manufacturing plant, be accompanied by **technical documentation demonstrating that the declared life cycle carbon footprint value, is below the maximum threshold** established in the delegated act adopted by the Commission pursuant to the third subparagraph.
>
> The requirement for a maximum life cycle carbon footprint threshold in the first subparagraph shall apply as of 1 July 2027 for electric vehicle batteries and for rechargeable industrial batteries.
>
> The Commission shall, no later than 1 July 2026, adopt a delegated act in accordance with Article 73 to supplement this Regulation by determining the maximum life cycle carbon footprint threshold referred to in the first subparagraph. In preparing that delegated act, the Commission shall take into account the relevant essential elements set out in Annex II.
>
> The introduction of a maximum life cycle carbon footprint threshold shall trigger, if necessary, a reclassification of the carbon footprint performance classes of the batteries referred to in paragraph 2.

As apparent from Table 12, Article 7 the Battery Regulation proposes a requirement on carbon footprint specifically for electric vehicle batteries and rechargeable industrial batteries. The requirement is divided in three steps, which supports a gradual stricter requirement. The three steps are:

1. As of 1 July 2024, the batteries in scope shall be accompanied by technical documentation that includes a carbon footprint declaration
2. As of 1 January 2026, the batteries in scope shall bear a conspicuous, clearly legible, and indelible label indicating the carbon footprint performance class that the individual battery corresponds to
3. As of 1 July 2027, the batteries in scope shall be accompanied by technical documentation demonstrating that the declared life cycle carbon footprint value, is below the maximum threshold

Article 2 (18) defines carbon footprint as the sum of greenhouse gas (GHG) emissions and GHG removals in a product system, expressed as carbon dioxide (CO2) equivalents and based on a PEF study using the single impact category of climate change (European Commission 2020d). Hence, clearly referring to the use of the PEF methodology.

To support the requirements, the Commission shall adopt a delegated act establishing the methodology to calculate the total carbon footprint, and an implementing act establishing the format for the carbon footprint declaration (European Commission 2020d). Furthermore, the Commission shall adopt a delegated act establishing the carbon footprint performance classes and an implementing act establishing the formats for the labelling (European Commission 2020d). Finally, the Commission shall adopt a delegated act determining the maximum life cycle carbon footprint threshold (European Commission 2020d).

Annex II of the proposal to the Regulation for batteries and waste batteries features the essential elements for how to calculate the carbon footprint. The Annex specifically states that *The harmonised calculation rules referred to in Article 7 shall build on the essential elements included in this Annex, be in compliance with the latest version of the Commission Product Environmental Footprint (PEF) method and relevant Product Environmental Footprint Category Rules (PEFCRs) and reflect the international agreements and technical/scientific progress in the area of life cycle assessment* (European Commission 2020d). Comparing the suggested method in Annex II to the PEFCR on High Specific Energy Rechargeable Batteries for Mobile Applications (Siret et al. 2020), it appears that calculations of functional unit and reference flow are identical. As regards the system boundary, this includes all life cycle stages and the two methods are identical except for the exception listed in Table 13.

Table 13: Exceptions to the system boundary listed in Annex II (European Commission 2020d) *and in PEFCR* (Siret et al. 2020).

Exceptions listed in Annex II, and not mentioned in PEFCR	**Exceptions listed in PEFCR, and not mentioned in Annex II**
The use phase should be excluded from the life cycle carbon footprint calculations, as not being under the direct influence of manufacturers unless it is demonstrated that choices made by battery manufacturers at the design stage can make a non-negligible contribution to this impact.	Detailed transport operations description for raw materials, product distribution or end of life: as the impact has been calculated as negligible, only the default data provided shall be used, unless primary data of required quality (see parag 5.4) is available.
	Secondary data are used for the environmental impact of assembled electronics and mechanical parts, based on the materials composition used.

As regards the carbon footprint classes, Annex II clarifies that a meaningful number of classes will be defined depending on the *distribution of the values of the batteries' carbon footprint declarations placed in the EU internal market* (European Commission 2020d), and category A defined as the best class. The threshold identification for each performance class is based on the performance of the batteries placed on the market in the previous three years. The performance classes and thresholds will be reviewed by the Commission every three years (European Commission 2020d). Furthermore, the Commission will identify maximum life cycle carbon footprint thresholds based on (European Commission 2020d):

- the information collected through the carbon footprint declarations
- the relative distribution of the carbon footprint performance classes of battery models placed on the market
- the scientific and technical progress in the field

7 IMPLEMENTING THE PEF METHOD IN MEERP - OPPORTUNITIES AND BARRIERS

The following chapter provides an overview of the opportunities for implementing the PEF method and the PEFCRs into the Ecodesign Directive on the short, medium, and long term. This is followed by a section on how the PEF method can support the uptake of material efficiency requirements in future ecodesign regulations. Hereafter, some of the barriers for the use of the PEF method and the PEFCRs in the context of the Ecodesign Directive are elaborated.

7.1 THE OPPORTUNITIES FOR IMPLEMENTING THE PEF METHOD INTO THE ECODESIGN DIRECTIVE

As our studies have revealed there are currently different possibilities in play for implementing the PEF method into the Ecodesign Directive on the short, medium, and long term.

7.1.1 THE USE OF THE PEF METHOD IN THE MEERP REVISION

The MEErP revision covers elements which were stressed by the stakeholders as in need of a revision, such as circular economy, improved impact assessment methods for impact category beyond the GHG, update and improvement of the background datasets, better assessment of the end-of-life modelling of the product, extended lifetime, embodying the life cycle costing, external environmental cost, a review of critical raw material assessment method and initial analysis of social aspects related to sustainable sourcing of materials (JRC 2021). Elements from the PEF method will be implemented into MEErP in the ongoing revision. On the short term, and already work in progress, is the implementation of the PEF impact categories, the EF datasets and the simplified version the CFF into the EcoReport Tool. Still, the EcoReport Tool will remain in its initial form as a simplified LCA tool (JRC 2021).

The ongoing MEErP revision is not an extensive one (JRC 2021), as the Ecodesign Directive is, as part of the SPI, under revision and its scope will be extended to also cover non-energy-related products. However, the ongoing revision of MEErP may also have a role to play on the longer term, in the revised Ecodesign Directive, as explained by one of the representatives from the MEErP revision team (JRC 2021):

> *The Commission is currently revising the MEErP methodology for a policy (the Ecodesign Directive), which is going to be revised and extended in scope by a broader ongoing policy (i.e. the SPI). On one hand, it is still not known if / when a new methodology will be in place. On the other hand, the current revision of the MEErP is already exploring aspects that will be crucial for the implementation of the SPI.*

Hence, these alterations to MEErP may not only cover the transitional period until the revised Ecodesign Directive steps into force but may also constitute valuable learnings for the future EU product policies. More information on this topic is provided in section 7.4.

7.1.2 THE USE OF THE PEF METHOD IN THE BATTERY REGULATION AND THE PREPARATORY STUDY FOR BATTERIES AND PV MODULES, INVERTERS AND SYSTEMS

The ongoing MEErP revision also covers an examination of a more systematic inclusion of environmental footprint or ecological profile in the design options. Thus, this part of the study is not finalised by the end of 2021. However, according to the representatives from the MEErP revision team (JRC 2021), related relevant experiences are the preparatory study for PV modules, inverters and systems, the preparatory study for batteries and the proposed Regulation on batteries and waste batteries.

In Chapter 6, we studied the preparatory study on rechargeable batteries and the proposed Regulation on batteries and waste batteries. Both propose information requirements on carbon footprint based on PEFCR. In both cases, a multi-tier approach is proposed, with the first tier being an information requirement on the carbon footprint performance. Also, in both cases recommendations are to set up thresholds as a later requirement. Furthermore, the Regulation on batteries and waste batteries proposes to develop carbon footprint performance classes and propose as a tier 2 requirement that batteries shall be labelled according to the performance class they correspond to. As further elaborated by the PEF representative (PEF representative 2021):

So, in case of the battery regulation, we will have information requirements at the beginning. Where, basically the economic operator placing the battery on the market, will have to tell us what the carbon footprint for that battery is, according to the rules. That is not the minimum requirements. Then the idea is with time, we will look into this performance, and we will establish minimum requirements and classes of performance.

On the same note, the preparatory study on PV modules, inverters, and systems, proposes to set up an information requirement on life cycle GER and GWP product declaration, based on EPD (EN 15804) or PEFCR. No thresholds or performance classes are recommended. However, according to the PEF representative the possibility for setting minimum requirements is also currently under consideration and study (PEF representative 2021):

For photovoltaic modules, the instruction that we got from the higher political level, was to already look into the possibility of setting minimum requirements from day one. So, this is what we are now looking into. It doesn't mean that this will necessarily happen, it only means that we are looking to that and we will make some proposal to the ecodesign forum as part of the impact assessment.

Hence, on the medium and long term the PEF method and the PEFCRs could serve as the methodological outset for including environmental footprint or ecological profile in the design options.

7.1.3 SUB-CONCLUSION: THE USE OF PEF ON THE SHORT, MEDIUM AND LONG TERM IN THE ECODESIGN DIRECTIVE

An overview of the potential use of the PEF method in the context of the Ecodesign Directive is provided in Figure 4. On the short term, elements from the PEF method will be implemented into the EcoReport Tool as part of the ongoing revision of MEErP. It covers elements such as the EF datasets, the simplified version of the CFF and the impact assessment methods from the PEF method.

In the medium term, the PEF method and PEFCRs will be used as the methodological outset for the information requirements on carbon footprint in the Battery Regulation and for potential other product requirements (as e.g. the GER and GWP in product declaration for PV modules, inverters, and systems). On the longer term, these information requirements could be potentially expanded further (e.g. to develop performances classes and carbon threshold requirements). The impact categories may also be expanded from energy and CO_2 emissions to other relevant impact categories (e.g. resources and water consumption) (JRC 2021). This does not imply that all new implementing measures will include information and threshold requirements related to an environmental life cycle impact indicator. As explained by the PEF representative (PEF representative 2021):

> *It will be a case-by-case discussion for the product groups, where we will decide if we should introduce life cycle indicators. For sure it will happen as an information requirement and probably it will be connected to the digital product passport. That does not exclude the possibility, because we are introducing that in the legal text, of having also minimum requirements, at the level of life cycle indicator. So, in the future we might have requirements saying that a certain T-shirt cannot be placed on the market if the climate change values is higher than a certain value. We will make it explicit that this is possible in the future.*

Hence, the decision to include life cycle environmental information in the ecodesign requirements in the Implementing measures will be based on a specific evaluation of the product or product group in question. This is also in accordance with the traditional approach in the Ecodesign Directive, where the recommendations for ecodesign requirements in the implementing measures are based on the preparatory study. Furthermore, whereas information requirements for environmental profile are possible (and policy proposal are currently under development), there are still some uncertainties in connection with potential threshold requirements.

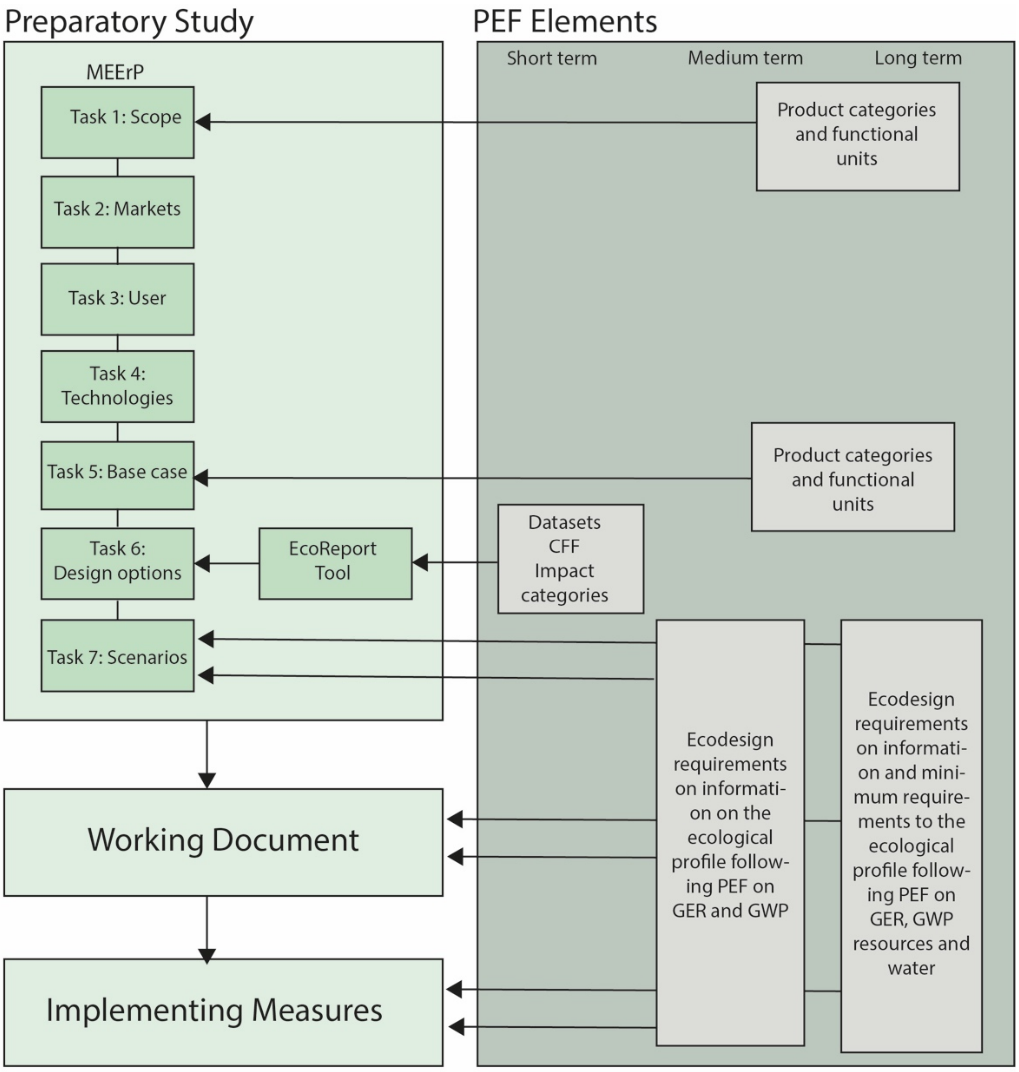

Figure 4 Overview of the elements from PEF, which could be implemented into the Ecodesign process on the short, medium, and long term. The Ecodesign process does not cover the consultations phases in between the different elements.

7.2 MATERIAL EFFICIENCY ASPECTS FROM PEF

One of the aims of this project it to determine how the implementation of PEF elements into MEErP can support material efficiency aspects on the short, medium, and long term in the ecodesign regulations. Therefore, the following section will elaborate on how the aspects from PEF method implemented into the Ecodesign process potentially can support material efficiency aspects.

On the short term, it is primarily the introduction of the simplified version of the CFF from the PEF method into the EcoReport Tool, which can support material efficiency aspects such as recyclability and recycled content. The modelling of end-of-life in the current EcoReport Tool has several limitations, such as low transparency of assumptions for certain materials and the high risk of inconsistencies across different datasets (Caldas et al. 2021). Furthermore, the current EcoReport Tool only have data on recyclability benefit rates for plastics and datasets on recycled materials are generally limited (Caldas et al. 2021). Hence, the introduction of the simplified CFF in the EcoReport Tool will improve consistency of the end-of-life modelling also with other policy tools and improve transparency and the data basis. Overall, it will be an improvement of the end-of-life modelling. However, the introduction of the simplified CFF into the EcoReport Tool is not a straightforward process. As expressed in the interview with the representatives from the MEErP revision team (JRC 2021: 36:00):

The difficulty here is that the circular footprint formula should be tailored to the product under study, whereas the Ecoreport tool should remain lean and flexible to be suitable for all product groups covered by the Ecodesign Directive. So, it is currently challenging to find the right balance between being comprehensive and robust, from one hand, and not too difficult from the other. Therefore, the Ecoreport tool revision aims to make this implementation of the CFF feasible and relatively easy also for non-expert on PEF

Hence, it is not easy to adopt the product or product category specific CFF into the generic EcoReport Tool, which should cover potentially all energy-related products. Furthermore, the simplifications needed to make the CFF fit for the EcoReport Tool, which should be possible to use for non-experts, also implies that flexibility and consistency is decreased.

In the long and medium term, the introduction of impact categories related to material efficiency aspects such as the resource use (minerals and metals) and resource use (fossils) may also increase the focus on material efficiency aspects. However, as explained more in detailed in section 7.3.1, there are no indications of how these impact categories should be used in the preparatory studies. Therefore, it is difficult to assess, if the introduction of the 16 impact categories from the PEF method will have any impact on the preparatory study or the development of ecodesign requirements.

Other aspect related to material efficiency such as durability, reliability, repair, upgradability and remanufacturing, CRMs will not be affected or improved directly by the introduction of PEF elements into MEErP or the EcoReport Tool. As elaborated by the PEF representative (PEF representative 2021, 42:00):

If you think things like repairability, reliability and spare parts, they are not at all addressed. If you think about for example durability, that is indirectly addressed, because when you define the functional unit then you must look at the issue of durability, longevity you name it. For example, repairability is not really addressed again very, very indirectly. That is why for example repairability, JRC has been looking into a repairability score and developing a specific approach on that. For other issues the intention is not to change PEF and adapted it to enable it to look into this, but rather to develop specific approaches that better allow us to gather the information that we need. So, we don't see PEF as the silver bullet for doing everything. I think it does very well certain things and we want to use it for those things.

Hence, the introduction of PEF elements to the EcoReport Tool will mainly improve the end-of-life modelling such as recyclability and recycled content and the PEF method should not be considered the only approach to ensure that material efficiency aspects are covered in the ecodesign process. Consequently, the current MEErP revision also includes a new method to model durability building on the EN4555x series of standards and a scoring system for repair and upgrade developed by JRC (Cordella, Alfieri, and Sanfelix 2019). Furthermore, a new step-by-step approach is introduced for CRMs.

7.3 BARRIERS FOR THE USE OF THE PEF METHOD IN THE ECODESIGN DIRECTIVE

7.3.1 THE 16 IMPACT CATEGORIES FROM PEF

As mentioned, the 16 impact categories will be implemented into the EcoReport Tool and partially replace the existing impact categories. This will improve and contribute to align the results of the EcoReport Tool and the PEF method. It will also make the EcoReport Tool more flexible and provide more information on the topic. However, it is still unclear how this additional information with more impact categories will affect the ecodesign process, as it is still under debate how this additional information should be used in the ecodesign process. As expressed by one of the representatives from the MEErP revision group (JRC 2021: 25:00):

The 16 of the PEF impact categories will be implemented into the EcoReport Tool plus some additional information, which still has to be investigated. Still, this is a tool applicable to any product in the scope of the Ecodesign. Therefore, it will be left to the freedom of the consultant doing the preparatory studies, to decide how to use this information within the preparatory studies and to define implementing measures specific for the product in study. Still this additional information has to be fed into the consolidated process to define implementing measures

Hence, the question remains if the LCA information from the 16 impact categories will be used in the ecodesign process, as there has been a tradition to merely focus on energy and GWP in previous preparatory study. Furthermore, a critique in the scientific publications is that the impact categories are selected without sufficient consideration for the maturity level of the methods (Finkbeiner 2013a; Six et al. 2017).

7.3.2 THE HIGH COST ASSOCIATED WITH LCA STUDIES

It is not yet clear if and how the PEF method will decrease or increase the cost of doing an LCA. However, in the context of the Ecodesign Directive, imposing too high costs can pose a challenge, as the directive specifies (European Commission 2009b, 10):

In the interest of sustainable development, continuous improvement in the overall environmental impact of those products should be encouraged, notably by identifying the major sources of negative environmental impacts and avoiding transfer of pollution, when this improvement does not entail excessive costs

Hence, the ecodesign requirements should not entail any excessive costs. The question is therefore when something is excessive. Ecodesign minimum information and performance requirements using PEFCR are already under consideration for photovoltaics, indicating that it will not pose a barrier. Furthermore, it is also under consideration to develop life cycle assessment tool that can be used as basis for the specific calculation potentially reducing the costs.

7.3.3 INTELLECTUAL PROPERTY RIGHTS OF THE EF DATASETS

When the PEF idea was initiated in 2012 it was from the beginning a clear priority to ensure that the PEF studies were based on data of a high quality (PEF representative 2021). However, buying that type of data comes at a high cost, and at that time resources for acquiring data was limited (PEF representative 2021). Consequently, an agreement was made with the data providers, that instead of “buying property right” they could buy “the rights to use” the data in a specific situation (PEF representative 2021). This made it possible to start up the work of developing and testing the PEF method and the PEFCRs (PEF representative 2021). However, it prompts now new challenges, when moving beyond the narrow contractual boundaries specified in “the right to use” contractual setup (PEF representative 2021). This becomes a challenge when moving to the actual potential policy applications. This is not only a challenge in relation to the use of the EF dataset in the Ecodesign Directive, but also in the other policy initiatives, where PEF or OEF play a role, such as the sustainable taxonymy regulation and the initiative on green claims (PEF representative 2021). At the time of the interviews, a solution regarding intellectual property rights was not yet in place, but work is ongoing on reaching an agreement (PEF representative 2021).

7.3.4 THE OPEN GOAL AND POLICY APPLICATION OF PEF

A challenge identified in section 3.2.1, is what the PEF method and the existing PEFCRs are developed without a specific goal and policy application in mind. The reasoning is that a robust PEF method and PEFCRs needs to be in place and well tested before the actual policy application is possible (PEF representative 2021). However, this approach also has some drawbacks. For both the Battery Regulation and the preparatory study for photovoltaic modules, inverters and systems, the idea is to use the PEFCRs as the methodological outset to carry out the environmental footprint or ecological profile. However, in both cases, it was necessary to make additional studies on deviations from the available PEFCRs. The same was the case for the Battery Regulation, as explained by the PEF representative (PEF representative 2021):

In the decision for batteries JRC was asked to do the update of the PEFCR in close collaboration with industries. The need for the update was basically due to two different issues. One is that some technologies were not included in the original PEFCR. So, we need to extend the scope of the PEFCR. But there were also some secondary datasets that were not considered and needed to be updated.

This indicates that it is not possible to apply the PEFCRs directly, as there are differences in the scope of the two initiatives. Some of these challenges could be mitigated, if the product categories and functional units in the PEFCRs and the bases cases in MEErP would be aligned, and if the PEFCRs and preparatory studies would be running in a parallel structure, as suggested in Wesnæs et al. (2019).

7.3.5 LIMITED OVERLAP BETWEEN PRODUCT GROUPS COVERED BY PEFCRS AND THE WORKING PLAN OF THE ECODESIGN DIRECTIVE

As illustrated in Chapter 5, the overlap between the product groups covered by PEFCRs and the working plan of the Ecodesign Directive is limited. Only, six of the developed PEFCRs are within the scope of the Ecodesign Directive, and only four were covered in the working plans. Out of the four only photovoltaic electricity production is still under consideration for ecodesign regulation and rechargeable batteries will be covered in the Battery Regulation. If considering the possible product scope of the revised Ecodesign Directive, more product groups covered by PEFCRs (or under development of PEFCRs) will be within the scope. The overlap between product groups covered by PEFCR (finalised or under development) and product groups within scope of the ecodesign directive or potentially covered by the extended ecodesign scope could be hot and cold-water supply pipes within the building, IT equipment – storage, T-shirts and apparel. Still, the overlap between the product groups covered by PEFCRs and product groups potentially covered by the Ecodesign Directive is limited. Hence, if the PEF method and the PEFCRs should be used as the methodological outset for a more systematic inclusion of life cycle environmental impacts in the design options, a larger overlap between the covered product groups is needed.

7.4 THE ROLE OF PEF IN THE SUSTAINABLE PRODUCTS REGULATION

The Ecodesign Directive is currently under revision, and in March 2022 a proposal for a new regulation establishing a framework for setting ecodesign requirements for sustainable products (SPR) was published repealing the old Ecodesign Directive. Due to its novelty, it is difficult to predict how PEF may be used in the SPR. However, based on one of our interviews, it is possible to make some preliminary indications. These indications are still uncertain as the negations were on going at the time of the interview.

It is the idea that the SPR should use life cycle assessments, in line with the Ecodesign Directive, as a hot-spot analysis to identify the relevant life cycle phases and environmental impacts, for which minimum performance requirements are developed (PEF representative 2021a). However, the SPR also differs from the Ecodesign Directive, as it will extend the focus from setting requirements to the product, to also setting requirements to the entire life cycle of the product (PEF representative 2021a). As explained by one of the interviewees (PEF representative 2021a):

> *It is important to understand that one of the major changes, that we are considering, is not only adding more product groups, which is of course the more evident, but it is also a different way of looking at products using much more the life cycle approach. In the sense that, now we are going beyond characteristics that can be measured on the product, which is the current Ecodesign approach. Now, we are looking at setting requirements that apply also to the manufacture process itself. So, the entire supply chain. That is where PEF enables us to do things that the EcoReport Tool does not.*

Hence, the SPR may not only set requirements measurable directly into the product, but also related to aspects that concerns the whole supply chain. Here, the main tool will be the life cycle assessment. The initial indications are that different LCA-approaches and standards will be considered in the SPR depending on the product group in question (PEF representative 2021a). An overview of these differences is provided in Table 14.

Table 14: Overview of LCA approaches and standards used in SPR based on product group (PEF representative 2021a)

Sustainable Products Initiative	Product groups	LCA approaches and standards
	Energy-using products or energy-related products where energy is the predominant impact	Simplified LCA approach based on MEErP and more specifically the EcoReport Tool
	Construction products	More comprehensive LCA approach based on EN 15804 Standard on Environmental Product Declaration (EPDs)
	Other product groups within the scope of SPR	More comprehensive LCA approach based on (1) PEFCRs, or (2) Existing PEF compliant studies if PEFCRs have not been developed or (3) if no PEF compliant studies exist, ISO14044 compliant studies should be used

Overall, the product groups can be categorised into three sub-categories, where different life cycle assessment approaches and standards will be applied: (1) Energy-using products or product where energy is the predominate impact, (2) construction products and (3) other product groups within the SPR scope (PEF representative 2021a).

(1) For energy-using products and energy-related products, where energy is still the predominate environmental impact, the approach and process will probably remain the same, as we know it from the Ecodesign Directive (elaborated in section 7.1) (PEF representative 2021a). Hence, the updated MEErP will be used as the methodological outset for the preparatory study, and a simplified LCA approach will be continued based on the updated EcoReport Tool (PEF representative 2021a).
(2) For construction products, where it is not possible to regulate the products within the framework of the Construction Product Regulation, the preparatory study may be based on a more comprehensive LCA (PEF representative 2021a). Here, the EN 15804 standard on Environmental Product Declarations (EPDs) may be the outset for the LCA (PEF representative 2021a). The EN15804 standard for construction products is selected to ensure continuity in the assessment of the products within the construction sector (PEF representative 2021a).
(3) For all other products within the scope of the SPR, the outset for the preparatory study might also be a more comprehensive LCA approach (PEF representative 2021a). Here, the assessment could be based on the PEFCRs if available (PEF representative 2021a). If PEFCRs are not available, the outset could be PEF compliant studies (PEF representative 2021a). Again, if these are not available either, then the outset could be 3rd party reviewed ISO14040 compliant studies (PEF representative 2021a).

8 CONCLUSIONS

In the short term, the aspects included from the PEF method to MEErP are: the impact categories, the EF datasets, and a simplified version of the Circular Footprint Formular (CFF). These aspects are under implementation into the EcoReport Tool. Besides the implementation of PEF aspects into the EcoReport Tool, the report by Wesnæs et al. (2019) also suggested that the ecodesign preparatory studies and the PEFCR could run in a parallel process and that the ecodesign preparatory study could benefit from using the concept of functional units as applied in the PEF method instead of the base cases. However, there are no plans, in the current MEErP revision, to further align the ecodesign preparatory studies and the PEFCRs. This would also require a better alignment of the product groups covered by the Ecodesign Directive and its working plans and the product categories covered by PEFCRs.

In the medium term, the PEF method and PEFCRs can be used as the methodological basis for the information requirements on carbon footprint in the Battery Regulation and the GER and GWP product declaration for PV modules, inverters, and systems. On the longer term, these information requirements may be expanded to threshold requirements and performances classes. Furthermore, the impact categories may be expanded from energy and CO_2 emissions to resources and water consumption and cover other product groups. Thus, the decision to include an environmental footprint or ecological profile in the ecodesign requirements will be based on a specific evaluation of the product or product group in question.

A limitation, to the use of the PEFCRs, as the methodological basis for a more systematic inclusion of environmental footprint or ecological profile in the design option, is the very limited overlap between the product groups covered by PEFCRs and the Ecodesign Directive. Additional limitation to the use of the PEF method and the PEFCRs in the Ecodesign Directive are: the missing guideline on how use the impact categories from the PEF method in the ecodesign process; the potentially high cost associated with conducting LCA studies; the intellectual property rights of the EF datasets; and that the PEF method and PEFCRs are not developed for this specific policy application.

The implementation of the EF datasets and CFF into the EcoReport Tool will improve its ability to model recycling and the potential offsetting for recycling. Furthermore, the introduction of the impact categories covering resource use could also potentially increase the focus on material efficiency aspects in future implementing measures. However, the implementation of elements from PEF into the MEErP and the EcoReport Tool will not directly support other circular economy aspects, such as repairability, durability and upgradability. Furthermore, the simplifications needed for the implementation of the CFF into the EcoReport Tool and the limitations to data availability might provide some limitations for the EcoReport Tool to fully model recycling. Thus, the MEErP method and the EcoReport Tool abilities to calculate and clarify other circular economy aspects are improved in the current MEErP revision through the new method for calculating product durability including also upgrade and repair options. However, these calculations methods do not rely on the PEF method but are based on the work from the 4555x series of standards and the repair index report developed by Joint Research Centre supplementing the PEF method.

Main conclusions and recommendations:

- On the short-term element from the PEF method will be introduced in the EcoReport Tool covering the EF datasets, the PEF impact categories and the simplified CFF. These elements will improve the EcoReport Tool also its end-of-life modelling (mainly recycling).

- On the medium- and long-term the PEF method can be used as the methodological outset for setting ecodesign requirements to the environmental footprint or ecological profile (informations and threshold requirements and performances classes). The ecodesign requirements on environmental footprint or ecological profile will provide an opportunity to set requirements to all lifecycle phases not only the product.

Recommendations if the OEF method should be used within the Ecodesign Directive:

- A better alignment of the product categories and functional units in the PEFCRs and the bases cases in MEErP is needed
- A better overlap between the product groups covered by the Ecodesign Directive's implementing measures and the PEFCRs is needed

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