BenchValue – Benchmarking the Sustainability Performances of Value Chains

ToSIA Gap Analysis – Literature Study

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Content

Preface

BenchValue – Benchmarking the Sustainability Performances of Value Chains – is a research project coordinated by the European Forest Institute (EFI) and funded under the framework of transnational ERA-NET network by national funding bodies in Austria, Finland, France, Ireland, Lithuania and Sweden. The project aims to facilitate improvements in comparisons of the sustainability performances between forest biomass-based vs. fossil/mineral-based value chains.

BenchValue describes value chains in a process-based approach aimed at decision making by assessing environmental, social and economic impacts of alternative chains using ToSIA (Tool for Sustainability Impact assessment). BenchValue focuses on the market place and develops generic indicators covering economic and socio-environmental aspects to be used in a benchmarking method that compares forest biomass-based materials against others.

This publication presents the results of the literature study conducted to identify improvements that can be made in ToSIA to make it a versatile tool for comparative sustainability assessments of wood-based and competing non-renewable products. This gap analysis was conducted by partners in Sweden, Austria, Finland and France, and is part of Work Package 2 of the BenchValue project.

Summary

Sustainable development has been adopted as a key political principle worldwide and evolved as the core paradigm for the continued development of our global society. The sustainability concept is essentially integrative and has become firmly associated with appreciation of the complexity of interrelated social and ecological systems. Sustainability assessments have become popular in the last decades to investigate sustainability effects of specific decisions and contribute to sustainable development.

A wealth of methodologies, methods, models, tools and indicators for sustainability assessments have been developed. Within BenchValue, the tool of choice is ToSIA, which stands for Tool for Sustainability Impact Assessment. This tool is developed and owned by European Forest Institute. The BenchValue project aims to refine ToSIA and expand it with a benchmarking method that allows for comparisons of wood-based products with competing non-renewable products in a lifecycle perspective.

To prepare for this development we carry through a gap analysis of ToSIA to shed light on what amendments, if any, are required in the tool. The gap analysis brings together current state of the art in sustainability science and the fundamental principles of indicator-based SA tools with the potentials of the current version of ToSIA to integrate these principles for cross-sectoral, comparative value chain assessments. The gap analysis discusses how well the current version of ToSIA meets criteria for sustainability assessments (Chapter 2), indicators (Chapter 3), the life-cycle perspective (Chapter 4), software tools (Chapter 5), and accurate modelling of climate impacts (Chapter 6).

The results of the gap analysis indicate that improvements can be made in all these aspects. However, most gaps identified are not gaps in the tool itself but rather in the instructions for use, in the established practice of ToSIA applications, and in the data so far collected for use in ToSIA. In order to address these gaps, we see the need for expanded, user-friendly guidelines for ToSIA practitioners. These guidelines should include well-specified protocols for data collection. If such protocols are widely used in ToSIA case studies, the data collected in the case studies can be compiled in a ToSIA database that will expand over time. All this would serve to make future case studies transparent, valid and replicable. This, in turn, would contribute to making ToSIA a more attractive tool for sustainability assessments.

The few gaps we found in the ToSIA tool itself concerns limitations on input data:

- If ToSIA allowed disaggregated economic input data that reflect how much money is spent in each process on purchases from each sector in the economy, it could be combined with economic input/output tables. This would reduce the need for cut-offs and, hence, make the assessment more comprehensive (Chapter 4).
- If data could be automatically imported from databases such as Ecoinvent, the studies would be more cost-efficient and the risk of typing errors would be reduced (Chapter 5).
- Allowing for input data on the time of different processes and activities might be necessary to fully account for the climate benefits and impacts of temporary storage and release of carbon (Chapter 6).

1 Introduction

1.1 The BenchValue project

In light of bioeconomy developments in Europe, bio-based solutions (e.g., raw materials, products) are gaining momentum across various levels within European societies. It is expected that renewable materials have the potential to unlock the full power of bio-based value chains and thus significantly contribute to the substitution of fossil-based materials or products and to the mitigation of climatic changes. To justify these hypotheses science must provide answers. Sustainability assessments (SA) have been in focus over the past decades to investigate sustainability effects and inform decision making at various scales. A wealth of methodologies, methods, models, tools and indicators for SA have been developed with the aim to contribute to sustainable development, providing efficient and reliable prospects when measuring progress towards sustainability and assessing related objectives and goals.

Within the BenchValue project, the Tool for Sustainability Assessment (ToSIA) is applied and further developed as a versatile and flexible decision support tool for cross-sectoral comparisons of value chains based on different materials. ToSIA is a flexible, entirely data-driven tool that has originally been developed for forest wood chains and has been used to compare renewable bioenergy with fossil energy chains, and for non-wood value chains (Lindner et al., 2010). The main aim of the project is to tailor ToSIA towards a comparative assessment tool for the construction sector by integrating a benchmarking routine that allows to analyse the difference in important sustainability aspects between certain construction materials, and structural materials (in case of BenchValue it will be wood material value chains against mineral and non-renewable value chains). The expansion of ToSIA will be tested in different case studies on typical construction value chains in: i) Austria, ii) France, iii) Ireland, and iv) Lithuania.

To come to grips with the strengths and weaknesses of ToSIA, in comparison with contemporary “standards” for SA tools and existing methods (e.g., Life Cycle Assessment, Life Cycle Sustainability Assessment), it is a prerequisite to identify potential gaps that may exist and that are likely to hinder the tool to unfold its potential for fulfilling the requirements for holistic SA of different construction materials. Thus, the gap analysis of ToSIA is among the most crucial tasks in the initial phase of BenchValue.

1.2 The gap analysis

By bridging the current state of knowledge on SA with the demands for a comparative decision support tool for construction materials in a value chain perspective, the gap analysis pin-points discrepancies in sustainability assessment methods and frameworks for different bio-, mineral- and fossil-based value chains and provide an in-depth analysis of ToSIA regarding its potential to meet the key methodological objective of Bench Value:

- expanding ToSIA with a method for benchmarking of wood material value chains against mineral and non-renewable value chains in a lifecycle perspective.

The gap analysis was carried out jointly by Bench Value project partners and started off from a knowledge-exchange and discussion group among responsible Bench Value researchers. Main questions addressed included:

- What are the criteria for holistic SA tools according to current scientific knowledge?
- Which indicators are available or required to assess the sustainability dimensions of construction value chains in relation to the current knowledge on the properties of indicators and indicator sets in general as well as in sustainability assessments?
- Are there any criteria on the good practice of indicator definition / development and how do current indicators covered by ToSIA consider such criteria?
- What activities in the economic or sociotechnical system should be included in life cycle studies and how should these parts be modelled in a viable tool for sustainability assessments in a life cycle perspective?
- How to cope with user-friendliness, flexibility and transparency in an expert software tool?
- What has to be taken into consideration when assessing the climate impacts of various construction materials and how can this be mirrored in an indicator-based expert tool?

Along the lines of the above mentioned questions, this report depicts the current state of ToSIA and its existing gaps that could be identified. Each chapter builds on the most recent literature and synthesizes existing knowledge towards the objectives of BenchValue and the further methodological development of ToSIA. In the following, identified gaps are discussed, rated and analysed towards their potential for amendment.

2 Criteria for sustainability assessments

2.1 Perspectives in the literature

Sustainable Development (SD) is the core paradigm our global society is striving for in recent years, adopted as key political principle worldwide. Since its introduction, as outlined in the Brundtland report (WCED, 1987), the commonly accepted definition of sustainability implies “to make development sustainable is to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs”. Three areas were originally identified that need to be sustained: i) nature, ii) life support systems, and iii) community (USNRC, 1999). Starting off from this notion, post-Brundtland perceptions of the sustainability paradigm recognized an even more holistic understanding of the sustainability concept. It is essentially integrative and has become firmly associated with appreciation of the complexity of interrelated social and ecological systems (Gibson, 2006). In relation to the key underlying documents (i.e., the Brundtland report, the Rio Declaration, Agenda 21) that the integrative concept of SD builds upon (Rösch et al., 2017):

- inter- and intragenerational justice, both equally weighted, as theoretical and ethical fundament
- a global perspective, by addressing key challenges of the global community and developing goals and strategies to achieve them and
- an enlightened anthropocentric approach including the obligation of mankind to interact cautiously with nature based on a well-understood self-interest

Overlapping and conflicting priorities, value systems and complexities of interlinked systems and sectors are among the challenges that have to be addressed when assessing pathways to a more sustainable future. As a response to these challenges, aiming to foster a transition to sustainability, sustainability assessment has evolved as a rapidly developing area.

Sustainability assessment (SA) is “a range of processes that all have as their broad aim the integration of sustainability concepts into decision-making” (Pope, 2006). It is one of the most complex types of appraisal methodologies that does not only entail multidisciplinary aspects (i.e., environmental, social, economic), but also cultural and value-based elements (Sala et al., 2015). Due to this complexity and multidimensional facets and in line with the global scientific awareness of long-term threats to our vulnerable ecosystems the development of a new discipline, sustainability science, started off as an emerging field whose domain was originally set by Kates et al. (2001) and consequently developed further. A plethora of methodologies, methods, models, tools and indicators for SA have been developed over the past decades. What they have in common is the aim to contribute to sustainable development, providing efficient and reliable prospects when measuring progress towards sustainability and assessing related objectives and goals. Ness et al. (2007) provide a categorization of sustainability assessment tools within the broader objective of lifting the understanding of SA from the environmental-focused realm to a wider interpretation of sustainability.

Sala et al. (2013) reviewed the state of the art in sustainability science from the perspective of LCA and LCSA and presented a set of 18-20 criteria for evaluation of LCSA approaches. They found, among other things, that methods for SA should ideally have a broad systems perspective and consider issues at different but interrelated geographical and temporal scales. They should also be transdisciplinary with a balanced participation of stakeholders with different perspectives. In addition to environmental, social and economic burdens, they should also consider positive impacts, limitations in resources and carrying capacity, and the vulnerability and resilience of ecological, social and economic systems. Furthermore, Sala et al. (2013) outlined the following requirements according to present understanding within sustainability science for SA methodologies and related methods:

- **analytical–descriptive**
  The methodologies and related methods must be appropriate in addressing the key features of sustainability problems, the current state, the potential systemic changes, consequences, feedbacks and lock-in and lock-outs of a particular development in specific areas.
- **solution-oriented**
  The methodologies and related methods have to: develop goal-oriented and actionable knowledge, that is sufficient for solving the problem at hand, and realize sustainable transition towards desirable state and goals; support transition management approach developing visionary, evolutionary learning process; assist the decision making in assessing sustainability at systemic level, making concrete both problems and solutions; assist in moving from predictive to exploratory analysis.
- **participative**
  The methodologies and related methods have to: be designed and developed in a participatory, interactive (non-extractive) collaborative way; be shifted from supply- to demand-driven; facilitate knowledge co-generation through participation processes of scientists and stakeholders interacting from problem framing to strategy

implementation, transparently balancing inputs and facilitating knowledge claims, shared control over the process and accountability of; increase trust, ownership and empowerment; to manage contested values by different stakeholders, different power dynamics and the urgency of decision making.

- **suitable for scalability, transferability and comparability**
  The methodologies and related methods have to allow for scaling-up and transferability of the solution options generated, ensuring comparison of alternative solution options and providing synthesis thereby strengthening the capability of solving sustainability problems.
- **capable to manage uncertainties of information…**
  …especially in broad trans-disciplinary systems in which complexity may dramatically increase. An example could be the analysis of the impact associated with biofuels, in which a number of direct and indirect environmental economic and social consequences are expected and are mutually affected (e.g. deforestation for biofuel production, competition of land for energy and food purpose, market reaction to increasing commodity costs).

Pinter et al. (2012) reviewed and updated the Bellagio Sustainability Assessment and Measurement Principles (BellagioSTAMP) that have been developed in 1997 by a group of leading measurement and assessment experts in order to provide guidance for evidence-based decision making (Table 1).

Table 1: Overview of the BellagioSTAMP principles and their rationale (Pinter et al., 2012).

Principle	**Definition**
Guiding vision	Assessment of progress towards sustainable development will be guided by the goal of delivering well-being within the capacity of the biosphere to sustain it for future generations
Essential considerations	Assessment of progress toward sustainable development will consider: - the underlying social, economic and environmental system as a whole and the interactions among its components, including issues related to governance; - dynamics and interactions between current trends and drivers of change; - risks, uncertainties, and activities that can have an impact across boundaries; and - implications for decision making, including trade-offs and synergies
Adequate scope	Assessment of progress toward sustainable development will adopt: - an appropriate time horizon to capture both short- and long-term effects of current policy decisions and human activities; and - an appropriate geographical scope

Framework and indicators	Assessment of progress toward sustainable development will be based on: - a conceptual framework that identifies the domains within which core indicators to assess progress are to be identified; - standardized measurement methods wherever possible, in the interest of comparability; and - comparison of indicator values with targets, as possible
Transparency	Assessment of progress toward sustainable development will: - ensure the data, indicators and results of the assessment are accessible to the public; - explain the choices, assumptions and uncertainties determining the results of the assessment; - disclose data sources and methods; and - disclose all sources of funding and potential conflicts of interest
Effective communications	In the interest of effective communication, to attract the broadest possible audience and minimize the risk of misuse, assessment of progress toward sustainable development will: - use clear and plain language; - present information in a fair and objective way that helps to build trust; - use innovative visual tools and graphics to aid interpretation and tell a story; and - make data available in as much detail as is reliable and practicable
Broad participation	To strengthen its legitimacy and relevance, assessment of progress toward sustainable development should: - find appropriate ways to reflect the views of the public, while providing active leadership; and - engage early on with users of the assessment so that it best fits their needs
Continuity and capacity	Assessment of progress toward sustainable development will require: - repeated measurement; - responsiveness to change; - investment to develop and maintain adequate capacity; and - continuous learning and improvement

2.2 Our criteria

Trying to bridge the holistic principles and/or criteria for sustainability assessment in general with the objectives of BenchValue and the comparative sustainability assessment of wood products with other products in a life cycle perspective, or more precisely the benchmarking of typical wooden house construction value chains in comparison with other mineral and fossil-based house construction chains (e.g., concrete, steel, cement) requests for an abstraction of science-based criteria and principles.

We propose the following criteria, as a minimum requirement for (a) viable SA tool(s), in order to analyse (assess) the sustainability impacts of competing, cross-sector value chains for construction (Table 2).

Table 2: Minimum requirements for Sustainability Assessment tools to assess the sustainability impacts of construction value chains.

Criterion	**Rationale**
Visionary	Supporting evidence-based decision making by assessing the sustainability effects of (a) current and future innovative value chain(s) to meet the needs of the present without compromising the ability of future generations to meet their own needs taking into consideration the capacity of our biosphere
Comprehensive	Providing a holistic assessment of social, economic and environmental effects of (a) value chain(s) (e.g., positive/negative feedback loops, relations, interactions and interdependencies of its components, substitution potentials, quantitative and qualitative aspects, ...)
Accurate	Defining proper organisational and spatial system boundaries allowing for scalability of results
Reproducible	Following contemporary standards and state of the art in sustainability science and specifically defining criteria and indicators for assessment, with precise instructions on data collection, calculation, assumptions and system boundaries
Transparent	Indicating data sources, data availability, data quality and their utilization. This includes information about input values, product and process definitions, material flows, assumptions.
Comprehensible	Supporting the efficient communication of sustainability effects between science-policy-practice and the general public
Participatory	Building upon broad stakeholder involvement / allowing for stakeholder engagement
Inclusive	Linking to existing and upcoming assessment frameworks, assessment methods, standards, statistics and databases to support decision making in policy, industry and consumption.

2.3 Assessment of ToSIA

In the following Table 3 we assess ToSIA towards the minimum criteria for a viable SA tool (see Table 2) and provide details on the identified gaps, if existing, or give an explanation on how the tool addresses the individual criteria. Descriptions thereof are always highlighted in italic letters under “rationale”.

Table 3: Assessment of ToSIA towards the minimum requirements (criteria) for SA Tools of construction value chains.

Criterion	**Rationale**
Visionary	Supporting evidence-based decision making by assessing the sustainability effects of (a) current and future innovative value chain(s) to meet the needs of the present without compromising the ability of future generations to meet their own needs taking into consideration the capacity of our biosphere --- *ToSIA analyses sustainability impacts of changes in value chains, present or future. However, behind every “effect” there must be a change. To assess whether “to meet the needs of the present without compromising the ability of future generations to meet their own needs taking into consideration the capacity of our biosphere”, thresholds are required to state what situation is within the capacity of the biosphere and what not. Other value chains compete for this same limited capacity – how can we determine which use of this capacity is justifiable, and what is not. This goal is simply unrealistic, but as such a GAP as thresholds are not typically collected for ToSIA indicators, although they could be collected.* *ToSIA does support decision making by making the sustainability effect visible, and provides Multi-Criteria-Analysis (MCA) to prioritise the different impacts against each other.*
Comprehensive	Providing a holistic assessment of social, economic and environmental effects of (a) value chain(s) (e.g., positive/negative feedback loops, relations, interactions and interdependencies of its components, substitution potentials, quantitative and qualitative aspects, ...) --- *ToSIA provides a balanced sustainability assessment framework, but it is up to the user designing a certain case study to identify and quantify the various facets of the case study such as substitution or interdependencies of case study components. There is no GAP here, but it requires a competent user. Improved documentation on this in the user guidance might be useful.*

Accurate	Defining proper organisational and spatial system boundaries, allowing for scalability of results --- *ToSIA captures steady states of value chains, which describe a given situation during one year. Theoretically, any other time period could be used as well, but typically data is not available to address this properly. The spatial dimensions of value chains are defined by the processes of each value chain – typically there is a trade off – the more accurate they are, the less scalable they are.*
Reproducible	Following contemporary standards and state of the art in sustainability science and specifically defining criteria and indicators for assessment, with precise instructions on data collection, calculation, assumptions and system boundaries ----- *ToSIA includes a rather detailed Data Collection Protocol (DCP), which already included a large amount of defined indicators with the instructions for their calculation, and guidance for avoiding double-counting. However, system boundaries are decided case-by-case, but with less clear instructions compared to LCA. However, as ToSIA is focussed on comparisons, the system boundary question changes to whether all "indirect effects" are relevant for the comparison. Also ToSIA indicators can be redefined or new ones can be created on a case-study basis, as this provides for robustness and better fit-for-purpose but overall comparability decreases. All used assumptions and definitions can be transparently documented in the tool. For the use of ToSIA in BenchValue, it will be relevant to agree on a joint set of indicators and their definitions.*
Transparent	Indicating data sources, data availability, data quality and their utilization. This includes information about input values, product and process definitions, material flows, assumptions. ---- *ToSIA provides the mechanism to give and display all used assumptions, data sources etc. It is up to the user to fill all this meta information*
Comprehensible	Supporting the efficient communication of sustainability effects between science-policy-practice and the general public --- *This is not the foremost task of the tool, but it is important to generate outputs and analytical tools that are user-friendly and don't require too exhaustive further processing of data for communication purposes. ToSIA does enable making consequences of policy decisions concrete and quantified, and thus can be used e.g., to support communicating the impacts of policies to the general public.*

Participatory	Building upon broad stakeholder involvement / allowing for stakeholder engagement ---- *ToSIA allows for stakeholder involvement. For example, the MCA integrated to ToSIA allows giving subjective preferences to sustainability impacts and thus supports stakeholder interpretation of the results.*
Inclusive	Linking to existing and upcoming assessment frameworks, assessment methods, standards, statistics and databases to support decision making in policy, industry and consumption. ---- *While this is a very generic target, ToSIA is a robust data driven tool, and can take in data from any sources where suitable data is available. Indicators to some extent can also be redefined to match desired standards or data formats.*

2.4 Assessment of the gaps

Given the contemporary opinion on what a SA tool has to fulfil (based on what is stated in the literature), it was our ambition to assess ToSIA against the criteria for good SA tools and identify possible gaps that should be considered when further developing the tool as envisaged within BenchValue. Although the criteria for SA and related tools are quite generally defined, they are useful to come to grips with the general vision of what SA should take care of in order to follow the state of the art in Sustainability Science. When applying these criteria in an assessment of a specific tool for SA, in our case ToSIA, it becomes obvious that the criteria are sometimes a bit too vague and may not be precise enough for the assessment to be possible. However, the assessment depicts potential strengths and weaknesses of a tool. These should be analysed in more detail to identify the feasibility of successfully aligning a tool with new paradigms of Sustainable Development.

As regards ToSIA and the selected criteria it can be recognized, that only a few gaps that could be identified:

- visionary
    - thresholds are currently not applied within ToSIA case studies (for indicators)
- comprehensive
    - usability to account for long term trade-offs among indicators

Given the general critique towards “sustainability” and the limited capacity of the biosphere that is universal, it has to be clarified that the gap related to the “visionary” criteria may only have a very limited effect on the power of the tool itself. However, it will be necessary to include thresholds (i.e., identify and agree upon maxima or minima for single indicators) to allow for the integration of benchmarking routines, one of the main development purposes of ToSIA within BenchValue.

The second gap related to the criterion “comprehensive” is not a real gap of ToSIA, but it reflects on the potential complexity of applying it within a decision-making context. As it is often the case, it depends on the know-how of the user to make most out of the functionality of a decision support tool. Therefore, it might be beneficial to improve existing handbooks to guide (new) users and provide additional training.

3 Criteria for indicators

This chapter first includes a general review related to the current knowledge on the properties of indicators and indicator sets in general and in sustainability assessments. It focuses on criteria for good indicators and indicator sets (e.g., clarity, comprehensiveness, etc.). A more detailed review of individual indicators (e.g., climate change, etc.) is included in subsequent sections.

3.1 Perspectives in the literature

Indicators are the tools of choice for measuring, monitoring and assessing progress towards defined targets. Indicators towards sustainable development have been in the centre of global political agendas over the past decades. They are often developed through dynamic participatory processes including a wide range of stakeholders. The most recent development in this respect is the formulation of the 17 Sustainable Development Goals (SDGs) that include 169 targets and a total of 230 indicators.

Since the use of indicators is widespread certain guidelines have been published that pinpoint proper indicator definition and selection (e.g., UN, 2007; UN, 2015). Good practice guidelines for indicator formulation and selection may include the following set of criteria (Advisory Committee on Official Statistics, 2009):

- *Valid and meaningful* – an indicator should adequately reflect the phenomenon it is intended to measure and should be appropriate to the needs of the user.
- *Sensitive and specific to the underlying phenomenon* – sensitivity relates to how significantly an indicator varies according to changes in the underlying phenomenon.
- *Grounded in research* – awareness of the key influences and factors affecting outcomes.
- *Statistically sound* – indicator measurement needs to be methodologically sound and fit for the purpose to which it is being applied.
- *Intelligible and easily interpreted* – indicators should be sufficiently simple to be interpreted in practice and intuitive in the sense that it is obvious what the indicator is measuring.
- *Relate where appropriate to other indicators* – a single indicator often tends to show part of a phenomenon and is best interpreted alongside other similar indicators.
- *Allow international comparison* – indicators need to reflect goals specific for the country or region of the study, but where possible should also be consistent with those used in international indicator programmes so that comparisons can be made.
- *Ability to be disaggregated over time* – indicators should be able to be broken down into population sub-groups or areas of particular interest, such as ethnic groups or regional areas.
- *Consistency over time* – the usefulness of the indicators is directly related to the ability to track trends over time, so as far as possible indicators should be consistent.
- *Timeliness* – there should be minimal time lag between the collection and reporting of data to ensure that indicators are reporting current rather than historical information

- *Linked to policy or emerging issues* – indicators should be selected to reflect important issues as closely as possible. Where there is an emerging issue, indicators should be developed to monitor it.
- *Compel interest and excite* - the indicator should resonate with the intended audience.

A more compound definition of criteria for indicators is given by Castro (2011) and highlights two established principles following Drucker (1954) and Schiavo-Campo & Tommasi (1999), SMART and CREAM. The criteria are summarized in Table 4.

Table 4: Quality principles for performance indicators - SMART and CREAM (Castro, 2011).

Concept	Rationale
SMART	**S**pecific (precise and unambiguous) **M**easurable (appropriate to subject) **A**chievable (of a reasonable cost) **R**elevant (serve to assess performance) **T**rackable (easy to validate or verify)
CREAM	**C**lear **R**elevant **E**conomic **A**dequate **M**onitorable

At present, an array of indicators is used in various different contexts (Hák et al., 2016). Indicator frameworks help to focus and clarify what to measure, what to expect from measurement and what kinds of indicators to use. Such frameworks include an array of different approaches, like: i) Driving force-state-response frameworks, ii) issue- or theme-based frameworks, iii) capital frameworks, iv) accounting frameworks, or v) aggregated indicators among others (UN, 2007). In the light of European bioeconomy developments, Wolfslehner et al. (2016) recently recapped the state of the art of indicator application in Europe and particularly addressed the role of forest indicators in this regard. Based on the results of a former study (European Forest Institute, 2013) they identified five major applications of indicator use in Europe:

- Reference framework for dialogue, communication, and streamlining the forestry debate.
- Tool for monitoring and reporting on the progress towards sustainable forest management, and improving quality and comparability of forest information among European countries.
- Reference framework for the development and adaptation of national policy instruments and/or forest-related policies.
- Assessment tool for measuring progress towards sustainable forest management and identifying emerging issues.
- Information tool for creating links to other sectors and global initiatives.

For the built environment several indicator frameworks have been developed and are applied, often in context of a rating system for environmental assessment of buildings. Castellano et al. (2016) provide a review of contemporary rating systems, including BREEAM, LEED, CASBEE, BEAM and others. Since the building (respectively construction) industry is considered to be one of the largest exploiters of natural resources and has regularly been in the centre of criticism regarding energy use, waste production, greenhouse gas emissions and impacts on the landscape sustainable construction has recently become a hot topic in construction research (e.g., Al-Nassar et al., 2016; Kibert, 2012; Kashap et al., 2003). In 2015 the European Commission initiated a study to develop an EU framework of core indicators for the environmental performance of buildings (LEVELs) and identified six macro-objectives that establish the strategic focus and scope for the framework of indicators (Table 5).

Table 5: Macro-objectives to identify performance indicators for buildings (Dodd et al., 2016a).

Type	**Objective**	**Definition**
Life cycle environmental performance	Greenhouse gas emissions from building life cycle energy use	Minimize the total greenhouse gas (GHG) emissions along a buildings life cycle, with a focus on building operational energy use emissions and embodied emissions.
	Resource efficient material life cycles	Optimize building design, engineering and form in order to support lean and circular flows, extend long-term material utility and reduce significant environmental impacts.
	Efficient use of water resources	Make efficient use of water resources, particularly in areas of identified long-term or projected water stress
Quality, performance and value	Healthy and comfortable spaces	Design, construction and renovation of buildings that protect human health by minimizing the potential for occupier and worker exposure to health risks.
	Resilience to climate change	The future proofing of building thermal performance to projected changes in the urban microclimate, in order to protect occupier health and comfort.
	Optimised life cycle cost and value	Optimisation of the life cycle cost and value of buildings, inclusive of acquisition, operation, maintenance, disposal and end of life.

Following the macro-objectives and building upon stakeholder consultation a suite of indicators was identified, with the following ones suggested as core indicators within the framework (Dodd et al., 2016b):

- Operational energy consumption
    - Total primary energy consumption
    - Final energy consumption
- Operational and embodied global warming potential (GWP)

- Building bill of materials
- Scenarios for life-span, adaptability and deconstruction
- Construction and demolition waste
- Use-stage drinking water consumption
- Airborne pollutant levels
    - Quantitative airborne pollutant levels
    - Qualitative airborne pollutant levels
- Indoor air class (ventilation, CO2 and relative humidity)
- Occupant thermal comfort
- Additional energy required
- Life Cycle cost
    - Utility costs
    - Acquisition and maintenance costs
- Value and risk factors

Standards have also been developed at ISO and CEN level to assess the sustainability of buildings on the three pillars: environmental impact, social impact and economic impact. The indicators contained in the general framework are described in the series of standards. The (EN 15643-1: 2010) standard corresponds to the general framework, the (EN 15643-2: 2011) standard to the environmental indicators, the (EN 15643-3: 2012) to the social indicators and the (EN 15643-4: 2012) to the economic indicators. The corresponding calculation methods at building level are described in the (EN 15978: 2012) standard for the environmental performance, the (EN 16309:2014) for the social performance and (EN 16627: 2015) for the economic performance. The environmental assessment at building level is obtained from Environmental Product Declarations which are calculated based on the (EN 15804: 2012) standard. This standard is further described in Section 4.1.

The indicators are as follows:

- Environmental indicators:
    - LCA indicators with a set list of indicators (see Table 6). Additional indicators are considered in the future amendment of the standard like: human toxicity (cancer effect), human toxicity (non-cancer effect), ecotoxicity (freshwater), land use related impact (soil quality), particulate matter emissions, and ionising radiation (human health).
- Social indicators (building related for the fabric and user and control system related):
    - Accessibility (accessibility for people with specific needs, access to building services);
    - Adaptability;
    - Health and Comfort (thermal characteristics, characteristics of indoor quality, acoustic characteristics, characteristics of visual comfort, spatial characteristics);
    - Loadings on the neighbourhood (noise, emissions, glare/overshadowing, shocks vibration);
    - Maintenance (maintenance operations);
    - Safety / Security (resistance to climate change, accidental actions (earthquake, explosions, fire and traffic impacts), personal safety and security against intruders and vandalism, security against interruptions of utility supply);

  - Sourcing of materials and services (not yet ready for standardization); and
  - Stakeholder involvement (not ready for standardization).
- Economic indicator:
  - The cost of the building over its life cycle; and
  - Monetary value.

Based on the success of the above described standards, many European countries (for example France and Finland) have started to introduce labels mainly on carbon and energy considering the whole life cycle of the building and not just the use phase. This is the case for instance in Finland and for France with the objective of introducing an environmental regulation based on life cycle assessment alongside the thermal regulation at the 2020-2025 horizon. First a methodology for assessing the environmental impact of building is developed based on existing standards, then a label or certification is introduced. This label or certification is experimented to test certification levels which will be updated to produce the regulatory thresholds. In France, the E+C- (Energy plus Carbon minus) label has been launched end of 2016. Four energy performance levels have been defined for positive energy buildings, along with two environmental performance levels regarding greenhouse gas emissions.

3.2 Our criteria

Different approaches to further develop indicators can be discerned based on a study on sustainability indicators for a bioeconomy by Wolfslehner et al. (2016) The options have both structural and thematic implications:

- Option 1 is complementing existing indicator sets with specifically required additional indicators. In the context of ToSIA, this would mean that principal sustainability assessment framework of the tool is maintained and complemented with (few) additional indicators, such as an LCA indicator, a land use indicator, etc. This approach could also take inputs from the stakeholder workshop into account
- Option 2 is creating subsets of indicators to respond to the 5 major challenges of a bioeconomy. This is more a structural change that identifies indicators that can assess the contribution to climate change mitigation, sustainability of operations, reducing the dependence on fossil fuels, or competitiveness and job creation. Modalities of indicator aggregation and indices could be explored. For instance, LCA indicators could come in as a composite element in such an approach.
- Option 3 is creating a new set of key indicators, here for sustainable wood construction. The idea is to identify a few indicators that are highly robust for explaining the topic and leave out material and data that have only informational nature.

Table 6: List of indicators in the current version of the EN15804.

Parameters describing environmental impacts	
Global warming potential	kg CO_2 eq. / FU
Depletion potential of the stratospheric ozone layer	kg CFC-11 eq. / FU
Acidification potential of soil and water	kg SO_2 eq. / FU
Eutrophication potential	kg PO_4^{3-} eq. / FU
Formation potential of tropospheric ozone	kg ethene eq. / FU
Abiotic depletion potential (ADP-elements) for non fossil resources	kg Sb eq. / FU
Abiotic depletion potential (ADP-elements) for fossil resources	MJ / FU
Air pollution	m^3 / FU
Water pollution	m^3 / FU
Parameters describing resource use	
Use of renewable primary energy exluding renewable primary energy resources used as raw materials	MJ / FU
Use of renewable primary energy resources used as raw materials	MJ / FU
Total use of renewable primary energy resources	MJ / FU
Use of non renewable primary energy excluding non renewable primary energy resources used as raw materials	MJ / FU
Use of non renewable primary energy resources used as raw materials	MJ / FU
Total use of non renewable primary energy resources	MJ / FU
Use of secondary material	kg / FU
Use of renewable secondary fuels	MJ / FU
Use of non renewable secondary fuels	MJ / FU
Net use of fresh water	m^3 / FU
Parameters describing waste categories	
Hazardous waste disposed	kg / FU
Non hazardous waste disposed	kg / FU
Radioactive waste disposed	kg / FU
Parameters describing output flows	
Components for re-use	kg / FU
Materials for recycling	kg / FU
Materials for energy recovery	kg / FU
Materials for energy recovery (heat)	MJ / FU
Materials for energy recovery (electricity)	kWh / FU

These approaches are not mutually exclusive but depend on the data collection and processing burdens that are foreseen as reasonable for the assessment. In principle, the aim should be:

- To have a balanced set of indicators, i.e., that the economic, environmental, and socio-economic aspects are considered equally, and/or the bioeconomy challenges are tackled comprehensively
- To have an accepted set of indicators, which requires uptake of the stakeholder workshop results to the extent possible
- To have indicators that can be connected to data and statistics from other sectors (e.g., steel, concrete, wider EU statistics)

One step further, the idea of trade-off indicators could be investigated, at least in an exploratory way. Trade-off indicators bring together pairs or larger numbers of indicator to depict causal relationships among indicators (e.g., biomass-biodiversity, bioenergy-land use). This approach is meant to bring additional analytics into SIA and could be used for improved communication of complex systems analysis.

The stakeholder workshop revealed the following most important topics to be considered for ToSIA application:

- Local impacts, e.g., local economic benefits, optimized resource use, political responses
- Waste management, e.g., LCA indicators, share of prefabrication, types of waste
- Health and well-being, e.g., exposure time and rate, air quality, comfort
- Resource depletion, e.g., land use effects, use of renewable resources, species diversity
- Adaptability, e.g., reuse of material, flexibility of buildings, risk and climate change adaptability
- Beauty and Biophilia, e.g., social effects, social acceptance, safety
- Employment, e.g., direct and indirect employment effects
- Climate impacts, e.g., carbon footprint, GHG balance, fossil CO_2

Respective operational indicators for ToSIA will be scrutinized and tested against the principal criteria as set out in the beginning in the further course of BenchValue.

3.3 Assessment of ToSIA

ToSIA has been originally designed around a classical sustainability approach of satisfying the three pillars of sustainability. Similar to reports from literature, socio-economic indicators tend to be underrepresented due to lack of data (e.g., Gough et al., 2008), or difficulties to quantify socio-economic aspects in a material-driven SIA tool. The results from the stakeholder workshop also makes it evident that stakeholders consider socio-economic issues important, for example local impacts, health and well-being, or beauty and biophilia (Ekvall et al., 2017). These areas seem to be major fields for further ToSIA development, while aspects such as waste, climate change or resource depletion seem to be already properly addressed.

However, additional indicators have to be considered carefully in the given time and resource frame of BenchValue.

3.4 Assessment of the gaps

Since ToSIA allows for indicator development and definition along the three pillars of sustainability, it becomes obvious that there is no gap as such in relation to the desired indicator portfolio. However, there seems to be a clear underrepresentation of the social dimension currently, as stated above. Nonetheless, ToSIA provides the opportunity to introduce new indicators according to the specific needs of a case study/the user. This has to be done in accordance with the "data collection protocol for ToSIA indicators" (Tuomasjukka, 2014), to have a common format for each indicator regarding measurement units, boundaries, recommendation and sources and means to procure and calculate values on indicators. All indicators are defined in a general setting, with specifications for different sectors. There are also spaces for module specific recommendations and key definitions that should be considered in order to have a defined data quality.

4 The life-cycle perspective

This chapter discusses what activities in the economic or sociotechnical system should be included in life cycle studies and how these parts should be modelled. To be a viable tool for sustainability assessments in a life cycle perspective, ToSIA should facilitate the inclusion of these activities in the model. The manuals or guidelines produced for ToSIA should also guide the users towards including these activities.

4.1 Life cycle perspectives in the literature

The life cycle perspective is probably most elaborately debated and described in life cycle assessment (LCA). The international standard on principles and framework for LCA (ISO 14040) defines the life cycle as the consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal. The life cycle in addition includes the production of ancillary inputs, which are used for producing the product but which are not part of the finished product, and also the production and use of the product itself. The life cycle can include cycles of recycling and reuse and it can also include energy recovery from waste management (§4.4 in ISO 14040). On a more detailed level, an LCA practitioner should consider the following (§5.2.3):

- acquisition of raw materials,
- inputs and outputs in the main manufacturing/processing sequence,
- distribution and transportation,
- production and use of fuel, electricity and heat,
- use and maintenance of products,
- disposal of process wastes and products,
- recovery of used products, including reuse, recycling and energy recovery,
- manufacture of ancillary materials, manufacture, maintenance and decommissioning of capital equipment (factories, machinery, vehicles, etc.), and
- additional operations such as lighting and heating.

ISO 14040 (§4.4) states that the life cycle in LCA is regarded as a product system that fulfils one or more defined functions. The function of the system is quantified in functional units (§5.2.2). The functional unit is the reference to which the impacts of the product system are related. Such a reference is necessary to make it possible to compare the impacts of different life cycles. ISO 14040 (§4.4) also states that the life cycle is divided into unit processes. Unit processes are the smallest element in the model of the life cycle; they are the human activities for which input and output data are collected in the study.

The international standard on requirements and guidelines for LCA (ISO 14044) gives more specific guidance on a few methodological issues. It states (§4.2.3.3.1) that the system boundary determines which unit processes are included in an LCA, and that the criteria used when defining the system boundaries shall be explained in the study. It specifies that life cycle stages, processes, inputs or outputs should be excluded from the life cycle model only if they do not significantly change the overall conclusions of the study. ISO 14044 (§4.2.3.3.2) argues that it is helpful to describe the system using a process flow diagram that shows the unit processes and their interrelationship. Each unit process should be described to define where it begins and ends and what transformations and operations occur within the unit process.

The boundaries of the product system have been discussed in many scientific publications. In contrast to ISO 14040 and 14044, several of these publications distinguish between attributional and consequential LCA. Simply put, attributional LCA (ALCA) aims to quantify the part of the global environmental burdens that should be associated with the product investigated and its life cycle (see Figure 1). Consequential LCA (CLCA) aims to quantify the foreseeable impact of the product (or of changes made in the product life cycle) on the global environmental burdens. However, the definitions of the two approaches vary slightly between different publications (Ekvall et al., 2016). Sonnemann and Vigon (2011), for example, defines the attributional approach as system modelling where inputs and outputs are attributed to the functional unit of a product system by linking and/or partitioning the unit processes of the system according to a normative rule. They define the consequential approach as system modelling where activities in a product system are linked so that activities are included in the product system to the extent that they are expected to change as a consequence of a change in demand for the functional unit.

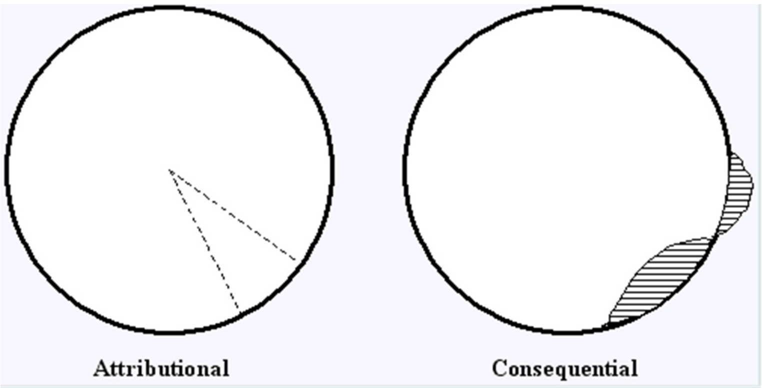

Figure 1: Simplified illustration of the difference between attributional and consequential LCA (Weidema, 2003).

4.1.1 System boundary towards nature

The life cycle has a system boundary towards nature. In LCA, the life cycle should ideally be modelled in such a way that the flows across this boundary are elementary flows. This means that the life cycle should include all human transformation of the flows. However, processes that do not significantly affect the conclusions of the study need not be included in the model (§5.2.3).

As stated by, for example, Finnveden et al. (2009), it is often not known in advance which activities are insignificant and can be excluded from the model. Finnveden et al. indicate that the significance of excluded activities could be estimated through the use of input-output analysis and/or through accumulated experience of, for example, the importance of capital equipment. Activities of unknown significance can be included in the model but based on rough, easily accessible data. This gives an initial estimate of the importance of the data. The model can then be refined through the collection of better data to the extent it is possible and necessary for the purpose of the study.

The boundary towards nature can be difficult to define when the life cycle includes activities that integrate technology and nature, such as agricultural activities and forestry. Soimakallio et al. (2015 and 2016) argue that an ALCA should model land-use as the difference between the actual land-use and a baseline that represents nature. They discuss several different options for baseline. They argue that the most coherent baseline is natural generation, because natural generation is what happens if no further forest or agricultural products are produced. This suggests that ACLCA should model forestry as the difference between the actual, managed forest and a forest that is abandoned to develop on its own. Using natural generation as baseline means that any extraction of biogenic carbon will be accounted for as a reduction in the stock of carbon in the forest. If the wood is used in buildings, most of the carbon will be stored there instead. However, extraction of wood for production of short-lived products, such as packaging or newsprint, will result in a net total reduction in carbon stock and an associated impact on the climate, if the baseline is natural generation. On the other hand, such an ALCA should also account for any increase in the carbon stock that results from continued forestry processes.

Brander (2015 and 2016) agrees that an ALCA needs a baseline and that this baseline should represent nature. However, he questions the arguments and conclusions of Soimakallio et al. Brander emphasises the parallel between ALCA and other accounting systems, for example national carbon accounting, and argues that natural generation cannot be used as baseline in such a system. He claims that a baseline that represents nature should instead be the more or less stable sequestration of carbon that would occur in a natural ecosystem if no forestry or agricultural processes ever took place there. An ALCA of a wood product would then account for the difference in carbon sequestration between the managed forest and a natural forest. This would result in a lower net climate impact of wood products.

The issue has not yet been scientifically resolved. In practice, the baseline in ALCA often does not represent nature. Erlandsson & Zetterberg (2017), for example, use the carbon stock of current forest management as the baseline. If no change in forest management occurs, no change in the average carbon stock occurs. The ALCA of a wood product will not account for any change in carbon storage in the forest. It will, of course, include carbon emissions from machines used in the forestry. On the other hand, Erlandsson & Zetterberg account for temporal storage of carbon in the wood products and an associated reduction in climate impacts (cf. Chapter 6).

4.1.2 System boundary in the technosphere - allocation

The life cycle also has a system boundary towards other life cycles. Products can flow across this boundary (§4.4). A life cycle study that includes a flow of products, material or energy from one product system to another, encounters an allocation problem: what part of the environmental impacts of the production of this product, material or energy should be assigned to the product system investigated? An allocation problem can be managed in various ways – individually or in combination (Heimersson et al., 2017):

- by subdivision: reduces the magnitude of the allocation problem by identifying parts or aspects of the system that clearly belong to only one of the functions,
- by system expansion: avoids the problem by expanding the study to include all functions of the system,
- by substitution (often also called system expansion): avoids the problem by expanding the study to include the processes displaced by the other functional output(s) of the system. What to replace depends on what is considered as foreseeable consequences of the studied change within the studied time frame, or
- by partitioning: solves the problem by dividing the potential environmental impacts of the joint processes between the functions of these processes.

ISO 14044 (§4.3.4.2) states that allocation problems should be reduced or avoided when possible. Allocations that cannot be avoided should be solved through partitioning, preferably in a way that reflects how the inputs and outputs of the unit process are changed by a change in the products or functions provided by the system.

The allocation problem might occur because a material is recycled from one product system into another. If the recycling does not affect the inherent properties of the recycled material, ISO 14044 (§4.3.4.3.3) allows for avoiding such allocation problems by modelling the recycling as a closed loop within the investigated product system.

In CLCA, allocation problems are often avoided through substitution (Finnveden et al., 2009), because a CLCA should include the activities that are affected by the production and use of the product, regardless of whether these activities are within or beyond the boundaries of the life cycle. An ALCA, in contrast, includes only activities inside the life cycle. This excludes substitution as way to avoid allocation. Instead, allocation problems are typically solved through subdivision and/or partitioning.

4.1.3 Rules for application in environmental declarations

Environmental Product Declaration (EPD) is an important application of LCA. It is designed for communication from business to business, particularly as basis for purchasing decisions. The EPD system includes specific methodological rules for different product categories to allow for comparison of EPDs of competing products also when the EPDs are made by different LCA practitioners. An EPD is typically based on an ALCA, because this approach is more robust and easier to standardise. However, the international and European standards for EPD of building products (ISO 21930 and EN 15804) allow for including substitution as a method to avoid allocation in the waste management phase.

ISO 21930 and EN 15804 builds upon the standards for LCA (ISO 14040 and 14044) and also on the international standards for environmental declarations. They include additional rules for EPD of construction products. For example, EN 15804 (§5.3) stipulates that the comparison of construction products shall take into account how they affect the impact of the whole building during its life cycle. It also states (§6.2.1) that the information shall be divided into four life cycle stages (product stage, construction process, use stage, and end-of-life stage) and a fifth module with the substituted production of material and energy for the waste produced at the construction site, during the use phase and at the end of life. As a rule, partitioning should be done at the production phase and no benefits from recycling and energy recovery can be accounted. The use stage includes the use of the product but also maintenance, repair, etc.

EN 15804 (§6.3.5) requires that activities be included in the model if data are available. If data are not available, an activity can be excluded if it represents less than 1% of renewable and non-renewable primary energy. However, the sum of energy and mass of activities excluded within a life cycle stage must not exceed 5%. ISO 21930 (§6.2.7.2) states that a maximum of 5% of the total mass can be excluded at the starting point, but that the exclusion of activities in the end needs to be justified based on the environmental impacts of such exclusion.

The reporting rules in EN 15804 are further explained in a technical report: CEN/TR 16970. The European standard EN 16485 builds on EN 15804 but adds rules specific to wood-based products. For example, it includes rules on how to report flows of biogenic carbon.

4.1.4 Life cycle costing

The life cycle perspective has also been discussed in the context of life cycle costing (LCC; see, e.g., Hoogmartens et al., 2014). Traditional LCC has a user perspective and includes the acquisition costs, costs of use and maintenance, and disposal costs, if any. The actual costs of production and waste management are not included in such an LCC; however, the acquisition costs and disposal costs can be regarded as proxies for the costs of production and waste management, respectively. When LCC is used with the purpose to add economic costs to the environmental impacts described by an LCA, the LCC should ideally have the same system boundary as the LCA. This means it should include the actual costs of production and waste management.

An LCC practitioner also needs to decide what type of costs to include in the study. A monetary flow is a cost for one stakeholder but revenue for another. The LCC could calculate the company costs, including taxes. Alternatively, it could take a more societal perspective where taxes are not a cost but as a transfer within the system. Such an LCC would calculate the costs excluding taxes.

4.2 BenchValue requirements on life cycle modelling

We propose that ToSIA should facilitate attributional life cycle modelling, i.e., the development of models that quantify what impacts should be associated to the product investigated and to its life cycle. As indicated by ISO 14040 the life cycle includes, for example:

- Raw materials acquisition (for the forest products this includes: silviculture, harvesting, and forwarding),
- inputs and outputs in the main manufacturing/processing sequence (for a wood building this can include, for example: sawing or veneer or board manufacturing; second transformation into finished products such as building products, furniture, paper, packaging or energy; construction of the building; and demolition of the building),
- distribution and transportation,
- external production and use of fuel, electricity and heat,
- use and maintenance of products,
- disposal of process wastes and products,
- recovery of used products, including reuse, recycling and energy recovery,
- manufacture of ancillary materials, manufacture, maintenance and decommissioning of capital equipment (factories, machinery, vehicles, etc.), and
- additional operations such as lighting and heating.

These activities should be included in the life cycle model if they significantly affect the conclusions of the study, regardless of where in the world the activities take place. They can be excluded from the study if they have little impact on the sustainability or if the sustainability impacts are similar in all compared options; however, ToSIA should facilitate the inclusion of the activities to make it possible to include them when they are important for the conclusions.

A comparative sustainability assessment should focus on the aspects that are the most important for the comparison: most effort should be spent on getting the important parts and aspects of the life cycle accurate. The most important part of the life cycle is typically in the process industry, the use phase, or the waste management. ToSIA and its database and manual/guidelines should facilitate accurate modelling of these activities.

Ideally, ToSIA should also assist in identifying what activities are insignificant for differences in sustainability impact values and can be excluded from the model. A very rough estimate of the significance of different activities can be obtained through the use of economic and environmentally expanded input-output models. If ToSIA can be easily used together with input-output (I/O) tables, this could add to the viability of the tool.

To facilitate attributional modelling, ToSIA should allow for allocation, i.e., for including in the model only part of the processes that provides products or functions to other product systems as well as to the product investigated. ToSIA should also allow for transparent descriptions of how this partitioning has been made. A discussion should take place on the partitioning rules to be used for the silviculture and harvesting steps. For example, the EN 15804 recommends the use of economic partitioning if there is a large difference in revenues from different co-products. An alternative position is that emissions and waste associated with physical properties (carbon and energy content) should be allocated on a mass basis.

Transparency of the life cycle model is important to reduce the risk of significant errors and to help interpreting the results. As suggested by ISO 14044 (§4.2.3.3.2) it is helpful to describe the life cycle using a process flow diagram that shows each unit process, including, for example, the production of each energy carrier and ancillary material used in the life cycle. ToSIA should ideally facilitate such modelling. It should also be possible to describe each unit process in terms of, for example, where it begins, where it ends, and what transformations and operations occur within the unit process.

It does not seem necessary to apply EPD requirements to the ToSIA tool and ToSIA studies in general. Sustainability assessments can be made with a life cycle perspective without adhering to the specific rules of EPDs. However, EPD is an important application of LCA and if ToSIA users in the construction sector structure the life cycle into the four stages (product stage, construction process, use stage, and end-of-life stage) it will help increase clarity and gain some comparability to EPDs.

4.3 Assessment of ToSIA

There are no gaps in ToSIA itself related to our requirements on life cycle modelling if the ALCA approach is chosen. Almost everything that we want the user to be able to model can be modelled in the current version of ToSIA. However, there are gaps in how ToSIA has been used in all or most projects so far. Because of this there are also gaps in the data that has so far been collected for use in ToSIA. To be more specific, such gaps can be found in data related to, for example:

- external production of fuel, electricity and heat,
- environmental and social impacts of manufacturing of ancillary materials and capital equipment, construction, use and demolition of buildings

The only gap we found in the ToSIA tool itself concerns the possibility to combine ToSIA with I/O tables. Linking a process in ToSIA to I/O tables requires data on how much money is spent on purchases from different sectors in the economy. The ToSIA structure allows for data on how much money is spent on purchases in each process. These data can also be disaggregated into a few categories. Currently, however, they cannot be disaggregated into purchases from each sector in the economy.

Allocation can be made in ToSIA (see below). The various case studies in the BenchValue project are likely to have use for this function.

4.3.1 Allocation in ToSIA

According to Palosuo et al. (2010), “A Tool for Sustainability Impact Assessment (ToSIA) has been developed for assessing sustainability impacts of forest-wood-chains (FWCs). Sustainability is determined by analysing environmental, economic, and social sustainability indicators for all the production processes along the FWC. Results of the tool can be analysed at an aggregated level for complete FWCs, but for some applications, it is useful to assign the indicator results to products of the chain.” The allocation procedure of ToSIA was proven to be flexible allowing different criteria and still consistent in allocation of the various sustainability impacts of the FWCs.

Palosuo et al. (2010) presented a procedure in ToSIA to assign sustainability impacts to multiple output products of FWC. The procedure was tested and demonstrated with an example FWC from Scandinavia that included furniture and bio-energy production. Two different allocation criteria, carbon-based and economic value based, were applied with different options for assigning the impacts on the sub-products of the chain. The results indicated that the allocation criteria greatly affect the indicator results assigned to the different products of FWCs. The selection of the allocation criterion depends on the question approached and on the availability of the needed process related data. The data availability is assured for the carbon-based allocation within ToSIA, as following the carbon flows within the chain is mandatory for any ToSIA application. Economic values of products, on the other hand, are more closely linked to the aims of the production processes of the value chains and are thereby meaningful allocation criteria in many cases.

Figure 2 shows how a subgraph of a value chain is highlighted based on the selection of a product. This subgraph visualises those processes and flows that contribute to the creation of the selected product via direct material flow connections. The share that all processes contribute towards the selected product, can be selected and calculated, as discussed in Palosuo et al. (2010), based on available information as e.g., organic carbon mass, real mass, or economic value. This mechanism can therefore be used for mass-based or value-based allocation.

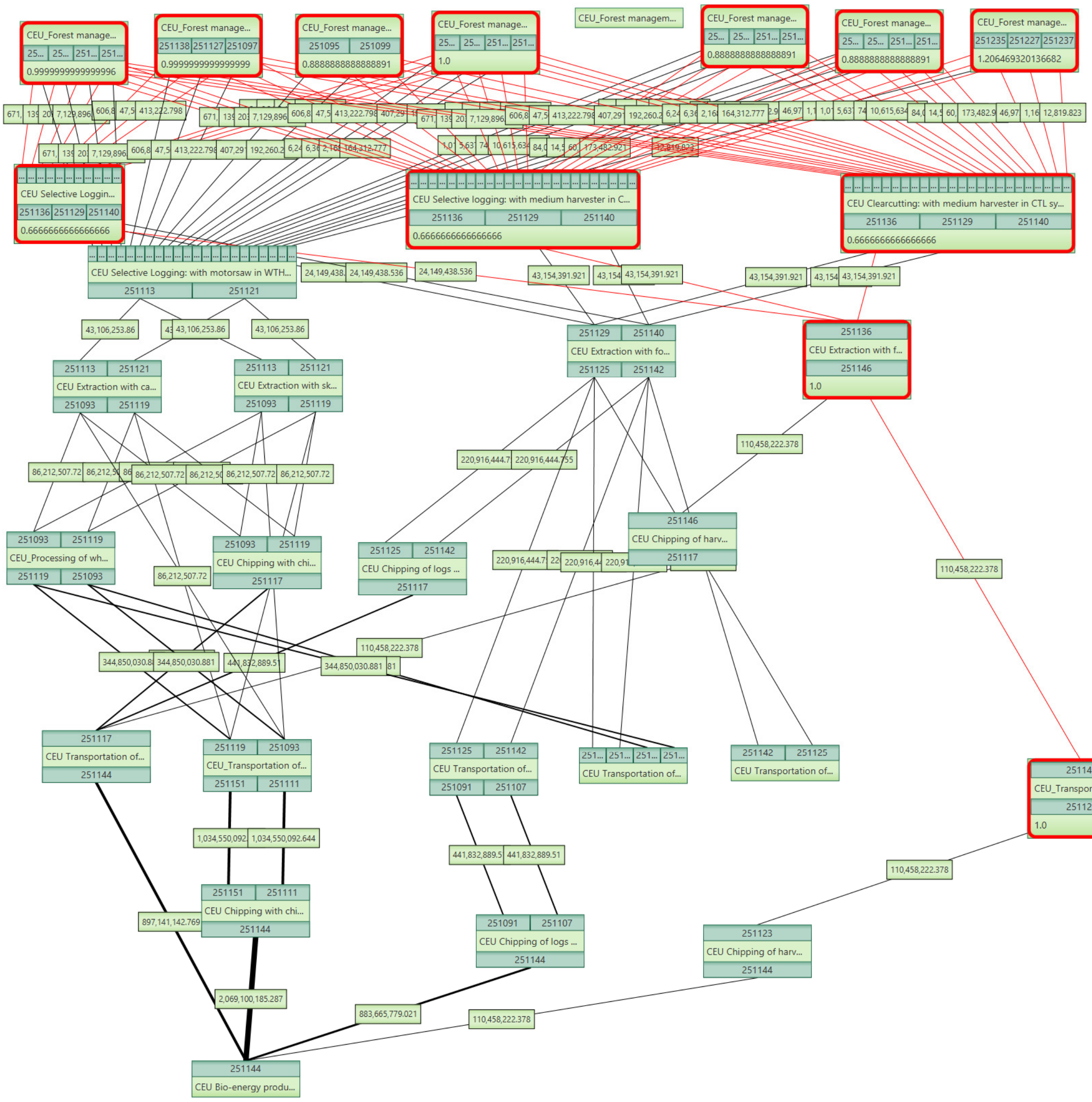

Figure 2: illustration of allocation in ToSIA.

4.4 Assessment of the gaps

The only gap we found in ToSIA itself relates to the ability to link ToSIA models to I/O tables. As stated in Section 4.1, such linking could add to the viability of the tool by assisting in identifying what activities can be excluded from the ToSIA model. The gap is not important, however, as a ToSIA user might anyway find it too difficult to find and interpret a relevant I/O table and link it to the ToSIA model. The fall-back option is to apply expert judgement for deciding what activities to include or exclude in ToSIA. This approach might reduce the accuracy of the ToSIA model, but it is much easier to apply and will gain in accuracy as the ToSIA practitioners gain more experience.

The gaps in data on external production of electricity and heat are important for the usefulness of the ToSIA tool in general. The gaps in data on the construction, use and demolition of buildings are important for the specific case studies in the BenchValue project. We do not recommend changes to be made in the ToSIA tool based on the criteria discussed in this chapter.

To guide the users of the tool and establish good practice, we recommend that a discussion be held on how to model the life cycles of buildings and building components. This discussion can be a joint task between BenchValue WP3 (where methods are developed) and WP4 (the case studies where methods are applied). The scope of the discussion should include, at least:

- the definition of the boundary between the life cycle and nature,
- the choice of allocation methods, and
- what kind of costs to include in the cost calculations.

The discussion should take into account both international standards, such as EN 15804, and the scientific state of the art.

5 Criteria on the software tool

This chapter discusses what should be required from a useful software tool. This is because ToSIA is a software tool. To be a viable tool for sustainability assessments, ToSIA needs to meet the essential requirements for software tools designed for use by experts.

5.1 Perspectives in the literature

Morana et al. (2017) reviewed research in information systems for decision-support and came up with an “Integrated taxonomy of guidance design features” and “Effects and outcomes of guidance design features”. The Integrated taxonomy of guidance design features included the elements in Table 7. Guidance design features include elements as listed in Table 8:

User guidance is one of the main philosophies behind the oppla platform (www.oppla.eu). Good practice guidelines for instrument choice and tutorials for instrument application was detailed in Deliverable 4.5 (http://www.oppla.eu/product/17827). In this deliverable four types of user guidance in relation to software tools where specified:

a) Guidance to the tool, with an overview of tools and help in selecting a suitable tool

b) Guidance about the tool, with metadata on the tool

c) Guidance on the tool, complete with handbooks, manual, online help, interactive pdfs, etc.

d) Guidance on use cases, providing links to earlier case studies, link to other tools and methods

Table 7: Integrated taxonomy of guidance design features according to Morana et al. (2017).

<table>
<tr><td>Target (32)</td><td></td><td colspan="6">Choosing (13)</td><td colspan="6">Using (21)</td></tr>
<tr><td>Directivity (39)</td><td></td><td colspan="4">Suggestive (31)</td><td colspan="4">Quasi-suggestive</td><td colspan="4">Informative (22)</td></tr>
<tr><td>Mode (31)</td><td></td><td colspan="4">Predefined (23)</td><td colspan="4">Dynamic (8)</td><td colspan="4">Participative (5)</td></tr>
<tr><td>Invocation (36)</td><td></td><td colspan="4">Automatic (18)</td><td colspan="4">User-invoked</td><td colspan="4">Intelligent (1)</td></tr>
<tr><td>Timing (32)</td><td></td><td colspan="4">Concurrent (12)</td><td colspan="4">Prospective (9)</td><td colspan="4">Retrospective</td></tr>
<tr><td>Format (45)</td><td></td><td colspan="3">Text-based</td><td colspan="3">Image (17)</td><td colspan="3">Animation</td><td colspan="3">Audio (2)</td></tr>
<tr><td>Intention (34)</td><td></td><td colspan="3">Clarification</td><td colspan="3">Knowledge</td><td colspan="3">Learning (7)</td><td colspan="3">Recommendin</td></tr>
<tr><td>Content Type (23)</td><td></td><td colspan="3">Trace (16)</td><td colspan="3">Justification</td><td colspan="3">Control (8)</td><td colspan="3">Terminologic</td></tr>
<tr><td>Audience (16)</td><td></td><td colspan="6">Novice (16)</td><td colspan="6">Expert (8)</td></tr>
<tr><td>Trust-Building (5)</td><td></td><td colspan="6">Proactive (5)</td><td colspan="6">Passive (0)</td></tr>
</table>

Table 8: Elements of guidance-design features according to Morana et al. (2017).

Cluster	**Observed variable**
Performance	Accuracy, performance, quality
	Group consensus
Time	Time, speed
Learning	Knowledge acquisition/transfer, learning
	Model/system understanding
Trust	Confidence, trust
	Adoption and use Acceptance
	Ease of use, intention to use, usefulness
	Helpfulness, value
	Satisfaction
Cognitive effort	Cognitive effort, information overload, mental workload

5.2 Our criteria

ToSIA would benefit particularly from two of the types of guidance in the oppla platform:

b) “Guidance about the tool, with metadata on the tool”, and

c) “Guidance on the tool, complete with handbooks, manual, online help, interactive pdfs”.

In terms of using a software flexibility of application scope and study object (= general tool) are important, and easy access to up-to-date and reliable data needed for running the tool. Transparency of data sources, assumptions and the possibility to re-construct the calculation of results are crucial for meaningful assessments.

Based on previous knowledge and on the brief literature review above, the following criteria are essential for ToSIA to be a viable software tool:

- Flexibility
- Transparency + Room for metadata
- Clear instructions for users
- Easy access to the tool (availability at a low cost and without cumbersome administration)
- The tool should increase the productivity of the user; this relates to, e.g.:
    - A database with data from completed projects, including metadata
    - User-friendly interface
    - Reliability (no bugs or other technical problems; correct calculations)
- Compatibility with accepted standards or frameworks or procedures
- Possibility to expansion which changing frameworks

The following information should be easily accessible:

- A short description of the instrument
- A detailed factsheet / poster with a modified SWOT analysis (advantages, constraints) and with metadata information like product requirements, uses of the software, quality assurance, accessibility, links, additional information, case study examples, DOI reference, contact details and involved partners.
- Source to webpage and access, Pre-requirements (software, licenses, fees)
- Data needs to run software and type and format of results
- Time estimate to learn and to use software
- Handbooks, manuals, webinars, interactive help, hotline, etc.

5.3 Assessment of ToSIA

ToSIA can be improved on several of the points listed in Section 5.2. As an example, it would be an advantage to be able to import LCI data as well as impact assessment methods from databases such as Ecoinvent and to calculate impact assessment indicators automatically instead of having to insert indicators one by one. This would increase the user-friendliness of the tool and help it further increase the productivity of the user. The Ecoinvent database also contains costs data for all the consumables and energy flows, what could be an additional asset.

6 Assessing climate impact

This chapter discusses what should be required to accurately mode climate impacts, accounting for temporary storage and release of carbon. Climate is just one of the environmental aspects relevant in a sustainability assessment. However, it has earned particular focus in the debate during the past two decades. Temporary storage and release of carbon is a potentially important aspect of forestry and long-lived products like buildings, as expanded on below.

6.1 Perspectives in the literature

6.1.1 CO2 and dynamic carbon flows

The most important component currently driving human-induced climate change is CO_2 emissions caused by human activities (IPCC, 2014). This gas is also important in a comparison between buildings and building components produced from different construction materials such as steel, concrete and wood. Production of steel is associated with large emissions of fossil CO_2. Most steel is produced from iron ore that include iron oxides. The oxygen in the ore reacts with carbon from coal-based coke in a blast furnace, forming CO_2 and CO. The latter also forms CO_2 when the blast furnace gas is combusted. If the blast furnace gas is instead released into the atmosphere, the CO eventually reacts with oxygen in the air to form CO_2. A significant share of the steel is produced from scrap in electric furnaces. This process has little CO_2 emissions; however, the production of electricity used in steel recycling is to varying degrees associated with combustion of fossil fuel in power plants.

Concrete is a mixture of cement and coarse aggregates. The cement is typically produced from limestone (essentially calcium carbonate, $CaCO_3$), which is calcinated to lime (calcium oxide, CaO) at a high temperature in a cement kiln. The production of cement is associated with large quantities of CO_2, partly from the combustion of fuel in the kiln and partly released from the carbonate itself. Part of the latter is eventually recaptured by the concrete as the cement is slowly carbonated in air (Andersson et al., 2013). However, also the recaptured CO_2 contributes to climate change for the time period when it is in the atmosphere.

The CO_2 associated with wood products is mainly biogenic and part of a circular flow between the forest and the atmosphere. However, forestry operations affect the sequestration and stock of carbon in the forest (cf. Chapter 4) and, hence, the current and future quantities of CO_2 in the atmosphere. Carbon is also stored in wood products. By forest harvesting, a significant amount of biogenic carbon is removed from the forest and could be stored for decades in harvested wood products (Anderson et al., 2013). This carbon is kept from the atmosphere for a shorter or longer period of time, depending on the service life of the product and on the waste management process at the end of the service life. The service life varies between products and can also depend on economic cycles or fashion trends, which very likely vary from one country to another (Chang et al., 2014). The service life for wooden houses can be 100 years or more (Skog & Nicholson, 1998), which means the carbon can be stored in the building for a long time. Such temporal storage of carbon contributes to reducing the climate impacts during the time of the storage.

Increased wood use for material or energy might substitute considerable amount of fossil material and fuels, because materials like concrete, aluminium and steel require a lot more energy in the production process (Gustavsson & Sathre, 2011). Material substitution effect appears when wood products replace more energy-intense materials and can contribute to climate change mitigation (Eriksson et al., 2012). Comparative life cycle assessment studies on concrete and wood-framed buildings demonstrated that wood-framed construction requires less energy, and emits less CO_2 to the atmosphere, than concrete-framed construction. Comparing two functionally equivalent buildings made with a wooden frame and a reinforced concrete frame, the manufacture of material for the wooden building used 28 percent less primary energy and emitted 45 percent less carbon than the manufacture of materials for the concrete building (Sathre and Gustavsson, 2009). The meta-analysis by Sathre and O'Connor (2010) based on 21 studies identified the average displacement factors of wood products substituted in place of non-wood materials. The average displacement factor when wood is used for material was found to be 2.1 and 0.7 when wood is used for energy. This means that for each tonne of carbon in wood products substituted in place of non-wood products on average GHG emission reduction is from 0.7 to 2.1 tonnes of carbon. The displacement factors as calculated in Rüter et al. (2016) are lower but also show a benefit of using wood instead of alternative materials.

Kirschbaum (2006) observes that global warming has three types of effects: instantaneous effects related to a higher temperature (e.g., health impacts of heat waves), effects that relate to the rate of temperature change (on ecosystems and technological systems that require time to adapt), and effects that relate to the long-term average temperature (e.g., sea level rise). He argues that all three types of impacts are important, but that temporal carbon storage only reduces the last type of effects. He concludes that temporal storage is not important enough to warrant policy incentives. Other researchers (e.g., Helin et al., 2013) argue that the time of carbon capture and release should be taken into account in climate assessments.

Temporal release of CO_2 and temporal carbon storage are not taken into account in calculations of Global Warming Potential (GWP), the traditional indicator for climate change as calculated using the LCA methodology as defined in the ISO-14040 and ISO-14044 standards. This indicator accounts for radiative forcing from the time of the emission and a fixed number of years after that (often 100 years), independent of when the emission occurs. This means it does not distinguish between emissions at different points of time and, hence, does not account for any delay in the emission.

For estimating temporal carbon storage (carbon stocks changes) in the pool of wood products, IPCC good practice guidelines propose to apply the first-order decay function which is a flux data method that takes into account carbon sinks and emissions during the certain period of time (IPCC 2014).

Other methods have been suggested to account for delays in emissions and for temporal storage and release of carbon. The simplest methods propose to model the climate impact of CO_2 with a linear reduction of 0.76% (Clift & Brandao, 2008) or 1% (European Commission 2010) per year of delay in the emission. More accurate methods take into account that CO_2 and other greenhouse gases are removed from the atmosphere or decay in a non-linear rate. Instead of integrating radiative forcing from the time of the emission until a fixed number of years afterwards, Levasseur et al. (2010) integrate the radiative forcing from the time of the emission until a fixed time horizon in the future. If the emission is delayed until a point in time closer to this time horizon, the results of the integration will be reduced.

Brandao et al. (2013) discuss these and other approaches to climate assessment. They conclude that the results do not diverge very much between linear and non-linear methods, indicating that linear approximations to the non-linear methods can at least in some cases be sufficient. They also observe that storage of carbon for a given number of years will be more important if the time horizon of the assessment is short.

6.1.2 Other climate forcers

Human activities affect the climate in many ways besides emissions and sequestration of CO_2 (IPCC 2013). We emit CH_4, N_2O and halocarbons that contribute to radiative forcing around the globe. Short-lived gases such as CO and non-methane volatile organic compounds (NMVOC) react in the atmosphere to form the greenhouse CO_2, CH_4 and O_3. Emissions of NO_X also contribute to the formation of O_3; however, due to other mechanisms NO_X is more likely to cool the planet than to warm it. Emissions of SO_2, NH_3, mineral dust, and organic carbon contribute to cooling the planet through the formation of particles that reduce the flux of solar radiation to Earth. Emissions of black carbon, however, increase global warming. This effect is particularly strong when the black carbon is deposited in snow, because the black carbon reduces the albedo of the snow, i.e., the part of solar radiation that is reflected back into the atmosphere and space. Deforestation, reforestation and other land-use changes can affect the albedo at the site where the changes occur.

The indirect impacts of short-lived gases can be important to account for in a sustainability assessment. The most recent version of the weighting method EPS (Steen 2015a; 2015b), for example, gives a greater weight to the cooling effect of NO_X and SO_2 than to the acidification and eutrophication they cause. On the other hand, the uncertainty in these indirect climate impacts is high. After consulting the UNEP-SETAC Life Cycle Initiative, IVL (2017) decided to present the EPS method both with and without the secondary climate impacts of NO_X and SO_2.

6.2 Our criteria

There is a large difference in terms of temporal storage and release of carbon between construction materials. Wood components in a building store carbon at least until the end of their service life. Cement production releases carbon, but part of this carbon is absorbed by the cement over time.

Kirschbaum (2006) argue that temporary storage and release of carbon is only important for health impacts of heat waves and other instantaneous effects related to a higher temperature. The frequency and temperature of heat waves in the near future are not affected by decisions based on future ToSIA models. A temporal storage or release of carbon for a century or two can, however, affect heat waves that occur from a few decades to a few centuries into the future. Hence, accounting for temporal storage and release of carbon is important at least when assessing climate-related health impacts that occur in the time range from a few decades to a few centuries into the future.

To account for the climate benefit of temporal carbon storage and the climate impacts of temporal carbon release, ToSIA would need to manage information on the point of time for carbon capture and CO_2 emissions.

The development of one or more indicators for climate impacts should consider the scope of validity of the indicator(s).

The methods proposed by Clift & Brandao (2008), the European Commission (2010), and Levasseur et al. (2010) all reflect an implicit assumption that radiative forcing should be fully accounted for until a fixed time in the future, but not at all after that point in time. This assumption seems difficult to defend. The development of indicator(s) for climate impacts should consider ways to avoid this assumption.

The development of indicator(s) for climate impacts should also consider whether or not to account for uncertain but potentially important indirect climate impacts of, for example, NO_X and SO_2.

6.3 Assessment of ToSIA

The ToSIA was designed for sustainability impact assessment of forest wood chains (Päivinen et al., 2010). However, this tool is suitable for prospective scenario assessments and already includes carbon-based material flow calculations in the value chains. Those chains usually consist of processes starting from forest planting to the end use of wood products. The material flow is tracked over those processes, so the ToSIA model could potentially be applied at the different levels in order to estimate the carbon pool in wood products by using case-specific data. ToSIA also has a possibility of including recycling and decomposition processes in the value chain, meaning that by applying ToSIA detailed carbon flows could be tracked and captured during the particular study time “snapshot”. However, for estimating temporal carbon storage, time dimension is needed.

Since ToSIA is based on carbon-flow analysis, it can estimate temporal carbon storage in wood products through specifying (i) annual carbon inflow over the time and (ii) service life of products. Hence, it allows for calculating how much carbon is stored and for how long it is stored. However, the carbon stock might change over time, and this kind of dynamics is not captured by ToSIA. Also, the temporal release of carbon in cement production is not accounted for. A full coverage of temporal storage and release of carbon might require that ToSIA is modified to allow for input data on the time of different processes.

The rest of our criteria do not concern the ToSIA tool itself, but rather the practice of data collection and of interpretation of the output from the model.

6.4 Assessment of the gaps

The lack of time dimension for estimating temporal carbon storage and release is important, at least in assessments of climate-related health impacts that occur from a few decades to a few centuries into the future. Adding a time dimension in ToSIA might not be feasible, since ToSIA is from the beginning a tool for modelling the flows during a single year. The ToSIA approach (material flow analysis) is a good method for estimating stationary carbon flows (i.e., carbon flows that are constant) into the pool of wood products using case-specific data. Dynamic carbon flows (i.e., flows that change over time) should be analysed externally, for example using Excel sheets or other user-friendly tools.

7 Conclusions and further work

Given contemporary state of the art in Sustainability Science and the demand for holistic Sustainability Assessment tools, there seem to be only a few gaps in the ToSIA tool itself, in the sense that the tool is flexible enough to lend itself to sustainability assessments of a broad range of products and systems. There are, however, several points where ToSIA and its support systems can be improved to make the tool more effective and efficient for comparative, cross-sectoral analysis. A basic requirement is robustness and reliability. It should not contain significant bugs but have stable performance during execution. The current database needs to be expanded with data related to materials other than wood and production systems that go beyond the forest sector. Such an endeavour would be supported by an increased ability of ToSIA to communicate with other databases or input data, respectively. Making it possible to import input data from existing databases, such as Ecoinvent, would reduce the work needed to develop a ToSIA-specific database (cf. Chapter 5).

Sustainability assessments require many methodological decisions. Clear and understandable methodological guidance to ToSIA practitioners would contribute to making ToSIA studies even more reproducible and accurate. The further development of such guidance, based on information on the current ToSIA users, would benefit from consensus on difficult methodological issues such as allocation as well as system boundaries towards nature (see Chapter 4). This can also require the adaptation of new indicators (cf. Chapter 3) and of methods not previously used in ToSIA studies, such as indicator thresholds (Chapter 2) and a method for assessing dynamic carbon flows (Chapter 6).

Several of these shortcomings will be addressed and are to be further elaborated in the future work of the project BenchValue. This includes activities to improve both the tool and the methodology. As a proof of concept, the tool is tested in several case studies in the construction sector.

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French Institute of Technology for forest based and furniture sectors (France)

Lithuanian Research Centre for Agriculture and Forestry (Lithuania)

National University of Ireland, Galway (Ireland)

Swedish Environmental Research Institute (Sweden)

University of Limerick (Ireland)

University of Limoges (France)

University of Natural Resources and Life Sciences (Austria)