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a systematic review

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1 **Challenges with Product Environmental Footprint – a** 2 **systematic review**

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7 **Abstract**

8 **Purpose:** This paper aims to review the current literature on PEF to answer the following questions: 1) What
9 methodological issues have been dominant in the discussion of PEF, and how do the suggested updates address
10 them? 2) What are the challenges of using PEF in policies and how can these be resolved?

11 **Method:** The research questions were answered through a structured literature review of publications on the
12 PEF method. The search was conducted in three databases: Scopus, ProQuest, and ScienceDirect using the
13 search words: “Product Environmental Footprint,” “Product Environmental Footprint Category Rules,” and
14 PEFCR.

15 **Results and discussion:** The methodological issues in the PEF method have caused ongoing discussions. Some
16 of the identified issues have been addressed by a subsequent update of the PEF guidance, but there are still some
17 open questions. These are: The defined functional units in the PEFCR are inadequate to ensure a fair
18 comparison of products, impact categories for biodiversity and indirect land-use change are still being
19 developed, secondary data is not available in an easy-to-use format, the existing and new PEFCR need to adopt
20 a benchmarking method, uncertainty exists about how the costs of making an LCA study are affected by PEF,
21 and it is unclear how the results of a PEF study should be communicated.

22 **Conclusion:** The PEF method could play an essential role in developing a market for green products, but it has
23 met substantial critique from academia. Some of the issues identified in the critique are addressed by the
24 updated PEF method, but there are still open questions that should be addressed to improve the PEF method.

25

26 **Keywords:** Product environmental footprint, PEF, Product Environmental Footprint Category Rules, PEFCR,
27 LCA, Policy, Barriers

28 1 Introduction

29 As part of the European Commission's communication *Roadmap to a Resource Efficient Europe*, the
30 Commission would establish *a common methodological approach* that would enable the Member States and the
31 private sector *to assess, display and benchmark the environmental performance of products, companies, and*
32 *services based on an assessment of the environmental impacts during its life cycle* (European Commission,
33 2011, p. 7). This initiative aimed to promote sustainable consumption and production by providing accurate
34 information to help guide consumption decisions. Many methods and standards for assessing the environmental
35 impacts already existed, but an analysis of the existing methodologies for environmental assessments concluded
36 that these methods did not provide an adequate basis for comparative assertions (Chomkhamsri & Pelletier,
37 2011). The proliferation of methods for assessing environmental impacts made it too complicated and expensive
38 for companies to make environmental claims about products. Therefore, the Commission argued that there was a
39 need to provide a new solution built on existing methods by combining suitable approaches and further
40 development (Galatola & Pant, 2014). This resulted in the development of the Product Environmental Footprint
41 (PEF), a life cycle assessment (LCA) method to assess the environmental impacts of products.

42
43 In 2013, the Commission began the development and testing of the method during a pilot phase. Two hundred
44 eighty organizations and approximately 3.000 stakeholders participated in the process (Partl et al., 2019). By
45 April 2018, 20 Product Environmental Footprint Category Rules (PEFCR) had been developed, of which eight
46 were within the food and agriculture industry. A PEFCR is a consistent and specific set of rules for calculating
47 the relevant environmental information of products belonging to the product category in scope (Zampori &
48 Pant, 2019). The primary objectives of PEFCR are to determine a consistent set of rules to calculate the
49 environmental information of products within the same category and to enable comparisons and comparative
50 assertions in all cases, where it is considered feasible, relevant, and appropriate (European Commission, 2017).
51 Since 2018, PEF has been in a transition phase planned to run until the end of 2021. There are three aims of this
52 period 1) monitoring the implementation of existing PEFCR, 2) develop new PEFCR 3) advancing
53 methodological developments. There is no available description of how the implementation of existing PEFCR
54 is conducted and progressing. A report called *Suggestions for updating the Product Environmental Footprint*
55 *(PEF) method* (Zampori & Pant, 2019) was published during the transition phase. It contains changes to the PEF
56 method that has already been implemented.

57

58 The European Green Deal is The European Union's new agenda for sustainable growth. As part of this agenda,
59 the Circular Economy action plan has been presented, with PEF mentioned explicitly: (...) *the review of the*
60 *Ecodesign Directive as well as further work on specific product groups under the Ecodesign framework or in*
61 *the context of other instruments, will build, where appropriate, on criteria and rules established under the EU*
62 *Ecolabel Regulation, the Product Environmental Footprint approach and the EU GPP criteria* (European
63 Commission, 2020b, p. 4). As part of the Circular Economy Action Plan, the Commission also proposed that:
64 (...) *companies substantiate their environmental claims using Product and Organization Environmental*
65 *Footprint methods* (European Commission, 2020b, p. 5). The Commission will also (...) *test the integration of*
66 *these methods in the EU Ecolabel* (European Commission, 2020b, p. 5). In the Farm to Fork Strategy, the
67 Commission refers to a method for calculating environmental footprints: (...) *the Commission will promote*
68 *schemes (including an EU Sustainable food Labelling framework) and lead the work on international*
69 *sustainability standards and environmental footprint calculation methods in multilateral fora to promote a*
70 *higher uptake of sustainability standards* (European Commission, 2020a, p. 18). It is unclear which method will
71 be used in a coming EU Sustainable food labeling framework or which environmental footprint calculations the
72 strategy refers to. PEF has previously been mentioned in the context of a new type of sustainability labeling
73 where the European Commission tested different communication vehicles for providing environmental footprint
74 information (Lupiáñez-Villanueva et al., 2018). From these plans three possible policy application areas for the
75 use of PEF are identified. 1) The PEF method will be used for background studies in existing policies, e.g., the
76 Ecodesign Directive. 2) The PEF method will be used for business-to-consumer communication and in the EU
77 Ecolabel. 3) The PEF method will be used by companies that wish to make environmental claims for their
78 products.

79

80 From the scientific community there has been some resistance and critique towards the PEF method during the
81 development and testing of the method. The critique stems from disagreements on the method itself as it
82 prescribes a way of making LCA that not everyone agree with. An overview of the subjects which has been
83 discussed in academic literature is given in Table 1. The PEF method is a moving target as it is continuously
84 updated with new guidelines which complicate the discussion of the method. The latest update of the PEF
85 method was made available with the publication of the *Suggestions for updating the Product Environmental*
86 *Footprint method* (Zampori & Pant, 2019). The aim of this paper is to identify the issues that are still relevant

87 and based on those result analyze what are the challenges of using the PEF method in the identified policy
88 application areas and how those challenges can be solved. This paper answers the following research questions:

- 89 • What have been the methodological issues in the discussion of PEF, and how do the suggested updates
90 address them?
- 91 • What are the challenges of using PEF in policies and how can these be resolved?

92 2 Method

93 The first research question is answered through an extensive literature review conducted on PEF. Literature review
94 was chosen as the method in order to summarize the knowledge about PEF since it was initiated in 2012. The
95 search was conducted as a systematic review as described by (Jesson et al., 2011). The screening of the literature
96 began in August 2020 and ended in November 2020. The publications fitting the scope of this study were
97 published in the period 2014 to 2020. The systematic search was undertaken in the databases ProQuest,
98 ScienceDirect, and Scopus and was limited to articles in English. The search words were 'Product Environmental
99 Footprint,' 'Product Environmental Footprint Category Rules,' and PEFCR, which were searched using a single
100 search string: TITLE-ABS-KEY ("product environmental footprint" OR "product environmental footprint
101 category rules" OR pefcr). The abbreviation PEF was excluded as a search word because this abbreviation is used
102 in many other fields of research as well. The initial search identified 234 publications, and after the removal of
103 duplicates, there were 140 publications. Each abstract was screened for any results, discussion, or conclusions
104 addressing methodological issues of PEF or any challenges of using PEF. The final number of publications
105 matching the scope of this paper was 68, covering the subjects shown in Table 1. Each subject is addressed in the
106 result section. The second research question is answered through an analysis of the challenges for each of the three
107 policy application areas. The challenges are identified by analyzing how the issues that are still relevant could
108 affect the policy application area.

109 3 Results from the literature review

110 This chapter presents the systematic review results and identifies also the issues addressed by the newest version
111 of the PEF guidance. The chapter is structured around the two research questions, which will be addressed in
112 each section. Section 3.1 presents the methodological issues identified in the papers on PEF. Section 3.2 focuses

113 on the challenges of using PEF while conducting LCA studies. Section 3.3 give an overview of which issues are
114 still open and which are solved with the updates to the PEF method.

115 **3.1 The methodological issues of PEF**

116 This first section focuses on highlighting the most relevant discussions regarding the methodology used in PEF.
117 The *Suggestions for updating the Product Environmental Footprint method* (Zampori & Pant, 2019) has
118 addressed some of the issues identified in the literature, and their continued relevance will therefore be
119 discussed. The structure follows the PEF method beginning with the definition of scope and ending with
120 benchmarking.

121 **3.1.1 Definition of scope and functional unit**

122 The functional unit (FU) is the quantified performance of a product system for use as a reference unit. In the
123 PEF method, it is required that the FU is defined based on the four elements "what," "how much," "how well,"
124 and "how long" (Zampori & Pant, 2019). However, some of the FUs defined in the PEFCR do not address the
125 requirements set in the PEF method on including performance and quality of products in the definition of the FU
126 (Bach et al., 2018). Therefore, the FU is unsuitable for making meaningful comparisons, as the products'
127 relevant performance and quality aspects are neglected as a parameter in the assessment (Lehmann et al., 2016).
128 Without these aspects, it will not be possible to make a fair comparison of products. An example of a PEFCR
129 that does not fulfil the requirements for the FU is the PEFCR for dry pasta. The FU of the PEFCR for dry pasta
130 is *1 kg of dry pasta ready to be cooked at home or at restaurant*. This FU does not include any quality aspects as
131 the only parameter included is the weight of the pasta. The main function of pasta is to make a person satiated
132 and provide nutrients, and this should be reflected in the FU to allow for fair comparison. The FU could be:
133 Prepared pasta (what) to keep one person (how much) satiated (how well) for four hours (how long). This is an
134 essential critique of the developed PEFCR as one of the objectives of developing the PEF method was to
135 compare products. However, not all the developed PEFCR has this problem. For example, the PEFCR for paint
136 fulfills all criteria, as it answers the four questions: What? "*Provide decoration and protection of a substrate,*"
137 how much? "*Coverage of 1 m² of substrate,*" how well? "*with a minimum 98% opacity,*" how long? "*for 50*
138 *years*" (Technical secretariat decorative paints, 2018). The issue seems most significant for the product
139 categories where it is difficult to answer the four questions, e.g., in the PEFCR for food products. There are
140 several functions of food products, e.g., satisfy hunger, taste, nutrition. In the example with pasta satiety was

141 used as the function, but there is not a consensus on the function of food products in LCA studies. In our view
142 there is a need for further research on developing a method for assessing the function of food.

143 **3.1.2 Data requirements**

144 The PEF method requires that company-specific data is used for all known inputs and outputs from the
145 processes, e.g., energy, water, land, products, co-products, or waste. Previously no cut-off criteria were allowed,
146 which meant a considerable workload for gathering data related to processes with minimal influence on the
147 results. With the updated PEF guidance, a cut-off is allowed on the processes that account for less than 3% of
148 the total material and energy flow.

149

150 The need for reliability in a PEF study requires strict attention to data quality (Galatola & Pant, 2014).

151 Therefore, the PEF method includes data quality requirements, which could contribute to the comparability and
152 reliability of PEF studies (Ojala et al., 2016). However, too many requirements for primary data could become a
153 barrier for using the PEF method, as access to primary data is limited for some product groups, e.g., packaging
154 materials and chemicals (Golsteijn et al., 2018). Besides, book-keeping data is not directly usable as life cycle
155 inventory data as it needs to be processed, transformed, or completed using literature data or calculation models
156 (Six et al., 2017), which also makes the use of primary data costly (Russo et al., 2016). The costs of collecting
157 primary data are mainly an issue for SMEs, and therefore the future use of PEF depends on the assurance that it
158 will be as easy for SMEs as for larger companies to use PEF to make LCA (Russo et al., 2016). In our view, the
159 development of PEFCR that specify which data should be collected and where the cut-off is could reduce the
160 cost of collecting primary data.

161

162 In the PEF method, secondary data is allowed for processes outside the company's control. The problem with
163 using secondary data is that there is uncertainty within the secondary data (Raffn et al., 2019). Using secondary
164 data for background processes also risks decreasing the fair comparability of products as one product's
165 potentially higher environmental impacts are omitted when secondary data is used (Bach et al., 2018; Corradini
166 et al., 2019). This issue has been partly solved by the development of EF-compliant datasets and implementation
167 of the Data Needs Matrix. However, the use of secondary data will reduce the resources required to make a PEF
168 study, and it could also increase the reproducibility of studies (Lehmann et al., 2016). The limits set in the PEF
169 method towards when secondary data is allowed should limit the drawbacks of using secondary data.

170 3.1.3 End-of-Life

171 When the PEF method was first published, the end-of-life method was based on an adapted version of the 50/50
172 method from the French environmental footprint (BPX 30-323). Half the benefit of recycling material is
173 assigned to the company, which sends the material to recycling, and the other half is accounted to the company
174 using the recycled material. The choice of this method met some critique. Firstly, the method neglects that some
175 materials are recycled multiple times (Allacker et al., 2017; Hohenthal et al., 2019; Lehmann et al., 2016).
176 Secondly, incineration was favored over reuse or recycling, as the benefit of incinerating a product at the end of
177 life was set to 100%, while the benefit of recycling a product was only set at 50% (Lehmann et al., 2016).
178 Thirdly, the method required more data than other end-of-life methods, as it requires a more considerable
179 amount of material coefficients (Mengarelli et al., 2017). Fourthly, the practical application of the method was a
180 challenge because of its many different variables and terms (Wade et al., 2018). Finally, the method implied that
181 the consumption of recycled material and the production of recycled material had an environmental benefit
182 (Schrijvers et al., 2016). Overall, the end-of-life method used in the first versions of PEF risked reducing fair
183 comparability because it removed the flexibility from the modeling (Lehmann et al., 2016) and lead to
184 misleading conclusions, as it did not take all the aspects mentioned above into account (Hohenthal et al., 2019).
185
186 During the PEF pilot phase, the end-of-life method was changed. In v.6.3 of the PEF method, the current end-of-
187 life model was published. An end-of-life scenario shall now use the *Circular Footprint Formula*, a formula
188 developed by the European Commission to assess the environmental impacts of the end-of-life scenario for a
189 final product or intermediary products (Zampori & Pant, 2019). The formula includes the three aspects material
190 recycling, energy recovery, and disposal. As this method for the end-of-life is relatively new, only two peer-
191 reviewed papers published at this time have identified any challenges of using the new method. The papers
192 conclude that the new method does not favor incineration over reuse and recycling anymore. However, some
193 challenges are present. The number of cycles a material is reused is not accounted for (Bach et al., 2018). A
194 material that is only recycled once gets the same “credit” as a material that goes through several cycles. The
195 default data provided for the quality of recycled materials is not adequate to reflect the differences in quality for
196 different materials (Bach et al., 2018). The new method also contradicts ISO 14044, as it only allows for 80%
197 of the credits for recycling a material to go to the product system and not 100%, which is allowed in ISO 14044
198 (Bach et al., 2018). Another challenge is a lack of compatible databases, making the end-of-life model more
199 time-consuming to use (Mirzaie et al., 2020). On the positive side, the allocation and quality parameters

200 increase the realism of the results on recycled content and end-of-life impacts as these parameters enable more
201 realistic modeling of the end-of-life scenario.

202 **3.1.4 Impact Assessment**

203 Compared with other methods and standards, the PEF method differs by providing a specific set of impact
204 assessment methods to be used. In the ISO 14044 standard, there are no requirements for which impact
205 assessment methods to use (Lehmann et al., 2015). Some argue that because the ISO 14044 standard does not
206 set a specific requirement for which impact categories to use, the results based on the ISO standard will be
207 inconsistent. Comparative assertions cannot be made based on the results (Manfredi et al., 2015).

208

209 In a PEF study, 16 different impact categories shall be considered (Zampori & Pant, 2019). An identified
210 challenge in the literature is that the impact assessment methods applied in PEF are used without proper
211 precautions to the maturity level of the methods (Finkbeiner, 2014). The risk is that including the results from
212 the impact categories with a high uncertainty can lead to misunderstandings (Six et al., 2017). When the PEF
213 method aims to harmonize methods, selecting established methods could have been better than proposing new
214 and unproven methods (Finkbeiner, 2014). The insufficient maturity level of some impact assessment methods
215 is recognized in many of the PEFCR (Lehmann et al., 2016), and half of the impact categories are not
216 considered to be adequate for decision support (Lehmann et al., 2015). The Commission acknowledges that
217 some impact assessment methods could become outdated, but they will continue to be included in the PEF
218 method until a better substitute is identified (Galatola & Pant, 2014). With the publication of the updated PEF
219 guidance, an ongoing process of improving and updating the model is apparent for some impact categories. So
220 far, the characterization model for water use, land use, resource use, particulate matter, human toxicity cancer,
221 human toxicity non-cancer, and ecotoxicity freshwater has been updated. The characterization factors for ozone
222 depletion and climate change have also been updated. Therefore, the issues with the impact assessment models
223 seem to be less critical now than previously because of the continued work with improving the models.
224 However, changing an impact assessment method will require a revision of the PEFCR because the impact
225 categories, which have been identified as the most relevant in the PEFCR, might not be the same when using the
226 updated version of an impact assessment method (Lehmann et al., 2016).

227

228 Another challenge with the impact assessment is that the included impact categories only reflect a portion of the
229 environmental impacts of a product, and some impact categories like biodiversity are still not included in the
230 assessment and should be considered qualitatively (Lehmann et al., 2015; Pyay et al., 2019). In the PEF guide
231 (v. 6.3, 2018) it is also argued indirect land-use change shall not be included because the methods and data
232 requirements for calculating indirect land-use change are not fully developed yet. In our view, the indirect land-
233 use change have to be included in the assessment of bio-based products, because the inclusion of indirect land-
234 use change gives an indication of a hotspot related to bio-based products and make the studies of bio-based
235 products more accurate (Muñoz et al., 2014).

236 **3.1.5 Weighting and normalization**

237 Alongside the development of the PEF method, a set of normalization and weighting factors were developed. In
238 other environmental policies and ISO type I labels, the weighting was hidden, which was not considered
239 appropriate (Galatola & Pant, 2014). However, weighting is problematic as it is more a political issue than a
240 scientific, and it should not be part of a scientific assessment method (Bach et al., 2018). Previously, a global
241 consensus was that weighting should not be used to make publicly available comparative assertions (Finkbeiner,
242 2014). One challenge of the weighting is that identifying the most relevant impact categories for each PEFCR
243 could lead to burden shifting. The reason is that the improvement of a product will be focused on the selected
244 impacts at the expense of the other impact categories (Lehmann et al., 2016). Another challenge is that there is
245 an implicit weighting of the different impact categories, when there is only one impact category for land use but
246 three for eutrophication (Bach et al., 2018).

247

248 The normalization factors used in PEF is also a challenge. It assumes that if the emission is relatively low
249 compared to, e.g. the global emissions, then that impact is less relevant, which is not always true (Bach et al.,
250 2018). One publication also found that the normalization factors had an inconsistent geographical scope (Wade
251 et al., 2018). These challenges indicate that the normalization method is not sufficiently mature, which reduces
252 the reliability and comparability of PEF studies (Ojala et al., 2016). In the updated PEF guidance, default
253 normalization factors are provided, and this will resolve the issue of an inconsistent geographical scope.
254 However, it will not solve the assumption that a low emission relative to a global emission is less critical than a
255 high emission relative to the global emissions.

256 **3.1.6 Benchmarking**

257 PEF recommends that each PEFCR develop a benchmark method that can be used to compare products. The
258 benchmarking is based on a single score result given by the weighting and normalization methods. So far, only a
259 few PEFCR have presented ideas for defining environmental performance classes (Lehmann et al., 2016). The
260 lack of benchmarking could be explained by the insufficient guidelines for making a benchmark in the PEF
261 method (Lehmann et al., 2016), but in the updated PEF guide, there is a suggestion for how to establish
262 performance classes. Therefore, the PEFCR under development can be expected to include a benchmark method
263 that companies can use.

264

265 A challenge of the benchmarking method is that the product lifetime is included since the consumers' behavior
266 and practices are critical for the product's expected lifetime which make it difficult to include (Gül et al., 2015).
267 In the authors view, it should however be possible to estimate the life time of a product based on an assumption
268 about the average use pattern of the product type. Building the benchmarking on a hot spot analysis also risks
269 ignoring minor critical impacts in the product's life cycle and ignoring impacts related to impact categories not
270 included in the assessment (Gül et al., 2015). For those PEFCR where a benchmark has been developed, there is
271 also a lack of supporting studies, which can confirm the benchmarks set in the PEFCR (Lehmann et al., 2016).
272 Overall, the benchmarking contradicts the ISO standards, which states that life cycle impact assessment should
273 not be used as the sole basis for comparative assertions (Lehmann et al., 2015).

274 **3.2 Challenges of using the PEF method for conducting LCA-studies**

275 In the publications on PEF, two main problems are identified for using the PEF method for making LCA on
276 products: 1) the costs of making LCA in a company could increase if the PEF method becomes mandatory 2) the
277 communication of the results of a PEF study is challenging.

278 **3.2.1 The costs of making a PEF study**

279 The cost of making an LCA is expected from the Commissions side to be reduced by approximately 30-50%
280 compared to the situation before PEF (Galatola & Pant, 2014), while others predict that the costs will be doubled
281 (Finkbeiner, 2014) or around 100.000€ (BDI, 2015). The expected cost increase comes from the requirements for
282 data quality, regionalized inventory data, the verification scheme (Finkbeiner, 2014), and the numerous predefined
283 impact assessment categories (Cimini & Moresi, 2018; Ojala et al., 2016). The requirements are extensive and

284 require a substantial effort from the companies involved in the assessment (Wade et al., 2018). Some requirements,
285 like the data quality criteria, are also expected to have little real value due to its subjectivity as it is based on
286 subjective quantifications of qualitative parameters (Six et al., 2017). Others argue that the many predefined
287 requirements could decrease the costs of an LCA as only a few definitions and decisions then need to be made by
288 the LCA practitioner (Galatola & Pant, 2014). These estimated costs of a PEF study were published early in the
289 process of developing PEF. In our view there is a need for research on the actual costs of making a PEF study.

290 **3.2.2 Communication of results**

291 Consumers are positive towards green claims as they have a strong interest in knowing more about the
292 environmental impacts of the products that they purchase (Iraldo, 2018). Using environmental labels for
293 communicating environmental impacts is also considered positive by the consumers, especially when designed
294 clearly and simply (Iraldo, 2018). However, some think that LCA for consumer communication risk confusing
295 the consumers (Finkbeiner, 2014) and that a PEF label will only add to the already abundant collection of
296 product labels (Lehmann et al., 2016). Meanwhile, a specific challenge is to communicate the results of all the
297 impact categories to environmentally unconscious consumers (Cimini & Moresi, 2018).

298
299 Using PEF as a supportive method in developing eco-labels has also been investigated in some publications.
300 Compared with PEF, the method used in the EU Ecolabel is more flexible as it includes non-quantifiable
301 information and qualitative expert judgments in the criteria setting (Minkov et al., 2020). The EU Ecolabel sets
302 restrictions and requirements to the product's performance, identify improvement potentials in the design of
303 products, and advises the users on how to handle the product in the best possible way. At the same time, the PEF
304 method only delivers information on the potential environmental impacts (Minkov et al., 2020). A discrepancy
305 also exists between the processes identified as most relevant by the PEFCR and the EU Ecolabel (Minkov et al.,
306 2020). Despite their differences, or maybe because of these, some publications recommend that the methods are
307 used in combination (Minkov et al., 2020; Saotuer et al., 2018). The EU Ecolabel performance criteria could be
308 used to determine the FU in a PEFCR (Minkov et al., 2020). The two different methods used in the EU Ecolabel
309 and the PEF method for assessing the toxicity of a product complement each other by focusing on different parts
310 of the product's life cycle. The method used in the EU Ecolabel answers how toxic the substances in the product
311 are, while the method used by PEF provides a broader and long-term perspective on the toxicity (Saotuer et al.,
312 2018).

313

314 Another way to communicate the environmental impacts of products is an Environmental Product Declaration
315 that is applied in business-to-business relations. One of the ways LCA is used in companies today is by applying
316 EPDs for assessing products' environmental impacts. Even though the EPD scheme and the PEF method have the
317 same scope, several publications have highlighted that there are apparent differences in the way the two methods
318 handle cut-off rules, goal and scope definition, life cycle inventory, life cycle impact assessment (both impact
319 categories and characterization methods), data quality requirements, end-of-life allocation, allocation rules and
320 interpretation of results (Del Borghi et al., 2019; Durão et al., 2020; Passer et al., 2015). Furthermore, due to the
321 PEF method's current level of maturity, the absence of scientific agreement, and its European scope, PEF cannot
322 serve as a solution for global harmonization of PCR development rules (Minkov et al., 2015).

323 **3.3 PEF is a moving target**

324 The PEF method is a moving target that has been developed continuously over the past 10 years. Some issues
325 identified in this literature review are now addressed with the updated version of the PEF method. Other issues
326 are still open for clarification and discussion. An overview of open and addressed issues is presented in Table 2.

327 **4 Challenges regarding policy implementation**

328 The second purpose of this article is to identify the challenges that the PEF method is facing in the transition
329 from a development phase to being used by companies and governments across Europe. There are three possible
330 policy application areas for using PEF. 1) as background studies for existing legislation, e.g. the Ecodesign
331 Directive. 2) as for business-to-consumer communication and in the EU Ecolabel. 3) as used by companies to
332 make environmental claims for their products.

333

334 1)

335 The PEF method can be used for background studies in existing policies to assess the environmental impact of
336 products and the effect a policy proposal could have on the environmental impact, e.g., in the Ecodesign
337 Directive. The challenge is that the PEF method only assesses the product's environmental impact while the
338 existing method for the Ecodesign Directive also assess other aspects, e.g., product quality, social issues, and
339 economic effects. These aspects would still need to be assessed using the existing method. Therefore, the added
340 benefit of using the PEF method instead of the existing method is uncertain.

341

342 2)

343 For business-to-consumer communication, PEF faces several challenges. First, communicating PEF results to
344 consumers will require that the results are presented in a straightforward format. The benchmarking results
345 could be used for business-to-consumer communication, but that is still limited until the PEFCR contains a
346 benchmarking method for all products. A second challenge is benchmarking products without adequately
347 assessing the quality of the product (Gül et al., 2015). This could misguide the consumers to buy a product of
348 inadequate quality if the product has a good environmental performance. Excluding these aspects means that it
349 is impossible to choose the best product based solely on the PEF results, which creates a barrier for using PEF to
350 make comparative assertions. A third challenge is that PEF is limited to environmental impacts. Allowing
351 companies to make comparative assertions based solely on environmental parameters could create issues of
352 neglecting other sustainability parameters such as social issues in the value chain or animal welfare for food
353 products.

354

355 3)

356 Making PEF the required method for a company that wants to make a green claim also raises several challenges,
357 including that it is only possible to make green claims for products where a PEFCR is available. Only few
358 enterprises have in-house competencies for making a PEF study. Therefore, the costs of making a PEF study
359 could become too high for SMEs, which could have the unintended consequence that small and medium-sized
360 enterprises would not be able to make these claims. Another challenge is that there are some green claims where
361 using the PEF method to substantiate the claims will not increase the credibility of the claim. A few examples
362 can be listed: The amount of recycled material in a product, extended lifetime of a product, the possibility to
363 repair and maintain a product. Finally, in some cases with greenwashing, companies use words that are too
364 positive with consideration to the environmental impact of their product. This issue will not be solved by
365 making PEF the required method to substantiate green claims, as the challenge also is to define when companies
366 can use certain words to describe their products.

367 5 Recommendations to tackle the challenges to make 368 PEF adaptable for policy

369 How the PEF method should tackle the challenges depend on the policy application area. However, a few
370 general recommendations can be made regardless of the policy instrument.

371

372 If PEF is to be used for one or more of the analyzed policy application areas, the first recommendation is to
373 develop more PEFCR as it will enable the use of the PEF method in more sectors. The Commission are
374 working on this with five new PEFCR under development within packaging, flowers, apparel, synthetic turf, and
375 marine fish. When identifying which product categories to develop new PEFCR on the focus should be on the
376 most relevant products from a sustainability perspective, e.g., food products or construction materials. How
377 narrow or wide the scope of the new PEFCR should depend on which products that the companies should be
378 able to benchmark their products against and which products the consumers should be able to compare. If the
379 objective is to encourage companies to make incremental improvements to their products to push the production
380 of products in a more sustainable direction, then the scope of the developed PEFCR should be narrowed in on
381 specific products, e.g. meat from beef, milk from cows, or t-shirts made from cotton. If the objective is to push
382 consumers towards taking more sustainable choices then the scope of the new PEFCR should be wider so the
383 scope includes all products that could fulfill the same function from a consumer point of view, e.g. foods with
384 high protein content like meat, meat substitutes and beans, or dairy products and dairy substitutes, or t-shirts
385 made from different raw materials. The PEFCR's with an inappropriate FU, should also be updated so their FU
386 satisfy the requirements set in the PEF method. This will ensure that relevant quality and durability aspects of
387 the product are included in the assessment. This will ensure fair comparability of products with the same
388 function. The update should also ensure that the system boundaries in the PEFCR are clear. The
389 recommendations for each policy application area are presented below.

390

391 1)

392 In the background studies for the EU Ecolabel and the Ecodesign Directive, the PEF method could be used for
393 identifying the environmental hotspots for new product groups by using the identified hotspots in the PEFCR for
394 identifying the most relevant processes and impact categories.

395

396 2)

397 When the PEF method is used for business-to-consumer communication, the communication should be based on
398 a benchmark procedure that also include performance classes. An example where such a benchmark procedure
399 is used is in the voluntary label scheme called *Made Green in Italy*, which is based on the PEF method (Masoni,
400 2017). In that scheme companies can communicate their performance for each of the relevant impact categories
401 divided in three classes called A, B, and C. It enables consumers to compare products in a simple way based on
402 PEF results. However, if PEF is to be used for business-to-consumer communication, then the PEF result should
403 not stand alone to guide the choice of consumers. The PEF result should be supported by other parameters such
404 as quality measure, nutrition value, social aspects, or animal welfare to ensure that the consumers have the
405 relevant sustainability parameters presented to them.

406

407 3)

408 Reducing the costs of making a PEF study is especially important if the PEF method becomes mandatory to use
409 for substantiating a green claim about a product or service, as small- and medium sized enterprises should be
410 able to make the same claims about their products as large enterprises can. This can be ensured through a
411 continued delivery of open access secondary data and by reducing the complexity of making a PEF study. In the
412 continued development of the PEF method, it should be a priority and focus point to ensure that the modelling
413 complexity does not become too high. Keeping the requirements for primary data at a minimum could also
414 contribute to reducing the costs of making a PEF study.

415

416 Specifying what type of green claims the PEF method should be used to substantiate is necessary as the policy
417 should avoid making it too costly and difficult to make green claims. Some of the green claims where
418 substantiating the claim with the PEF method could increase the credibility could be those using the words CO₂-
419 neutral, climate friendly, environmental friendly, and sustainable. A clear definition of when a company can use
420 the words in their green claims should also be developed. This definition could include thresholds for each
421 impact category in the PEF method that the product should stay within for the company to use a certain word in
422 its claim.

423 6 Discussion

424 With this paper we have tried to create an overview of possible policy application scenarios for the PEF method
425 and analyze challenges for each of these applications. The focus has been on issues identified in the academic
426 literature. It limits the conclusions from this review to be exclusively from an academic point of view, which
427 could be a limitation of this study as some of the most critical voices have communicated through other media,
428 e.g., blog posts or letters of opinion. Much of the critique identified in the literature review in this paper come
429 from one institute. The critique presented in this paper should therefore not be interpreted as the general
430 viewpoint in the academic society. The critique is however still valuable.

431 7 Conclusion

432 With the European Commission as the facilitator, the PEF method results from an effort by stakeholders across
433 corporations, academia, and public authorities to develop a standard ruleset for how LCA studies should be
434 made for each product group covered by a PEFCR. The PEF method could play an essential role in developing a
435 market for green products. With the aim of identifying which challenges PEF is facing and analyzing the
436 challenges that PEF is facing as it moves closer to policy implementation a literature review of academic papers
437 was conducted. The review made it clear that there still are some open issues that should be dealt with to make
438 PEF more adaptable for policy implementation. If PEF should be used for background studies in existing
439 policies or for business to consumer communication, it is a challenge that PEF only assess environmental
440 impacts and do not include social aspects. A PEF study should therefore not stand alone but be supported by
441 other type of information. Another challenge is that the quality of the products is not considered in some of the
442 PEFCR. This aspect should be part of the FU that is defined in the PEFCR. A third challenge for PEF in
443 business to consumer communication is that a framework for how to communicate the environmental impacts
444 does not exist yet. The initiative called *Made Green in Italy* could be used as an inspiration for the development
445 of a communication framework. If PEF become mandatory for substantiating green claims the first challenge is
446 that the costs of making a PEF study could be too high for SMEs. Keeping the costs of making a PEF study low
447 enough to ensure that it is possible for SMEs to make green claims should therefore be a focus in the continued
448 development of PEF. Another challenge for using PEF to substantiate green claims is that there are some green
449 claims where the use of PEF does not increase the credibility of the claim. PEF should therefore only be

450 mandatory to use for the claims where it adds credibility. There are most likely other challenges before PEF can
451 be used in policies but a key takeaway point from this study is that there are different policy application areas
452 for PEF, but for all of them there are still some challenges. These challenges are not unsolvable, but it will
453 require further development of PEF before the authors of this paper will recommend it for policy
454 implementation. A couple of areas for further research were also identified in the paper. The first is that there is
455 a need for developing a FU for food products that enable a comparison of these products based on something
456 else than their weight. Another area for further research is to make an analysis of the costs of making a PEF
457 study.

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587

588 9 Tables

589 *Table 1 Subjects derived from the literature.*

	Subjects	Sources
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The methodological issues of PEF	Definition of scope	(Bach et al., 2018; Corradini et al., 2019; Egas et al., 2019; Lehmann et al., 2016; Zampori & Pant, 2019)
	Data requirements	(Bach et al., 2018; Corradini et al., 2019; Galatola & Pant, 2014; Golsteijn et al., 2018; Lehmann et al., 2016; Ojala et al., 2016; Raffn et al., 2019; Six et al., 2017; Golsteijn & Vieira, 2019; Poolsawad et al., 2017; Russo et al., 2016; Wade et al., 2018)
	Co-product allocation	(Egas et al., 2019; Manfredi et al., 2015; Schrijvers et al., 2016)
	End-of-life	(Allacker et al., 2017; Bach et al., 2018; Hohenthal et al., 2019; Lehmann et al., 2016; Mengarelli et al., 2017; Mirzaie et al., 2020; Schrijvers et al., 2016; Wade et al., 2018)
	Impact assessment	(Bach et al., 2018; Del Borghi et al., 2020; Finkbeiner, 2014; Galatola & Pant, 2014; Lehmann et al., 2015; Lehmann et al., 2016; Manfredi et al., 2015; Pyay et al., 2019; Saouter et al., 2017; Six et al., 2017)
	Weighting and normalization	(Bach et al., 2018; Finkbeiner, 2014; Galatola & Pant, 2014; Lehmann et al., 2016; Ojala et al., 2016; Wade et al., 2018)
	Benchmarking	(Gül et al., 2015; Lehmann et al., 2015; Lehmann et al., 2016)
Challenges of using the PEF method for conducting LCA-studies	Cost of making a PEF study	(BDI, 2015; Cimini & Moresi, 2018; Finkbeiner, 2014; Galatola & Pant, 2014; Kuo & Lee, 2019; Manfredi et al., 2015; Ojala et al., 2016; Six et al., 2017; Wade et al., 2018)
	Communication	(Cimini & Moresi, 2018; Cristóbal et al., 2016; Del Borghi et al., 2020; Durão et al., 2020; Finkbeiner, 2014; Iraldo, 2018; Lansche et al., 2016; Lehmann et al., 2016; Minkov et al., 2015; Minkov et al., 2020; Passer et al., 2015; Russo et al., 2016; Saotuer et al., 2018; Walker & Rothman, 2020)

590

591 *Table 2 Addressed and open issues with the PEF method.*

Issue	Status
Functional unit	Still open: The issue continues until the FU is updated in all PEFCR containing an incomplete FU in relation to the “what”, “how much”, “how well”, and “how long”.
Data requirements	Addressed: Cut-off of processes that account for less than 3% of the material and energy flow has been introduced.
End-of-life model	Addressed: The Circular footprint formula, which includes the three aspects of material recycling, energy recovery, and disposal, has been developed.
Impact assessment models	Addressed: The characterization model has been updated for water use, land use, resource use, particulate matter, human toxicity cancer, human toxicity non-cancer, and ecotoxicity freshwater. The characterization factors have also been updated for ozone depletion and climate change.

Impact categories	Still open: Biodiversity and indirect land-use change are only included as "additional environmental information."
Normalization and weighting	Addressed to some degree: Default normalization factors have been introduced, but there are still underlying issues with the normalization method.
Benchmarking	Still open: The existing and new PEFCR need to adopt a benchmark method.
Costs of making a PEF study	Still open: Primary data collection is expected to be costly especially for SMEs.
Communication of PEF results	Addressed to some degree: There is a risk of misguiding consumers if PEF results are communicated without addressing the social and environmental impacts outside the PEF methods scope.
Availability of data	Still open: Primary data is expected to be costly to collect for especially SMEs.

592