Supplementary Materials

Assessing the Robustness of the Cradle to Cradle Certified™ Products Program to Determine the Environmental Performance of Products

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1. Criteria-based Assessment Scheme

The criteria-based assessment scheme is applied to analyze the C2C method in step 2) and LCA, PEF and MFA in step 3). It consists of overall five criteria *stakeholder acceptance, documentation and review, environmental relevance, scientific soundness* and *applicability* (see Table 1 in manuscript). Each criterion is further specified by one or more sub-criteria.

The criterion *stakeholder acceptance* (criterion 1) consists of three sub-criteria: a) *useable for policy*, b) *authoritative body endorses the method* and c) *stakeholder participation*. The method is *used in policy* (sub-criterion 1a) when it can be linked to concrete political measures (e.g. the critical load concept of the impact assessment method [1] to address acidification is also applied by the European Environmental Agency and European states to monitor acidifying impacts in Europe [2]). By fulfilling this criterion, the validity of the method has already been recognized by policy. If the *method is endorsed by an authoritative body* (sub-criterion 1b) (e.g. UNEP, EU, Federal states, etc.) it has been given formal recognition. Thus, it can be assumed that it is robust (or more robust compared to methods not endorsed by an authoritative body). As the acceptance of different stakeholders increases, when they are able to participate in the methods development and/or update, involved *stakeholders* as well as the opportunity to get involved are identified (sub-criterion 1c).

For the criterion 2) *documentation and review* two sub-criteria are taken into account. First, it is analyzed if the *method is documented* (sub criterion 2a), e.g. guidelines, providing information on how the method shall be applied, exist. The extent of the documentation can vary, ranging from several guidelines and case study reports (e.g. Organizational LCA [3]) to a very short summary of the method (e.g. ReCiPe [4]). Second, it is analyzed if *uncertainties are addressed* (sub-criterion 2b). These uncertainties refer to limitations and challenges of methods. It is considered whether instructions are provided how uncertainties can be identified and quantified (e.g. carrying out a sensitivity analysis, an uncertainty analysis as well as a gravity analysis is a fixed requirement within LCA [5]) or/and quantified error estimations are already provided. To determine the *environmental relevance* (criterion 3) of the method three sub-criteria are established. The first sub-criterion a) *broad coverage of substances* defines if relevant substances are taken into account. For example: to determine acidifying impacts on the environment all substances causing acidification should be accounted for [6]. Further, it is acknowledged whether all *relevant environmental impacts are addressed* (sub-criterion b). For example: It has been recognized that not only climate change, but also other environmental impacts have to be taken into account [7–9]. Relevance of substances as well as environmental impacts can be determined by considering existing scientific publications as well as international and national laws and regulations. Last, it is determined if the *method considers the entire life cycle* (sub criterion c). Considering upstream and downstream production processes is necessary to avoid trade-offs between the different life cycle stages as well as environmental impacts [10].

The criterion 4) *scientific soundness* is determined by analyzing if the *method has undergone a scientific review* (sub-criterion 4a), *is subject of scientific work* (sub-criterion 4b) and if it *allows for reproducibility* (sub-criterion 4c). Sub-criterion 4a) can overlap with the sub-criterion 1c) *stakeholder participation*. When multiple stakeholder are involved in the method development, it is more likely that different scientists

also have reviewed the method. If the method is set up by a small and non-versatile group of stakeholders it is less likely that it was reviewed scientifically and that broad experts' opinion is considered. However, this depends on the involved stakeholders, because also within a small stakeholder group a thorough scientific review is possible. If the method is published in a peer-reviewed journal it is more likely that challenges and limitations are addressed as well as methodological inconsistencies are eliminated. Within sub-criterion b) it is analyzed if the *method is object of scientific work*, which means that scientists frequently publish papers discussing methodological issues and applying the method to carry out case studies. By doing so, the method is improved consistently and users are more aware of existing shortcomings. Within the last sub-criterion 4c) it is checked if the method allows for reproducibility, meaning that different users reach the same results when applying the method.

The 5. criterion *applicability* consists of three sub-criteria. First, it is analyzed if the method is *globally valid* or can only be applied for certain regions (sub criterion 5a). If the method is only valid for a certain region its applicability is reduced (e.g. several impact assessment methods like ReCiPe [4] and Traci [11] only take into account the fate of substances in Europe and the US, respectively. Thus, these methods cannot be applied to assess impacts in other areas, e.g. China). Next, *efforts to collect data* is identified (sub criteria 5b). If users have to spend many resources (time and costs) on data collection, the applicability of the method is reduced significantly. The last sub-criterion refers to a *tool to support application* of the method (sub criteria 5c). Proving a tool can reduce the complexity of the method application as well as can save resources, e.g. for LCA case studies commercial as well as publicly funded software tools and data are available to model the life cycle of the considered product [12].

With one exception all sub-criteria can be answered with *yes*, *partly* and *no*. *Yes* means that all requirements of the criteria are fulfilled. *No* means that none of the requirements are fulfilled and *partly* means that only some of the requirements are fulfilled. The criterion *effort to collect data* (sub-criterion 5b) cannot be answered with *yes*, *partly* or *not*, because the term effort is not quantitatively defined. Thus, possible answers for this criterion are *low*, *medium* and *high*. For the criterion *authoritative body endorses the method* (sub-criteria of criterion 1) the answer is specified into *one*, *several* and *multiple*, because the number of authoritative bodies endorsing the method differs.

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