

ORIENTING

D1.6

Best available approaches for LCSA

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Acronyms

GLAM	Global Guidance for Life Cycle Impact Assessment Indicators and Methods
HANPP	Human Appropriation of Net Primary Production
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCIA	Life Cycle Impact Assessment
LCSA	Life Cycle Sustainability Assessment
PEF	Product Environmental Footprint
PSILCA	Product Social Impact Life Cycle Assessment
s-LCA	Social LCA
SHDB	Social Hotspot Database
SOC	Soil Organic Carbon
UNEP	United Nations Environmental Programme

Executive summary

ORIENTING is a Horizon 2020 project with the main objective to develop a robust and operational methodology for life cycle sustainability assessment (LCSA) of products. The project is structured in seven work packages (WP). WP1 (“*Concept and specifications*”) has the goal to identify and select the best available (and/or promising) methods and tools to be considered in the ORIENTING project, per sustainability topic. The methods and tools for the different topics were evaluated against a set of criteria. The objective of this document, Deliverable D1.6, is to compile in a summarized manner the main outcomes of WP1, discussing the key messages and limitations, on top of an outlook for WP2 (“*LCSA Methodology*”).

WP1 concluded by topic:

- Regarding the environmental topic, the PEF methodology will be taken as the point of departure while seeking to improve the way in which land use impacts are assessed. Several land use methods were analysed, for biodiversity, erosion and soil organic carbon impacts, on top of biotic production related impacts. A few methods were identified as the way forward for ORIENTING’s contribution to these environmental concerns in WP2, i.e., to further develop them to tackle their current methodological limitations.
- For the social topic, methods, databases and other data sources were analysed. It is suggested to take the “reference scale assessment” (as distinguished from the “impact pathway assessment”) as starting point in WP2. More specifically, the UNEP Guidelines for s-LCA and the Handbook for Product Social Impact Assessment are the most promising available methods for this. Several items still need to be defined in ORIENTING’s LCSA framework to allow further improvements and recommendations.
- For the economic topic, several economic approaches were analysed. Even if they all adopt a life cycle perspective, they have different goals and scopes (e.g., techno-economic assessment vs. total cost of ownership). In WP2 it is proposed to elaborate a hybrid and modular approach, which considers complementary functions of these different approaches according to the user needs (e.g., conventional life cycle costing can be further expanded into environmental life cycle costing).
- For (material) criticality topic, both methods from LCSA and outside of LCSA were analysed. The European Union’s criticality assessment and the GeoPoLRisk method were identified as most promising ones. Nonetheless, several scientific challenges were identified to be further explored and tackled in WP2.
- For circularity topic, several methods and indicators were analysed. No approach appeared as absolutely superior to others. Furthermore, how to integrate circularity in LCSA was shortly explored. In WP2, a more robust analysis should be performed in that respect.
- Finally, for the integration topic, several integration methods (including methods with a promising visualization approach) were described and analysed, without being able in the end to disregard any method for further use in ORIENTING because the goal and scope of the LCSA framework of ORIENTING still needs to be defined. Nonetheless, the categorization and analysis of those approaches can be taken further in WP2. On top of that, several items were discussed that will be relevant when integrating all the topics into LCSA (e.g., to avoid double-counting or to consider weak/strong sustainability).

Due to restrictions in time and resource availability, the analysis that is carried out in WP1 has a number of limitations. First of all, the evaluation results should be interpreted with care, because specific details of some methods could not be further analysed with the criteria proposed; while the weighting approach may have imposed some additional limitations into the overall scores obtained. Moreover, as WP1 took place at the beginning of the project and the LCSA framework of ORIENTING is not yet established and defined (as it intends to be highly based on stakeholder involvement), another limitation of WP1 is that it could not always provide definite suggestions/recommendations.

In parallel to the WP1 work, a stakeholder workshop (organized by WP5) took place that provided relevant information for the project, including WP1. In particular, the relevance of aggregation (into a single score) in LCSA is acknowledged as it can ease communication, however methodological concerns were also raised. Moreover, circularity should become more prominent in LCSA frameworks. At the same time, it should be considered that it is already intrinsically accounted for also with several indicators used in environmental life cycle assessment, while the extent to which circularity (and also criticality) affect social and economic aspects is less addressed. Other key issues related to WP1 are also discussed in this document. While the aspects raised in this event do not mean a consensus was reached by all stakeholders (it was rather gathering different views), these items should be considered in WP2, at its early stages, together with WP1 findings.

It is intended that the information provided by WP1 is further used in WP2 (and, more in general, in the ORIENTING project), with the ultimate purpose of facilitating the interpretation of what is available in the field, and allow the work of WP2 to become more efficient. As the ORIENTING's approach is to build upon what is already available to establish an operational LCSA framework, WP1 brings a crucial contribution to support the goal of ORIENTING to achieve that in a relatively short term (i.e., within a 3-year research project).

1. Introduction

ORIENTING is a Horizon 2020 project with the main objective to develop a robust and operational methodology for life cycle sustainability assessment (LCSA) of products. It is intended to be a holistic life-cycle approach that considers environmental, social and economic topics in a consistent and integrated way, considering circular economy and criticality issues.

The project is structured in seven work packages (WP). WP1, entitled “Concept and specifications”, has the goal to identify and select the best available (and/or promising) methods and tools to be considered in the ORIENTING project, per sustainability topic, as a basis to assess sustainability from a life-cycle perspective. WP1 is divided into six tasks, as listed below:

- Task 1.1: Criteria selection for the evaluation of existing methods and tools for the analysis of sustainability domains, including material criticality, circularity and their integration;
- Task 1.2: Environmental approach;
- Task 1.3: Social approach;
- Task 1.4: Economic approach;
- Task 1.5: Materials and circular economy in LCSA;
- Task 1.6: Sustainability integration framework approach.

Task 1.1 was dedicated to develop a set of criteria that could be used in the other tasks, in order to critically evaluate different methods and tools available in literature. Its results can be seen in Milestone MS1, and in all deliverables from WP1.

Using as basis the product environmental footprint (PEF) approach, Task 1.2 focused on how ORIENTING could scientifically advance discussions on the environmental topic of a LCSA framework, notably regarding land use impacts. Task 1.3 and 1.4 focused on the social and economic pillars of LCSA, respectively, aiming to identify the best available approaches in the field. Task 1.5 was dedicated to explore how criticality and circularity could fit into a LCSA framework, while Task 1.6 was dedicated to the integration scientific challenges and procedures for LCSA. These tasks results are available in the deliverables D1.1 (ORIENTING, 2021a), D1.2 (ORIENTING, 2021b), D1.3 (ORIENTING, 2021c), D1.4 (ORIENTING, 2021d) and D1.5 (ORIENTING, 2021e), respectively.

The objective of this document, Deliverable D1.6, is to compile in a summarized manner, the main outcomes of the aforementioned deliverables, mentioning and discussing the key messages and limitations of WP1, on top of an outlook for WP2 (“LCSA Methodology”). The document is structured as follows: section 2 provides a summary and key messages of the work done in WP1; section 3 brings a discussion about particular limitations of WP1; section 4 summarizes the stakeholders input related to WP1; and in section 5 some conclusions are drawn. While section 2 is fully based on Deliverables D1.1, D1.2, D1.3, D1.4 and D1.5, their reading should not be replaced by this document, since more dedicated/specific information is provided in the aforementioned documents.

2. Summary and key messages of work done in specific tasks of WP1

This section summarizes the main work performed in WP1 and the key messages that can be obtained from the work done so far in ORIENTING. It is divided into five subsections, i.e., environmental topic, social topic, economic topic, criticality and circularity issues, and integration topic.

2.1. Environmental topic

2.1.1. Approach for the analysis

For the environmental topic of the ORIENTING LCSA methodology, the initial proposal is that it will build upon the Product Environmental Footprint (PEF) methodology, but proposing additional developments for the land use impacts. Therefore, amongst other items discussed in the deliverable (e.g., discussion of the state of the art on LCA), an evaluation of life cycle impact assessment (LCIA) methods related to land use was provided.

For that, a search on literature sources was made via scientific search tools (e.g. web of science). Since the number of articles found was very high (>3000), an artificial-intelligence-assistant-tool was used for further screening and pre-selection. After a few interactions, which included a final selection by experts, the evaluation (based on the criteria from Task 1.1) was made on seven LCIA methods for Biodiversity, six LCIA methods for Biotic production related impacts, four LCIA methods for Erosion and two LCIA methods for soil organic carbon (SOC) impacts (all evaluated sources are available in ORIENTING (2021a)).

2.1.2. Evaluation, discussion and key messages

For **land use impacts on Biodiversity**, Chaudhary et al. (2015) and Brentrup et al. (2002), presented the best overall scores. However, due to certain limitations on the evaluation criteria scheme (as discussed in section 3 of this deliverable) and considering that there has been previous criticism by literature on these two sources; **it is suggested that WP2 explores whether these limitations can be effectively tackled or even includes new approaches that were not considered in the evaluation**, especially those that may have received good feedback in the PEF Agricultural Working Group (AWG) (e.g., Maier et al. (2019)).

For **biotic production related impacts from land use**, with a focus on terrestrial aspects, Alvarenga et al. (2015) and Taelman et al. (2016) had the highest scores. Nonetheless, due to certain limitations in their methodologies, it is suggested to consider enhancing both approaches in WP2, and/or **use their concept for an indicator based on the Human Appropriation of Net Primary Production in the improved framework**.

For **land use impacts on Erosion**, the best scoring method was Bos et al. (2020), **but the shortcomings (e.g. land use intensities) should be further developed in WP2**, e.g., by considering the approach from Sonderegger et al. (2020).

For **land use impacts on SOC**, none of the methods scored sufficiently well. Nonetheless, **it is recommended to build upon the main approaches used, for further development in WP2**, eventually also building up on ongoing activities, e.g., GLAM – Phase 3; and/or expand other methods (e.g. Boone et al. (2018)).

2.2. Social topic

2.2.1. Approach for the analysis

Social LCA (s-LCA) is one of the pillars of a LCSA framework. However, while the environmental pillar (LCA) can be interpreted as more developed/operational, the social one is at earlier development stages. Therefore, in order to operationalize s-LCA into LCSA, several aspects still need to be identified, discussed and developed; i.e., the analysis has

a broader scope than other (more developed) pillars/topics. Thus, in Task 1.3, different aspects related to s-LCA were investigated, i.e., s-LCA methods, s-LCA databases and other data sources.

Regarding the methods, several types of sources were gathered via literature search (in typical scientific platforms, such as web of science; but also, through grey literature). After initial screenings, where certain aspects were used to exclude some publications (e.g., relevance or completeness of documentation), the following methods or group of methods were selected to be evaluated through the criteria proposed in Task 1.1: The Handbook on Product Social Impact Assessment (HPSIA) (Goedkoop et al., 2020); the United Nations Environmental Programme (UNEP) Social LCA Guidelines (Benoît Norris et al., 2020); a group of methods from literature focused on Reference Scale Assessment; a group of methods from literature focused on Impact Pathway Assessment; the Life Cycle Sustainable Development Goals (SDG) Assessment; the Life Cycle Working Environmental (LCWE); the Anker Living Wage Methodology; the Social Footprint (Weidema, 2018); and the method for monetizing social impacts from Van der Velden and Vogtlander (2017).

For databases and data sources, the pre-selection was mainly done based on expert knowledge. Two databases were evaluated (Social hotspot database – SHDB, and Product Social Impact Life Cycle Assessment - PSILCA). Six data sources were considered ([Datamaran](#), [Ecovadis](#), [Maplecroft](#), [Reprisk](#), [Sedex](#) and [Supplyshift](#)). Finally, 11 additional data sources from non-governmental organizations (NGO's) and other international organizations were also considered. Nonetheless, for practical reasons, the evaluation (with the criteria from task 1.1) was focused only on the databases and the six data sources, i.e., the data from NGO's and international organizations were not critically evaluated because they are often narrow-scope and their usefulness is rather case specific.

2.2.2. Evaluation, discussion and key messages

The evaluation of methods was separated into qualitative (mostly reference scale approaches) and quantitative (mostly impact pathway) approaches. For the former (qualitative approaches), HPSIA and the UNEP Social LCA Guidelines had the best scores. For quantitative approaches, the Life Cycle SDG Assessment, the UNEP Social LCA Guidelines and the Social Footprint had the best scores. In general, the reference scale approaches are more complete than existing impact pathway approaches. Through the evaluation, it was also possible to identify some strengths and weaknesses in all methods (e.g., the complexity of the UNEP Social LCA Guidelines regarding quantitative methods).

For the databases and data sources, the analysis was less straightforward for a number of reasons. For databases, SHDB and PSILCA scored approximately the same results, not being possible to identify a best performing source. This was mainly due to low granularity of the questions from the criteria (as further discussed in section 3) and that the questions were rather for methods, not databases. Furthermore, for the six alternative data sources, their scores were also relatively close to each other. While it is possible to identify better and worse performances, it is preferred to mainly make use of such results as categorization and analysis, rather than selecting for further implementation (in WP2 or WP3), as these sources are dependent on use cases (not yet defined for ORIENTING's scope).

Considering the goal, scope and timeframe of ORIENTING, several identifications of gaps and directions for developments were proposed. First, for Social methods, **the differences of reference scale and impact pathway are identified, and the dependence of the use case is highlighted** as main driver for its choice of assessment. Moreover, the qualitative and quantitative approaches can possibly be implemented in both cases (i.e., reference scale and impact pathway), but it is acknowledged that the combination of qualitative and impact pathway is rarer. Second, **for Data, simplified decision-trees were proposed** regarding two aspects, (i) what is known about the life cycle process and (ii) what data is needed. For instance, if primary data at company level is required, only two data sources can provide such information. Finally, when analysing the combination of data and methods, **a certain harmonization between methods and databases/data sources is important** for practitioners, as different social topics are sometimes called by different terminologies in these systems, for instance. Also, **while all data sources can be used for reference scale methods, their use for impact pathway methods is more limited**. For instance, the medium-risk hours as provided in databases (SHDB and PSILCA) cannot provide the necessary information required in the impact pathway methods, e.g., to analyse the level of actual impact.

For ORIENTING, regarding the methods, the proposed starting point is to take the **reference scale assessment**, since it is identified as the most feasible and operational in the timeframe of ORIENTING (while monitoring other ongoing projects/initiatives). Furthermore, it is recommended to build a methodology using both **HPSIA and UNEP Social LCA Guidelines as main references**, while seeking for a harmonization (e.g., align reference scales and indicators). Moreover, several aspects of the LCSA approach of ORIENTING still need to be defined, in order to provide inputs for the development and further implementation of the social approach, including the use case and integration approach. Regarding the databases and data sources, as previously mentioned, **the choice of which source should be used in ORIENTING is highly dependent on the methodology's use case** as well. To tackle this aspect, it is proposed that ORIENTING could envisage a similar approach to that followed for the product environmental footprint (PEF) database, i.e., to elaborate a “social footprint” (SF) database, which ought to be composed by several data suppliers. For the data from NGOs and international organizations, their potential was identified (specially to fill in data gaps from other sources), however the use case of ORIENTING's product is key on this decision, on top of eventual additional work for mapping the connection of data and the social topics (impact categories).

2.3. Economic topic

2.3.1. Approach for the analysis

The analysis of the economic aspect has emerged far before the concept of LCSA; and its use considering the life cycle perspective can be traced back until almost 100 years ago. Nonetheless, with the emergence of sustainable development, the need to consider this aspect in combination with environmental and social issues became evident. In that sense, different approaches were adapted, focusing on different relevant items. In Task 1.4, a literature review of different approaches for the economic pillar in LCSA was made, providing a discussion on their differences, scientific gaps and way forward for further development within ORIENTING.

Considering Life Cycle Costing (LCC) as the umbrella terminology for approaches to assess the economic pillar in LCSA, seven approaches were identified, i.e., (i) conventional LCC (cLCC), (ii) environmental LCC (eLCC), (iii) societal LCC (sLCC), (iv) circular economy life cycle costing (CE-LCC), (v) total cost of ownership (TCO), (vi) techno-economic assessment (TEA), and (vii) material flow cost accounting (MFCA).

A detailed description and their differences can be found in Deliverable D1.3 (ORIENTING, 2021c). The various approaches can be classified and organized according to their system boundaries (or product's life cycle stages considered) and stakeholders' perspective (Figure 1). The cLCC seems to be the most complete in terms of life cycle stages and most flexible to integrate different kinds of internal costs. eLCC and sLCC have equivalent completeness in terms of life cycle stages, while expanding the assessment to soon-to-be-internalised external costs and societal externalities, respectively. Furthermore, although addressing the entire life cycle of technologies and products, the TCO seems to be focused on the use phase, while the TEA is focused on a gate-to-gate perspective for the business under study.

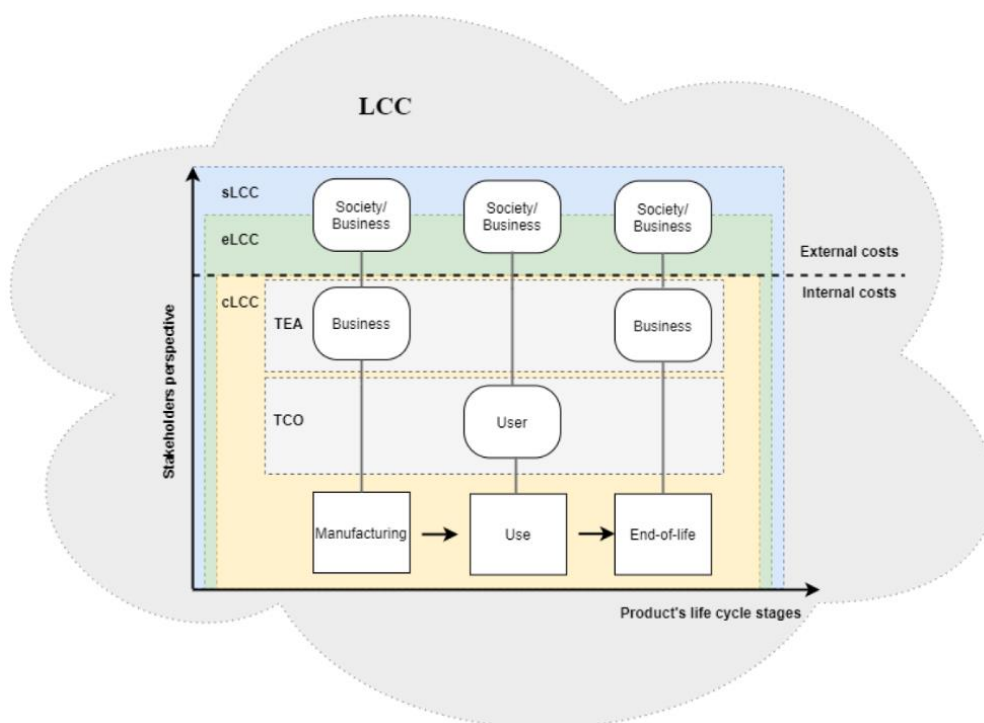


Figure 1: ORIENTING conceptual framework illustrating the system boundaries of different LCC approaches (source: ORIENTING, 2021c) (the MFCA and the CE-LCC are not represented in this figure)

2.3.2. Evaluation, discussion and key messages

These seven approaches were evaluated according to the criteria developed in Task 1.1. Their scores were relatively close to each other, with cLCC and sLCC having the best and worst overall scores, respectively. Nonetheless, more than simply analysing them via the overall score, it was important to use the criteria scheme to identify weaknesses and strengths of each approach. For instance, it was identified that sLCC performs worse on *applicability/complexity* and on *transparency*; while CE-LCC lacks on *stakeholder acceptance*, *credibility and suitability* and *transparency*. Regarding compatibility with life cycle approach, TCO, TEA and MFCA had lower scores since the different “xLCC” approaches (i.e., cLCC, sLCC, eLCC and CE-LCC) are more aligned with the life cycle assessment approach. As regards the core types of LCC (i.e., cLCC, eLCC and sLCC), it needs to be emphasised that they are not substitutes but need to be seen as complementary (as also discussed next).

The outcome of D1.3 for the ORIENTING project is to seek for a comprehensive methodological framework, linking life cycle stages and stakeholder perspectives. With this respect, **eLCC and sLCC seem comprehensive frameworks**. Nonetheless, it is also suggested to **develop a modular and incremental framework**, allowing users to select specific modules according to their needs. With that in mind, the methodology could **start with a basic cLCC module**, focusing on one perspective (e.g., if this focus is on users, “cLCC” could be equivalent to TCO), and then expand this by considering further perspectives and types of costs, i.e., eLCC and sLCC could be extensions of cLCC. In general, however, it needs to be made sure that each of these modules complies with the general principles of ORIENTING’s LCSA.

Furthermore, other technical aspects are highlighted in D1.3 that are to be carefully considered in Task 2.4. For instance, (i) how to consistently calculate and implement externalities, (ii) how to specify indicators according to stakeholders’ perspective, and (iii) the development of further guidance material.

2.4. Material's criticality and circular economy topics

2.4.1. Approach for the analysis

Materials' criticality and circular economy are "hot topics" in the European and global policy agenda. Although they are not traditionally or systematically considered in LC(S)A, there is a strong stakeholder interest to make them more evident in further developments of LCSA. With this context, Task 2.5 searched, analysed and evaluated different approaches/methods to consider both aspects in LCSA.

For criticality, a literature review of criticality methods, either related or not to LCSA, was performed using different search tools (e.g., web of science). From that search, 129 references were found, that were further pre-screened considering e.g., whether or not the publication described methods to assess criticality in terms of supply risks, or whether or not a give publication referred to the application of a method to case studies (i.e., without methodological work). After this first pre-screening, 65 documents were thus selected. They went through another level of pre-screening, to remove review articles (that did not present methods), or methods that have not been updated since 2015, amongst other topics. After that, finally, seven methods were selected: (i) National Research Council (NRC), (ii) European Commission's Critical Raw Material methodology (EC-CA), (iii) Yale methodology, (iv) ESSENZ, (v) GeoPolRisk, (vi) British Geological Survey (BGS), and (vii) Japan's Resource Strategy (NEDO).

For circularity, for practical reasons (considering the short-time frame of Task 1.5), the literature review took as starting point the methods mentioned in two recent review papers published in high quality journals, i.e., Moraga et al (2019) and Saidani et al (2019). Given that both review papers were published in 2019, methods published afterwards were also identified by screening publications that mentioned these two papers. From these methods/indicators, only methods that quantitatively evaluate the circularity of products (and the associated components or materials), that are not specific to just one product group/sector or geography, and that covered more than one circular economy strategy (out of a list of 9) were considered. Finally, nine methods/indicators were considering for final evaluation, i.e., (i) Product-level circularity metric (PLCM), (ii) Material circularity indicator (MCI), (iii) Longevity indicator, (iv) Circular footprint formula (CFF), (v) Product circularity indicator (PCI), (vi) Circularity index, (vii) Value-based resource efficiency (VRE) method, (viii) Sustainable circular index (SCI), and (ix) In-use occupation ratio (UOR) and final retention in society (FRS).

On top of the evaluation of specific methods/indicators for criticality and circularity issues, Task 1.5 also provided a critical evaluation on scientific challenges and integration procedures, that were further discussed based on literature and/or expert knowledge.

2.4.2. Evaluation, discussion and key messages

For criticality, the methods that had a higher score were EC-CA, GeoPolRisk and Yale. Considering the European context of ORIENTING (e.g. the YALE methodology is US-based), it was suggested that **the starting point for WP2 would be the EC-CA and the GeoPolRisk**. Moreover, low scores in a few specific sub-criteria raised some "red-flags", for instance, the lacking description of uncertainties for BGS and NEDO.

Regarding scientific challenges on the criticality issue in a LCSA framework, several issues were discussed in ORIENTING (2021d), including (i) mapping of critical materials and elementary flows in the LCI, (ii) the discussion whether criticality should be an integrative part of LCA, LCC, sLCA or LCSA, (iii) the use of subjective elements when defining criticality, (iv) the connection between criticality and circular economy; amongst others. **These aspects should be further reflected and discussed in WP2, especially when developing the methodological framework of criticality into LCSA.**

For circularity, a less straightforward recommendation as to which indicators to be further explored was made, since the evaluation generated more equal results, without bringing clearer conclusions. In summary, **six of the nine methods could be taken into further consideration in WP2, i.e., the PLCM, MCI, Longevity indicator, CFF, PCI and UOR/FRS.**

On top of providing a proposal for indicators, circular economy can be (or should be) better integrated into LCSA, via different ways. An initial discussion at WP1 targeted two possible ways of doing that, i.e., (i) adapting the functional unit

and proper definition of the reference flow (e.g., considering the aim to extend lifetime of a product); and (ii) distinguishing life cycle stages according to relevant steps in circular economy (e.g., “design” separate from “manufacturing” and “maintenance, repair, refurbishment” separate from the “use phase”). **These items and, potentially, other integration approaches, should be further investigated and discussed in WP2.**

2.5. Integration topic

2.5.1. Approach for the analysis

In Task 1.6, approaches usable for the integration¹ of the three sustainability domains (environmental, economic and social), as well as criticality and circularity aspects, were identified, followed by a critical evaluation of a selection of integration methods, on top of providing recommendations for further work in ORIENTING. This task therefore provided analysis and discussions at two different levels:

1. Specific integration and visualization methods, based on literature reviews searching for (i) integration methods across domains of LCSA, (ii) promising visualization approaches for LCSA results; and (iii) aggregation methods commonly used within the separate domains.
2. Relevant items that should be consistently addressed in a LCSA integration framework. The identification of these items was based on expert knowledge, backed-up by literature, and via discussions amongst Task 1.6 members.

For the first level (i.e., specific integration and visualization methods), a literature search for aggregation methods within sustainability domains was performed through scientific search tools (e.g. web of science). After a first search and additional pre-screenings, 26 studies were considered for further analysis. Furthermore, the equivalent procedure was made for integration methods across sustainability domains, where also after a first search and additional pre-screenings, it ended in a number of 23 references. On top, visualization methods and tools were also searched, which was mainly based on grey literature and/or expert knowledge.

Based on these literature reviews, a selection of 15 integration methods or sub-procedures, categorized into three groups, were further evaluated according to the criteria of Task 1.1:

- **Group 1 - Integration methods across sustainability domains (for LCSA):** (i) Simple Average Weighting (SAW), (ii) Analytical Hierarchy Process (AHP), (iii) Multi-Attribute Value/Utility Theory (MAVT/MAUT), (iv) Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), (v) Elimination And Choice Translating Reality (ELECTRE), (vi) Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE), (vii) Multi-criteria Optimization and Compromise Solution (VIKOR), (viii) Multi-Objective Decision Making (MODM) methods, and (ix) Data Envelopment Analysis (DEA) methods;
- **Group 2 – Integration methods with a promising visualization approach for LCSA:** (i) Life Cycle Sustainability Dashboard and (ii) SEEBalance;
- **Group 3 – Other aggregation methods or sub-procedures commonly used within the environmental and/or social domains:** (i) PEF normalization, (ii) PEF weighting, (iii) Distance to target weighting, and (iv) Monetary weighting.

¹ The Task 1.6 team defined “integration” as approaches that combine the outcomes of LCSA or individual LCA, sLCA, LCC, circularity or criticality assessments with or without the “aggregation” of results. Aggregation is defined as methods that combine (semi-)quantitative outcomes by generating aggregated or summary scores, which can be performed at different levels (at the level of LCSA, at the level of single sustainability domains or even at the level of sub-domains or stakeholder groups). A single score is thus understood as an aggregated score of results at different levels, and not only an overall summary score at the level of LCSA.

2.5.2. Evaluation, discussion and key messages

Based on a critical evaluation of these 15 integration methods or sub-procedures according to the criteria of Task 1.1, **it was, however, not possible to prioritize specific methods or sub-procedures at this stage**, to narrow the investigation of WP2. The reason is mainly because the scope of ORIENTING is necessarily unclear at this stage of the project regarding main LCSA principles and which methods to consider in the different domains, as well as in terms of application context. Because of the differences between the domains and the related challenges for integration, it is not desirable to distinguish between good and bad integration approaches, but rather between more and probably less appropriate approaches to address the integration challenge within a specific application context. Furthermore, regarding visualization of LCSA results, a balance between comprehensiveness of information (transparency) and easiness of interpretation (operability) must be pursued. Nonetheless, it was possible to describe in Task 1.6 the major ingredients for all possible application contexts, and to provide valuable insights that can effectively feed further methodological development in WP2. This also includes an indicative overview of the presence/absence of key features (e.g., potential to generate aggregated scores) in the evaluated methods, which can be used to assist the selection of methods and approaches to be developed in WP2.

Regarding other aspects to consider towards a consistently performed LCSA, the Task 1.6 team raised seven main relevant items, briefly discussed below, that should be further considered, debated and defined within ORIENTING:

- **Weak versus strong sustainability:** The difference between these two approaches was debated, which in summary can be distinguished by whether or not it is allowed to compensate amongst outcomes of LCSA, or single sustainability domains and even sub-domains, via generating aggregated scores. Weak sustainability, by allowing aggregated scores, consequently allows compensation within or across the sustainability (sub-)domains. Strong sustainability imposes that no aggregation of indicators should be allowed within or across the sustainability (sub-)domains;
- **Double-counting:** This issue can appear within a single sustainability domain and/or across domains. Typical examples of overlaps can be: (a) the characterization model for land use impacts on biodiversity, which are often based on observations, that not necessarily discriminate the cause; (b) certain social LCA topics such as “discrimination, treatment of indigenous peoples, and violence against women”; (c) the consideration of upstream costs in prices, leaving for interpretation of potential double-counting the latter; and (d) across the domains if areas of protection are chosen that are not consistently aligned;
- **Benefits and burdens:** In all domains, there is potential to consider benefits on top of burdens. While this is traditionally not considered in the environmental pillar, this is relevant for proper analysis of the social and economic pillars. Furthermore, the concept of handprint is growing, and this could be further analysed/considered in ORIENTING.
- **Relative and absolute sustainability:** LCSA is highly influenced by LCA, and the latter has a traditionally high comparative nature (i.e., it expresses relative sustainability). For this reason, LCSA has an equivalent nature. However, certain authors suggest the importance of shifting from a comparative/analysis oriented to a broader solution-oriented approach (via absolute sustainability). This is also an issue to keep in mind in ORIENTING’s further developments.
- **Communication purposes (internal versus external):** This discussion is related to the use case(s) (application areas) which ORIENTING target to have. Different factors (qualitative/quantitative; internal/external B2B/external B2C; aggregation or not; etc.) can define which type of approach is most suitable for a specific context. This is also linked to the first steps of WP2, where the principles of the LCSA will be defined (in Deliverable D2.1).

- **Uncertainty analysis:** Assessing uncertainty is an important aspect to keep in mind, as there are inherent elements of uncertainty in LCSA, e.g., missing link in the characterization of impacts to ecosystem services or gaps in the inventory of elementary flows (to mention a few related to the environmental pillar).
- **Policy linkages:** To further increase relevance, ORIENTING's methodology should as far as possible link with relevant policy initiatives and global objectives, such as the Sustainable Development Goals (SDGs) and the EU Circular Economy Action Plan. This is discussed in D1.5 and should be further reflected in WP2.

3. Limitations of WP1

This section is dedicated to analyse some particular limiting aspects on the outcomes of WP1. It is divided into three subsections: criteria for evaluation (from Task 1.1), unclarity of some recommendations, and topic-specific methods/tools not (deeply) evaluated.

3.1. Criteria for evaluation

The initial goal in Task 1.1 was to elaborate as far as possible a harmonized set of criteria for all topics and issues. On one hand, this approach resulted unviable due to inherent differences among the topics (e.g., s-LCA has very different scientific challenges than criticality methods in LCSA). Therefore, the last version from Task 1.1 (version 4) contained several (sub)criteria that were either solely dedicated to some topics/issues (e.g., s-LCA) or that were excluded for other topics/issues. Furthermore, every task enhanced this set of criteria (after version 4) in function of specific needs, as described in the respective deliverables. On the other hand, with that initial approach of attempting to have a single set of criteria, it was difficult to tackle specific items or investigate in further depth the specific challenges of each topic/issue. Consequently, **the evaluation results should be analysed with care, since the specificities (details) of some methods could not be deeply analysed within the criteria.** Thus, sometimes, methods evaluated as *weak* in other research initiatives presented *good* results in ORIENTING's evaluation (e.g., Chaudhary et al 2015, in the environmental topic – check section 2.1.2).

The final set had six criteria with different numbers of sub-criteria in each. In different topics (e.g., integration topic), one criterion could have more relevance than another. For instance, *stakeholder acceptance, credibility and suitability* (criterion #1) seems to be more relevant for the social topic than to the environmental topic. Ideally, each criterion would have had a weighting factor, based on stakeholder agreement, in order to systematically aggregate them into an overall/final score of each analysed method/tool. However, this procedure seemed to be unfeasible considering the resources on Task 1.1. Therefore, the practical solution was to set an **equal weight to all criteria**, even though this would not highlight the most relevant aspects. Furthermore, since some criteria had a small/limited number of sub-criteria (e.g., criterion #6 – *compatibility with life-cycle approach*) and others had a higher number of sub-criteria (e.g., criterion #4 – *scientific robustness* – had 10 sub-criteria for the environmental topic), the sub-criteria from a criterion with a high number of them (e.g., the latter case) automatically became “less relevant” since they would be divided by a high number (e.g., 10) in order to obtain the criteria's average score, while in the other case would be divided by a small number (e.g., 2). In other words, a sub-criterion could have five times lower relevance than another, from another criterion. Therefore, **the evaluation results, especially the overall/final scores, should be interpreted with care as well, due to the intrinsic limitations imposed by the weighting approach considered.** To limit issues associated with weighting, the evaluation has focused, as far as possible, on the identification of “red flags”, i.e. negative characteristics that a method must not present, complemented by an evaluation of separate and aggregate scores of criteria and sub-criteria.

Moreover, the answers in the criteria were based on expert knowledge because of resource and times reasons, while they could have benefitted from validations through consultations with stakeholders or via documented evidence. This can be quite relevant for certain criteria, e.g. criteria #1 (*stakeholder acceptance, credibility and suitability*). As this was not performed, **the answers provided were mainly based on the best of the expert's knowledge**, not peer-reviewed, which consequently implies taking additional care in the interpretation of the results of the analysis.

Besides, the evaluated methods/tools were answered by different experts involved in ORIENTING. Since the questions in a few sub-criteria were open for interpretation, a few answers could have been inconsistently given because of different method-evaluator combinations. This issue was especially relevant when the answer could have been either *not applicable* (N/A) or score “E” (the lowest). Due to the mathematical procedure behind, it would cause quite some difference in the results if “N/A” or “E” was to be applied (e.g. when no endorsement was found by a one stakeholder group): the latter would decrease the criteria result considerably (depending on the criteria). This issue was

adjusted/harmonized via discussions (e.g., in specific task meetings), trying to place everyone's understanding in the same relative level, between A and E, and having clear understandings on when a "N/A" should be considered. Furthermore, the evaluation was iterative to converge towards the most appropriate scores experts considered to assign.

3.2. Lack of specification of recommendations

According to the project proposal, WP1 started in the beginning of ORIENTING and provides relevant information for WP2 and WP3, which build upon the previous work done in WP1 as well as other WPs. However, several analyses in WP1 would have benefitted from further guidance and/or detailing of how the LCSA methodology proposed in ORIENTING will look like. For instance, how many indicators will it have in the end or for which use case should it be intended. The answers to these questions will only come during the further development of the ORIENTING project, through collaborative work of WP2 and other work packages (WP3, WP4, WP5 and WP6). **Notwithstanding this current open status, WP1 provides WP2 with valuable insights and possible ways to take in the ORIENTING methodology development**, also depending on future decisions not (fully) taken already. This is one of the reasons why some recommendations, especially in the social and integration topics, were less straightforward and lacked some degree of specificity. Nevertheless, the effort performed in WP1 will make the work in WP2 more efficient, e.g., as an in-house source and first analysis of methods/tools to be potentially considered.

3.3. Topic-specific methods/tools not (deeply) evaluated

Although extensive literature search was performed in all tasks, a few relevant methods were not evaluated according to the criteria from Task 1.1, mainly because they did not pass the screening stages (beforehand), or for other practical reasons (e.g., the evaluation of NGO's data in the social topic).

This section tries to highlight a couple of methods/tools that were not evaluated in WP1, but may have some relevance in the development of ORIENTING's LCSA methodology. Below these methods/tools are identified.

- **Environmental topic:** The methods from Boone et al. (2019) and Maier et al. (2021) were not critically evaluated but ought to be considered in WP2 due to the complementary aspects they could bring in the field of land use impact assessment;
- **Social topic:** The data from NGO's and other international organizations were not evaluated for practical reasons, i.e., a focus was provided on databases and the other six commercial data sources (that are generally more comprehensive). Nonetheless, as mentioned in ORIENTING (2021b), they may be further analyzed in case they seem to be relevant for WP2, as single issue data provider or with complementary purposes;
- **Economic topic:** For practical reasons the review of economic approaches was limited to those most established/acknowledged ones in the field. However, during the review, other promising conceptual frameworks were also identified, such as the "Economic LCA" (Neugebauer et al., 2016). This proposed framework can be further analyzed in task 2.4. as it promotes the use of midpoints and endpoints indicators in the economic domain (note that the indicators specification is one of the main goals in task 2.4), relating microeconomic activities to macroeconomic consequences and economic targets.
- **Circularity topic:** One well-known and used methodology for circularity is the World Business Council for Sustainable Development (WBCSD) toolkit. It was not considered in Task 1.5 because the indicators were provided at company level (not product-level, for LCSA) and it was based on several different indicators, while the analysis was focused on individual indicators/methods. Nonetheless, due to its relevance, it may be further considered in Task 2.5 how this could feed the methodological work of the ORIENTING project.

4. Stakeholder input

On April 23rd, 2021, ORIENTING hosted its first stakeholders' workshop. The outputs of this event are detailed in Deliverable D5.2 (ORIENTING, 2021f). In this section the most relevant feedback relevant for WP1 is summarised and discussed (shortly reported here). One important remark is that the points raised in the event and reported in D5.2 and here do not necessarily mean that a total consensus on these aspects was reached by the stakeholders, but rather describes particular items mentioned by some participants.

For aspects that relates to the **integration topic**, the following issues should be highlighted:

- **Aggregation** into single score can be a potential solution for the integration need, especially because it **can ease communication**. In that sense, it is also acknowledged that “why” and “how” to aggregate may depend on the different types of users, e.g., for consumers a single score may work best, while experts should be able to look into separate categories;
- On the other hand, there are some **concerns on how to perform weighting**. It is then further suggested to investigate multi-criteria decision analysis (MCDA) methods. Nonetheless, also **transparency is seen as a very relevant aspect**, which would require to present the indicators separately (with some guidance on how to aggregate based on the relevance of the indicators for the specific products analysed);
- Moreover, there were also some concerns about the **availability of benchmarks**, that can be relevant for e.g. single score comparison; as they cover a limited set of products.

For aspects that relate to the **circularity (and criticality) issue(s)**, the following issues should be highlighted:

- There is a **clear need to address circularity within the LCSA**. However, while having specific complementary indicators within LCSA was considered useful, **circularity aspects are already accounted for** also with several indicators and calculation methods used in (environmental) LCA.

For aspects that relates to the **social topic**, the following issues should be highlighted:

- The social value of the **use phase** (e.g., safety, convenience, aesthetics) of the product should be considered, since this influences the purchasing decision;
- The assessment should be governed by the **materiality**, to avoid an overly complex method with too many impact categories.

Furthermore, other issues mentioned in Deliverable D5.2 that are also relevant to WP1, but not necessarily linked to a particular topic/issue, are:

- The communication of **positive impacts** is of relevance for a company aiming to show its effort in improving its sustainability performance; however, it is necessary to ensure that giving importance to the positive impacts of a product or activity, does not come at the expenses of an effort of reducing negative impacts. This can be relevant specially for *economic, social* and *integration* topics.
- The LCSA could focus on gate-to-gate assessment, and allow for early-stage assessment. Considering the life cycle perspective to be considered in a LCSA, the aforementioned sentence actually supports a **modularity approach**, according to which, the total LCSA is obtained by adding up the impact for each actor in the product value chain. Nonetheless, it is important to highlight the relevance of having a life cycle perspective (i.e., beyond a gate-to-gate assessment) for LCSA studies.

The stakeholders provided several inputs that are relevant for ORIENTING. Above are the most relevant ones regarding the work done in WP1. Overall, those aspects were already considered somehow in WP1, thus the stakeholder workshop could corroborate some hypothesis from ORIENTING team. Therefore, it is important that WP2 considers, on top of Deliverables D1.1 to D1.5 outputs, the main messages from D5.2 as well.

5. Conclusions

WP1 critically analysed several methods/tools to be further considered in WP2's methodological development. While certain recommendations were more straightforward, others were less (or rather evasive) due to certain open questions still existing in ORIENTING. For the environmental topic, in general it gives indications on how to develop (new) land use impact assessment methods, not necessarily selecting which one should be considered. For the social topic, the work done gives a starting point, but leaving further recommendations for later, once clarifications on the LCSA framework are provided. Regarding the economic topic, the suggestion provided is to build a modular and encompassing framework, which connects the existing economic approaches and makes them functional according to the needs of the users. For criticality and circularity issues, a few methods are suggested to be taken further, but how to integrate them into LCSA was left to further exploration in WP2. Finally, for integration topic, deep analysis and discussions on relevant integration items and procedures were provided, but it could not yet provide recommendations as it is dependent on the actual paths that the ORIENTING's LCSA framework will take (and that will be defined/detailed in the upcoming months).

While WP1 provides a robust scientific research, through analysis of the methods/tools/approaches, the evaluation procedure via the set of criteria from Task 1.1 has some limitations that need to be acknowledged. Therefore, the results of the intermediate and overall scores should be interpreted with care. Furthermore, certain recommendations could not be already made due to other pending decisions on the LCSA framework (e.g., use cases of the ORIENTING's LCSA framework), as previously described. On top of that, certain methods/tools were not deeply evaluated, and may come back in WP2, if relevant. In addition to the work developed in WP1, the inputs obtained from stakeholders (at WP5) ought to be further considered already at early stages of WP2 (e.g., the communication of positive impacts is of relevance).

This document (Deliverable D1.6) attempts to summarize the work done and the key messages obtained in WP1. It is intended that the information provided by WP1 is further used in WP2 (and other WPs), with the ultimate purpose of facilitating the interpretation of what is available in the literature, already categorizing it in qualitative terms, in order to allow the work of WP2 to become more efficient. As ORIENTING's approach is to build upon what is available in literature into an operational LCSA framework, WP1 brings a crucial contribution to support the goal of ORIENTING to achieve that in relatively short term (i.e., within a 3-year research project).

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