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Abbreviations

Abbreviation	Description
AoP	Area of Protection
CBA	Cost-Benefit Analysis
CFC	Chlorofluorocarbon
CSR	Corporate Social Responsibility
DCB	Dichlorobenzene
EIA	Environmental Impact Assessment
ERA	Environmental Risk Assessment
IES	Institute of Environment and Sustainability
JRC	Joint Research Centre
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact assessment
LCM	Life cycle Management
LCSA	Life Cycle Sustainability Assessment
PRP	Performance Reference Point
RED	Renewable Energy Directive
SIA	Social Impact Assessment
SLCA	Social Life Cycle Assessment
SME	Small and Medium Enterprise
VDI	Verein Deutscher Ingenieure (Association of German Engineers)
YLL	Years of Life Lost

1 Introduction

1.1 Background

Nowadays, the concept of a biobased economy receives increasing attention. Within this context, the role of biorefineries is expected to gain further importance in the short and medium term. In brief, the concept of biorefineries is based on the principle of using (multiple) biomass feedstock to produce an array of valuable products (i.e. fuels, chemicals, materials, feed and energy) through a series of integrated and interlinked processes. The essential point is the efficient use of the biomass resource, hereby meaning the utilisation of the largest part of the feedstock, in order to produce a series of marketable products and avoid waste streams that can not be further exploited. Apart from the strictly technical challenges, concerning the integration and optimisation of different processes as well as the treatment of diversified feedstock sources, the biorefinery approach needs to be investigated under the scope of sustainability.

1.2 Goal of task 3.6 within Star-COLIBRI

Star-COLIBRI attempts to group biorefinery projects in order to analyse synergies, overcome fragmentation, facilitate industrial exploitation of research results and promote the further development of the biorefinery concept. A vital prerequisite for this development is the consideration of the dimension of sustainability, i.e. environmental, economic and social aspects.

Within this context, the goal of task 3.6 in Star-COLIBRI is to introduce the concept of sustainability assessment and discuss it in the context of biorefineries. Purpose of the task is to present the core components of sustainability as they are established in literature and highlight the importance of considering the entire life cycle of a product. Furthermore, to illustrate the challenges associated with the application of those concepts in biorefineries. Conducting an actual sustainability assessment for biorefineries is not the goal of this task. Nor is providing guidelines on how a sustainability assessment should be elaborated. Those tasks are more complex and their development within the biorefinery community is still at a preliminary stage. This report is to be seen as an overview of fundamental considerations regarding environmental, economic and social aspects of biorefineries from a life cycle perspective.

General goal of this report is to constitute an initial aiding material and a reference point for biorefineries that want to get involved in the concept of sustainability. By doing so, it is also setting the basis for task 3.7, where sustainability aspects within the formed Star Clusters will be discussed.

1.3 Methodology

The report is based on literature research concerning the development of the sustainability concept. In the first part of the report, the term “sustainability assessment” is analysed and an overview of its constituent parts is provided. The report is focused on the concept of life cycle thinking, pointing out that assessing impacts of a product or service should consider the entire supply chain. In the second part, a discussion about challenges that arise when attempting to apply principles of sustainability assessment in the context of biorefineries follows. In the third part, initiatives in the topic of sustainability assessment (e.g. in form of projects, workshops, guidelines) are listed, in order to examine how actively this subject is taken into account. Focus is given on bioproducts in general and not only biorefinery-oriented activities.

2 Sustainability assessment

2.1 Background

The definition of sustainability presented in the Brundtland report states that “a sustainable development is a development that meets the needs of present without compromising the ability of future generations to meet their own needs”. This definition stresses the responsibility of humankind towards the future generation /1/. Klöpffer noted that there is a high moral claim in this principle, but a lack of guidance how to reach this aim /2/.

Since then, different definitions of the term have emerged, but irrespective of how it is verbally defined, the fact is that sustainability is based on three pillars: economy, society and environment (Fig. 1). The interrelationships between these pillars characterise the sustainability concept and the area where they interconnect is the area where sustainability is achieved /3/; it is an area that evolves over time and has a strong geographical character /4/. A sustainability assessment attempts to investigate the performance of a product or service in these pillars. Given the wide spectrum of parameters that should be taken into account, a sustainability assessment is always dependent on the goal of the investigation.

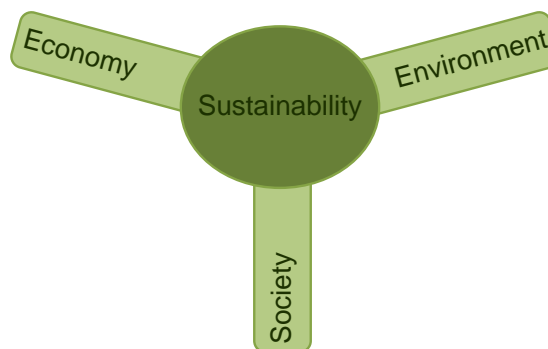


Fig. 1 Pillars of sustainability

During the World Summit on Sustainable Development in Johannesburg 2002 the “life cycle thinking” was introduced in connection with conducting a sustainability assessment. Since then, it is accepted that sustainability assessment should follow the approach of life cycle thinking, by taking into account the economic, environmental and social dimension of a product along its entire life cycle (i.e. from raw material acquisition, through production and use, to disposal) /3/, /5/, /6/. The consideration of the entire life cycle of a product or service is essential in order to avoid problem-shifting from one part of the life cycle to another /7/, /8/. This approach is summarised in Fig. 2 proposed by /9/, where life cycle assessment, life cycle costing and social life cycle assessment constitute the components of life cycle sustainability assessment.

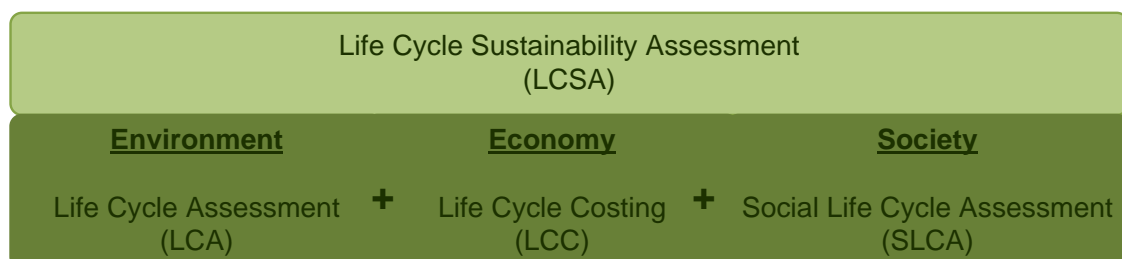


Fig. 2 Sustainability based on the life cycle thinking concept (adapted from /9/)

This report will focus on this approach and will attempt to illustrate core points of consideration within the context of biorefineries. Other types of environmental, economic or social assessment (e.g. Environmental Impact Assessment, EIA; Social Impact Assessment, SIA; Cost Benefit Analysis, CBA; Corporate Social Responsibility, CSR) will not be considered here.

The challenge of sustainability assessment lies in the fact that there is no “one” sustainability assessment that fits all purposes. The type of assessment (e.g. system boundaries, impact categories, indicators) will depend on the purpose and the objectives of the assessment (e.g. comparison between two products, evaluation of a facility, decision making), whom it is addressed to (e.g. decision makers, public, practitioners), where it is conducted, the depth of the analysis, etc /5/. Added to that, is the complexity of incorporating all stages along a product’s life cycle and handling information of economic, environmental and social nature. In the following, the three constituent parts in a sustainability assessment are elaborated.

2.2 Environment

2.2.1 Methodical considerations

On the basis of the abstract definition of sustainability (see chapter 2.1) it is difficult to develop tools that quantify and assess environmental sustainability in a concrete way. There are basically two methodical approaches: a case-by-case approach and a standardised approach.

Within a *case-by-case* approach usually criteria or indicators have to be deduced from the abstract definition of sustainability to estimate the environmental sustainability of a concrete issue. These indicators per se and the process to derive them are case specific. In a next step the derived criteria/indicators are measured and threshold values and/or conditions are determined to assign the indicator values to defined classes of sustainability (e.g. from very sustainable to less sustainable). The case specific indicators, the thresholds and conditions as well as the results can not be transferred to other investigations. Thus, this procedure has to be conducted for each individual case. Furthermore the approach is time-consuming (especially the process of development of indicators).

For that reason, there were efforts to develop *standardised* approaches. There are several approaches trying to develop a tool quantifying environmental impacts restricted to the assessment of products /9/. The Life Cycle Assessment (LCA) is recognised as an efficient instrument for the assessment of potential environmental impacts of services and products across their entire life cycle and the comparison of their environmental performance /7/, /8/. LCA is standardised through the ISO 14040 & 14044 standards and thus the only internationally standardised environmental assessment method /9/. In the ISO guidelines, LCA is defined as a compilation of relevant inputs and outputs of a product system for the evaluation of potential environmental impacts throughout its life cycle /10/, /11/.

In contrast to the case-by-case approach, LCA alone can not provide a statement of whether a product is environmentally sustainable or not. LCA determines the environmental performance of a product in comparison to a reference and in the absence of fixed standards. Thus, an absolute value of sustainability (or not) is impossible. However, the results can be used as a basis for the decision maker. By means of defined threshold values and/or conditions from the decision maker the calculated values of an LCA can be assigned to statements regarding environmental sustainability. LCA has four phases as illustrated in Fig. 3. Since LCA is an iterative process the results of a stage could result in adapting the determinations made in previous stages.

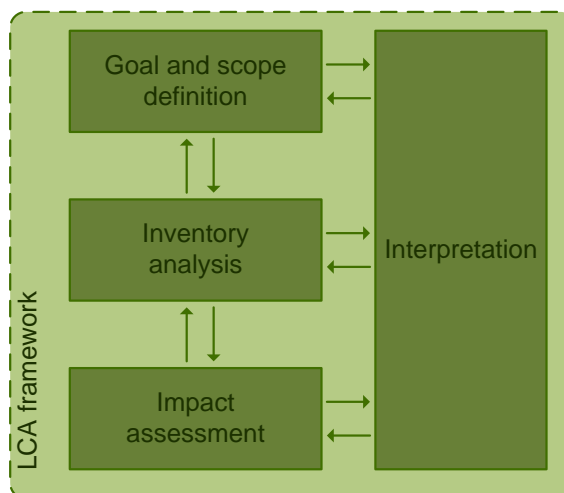


Fig. 3 Methodological approach according to ISO 14040 & 14044, based on /10/, /11/

- The **Goal and scope definition** phase determines, among others, the boundaries of the system under investigation, the level of detail for the LCA, the functional unit¹ for the subsequent calculations, the procedure for the consideration of occurring by-products and the environmental categories to be examined. In principle, LCA should follow all the processes associated with the life cycle of product system, but in practice this is not always possible, due to the lack of data. Therefore, the system boundaries should be clearly defined and any assumptions or “cut-off” criteria must be clearly described. Such cut-off criteria may, for example, be the inclusion of only those chemicals that are needed in a certain amount (e.g. more than 1gr per functional unit) for the conversion process, or the exclusion of parts of the production chain of an auxiliary, where input data are missing.
- The **Life Cycle Inventory (LCI)** phase lists all relevant process inputs (i.e. resources, energy and material use) and outputs (i.e. products, waste, emissions) for each intermediate step of the entire chain of production in relation to the functional unit.
- These data are then used in the **Life Cycle Impact Assessment (LCIA)**, where they are associated to specific environmental impact categories (e.g. global warming potential, consumption of finite energy, eutrophication potential, etc; see Tab. 1.) with the help of characterisation factors. For a simplified presentation and an increased comparability of the results, the environmental impacts can be normalised on the basis of a reference data e.g. population equivalent (environmental impacts related to 1, 100 or 1000 inhabitants). It is therefore possible to aggregate environmental impacts of different impact category to a common statement of environmental burden.
- In the **Interpretation** phase, the results of LCIA are discussed in relation to the objectives of the study, significant issues are identified and conclusions are drawn. Additionally, an evaluation that considers sensitivity analyses, completeness and consistency should be conducted. Ideally, the whole procedure is revised from external parties through independent critical review. /8/, /10/, /11/

Tab. 1 Environmental impact categories of LCA and their description /12/

Impact category	
Consumption of finite energy	Depletion of resources, focus of non-renewable sources e. g. coal, natural

¹ The functional unit is a quantitative measure of the function/performance that the product provides for use as reference unit /8/, /10/

	gas, mineral oil, uran
Global warming potential	Warming of global atmosphere due to anthropogenic climate relevant gases; most important greenhouse gases: CO ₂ and its equivalents e. g. CH ₄ (23 CO _{2eq}), N ₂ O (296 CO _{2eq})
Acidification potential	Shift of acid balance in soil and water through acid forming gases: SO ₂ and its equivalents e. g. NO _x (0.7 SO _{2eq}), NH ₃ (1.88 SO _{2eq}), HCl (0.88 SO _{2eq})
Eutrophication potential	Nutrient cycles in soil and water through PO ₄ ³⁻ and its equivalents NO _x (0.13 PO ₄ ^{3-eq}), NH ₃ (0.35 PO ₄ ^{3-eq})
Photo/summer smog	Formation of photo-oxidants (e. g. ozone) in atmosphere through interaction of sun radiation, indicated in ethylene equivalents
Depletion of stratospheric ozone	Destruction of ozone layer in the stratosphere by e. g. CFC, N ₂ O, indicated in CFC-11 equivalents
Human toxicity	Impacts of toxic substances e. g. DCB, NO _x NH ₃ , SO ₂ on human health, indicated in 1,4-DCB equivalents
Ecotoxicity	Impacts of toxic substances on e. g. freshwater-, marine aquatic- and terrestrial ecosystems, indicated in 1,4-DCB equivalents
Land use or land competition	Loss of land as a resource (natural resources, man-made environment), indicated in m ² * yr

2.2.2 Performances of Life Cycle Assessment

LCA focuses on products or rather the function that products provide, by using the cradle to the grave approach, i.e. from raw material production and supply, via production and use, to waste management /7/, /13/. It can be characterised as a decision support tool for authorities and companies /2/ as it facilitates to identify problems within the life cycle. By means of LCA the stages of a life cycle that contribute mostly to environmental impacts and thus should be improved regarding the releases of emissions can be identified; therefore optimisation potential within the life cycle of a product can be pointed out /7/, /13/. Within LCA, all mass and energy flows, resources, land use and the potential impacts are set in relation to a functional unit. The functional unit is a quantitative measure of the function that the product provides for use as reference unit /8/, /10/. This way, resources consumed as well as emissions can be attributed to the product and quantified.

There are two types of methods conducting an LCA: (i) an attributional and (ii) a consequential LCA.

- An attributional LCA focus on potential environmental impacts caused directly through the product's entire life cycle. Only the investigated system determined through the system boundaries is considered. The amount of GHG emissions, the consumption of finite energy or the acidification potential of bio-ethanol could be typical results of an attributional LCA.
- In contrast the consequential LCA describes also the effects of changes within the life cycle. For example, the consequences of the use of a different feedstock that leads to effects outside of the defined system boundaries (e. g. farmers cultivate other crops) could be investigated within a consequential LCA. A consequential LCA can also include social interactions that are caused by changes within the life cycle. /8/, /14/, /15/

Within a traditional LCA the characterisation methods (i.e. methods of converting an assigned life cycle inventory analysis result to the common unit of the category indicator) are based on midpoint modelling. A midpoint indicator indicates impacts somewhere between emission and endpoint in the environmental mechanism. An alternative type of characterisation is based on endpoint modelling, meaning that the

indicators are defined at the level of the areas of protection² /8/, /3/. An endpoint indicator could be the share of disappeared species to indicate the damage of an ecosystem. In contrast to the midpoint indicators the endpoint indicators are associated with a high uncertainty due to the additionally modelling assumptions, but they represent real damages and can have a higher relevance for decision support /19/.

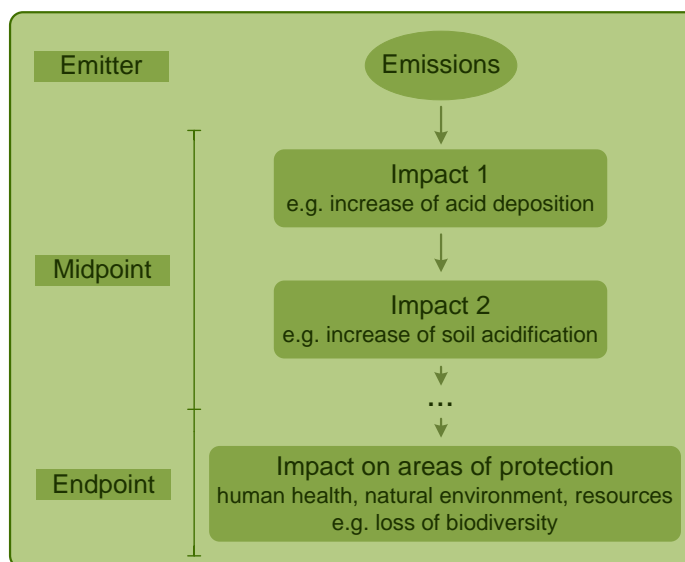


Fig. 4 Environmental mechanism underlying modelling of impacts in LCA (adapted from /8/, /20/)

Apart from providing indicators of the product's contribution to a wide range of potential environmental impacts, LCA is also a comparative method: two or more systems are compared on the basis of a common functional unit in a holistic way; comparisons between product improvement variations are possible as well. This comparison is only useful, if potential environmental impacts are considered along the entire life-cycle, with identical system boundaries and identical functions/performances for all product systems /2/, /7/.

LCA focuses on products or rather the function that a product provides. In some cases more than one product are produced within an investigated system. In such multi-functional processes it is challenging to allocate the resulting emissions, the used energy and resources between the main- and the co-products. The ISO 14044 describes a procedure for this case: wherever possible, allocation should be avoided by dividing the processes into sub processes or expanding the system boundaries to include the additional functions related to the co-products. In cases in which allocation can not be avoided, the environmental impacts could be allocated on the basis of physical relationships (e.g. lower heating value or mass) that reflect the relation between the inputs and the resulting outputs. If there is not a physical causation between the in- and outputs, the environmental impacts should be allocated in a way that reflect the relationships of them e.g. on the base of the economic value.

2.2.3 Limitations of Life Cycle Assessment

As with every methodology, LCA also has limitations. Since all impacts have to be related quantitatively to a functional unit, qualitative marks are mostly lost during the assessment. For example the loss of biodiversity or the loss of life-support functions such as available fertile soil and water resources is

² Areas of Protection (AoP) represent areas of values to the humanity that should be protected by monitoring the causes of damages to them (human health, natural environment, natural resources) /7/, /16/-/18/.

difficult to include because they can not be directly quantified in LCIA /9/, /2/. However, there are approaches to include indicators of biodiversity in LCIA /21/, /22/. Apart from that, not all types of environmental impacts are equally well covered in a typical LCA: while focus of investigations is so far given on global warming potential and consumption of finite energy, for some impact categories (e. g. human and ecotoxicological impact categories or depletion of stratospheric ozone) the impact models and the associated characterisation models are less investigated. Additionally, the methods for the assessment of impacts of land use as well as impacts on resources (such as freshwater) need to be improved /7/, /8/. It is noted that a lack of data influences the results and restricts the conclusions that can be drawn /7/.

It has to be mentioned that an LCA includes several methodological choices (e. g. system boundaries, cut-off criteria, allocation methods, characterisation factors) which are uncertain and may influence the results /8/. According to *Finnveden*, a general statement whether product A is environmentally preferable to product B can not be derived through LCA, because the result from an LCA is case-specific and a single observation statement (specific set of data, system boundaries etc.), whereas the statement that product A is in general environmentally preferable to product B is a universal statement /7/. Finally, within an LCA no statement can be made about emissions from other processes outside the product system, which affect the same ecosystem and health cohorts. The existing background environmental charge (e.g. concentration of certain contaminants) in these systems is not considered as well. So, depending on the goal of the assessment, LCA may not suffice and the decision making process may also require other complementary approaches like Environmental Risk Assessment (ERA) or Environmental Impact Assessment (EIA) /8/.

Handbook of International Reference Life Cycle Data System

Since the ISO 14040 & 14044 standards provide the general framework for Life Cycle Assessment in which there is a range of choices that influence the results and conclusions, the International Reference Life Cycle Data System (ILCD) handbook was developed by the European Commissions (EC), the Joint Research Centre (JRC) and the Institute for Environment and Sustainability (IES) to ensure quality and consistency of life cycle data, methods and assessment. So the handbook is a comprehensive guidance to support consistent and robust results. Since some questions, that occur when conducting an LCA of a concrete issue, are not determined in detail in the ISO guidelines, the ILCD handbook describes the procedure of conducting an LCA in detail step by step. /23/

2.3 Economy

2.3.1 General considerations

Today's economies, and the agents within them, operate in an environment of various challenges. These arise, among others, from globalisation, population increase, rising standards of living, the exploitation of finite resources and the impairment of the environmental quality. These developments fuel the need to organise economic activities sustainably, i.e. regarding all phases of life, in an integrated economic consideration – a life cycle cost analysis (LCC).

This applies particularly as competition is widely increased, as happened along with the advancing globalisation. Competition is dependent on the circumstances that prevail within the individual branches and is determined by market forces, such as the entry of new competitors, the intensity of the rivalry

within a market, the bargaining power of customers and suppliers and the threat of substitute products and services replacing the existing.

Beside the growing competition and cost pressure on globalised markets, further trends can be observed, that lead to a greater need for economic sustainability. These are, for instance, the increasing individualisation of products, shorter innovation cycles, changing customer's requirements (e.g. through demographic ageing or growing ecologic awareness), increased interconnectedness of businesses, combinations of products and services (e.g. leasing) or legal requirements (e.g. obligations to take back and recycle goods). These trends stress the need to deploy a firm's resources most efficiently and consider the whole life cycle when optimising an investment plan or product-project. This holds in particular in an environment of rising resource prices, which have a great influence on the whole lifecycle costs, as consumption and operation costs exceed the investment costs in many cases. The consideration of all costs along the whole life cycle is especially most relevant, when the share of the costs is high in the phases of usage and disposal in proportion to the height of the investment. /24/

2.3.2 Life Cycle Costing

Economic life cycle assessment or life cycle costing was first established in the 1960's to optimise projects in the military and building sector, where long life cycles and high follow-up costs can be widely observed. It is a holistic and systematic approach for the examination of costs and can be defined from the perspective of a consumer or a producer.

The user of a product shall be supported in choosing the most cost-effective alternative when making investment decisions, considering the total cost of ownership. The producer of a product shall be enabled to optimise his product in early project stages through timely providing information on costs that will occur in later phases and their interdependencies. Operation costs, which will have to be borne by the customer, can be included in the assessment, as they pose an essential parameter in their investment decision and therefore in the marketability of the product.

From the consumer perspective, only costs are relevant. For an assessment from the producer-perspective however, revenues can either be taken into account (LCC in the wider sense), or stay unconsidered (LCC in the narrower sense). Considering both costs and revenues seems however more practical, since revenues often vary cost-dependently. Implicit costs, such that are not accompanied by actual payments, stay however unconsidered, because only the consumption of production factors on a monetary basis (for example labour) is relevant in this consideration. The same applies to revenues.

Life cycle costs are hence defined as all costs for initiating, planning, realising, operating and decommissioning of a product or facility. The respective revenues are defined accordingly as the value added during the performance process. According to their frequency and regularity, revenues and costs can further be distinguished between those with recurring, and those without recurring character. Irregular costs are for instance those occurring in the design/development phase. Regular costs are for instance those for operation and maintenance.

Fig. 5 shows schematically how the cumulative costs develop over time within a typical life cycle. It also shows when these costs are determined, and what influence on them is left at every point in time within that life cycle. It is shown that the cumulative costs are relatively low at the development phase and rise quickly during the market and disposal phase. The possibility to influence on the costs is however the greatest at the beginning of the life cycle and then quickly falling as time proceeds. Most of the life cycle costs are hence determined earlier than they occur. This means that the influence on the life cycle costs is

big in the early life phases, while the costs actually accruing therein are relatively low. Farsighted optimisation of the life cycle costs is therefore needed most - and cheapest - in the development phase.

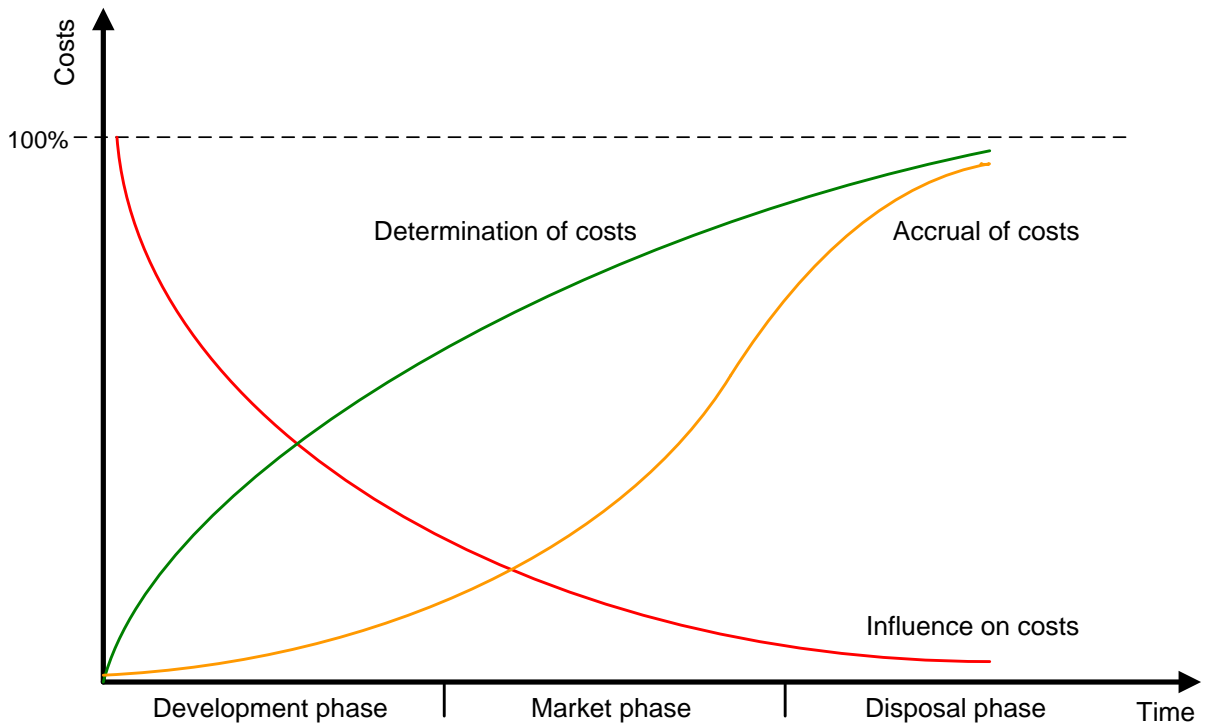


Fig. 5 Influence on, determination and accrual of costs within a typical life cycle (adapted from /24/)

Fig. 6 depicts how choosing an investment (or product-project) alternative, that requests a higher initial investment amount than another, can still be superior in terms of costs when considering the whole life cycle. That can be if lower follow-up costs are the result of this higher investment.

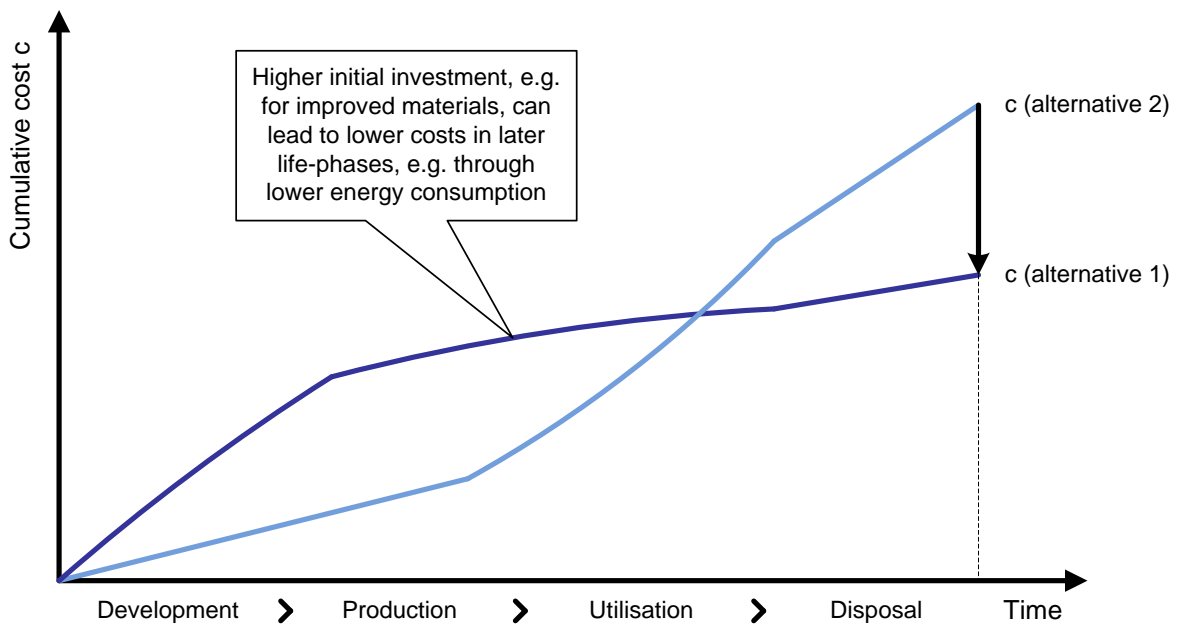


Fig. 6 Cost trade-off in LCC considerations (adapted from /24/)

Long-term LCC assessments revert to the methods of investment appraisal. Capital value method, modified internal rate of return and dynamic pay-off method are used to provide information for

evaluating investment alternatives in the strategic planning of business processes. These methods can assess the relative or absolute advantageousness of investment (or product-project) alternatives.

The capital value method is used to calculate the surplus yielded by an investment at the start of the life cycle. All costs and revenues that occur during the whole life cycle are transformed into comparable values by taking account of interests. They are discounted to present day value and then summed up to receive a positive or negative result. The higher the capital value is, the more profitable the investment is. A negative capital value indicates an unprofitable investment. The capital value hence allows the direct determination of the absolute economic efficiency as well as the identification of the most efficient investment alternative when comparing different investment options.

The method of the modified internal rate of return (MIRR) allows a prediction of the interest on the invested capital that can be achieved over the whole life cycle. The MIRR includes the assumption that positive net payments (revenues minus costs) in each phase of the life cycle are reinvested at the own-capital interest, while negative net payments are settled at debt-capital interest rates. The MIRR allows comparing project alternatives on the basis of their relative profitability this way. It is a measure to identify the project with the highest economic efficiency. This is also true, when investment objects with different service lives and different investment amounts are to be compared.

The dynamic pay-off method allows for comparing project alternatives on the basis of the time it takes to gain back the invested money. Although rather short-sighted, it is an important measure for the risk of a project, because of the uncertain nature of future payment sequences.

The growing importance of LCC is also reflected in the efforts to introduce accordant standards and guidelines. The VDI-Guideline 2884 and the DIN EN 60300-3-3 can be noted exemplarily in this regard. The VDI-Guideline considers costs and revenues and recommends the capital value method for a holistic consideration. The DIN EN standard focuses on the product's development phase as most of the costs are determined herein. The objective is the creation of a most dependable product or project./25//26/

A general approach to conduct an LCC is illustrated in Fig. 7. The framework for this stepwise analysis involves four consecutive phases. For each phase, one target dimension is defined and addressed. They are built upon each other and hence have to be dealt with one after another. The four target dimensions are the illustration of the cost structure, its explanation, its prognosis and its design.

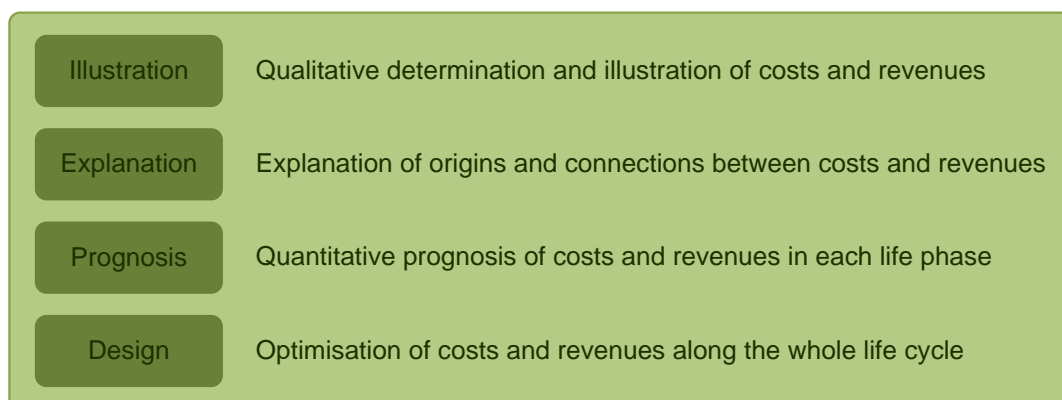


Fig. 7 Procedure to conduct a LCC (adapted from /24/)

Within the *illustration* phase, a product-specific life cycle model has to be developed, that chronologically structures all relevant life phases. All costs and revenues have then to be allocated to the life phases during which they occur. A qualitative determination and illustration of all costs and revenues

is the result, revealing the relevance of each life phase to the overall life cycle performance. The *explanation* phase refers to the fact that the relevant cost and revenue drivers need to be identified. Therefore the origins and connections between costs and revenues within the life cycle have to be detected. This is done by breaking down all costs and revenues according to the activity they are connected to and the life phase during which they occur. Within the *prognosis* phase, the costs and revenues need to be quantitatively prognosticated utilising methods of accounting. The resulting payments for every life cycle as well as the overall life cycle performance are however accompanied with uncertainty due to the nature of prognoses. A risk analysis is hence advisable. It can for instance be performed through a sensitivity analysis revealing the influence of the most uncertain parameters. Within the *design* phase, an optimisation of the success factors costs, revenues, quality and time is undertaken to design the most efficient product or project./24/

Life Cycle Costing within Life Cycle Sustainability Assessment

While the LCC assesses the direct costs and benefits that occur along a product's life cycle – the internal and internalised costs and revenues –, it does not consider externalities. These externalities are impacts that are generated by the product, its production, use or disposal, that are not included in the LCC through a monetary value. No actor along the life cycle of the product is hence charged for these externalities, and therefore they stay unconsidered when investing – irrespective of whether their impacts are positive or negative. A typical example for an externality is the pollution generated by a product or process. This pollution may affect a third party negatively, but if neither the producer, nor the user or disposer is charged for this negative impact, the accompanying costs are not considered an investment decision. To take externalities into account, LCAs and SLCA are carried out as explained in chapters 2.2 and 2.4, respectively. Fig. 8 shows the boundaries of the LCC and how it is embedded in the natural and social system that forms the boundary for the LCA and SLCA.

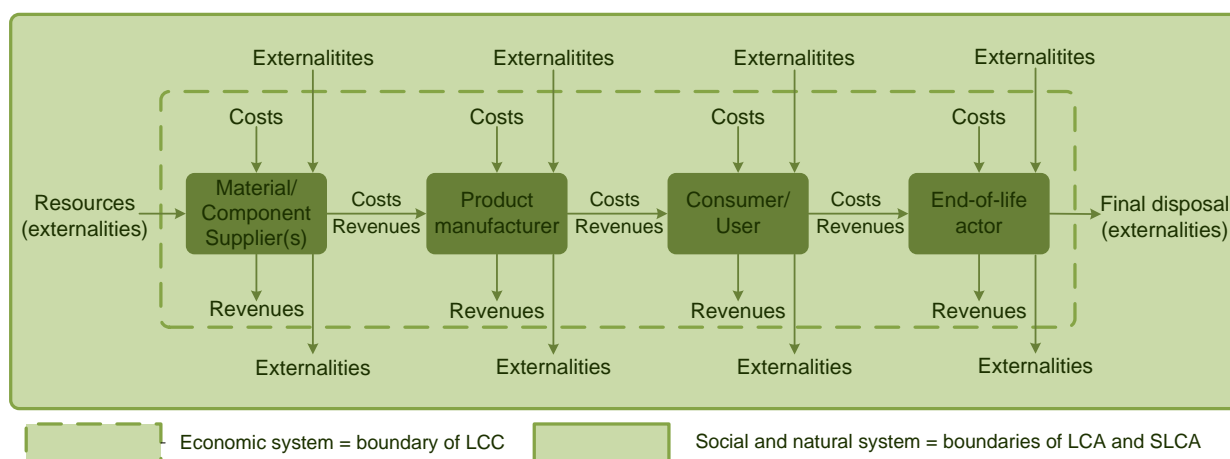


Fig. 8 Concept and boundary of LCC (adapted from /27/)

An LCC assesses all costs that are imposed directly on an actor along the life cycle including only such externalities that can be anticipated to be internalized within the lifetime of the examined product or project, e.g. through taxes or subsidies. If all externalities could be converted into monetary units through taxes and subsidies that were imposed on the actors along the products life cycle, the LCC could serve as a complete yet simplified LCM-approach, but it would only indirectly and not practically address environmental and social issues. That would however reduce the overall transparency and diminish operability through a drastically increased complexity of the analysis, so that this approach is not pursued

in practice. Furthermore, not all externalities may be able to be transformed into monetary units. In terms of a complete life cycle thinking approach, the LCC is required along with LCA and SLCA. /27/

2.4 Society

This part will focus on some general considerations concerning the social part of life cycle sustainability assessment as a continuation of 2.2, where the environmental dimension was discussed and 2.3, where the economic dimension was explained. It will then describe in more detail the United Nations Environment Programme (UNEP) guidelines, which is one of the first attempts to develop a framework for SLCA.

2.4.1 General considerations

The social dimension has gained in the course of time increasing attention and nowadays, investigating the social impact of a product life cycle is becoming equally important as the environmental and economic impact. The challenge of incorporating the social dimension in any assessment lies in its inherent complexity, since it is determined by a number of factors such as personal behaviours and perceptions, general moral values, interactions of social groups with the surrounding environment, geopolitical circumstances and others. This renders the development of a specific and strict framework for social assessment virtually impossible: social indicators that will help to capture the magnitude of social impacts can be numerous, have a strongly regional character, are different from case to case and contain a certain level of subjectivity in terms of importance.

There is an ongoing effort to overcome these issues and various studies stress the importance of the social dimension. Within the context of life cycle thinking, Social Life Cycle Assessment (SLCA) is considered an efficient methodology to capture this dimension, though not yet fully developed. The purpose of SLCA is ultimately to improve social conditions among stakeholders along the life cycle of a product system /28/, /29/.

The social dimension of a product is a very complex subject and as such, many aspects have to be considered. Among other issues, the selection of social impact categories, the determination of appropriate indicators and affected groups as well as the type of data required for the assessment are only some of the topics that are being discussed.

System boundaries

Considering the system under investigation, it is discussed whether the social impacts should relate to the processes for the production of a product or to the conduct of the companies performing those processes. In terms of system boundaries, inventory data and product allocation, these different approaches play an important role. In case the company as a whole is assessed, only those parts of the life cycle that the company influences directly would be included in the system boundaries. Furthermore, the assessment would require case-specific data, since the conduct of two companies producing the same products may have a very different social impact. On the contrary, if the products themselves are assessed (as in LCA), then the system boundaries are expanded to include the entire chain of production and generic data might be sufficient /17/, /31/, /32/.

Linked to this discussion is the influence of the regional element. A social impact, apart from the fact that it may evolve quickly over time, it does not affect all social groups in an equal manner /17/, /32/, /33/. Social impacts may be valued and perceived differently between regions or even not be considered

at all in some communities, whereas in others they might be of paramount importance /34/, /35/. For that reason social impact assessment is considered group-specific and has a strong regionalised character; in that sense, it differentiates from LCA that has a more global scope /16/, /32/. Following this, the question of whether SLCA makes sense when generic and not site-specific data are used appears again.

Allocation

Allocation of impacts is a crucial issue and in the social context it becomes even more complex since there is basically no way (contrary to LCA) to trace the path of a social impact and qualitatively link it to (allocate it between) products /32/. It is discussed that allocation makes sense only in the context of company assessment. *Jorgenssen et al* suggest that when the company as a whole is assessed, then allocation is not required /17/. On the other side, *Dreyer et al* and *Hauschild et al* suggest that even though this link is not straightforward, it is still possible to allocate impacts among companies that influence the production chain the most; this would be achieved by means of share factors that reflect the contribution/weight of each company to a certain attribute of the product (e.g. value, cost, hours to be produced, etc.) along the production chain /18/, /32/.

Impact categories and indicators

In a review of various studies dealing with social assessment, /17/ mentions a number of generalised impact categories (with respective indicators), like human rights, labour practices, work conditions and others. These categories can be divided into subcategories or aggregated to form over-categories; the types of possible classifications differ among sources. Furthermore, the use of terms such as “social indicators”, “impact categories”, “sub-categories”, “social criteria” also varies among sources. In any case, it is common ground that some categories are essential for a social assessment and this list can be further expanded according to the purposes of the assessment /32/. Tab. 2 provides an overview of social impact categories.

Tab. 2 Examples of social impact categories and sub-categories

Impact categories	Source	Comment
Life and longevity (mortality), Health (non-lethal impacts)	/16/	Subcategories for autonomy and anxiety mentioned
Autonomy		
Anxiety (safety, security, tranquillity)		
Equal opportunities		
Participation restrictions	/17/	Review article with a list of various impact categories aggregated into four basic groups
Human rights		
Labour practices and decent working conditions		
Society		
Product responsibility	/28/	Source /28/ is described into more detail in chapter 2.4.2 and Tab. 6, Annex.
Human rights		
Working conditions		
Health and safety		
Cultural heritage	/35/	Uses labour hours as indicator to reflect the ability to acquire social necessities
Governance		
Socio-economic repercussions		
Housing		
Health care		
Education		
Necessities		

Discrimination				
Child labour				
Forced labour				
Physical working conditions		/32/	Adopts the approach of SLCA from the perspective of a company's conduct	
Working hours				
Minimum wage and benefits				
Training and education of employees				
Development support towards local society				
Equality of opportunity and treatment & fair interaction	(i)	/33/		Defined as "social indicators"; arranged under stakeholder groups: (i) employees (ii) local & regional communities (iii) society (iv) users & consumers
Abolition of forced labour				
Safe and healthy living conditions	(ii)			
Respect of human rights				
Public commitment to sustainability issues	(iii)			
Employment creation				
Quality of product or service	(iv)			
Fair competition and marketing practices				
Permanent internal employment positions	(i)	/36/	Defined as midpoint categories; arranged under four main "social criteria" also described as social "Areas on Protection": (i) internal human resources (ii) external population (iii) macro-social performance (iv) stakeholder participation	
Possible health and safety incidents				
Comfort level / Nuisances				
Local employment	(ii)			
Access to education				
External value of purchases	(iii)			
Improvement of socio-environmental services				
Change in relationships with stakeholders	(iv)			

Every impact requires indicators that would permit the description of its performance. There is a differentiation between impacts and respective indicators at midpoint and at endpoint level, the difference referring to the location in the impact pathway. For example, the number of jobs may be considered as an indicator that would contribute to income improvement (midpoint level) leading to better health conditions, which would represent the endpoint level. The link between midpoint and endpoint level is, however, not always clear and strict and whether the one or the other or even both will be used depends on the system definition and the purposes of the assessment.

Another point of discussion is the nature of indicators. Indicators can be quantitative, i.e. able to be directly expressed with numbers and units, or qualitative, i.e. expressed in a descriptive way that needs to or could be translated into numbers through a scoring system /17/. According to /33/, neither quantitative nor qualitative data alone can suffice for a spherical assessment; a combination of both is needed.

The importance of quantification of impacts of social dimensions is stressed in /16/ and is considered as a means against their violation. Although it is reckoned that establishing relativity through quantification is disputable for a number of social aspects (e.g. violation of human rights is unacceptable in any form of severity), it is pointed out that not measuring a social impact entails the risk of not considering or ignoring it. For example, under the general heading of *Human life and well being*³, dimensions like life and longevity, health and non-health well being (autonomy, safety, security and tranquillity, equal opportunities, participation and influence) are "threatened" by stressors of varying severity. The grade of severity (from 0 to 1) multiplied by the duration of the stressor provides damage indicators that can be aggregated to reflect the reduction of overall life expectancy. For example, a stressor (e.g. disease) with a

³ An Area of Protection (AoP) to be added to the existing ones /16/-/18/; see also footnote 1 in chapter 2.2.1.

severity grade of 0.5 and duration of 1 year for 1 person represents a damage of 0.5 Years of Life Lost (YLL), which reflects a reduction of life expectancy of 0.5 years for 1 person. /35/ also uses a quantifiable indicator (number of working hours) and relates it to different social impacts by transforming working hours into the ability to acquire social necessities.

2.4.2 UNEP Framework for Social Life Cycle Assessment

Although LCA principles have been described many times, their application within the social context has not yet been established. The UNEP guidelines for SLCA are an attempt to develop a basic framework for the inclusion of social dimensions in the assessment of the life cycle of a product or service /28/. It provides guidelines that are in-line with the methodology of LCA and can, therefore, contribute to the establishment of the “life cycle thinking” approach in the sustainability assessment. It is, however, not to be directly compared with LCA since the difference in the focus (i.e. social/socioeconomic instead of environmental) may lead to differentiations in procedures and attributes. For example, while a small material input in the upstream chain can be disregarded in an LCA (as a result of cut-off criteria), the social impacts of its production may be of high relevance /33/. In that sense, the role of SLCA is complementary; it is important to have information on social dimensions during the life cycle of a product, but this alone is not sufficient for a decision.

This part provides an overview of the UNEP framework and the adaptation of LCA to the social dimension. Parts where the course of action is similar to LCA ISO guidelines are not mentioned in detail. Following those guidelines, the UNEP methodology of SLCA has four stages:

Goal and scope definition

The goal definition includes answers to questions like what the purpose of the assessment is (e.g. ensure social stability, improve market acceptance), what the intended application is (e.g. policy development) and who will use the results (e.g. stakeholders, NGOs, governments). The scope definition sets the framework of the assessment and covers, among others, aspects such as system boundaries, functional unit, impact categories, by-product consideration and level of detail.

For the majority of those aspects the same principle for their determination is followed as in LCA, with the exception of impact categories that are of different nature. The determination of system boundaries is achieved with the help of process flow charts that include all necessary stages along the production system. It is important for a consistent calculation that all components of sustainability assessment (LCA, LCC, SLCA) have - as much as possible - the same system boundaries. Assumptions and possible modifications in that context should be clearly stated and justified. The depth of the analysis and level of detail depends on the purpose of the assessment as stated in the goal definition and may include generic data, site specific-data or a combination of both. The limitations of the analysis represent possible cut-off criteria as well the borderline between SLCA, LCA and LCC.

The functional unit is important for the comparison between products and reflects an obligatory property of the product. Often, SLCA works with information on attributes or characteristics of organisations along the life cycle that are not directly related to product outputs and can't be expressed in terms of units. In that case results can be expressed with the help of attribute assessment /37/. Linked to that is the consideration of by-products, for which the UNEP framework follows in principle the ISO guidelines for LCA. The challenge lies on qualitative indicators that can not be expressed per unit of product output, which automatically renders quantitative allocation of impacts between products not possible. In that case, the form of reporting can be altered and not reflect a per-unit basis assessment, rather than an

assessment of a property (e.g. of an organisation) that affects the respective qualitative criterion (e.g. by violating it). Hence, there is no sense in allocating a property among products, rather than assessing the weight of a product system that exhibits this property along the production chain, thereby reflecting its importance /37/, /38/. Which this property will be, is an open topic /18/.

The question of impact categories has been a common discussion topic among experts of social assessment. The UNEP framework is based on the determination of *subcategories* of social/socio-economic impacts along the entire life cycle and uses a double classification approach: the subcategories are grouped under stakeholder categories and impact categories and their result is expressed by specific indicators.

- **Stakeholder categories** are clusters of stakeholders that can affect or be affected by the investigated product system, such as workers/employees, consumers, the local community, society and value chain actors. These categories are considered to be the main groups affected along the life cycle, but the list can be expanded to include other groups. Tab. 6 in Annex A.1 provides an overview of the classification of sub-categories based on stakeholder groups. These subcategories are set as minimum of social issues to be assessed during an SLCA. They are not exclusive nor do they apply to all cases. As already mentioned, the context and purpose of the assessment, the type of product and the regional character plays a very significant role in their determination.
- **Impact categories** are groupings of SLCA results, related to social topics of interest to stakeholders and decision makers. More on impact categories will be discussed in the life cycle impact assessment stage.

Life cycle inventory

This is the stage of collecting the necessary data to verify how the supply chain and the organisations involved perform on social and socio-economic aspects. These data are derived from elementary flows coming in and out of the process system, based on the system boundaries defined.

First, it is important to determine whether site-specific data is required or generic data is sufficient. The analysis of the complete range of social impacts for every process with site-specific data is a very time-consuming and expensive process; in that case estimation of the relative importance of the unit processes is desirable. The UNEP framework suggests that this could be achieved with the identification of “activity variables” that are common to all unit processes (e.g. worker-hours, added value) and can thereby illustrate which processes are most important and which require generic or site-specific data. A similar approach, but from the company’s perspective, is followed by /18/ and /32/, who suggest a share factor that would reflect the weight of each company’s social profile along the life cycle. Moreover, /38/ suggests that this resembles the life cycle attribute assessment approach /37/ (see also *Goal and scope definition*). Information on such variables can be derived from statistical agencies; it is however important to be treated with care as they may lead to errors (e.g. official worker-hours do not show unpaid or forced labour). A further procedure of data collection would be the determination of “social hotspots” through a generic analysis of where along the product’s life cycle the social concern is more significant. Both “activity variables” and the “social hotspots” should be seen as indicative and provide guidance on whether case-specific assessments are necessary or not.

Next stage is the collection of the necessary data on social inventory indicators. Collection of data can be conducted through desktop research, web-based reporting and site-specific investigation (e.g. auditing,

interviews, questionnaires). The kind of data that are needed depends on the indicators that express the respective impacts. The indicators, in turn, are determined by the impact (sub)categories defined in the goal and scope definition. They can be of qualitative, quantitative or semi-quantitative nature and as such, relating them to a unit of a process output or a functional unit is not always possible and may not make sense. Tab. 6 in the Annex A.1 provides an overview of examples of indicators for the different impact sub-categories defined in the UNEP framework. For definitions of the respective indicators the reader is referred to the website of the SETAC/UNEP initiative⁴. Important is that the validity, completeness and documentation of the data is secured and that the uncertainty is minimised for both generic and site-specific data.

Life cycle impact assessment

Purpose of the life cycle impact assessment is to link the inventory data to particular social categories (classification) by calculating the subcategory indicators and aggregating their results (characterisation). Following the discussion on the goal and scope definition, this is the stage where the second classification of subcategories under impact categories appears, besides the initial classification under stakeholder categories. The two classifications are considered complementary and not contradictory: the first one (impact) attempts to identify generalised impact categories for a better presentation of the results of the subcategories, while the second one (stakeholder) gives focus on the stakeholders that these subcategories refer to and affect.

As mentioned before (see *Goal and scope definition*) impact categories are seen as groupings of the SLCA results in social areas that are relevant to the stakeholders. The UNEP framework defines two types of impact assessment (Fig. 9).

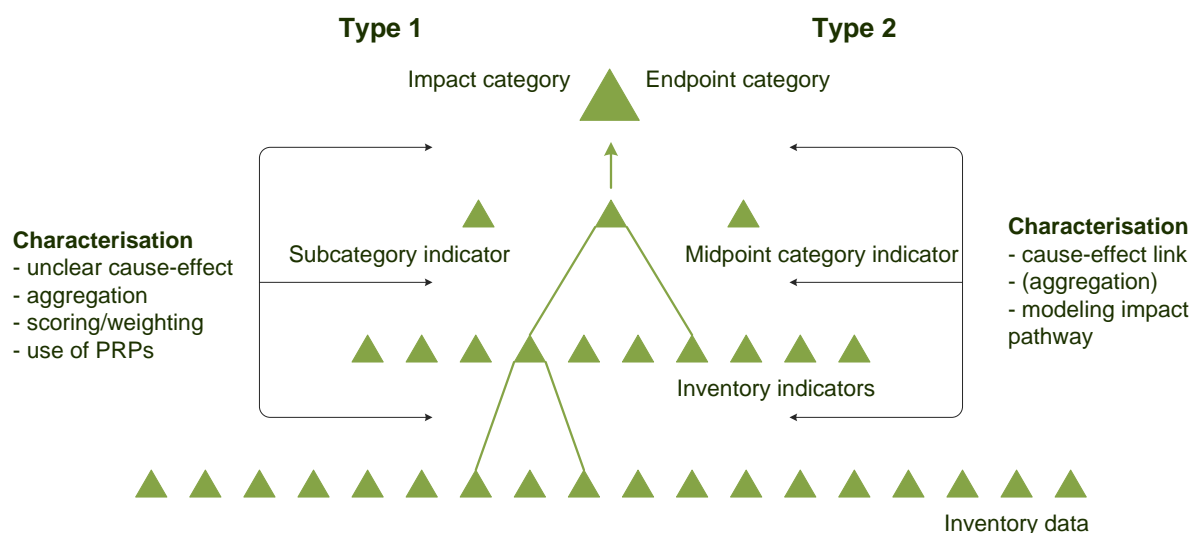


Fig. 9 Impact pathways of the UNEP methodology (adapted from /38/)

- The first one (type 1) aggregates subcategory indicator results into generalised results of impact categories (the UNEP framework suggests the following: human rights, working conditions, health and safety, cultural heritage, governance and socio-economic repercussions) that are relevant to the stakeholder groups defined in the goal and scope definition. Type 1 impacts consider the fact that a cause-effect chain that would permit the modelling of the entire impact

⁴ Visit: http://www.estis.net/sites/lcinit/default.asp?site=lcinit&page_id=A8992620-AAAD-4B81-9BAC-A72AEA281CB9

pathway is not always known or precise. In order to overcome this problem, an aggregation approach could be used instead of a direct model between indicator and impact. Here the inventory data are positioned against internationally set boundaries, referred to as Performance Reference Points (PRP); the difference in performance is reflected in the value of the indicator and can be expressed with a scoring system (e.g. indicator is 1 if workers that receive minimum payment are less than 5%, otherwise indicator is 0; see also /38/). The indicator scores can be aggregated with weighting factors to produce a total subcategory result and subsequently an impact category result (see also /38/). The translation of inventory data to indicator results (scoring) and the weighting procedure are still considered as “characterisation”, only not in the traditional form like in LCA that uses characterisation factors. For the time being, there is no agreed set of formulas for the aggregation of indicator results and the classification of the sub-categories under impact categories. It is reasonable to believe that a certain degree of flexibility is allowed based on the goals of the assessment.

- The second one (type 2) reflects the situation where the cause-effect chain can be established and their results are determined by means of modelling the *impact pathway* between the inventory data and the effect to a midpoint or endpoint damage category. Along this pathway, there can be midpoint and endpoint categories, determined by the position on the chain and the goal and scope of the assessment. Endpoint categories can be for example human capital, cultural heritage and human well-being, the latter having as midpoints longevity, health, autonomy, safety, security and tranquillity, equal opportunities, participation and influence. According to /38/, examples of this type of impact pathways are described in /16/ and /35/. As with type-1 impacts, there is no established characterisation model to express this kind of causal relationship between inventory data and mid-, endpoint effects.

The last stage of a SLCA is the interpretation stage, which includes the identification of significant issues like important social findings and methodological decisions, the evaluation of the consistency and completeness of the report, the drawing of conclusions and recommendations, as well as the reporting and the communication of the results. These actions are similar to the LCA principles and will not be dealt with further in this report.

3 Life cycle sustainability assessment of biorefineries

Chapter 2 provided an overview of basic consideration points of a life cycle sustainability assessment. This chapter will attempt to discuss the challenges of applying these considerations within the concept of biorefineries. This task is especially challenging, given the large number of possible configurations in terms of feedstock, processing technologies and products associated with biorefineries. It is nevertheless necessary since bio-based products do not automatically mean less use of non renewable resources or minimised economic, environmental and social impacts /6/, /39/. There is generally scarce information on this respect concerning biorefineries and most of them are focusing on LCA since it is already the approach that is most researched. For LCC and SLCA as such, information is virtually non existent although there are references that are discussing general economic and social aspects of biorefineries. Here, LCA is also discussed in greater detail and LCC and SLCA are examined in a more or less theoretical way, based principally on the discussion in chapter 3.

In order to deal with this task, a series of framework questions (or objectives) regarding sustainability assessment for biorefineries have been addressed. Even though sustainability assessment is regarded as a whole throughout the entire document, it is pointed out that these questions may be similar but can't be identical for all pillars. The different scope and focus of each pillar renders it necessary to adapt the discussion in a respective way. In that sense, issues that are for example crucial for LCA (e.g. handling of co-products) may not have the same significance in LCC or SLCA.

3.1 Environment

The methodical approach of LCA described in 2.2 shall be used below to assess the environmental sustainability of biorefineries and their products. This means that the four stages *goal and scope definition*, *life cycle inventory analysis*, *life cycle impact assessment* and *interpretation* will be followed. The determinations made in the goal and scope definition stage are of high importance since they influence substantially the total expenditure of the investigation, the procedure to generate results and the results per se. In a first step the objective of the investigation has to be defined. According to this objective the system boundaries, the handling of co-products, the functional unit and the impact categories to be considered, shall be determined. The decision on whether an attributional or a consequential LCA or whether a midpoint or an endpoint modelling will be conducted also depends on the objective of the investigation.

Objectives

One of the basic frame questions that arise regarding LCA for biorefineries concerns the objective of the investigation. In principle, an LCA for biorefineries could focus on the following two objectives:

- The product-oriented investigation, hereby meaning the investigation and eventually comparison of products produced in different biorefineries to each other and to their fossil references
- The concept-oriented investigation, hereby meaning the investigation and eventually comparison between different biorefinery concepts

In the first case, the product and only this specific product is the focus, while in the second case the entire concept that includes this specific product as part of the production is investigated. What is more

useful depends on the reason of the assessment and can't be beforehand determined in a fixed way. Each of these objectives raises a series of questions (Qn) that can be answered through a LCA /40/-/49/:

Product-oriented investigation (Q1-Q3)

- Q1: How many emissions can be saved by replacing a fossil product by its respective bioproduct produced in a biorefinery?
- Q2: *Comparing the entire life cycle of the same specific product*: Which way is environmentally most favourable to produce a specific product (e.g. 1 MJ bioethanol)? For this, several biorefinery pathways using different feedstock (e.g. cereals, wheat straw etc.) to produce the same product could be investigated.
- Q3: *Comparing the entire life cycles of different products within a specific product group*: Which way is the environmentally most favourable to produce biofuels (e.g. 1 MJ biofuel)? For this, several pathways using different feedstock (e.g. cereals, agricultural residues, waste etc.) to produce different biofuels (e.g. bioethanol, biodiesel, biomethane etc.) could be investigated.

Concept-oriented investigation (Q4-Q7)

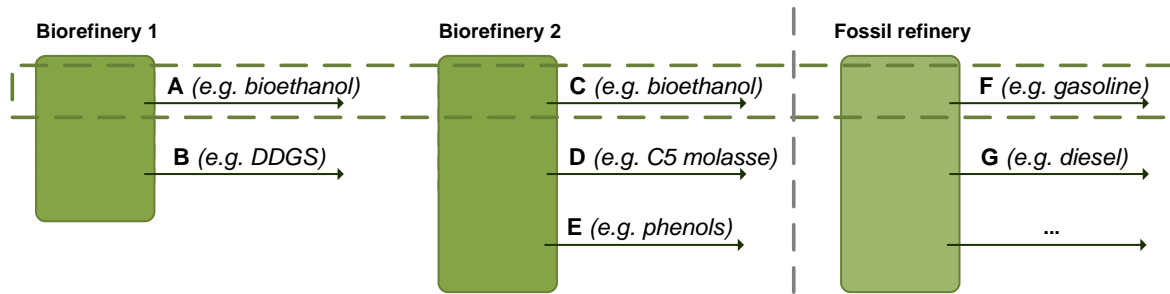
- Q4: Which *concept* is the environmentally most favourable in producing a specific product (e.g. bioethanol)? For this, several concepts of biorefineries using different feedstock (e.g. cereals, wheat straw etc.) to produce bioethanol and different co-products (e. g. animal feed, chemical compounds, energy, etc.) could be investigated.
- Q5: Which *concept* is the environmentally most favourable in producing different products within a specific product group (e.g. biofuels)? For this, several concepts of biorefineries using different feedstock (e.g. cereal, wheat straw, etc.) to produce different biofuels (e.g. bioethanol, biodiesel or biomethane) and different co-products (e. g. animal feed, chemical compounds, energy, etc.) could be investigated.
- Q6: Which biorefinery *concept* leads to the most sustainable use of the biomass feedstock and the respective land resources (irrespective of the product palette)? For this, results could relate to the biomass input or the land hectares /43/, /47/.
- Q7: How many emissions can be saved when comparing a biorefinery *concept* with an “imaginary refinery” producing the fossil references that are replaced by the biorefinery's products?

System boundaries and functional unit

The system boundaries contain all process steps within the process chain from the production and provision of the feedstock, the pre-treatment, the conversion of the biomass, the distribution of the product, its use and its disposal/recycling. In the case of biorefineries, the step which is especially challenging is the biomass conversion step.

To compare products or concepts of biorefineries it is necessary to investigate them in a similar level of detail. Additionally, the products or concepts to be compared should principally have the same performances (or benefits) and the same functional unit. The functional unit is used to ensure the comparability of the products and the concepts of biorefineries. The performances of products include the benefit of the desired product that is represented by the functional unit e.g. 1 MJ bioethanol (or 1 MJ biofuel) and other benefits resulting from the system in which the product is produced /50/.

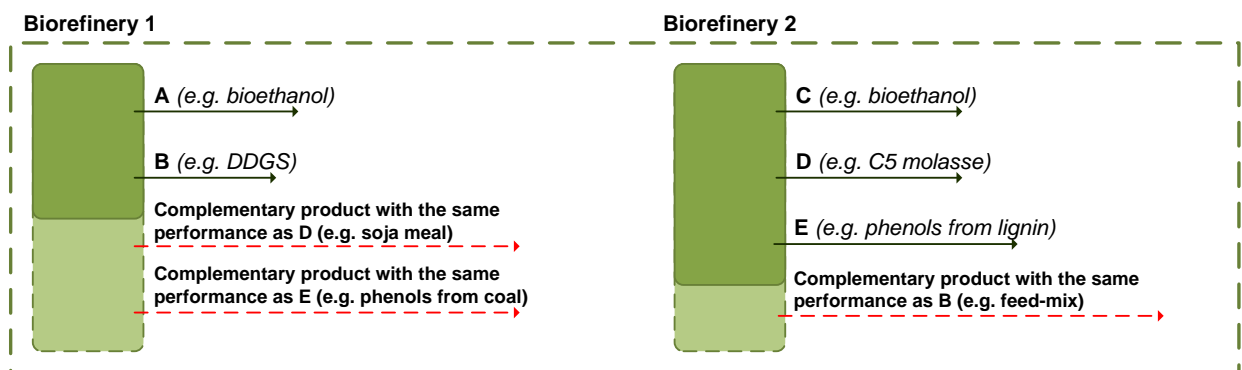
In cases where the focus of the investigation is the product only, the result corresponds to the amount of emissions that are released by producing the functional unit of the focused product; therefore the functional unit should be the same, when comparing different products, and should represent the benefit of this specific product (Fig. 10). The rest of the products do not alter the approach and how they could be handled is shown later on (see *handling of co-products*). This applies to all questions mentioned in the objectives (i.e. Q1-Q3).



Questions: Which is the environmentally most favourable way to produce a specific product (e.g. bioethanol)?
 How many emissions can be saved by replacing the reference product with the biorefinery product? **Product-oriented**

Fig. 10 Product-oriented investigation

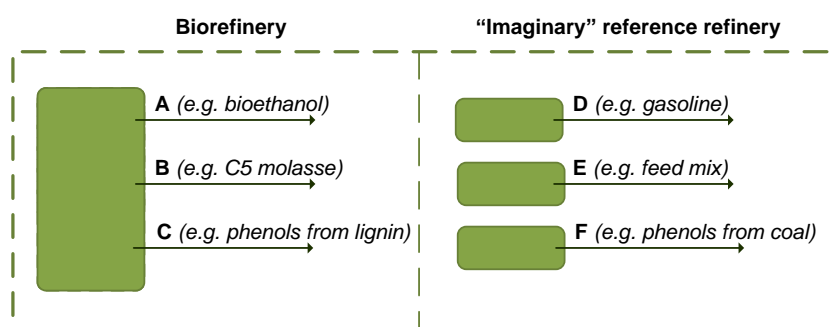
In the case of **biorefinery concepts** however and especially the investigation of a *specific product within the biorefinery system* (i.e. Q4-Q5), having the same functional unit is necessary but not enough. In order to be able to compare the systems (if comparison is desired), the product palette should be equal; otherwise a comparison of two products within different production systems is not valid. In that case, the performance of the biorefinery concept includes not only the benefit of the desired product (represented by the functional unit e.g. 1 MJ bioethanol), but also the benefits of the co-products produced in the biorefinery and these should be the same. For this, the product system has to be expanded by including the missing benefits that are produced additionally in the other product systems so that the product systems to be compared fulfil the same performances. The missing performance that has to be included should be achieved by the introduction of a product complementary to the product in the other product system (Fig. 11) /50/. The results of the investigation correspond to the emissions from producing all the products within the expanded system related to the functional unit of the desired product. The functional unit could also represent for example the total yearly emissions of the system; in that case the result would show which **concept** (without reference to the products) is environmentally more favourable, which is a valid comparison since the product palette is equal.



Question: Which biorefinery **concept** is environmentally most favourable to produce a specific product (e.g. bioethanol)? **Concept-oriented**

Fig. 11 Concept-oriented investigation among biorefinery products

Alternatively, a biorefinery concept can be investigated simply in terms of emission reductions, if compared to an “imaginary”⁵ reference concept that adds all individual processes that produce the reference products that are replaced by the biorefinery products (i.e. Q6). In this case, handling of co-products is not necessary since the concept is investigated as a whole and the emissions are considered as an aggregated value. The functional unit could still relate to a desired product and assign all emissions to that product or it could relate to the yearly emissions of the system (Fig. 12) /48/. While this may be suitable for a pair wise comparison between the biorefinery system and the “imaginary” reference one, it is not suitable for comparison between different biorefinery concepts, since comparing yearly emissions of systems that have different inputs, different processes and different products does not lead to useful conclusions. In this case, the expansion of the system should be followed as explained above.

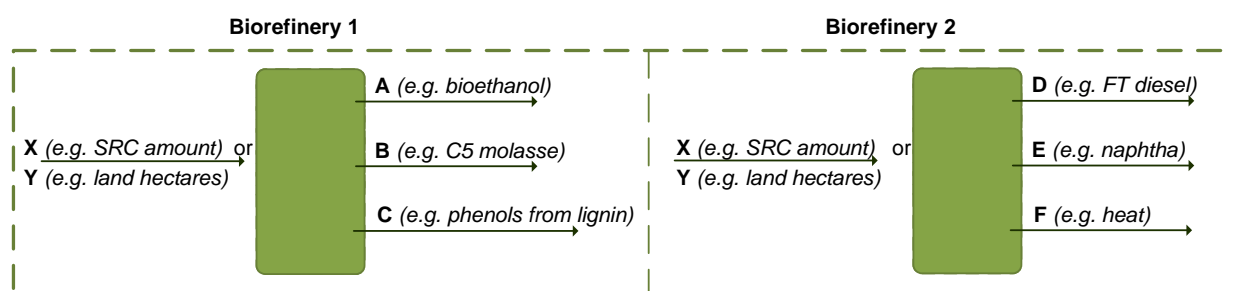


Question: How many emissions can be saved if the biorefinery products replace the ones of an “imaginary” reference refinery ?

Concept-oriented

Fig. 12 Concept-oriented investigation (for comparison with reference system)

Alternatively, one may wish to investigate which biorefinery concept ensures the most sustainable (from the environmental perspective) use of a specific biomass resource or even the most sustainable use of a specific land area. In this case, the product palette is again not the crucial part since the biorefinery is considered as a whole and the investigation targets, in principle, the impacts of the use of the resource and not the impacts of the production of the specific products. The functional unit could in this case relate to the amount of input material or the hectares of land dedicated to this purpose /43/-/45/.



Question: Which is the environmentally most sustainable biorefinery concept to use biomass or land resources ?

Concept-oriented

Fig. 13 Concept-oriented investigation (for examination of the use of resources)

The environmental questions/objectives related to the comparison of products produced in biorefineries and of concepts of biorefineries can be answered or achieved by conducting both an attributional and a

⁵ The word “imaginary” refers to the fact that there is no actual reference concept that has exactly the same product portfolio as the biorefinery concept.

consequential LCA. However, as mentioned in chapter 2.2, a consequential LCA is conducted to investigate the effects of changes within the process chain that lead to effects outside of the defined system boundaries and therefore includes aspects that were not considered before; in that sense, it has a wider scope than the one described by the aforementioned objectives.

Handling of co-products

Especially challenging for the concept of biorefineries is the handling of co-products and the allocation of environmental burdens, since the nature of the products can be very different (e.g. material, feed, energy). The procedure that is proposed in the ISO 14044 is already described in chapter 2.2 /11/. In order to determine which of the described methods is suitable when products and biorefinery concepts shall be compared, the different methods are explained below into more detail.

Dividing the unit process into sub-processes

The first objective in avoiding allocation procedure is to divide the unit process in that many sub-processes in a way that only one product is the result of each unit process. In practise this approach is often not feasible, since the process chain is divided in unit processes based on technical constraints (i.e. the configuration of the process is usually determined before the handling of co-products is determined) /15/.

Expanding the product system

Expanding the product system means that the system should be widened to include a complementary production of the product that is additionally produced in the other product system. Principally, this procedure can be applied for the investigation of both products and concepts.

In the case of **concept-oriented** investigation, the system is expanded with a complementary production of the product that is additionally produced in the other product system, as described in the discussion of the system boundaries (see Fig. 11). The complementary product should have in principle the same performance (or benefit) with the respective one from the other system. This is necessary otherwise the concepts can't be compared under a common ground. This approach is, however, time consuming and requires knowledge of the complementary production. In some cases there are several pathways to produce the required complementary product, which subsequently lead to different emissions depending on the pathway selected. Additionally, the entire system that contains the different products and the complementary products may become too complex /15/, /51/. Especially in cases, where the complementary product, is itself a new product system with several benefits, the analysis of the environmental impacts will be complicated and obscure. This method is simpler if the complementary product has only one production pathway /15/.

In the case of **product-oriented** investigation, the expansion of the product system could be better realised through a special case: the so called “substitution” (or “credit” method). Within the substitution, the expanded part represented by the complementary product has to be subtracted from the overall system, so that only the product that is the focus of the comparison is left. In other words: the expanded product system gets a credit for the environmental impacts that are caused by the complementary product, since this is replaced by the co-product. Thus the product system is reduced to the focused product /52/. Caution should be given to the fact that the complementary production should be again well known because its selection will influence the result (e.g. the more polluting the complementary production is the more environmentally friendly is the focused product after the subtraction). Since the

replacement of the complementary product by the focused product is a precondition for an application of this method, the substitution is not possible in cases where the market requires both the original product and the complementary product, in order to satisfy the demand.

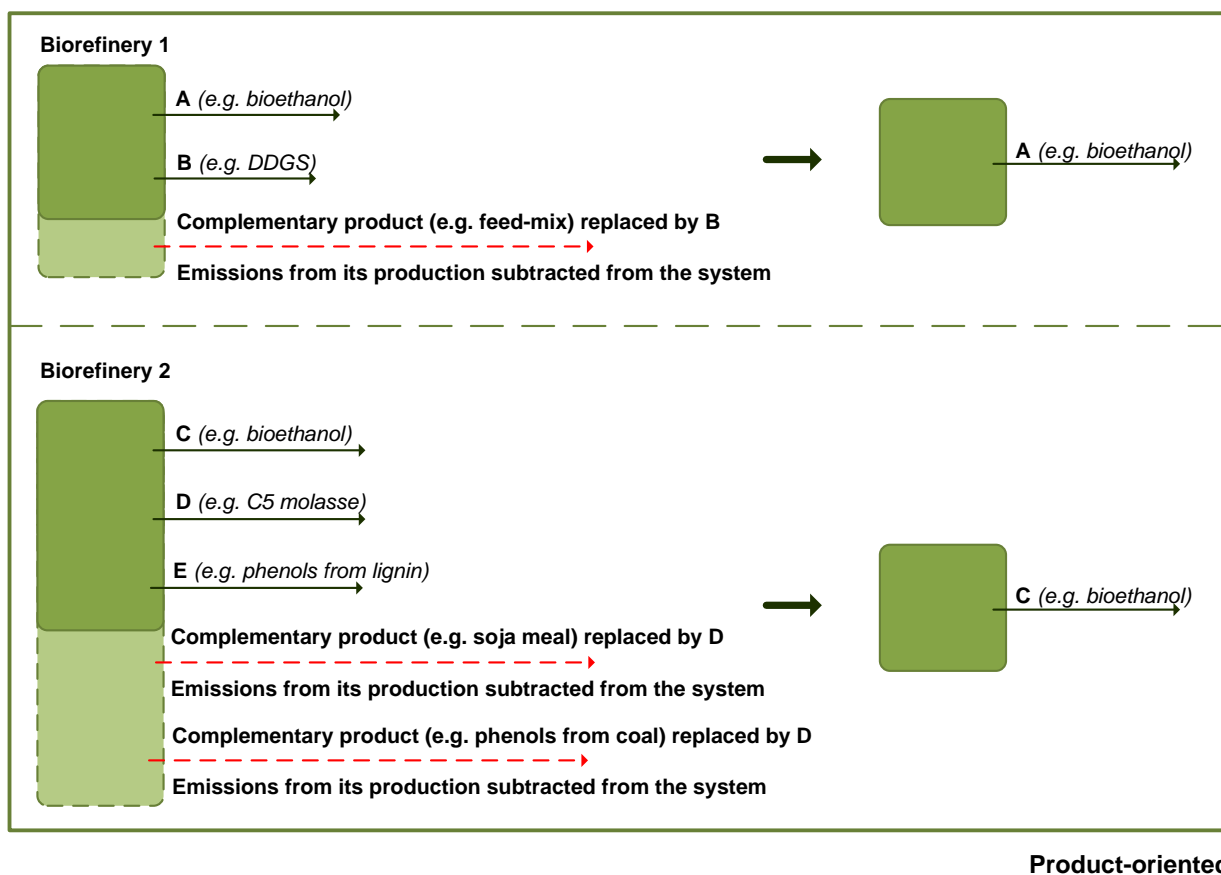


Fig. 14 Expanding the system for product-oriented investigation

Allocation

According to the ISO guidelines allocation methods should only be conducted in cases where dividing into sub-processes and expanding the system is not possible or very tedious and confusing (e. g. several ways to produce a complementary product) /51/. If only the product is the focus, the allocation method is suitable since the result would provide only the emissions that are caused by the production of this specific product /15/. However, investigation or comparison of concepts requires the system expansion and allocation is not suitable.

In ISO 14044 it is proposed to allocate the emissions between the products in a way that reflects the underlying physical relationships between them. So the allocation can for example be conducted based on a proportion of quantities (mass, volume) or on the base of energy (or exergy) content. In cases where physical relationships can not be used as basis, the allocation shall be made on the basis of other relationships e. g. economic values (e.g. market value, prices, and costs) /11/. The choice of the allocation method has a strong influence on the results /46/, therefore the choice has to be well justified. This influence can be illustrated by conducting sensitivity analysis /50/.

Summary

Tab. 3 summarises the possible approaches for handling of co-products and their relevance to the objective of the investigation. Dividing the process unit would eliminate the need to handle co-products, but it is mainly a theoretical approach and not really applicable in praxis. If the objective of the investigation is the comparison of products, the use of allocation method seems appropriate; the parameter of allocation should be carefully selected and results should be checked by means of sensitivity analyses. Expanding the product system with complementary products that are substituted by the biorefinery products is also an option, but the results depend on the choice of the complementary production and often the market mechanism is unknown as already mentioned.

Expanding the system with complementary products and investigating it as a whole (without substitution) is not suitable when the focus is the product, but if the objective of the investigation is the comparison of biorefinery concepts, it is recommended so that the resulting emissions can be compared directly and under the same basis. Substitution and allocation are not appropriate for a concept-oriented investigation.

Tab. 3 Possible methods of handling co-products related to the objectives of the investigation

Handling of co-products	Product-oriented investigation	Concept-oriented investigation
Dividing the process unit	-	-
Expanding the product system	-	+
Substitution	+	-
Allocation	+	-

Impact categories

Either for product investigation or for concept investigation, the impact categories that could be investigated are listed in Tab. 1. As already mentioned in 2.2 the investigation of some impact categories is associated with a high uncertainty. The listed impact categories base on midpoint indicators. Endpoint indicators are used when referring to direct damages on the human health, the natural environment or the resources and they can also be implemented in the case of biorefineries, but one should take into consideration that the application of endpoint indicators is also associated with a high uncertainty (see 2.2). Since most studies investigate consumption of finite energy, global warming potential, eutrophication and acidification, it is more likely that the results could be compared (under careful consideration of the different framework assumptions).

3.2 Economy

As in any other commercial enterprise, sustainable economic success is an important entrepreneurial objective when operating a biorefinery. To achieve sustainable economic success, the whole business model needs to be analysed and optimised for long-term profitability. LCC can help to find answers to the questions that arise during such a process: Which products shall be manufactured based on which raw materials and which quality should both have? Which process shall be used, which plant manufacturer be engaged and for what stress shall the equipment be designed? Which markets shall the products be addressed to? These are only few of the questions that influence the economic viability of biorefinery concepts. Foreseeable developments of parameters influencing profitability must also be included in the long-term optimisation.

When conducting an LCC analysis, all relevant cost and revenue drivers are disclosed based on a long-term assessment. It is a “cradle-to-grave”-concept examining all life phases of an investment project and is used to assess the profitability of investments as well as to help choosing the best of several investment alternatives.

In the case of a biorefinery, considering the total costs along the whole life cycle of capital goods is especially important, since the amounts invested are high, service lives are long and the capital costs make up a large share of the total manufacturing costs. Performing an LCC analysis can hence be considered indispensable when deciding on investment alternatives. The respective revenue structures should be considered as well, because different designs of biorefineries or parts of biorefineries depend on different end products or different specifications of the end products. The installation of equipment with higher life cycle costs may thus be justifiable, when higher priced end products (e.g. specialty chemicals) are manufactured this way. Taking all product streams into account is of great importance especially when analysing a biorefinery, because even such product streams that are considered by-products can decide the profitability of the concept. A typical co-product of biorefineries is, for instance, animal feed, since a biorefinery concept would not be developed only to provide feed. Animal feed has however stable selling markets and realises good prices. This makes it a key output factor in the long-term assessment of a biorefinery and can well decide if the examined concept is viable or not. The same might apply to any other output stream of the biorefinery. Hence, all costs and revenues need to be considered when examining possible investments.

An LCC can however also be performed to investigate alternative utilisation of individual process streams or mass flows within a biorefinery. Although the overall economic performance of the biorefinery as a whole is naturally the main objective of its operator, it is possible to allocate the costs of the proportionately utilized equipment and materials to the individual products. This can be done on a mass, energy or other basis and gives a picture of how cost-intensive the respective products are. LCC can help to find the most cost-effective way to treat the examined mass flows or process streams considering all involved costs and revenues. Opportunity costs are an important factor herein. For instance, a mass stream could accrue within the biorefinery that can only be disposed of or conditioned to a market-worthy product though an expensive process. Then, it can be optimal to accept the high conditioning costs and receive revenues in return as long as the opportunity costs of the disposal are high enough. An LCC can hence disclose such optimisation potentials for parts of the biorefinery as well as for the concept as a whole.

Standard LCC approaches can be applied in analysing and optimising the whole life cycle of biorefinery investments. As described in 2.3, all costs that will presumably occur during the whole life cycle of the examined equipment, from development to installation to use and disposal, are identified and quantified. These are all capital costs as well as the operation and consumption-linked costs (e.g. feedstock costs), as expected to occur in the intended operating mode. The revenues that are expected to occur through product and by-product sales are determined accordingly. Under the assumption of adequate interest rates, all these payments are discounted to their present value; their sum resulting in the net present value of the examined investment.

This way, it is possible to identify the most profitable configuration of a biorefinery based on a long-term comparison of several alternatives. This includes optimal processes, plant sizes, types and qualities of input factors and end products. And although LCC is generally facility-oriented, the local circumstances the biorefinery is exposed to, need to be considered. These are the competitive environments on the procurement and sales markets, as well as the political environment.

Expectable changes of factors influencing the biorefinery's economic environment, like policy changes or market entries of substitutes or competitors on the procurement or sales markets, need to be considered in a long-term LCC analysis. If, for instance, policy measures are taken that impose stricter sustainability criteria on the employed biomass, costs may rise. If that is likely to happen during the life-span of the examined investment, its economic environment is affected – a situation that needs to be included in the LCC-analysis.

Within LCC analysis for biorefineries, a specific reference to product-, concept-, producer- or even consumer-oriented investigation, like it is attempted for LCA or SLCA, can't be clearly established, because LCC does not analyse actual impacts in the sense that the former do /53/. Nevertheless, it might be reasonable to take the perspective of the consumer to optimize the business model. By thinking about what product would be best for the optimisation of the consumer's life cycle costs, products of higher quality to be offered may be identified. If the biorefinery were then adapted to producing those improved products, higher prices may be demanded, raising turnover and potentially improving the long-term profitability of the biorefinery itself, even if additional investments are required. What is best for current or potential customers in terms of optimizing their life cycle costs, might hence also provide benefits to the life cycle cost of the biorefinery.

The LCC analysis is a sound tool to assess the viability of different investment alternatives. But it has limitations, which are based on the uncertainty of preliminary simulations of systems as complex as a biorefinery and forecasts in general. While the capital costs can usually be well anticipated through well-defined financing modalities, most other costs are not easily forecast. Prices for input factors may vary a lot; especially those for the biomass feedstock, not unusually the biggest cost factor of all in a biorefinery. Also the prices of the goods produced may well vary over time. The value of some might even be diminished if produced in large quantities for a small sales market, as was observed when German biodiesel producers provided so much glycerine, that its value dropped (source). This could become a relevant factor, if the finally chosen biorefinery concept finds many imitators. The length of the periods under consideration give cost assessments further uncertainty.

The main challenges in conducting an LCC analysis are the definition of the investment alternatives and the specification of all of their relevant characteristics, as well as making plausible assumptions for all relevant influence factors like prices, interest rates, political incentives and so forth. Only through applying the most realistic assumptions can the LCC analysis be carried out successfully.

3.3 Society

Social impacts along the life cycle of a product have principally a dual source. On the one side they are the direct result of processes along the production chain of the product and on the other side they are a result of the conduct of the company/operator producing the respective product; the latter is ultimately **non** product-specific. In other words, the type of product determines the type of processes involved to produce it and thus part of the social impact of the production chain; how these processes are practiced is more or less product-irrelevant and depends on those practicing them. So, the basic question is whether SLCA should focus on specific products, on the product system as a whole or on the companies that produce them.

System boundaries

Biorefineries are a very prominent example of this problematic since they result in a palette of products (no distinction between main and secondary products) and the social impacts from these processes are altogether responsible for the social “performance”. In that sense, it is difficult and at the same time questionable whether social impacts can be assigned to a certain product and what advantages would this procedure have. A concept investigation would be able to aggregate impacts of different processes and provide an overall result, without the need of assigning impacts to specific products. In any case, this will show only a part of the general social effect, the one that comes as a result of the processes involved. In order for the assessment to be complete, the effect of the conduct of the biorefinery operators (and the companies involved along the entire bioproduct chain) has to be included. For that, it seems appropriate for the case of biorefineries to attempt a combination of those, the challenge being the identification of appropriate indicators and their handling.

Concerning the extent of the system boundaries, *Dreyer et al* and *Haushild et al* suggest that focus should be given on the influence of the manufacturing stage along the production chain, as a result of the fact that SLCA reflects mainly the conduct of the company manufacturing a product and is oriented in business decision-making /18/, /32/. The influence of manufacturers however, is fading out for stages that are further way (both upstream and downstream) in the production chain; as a result the role of those stages (and the companies involved) is underestimated. In the case of biorefineries, however, biomass is the starting point and particularly issues upstream the manufacturing process (land use, biomass availability and cultivation) are critical. In that sense, biobased products can not be perceived as typical products, simple outcomes of a manufacturing procedure, due to the complexity and implications of biomass exploitation. In a field where social concerns arise along the entire production chain, it seems appropriate for SLCA for biorefineries to consider the entire life cycle and not give focus to certain stages.

Impact categories and indicators

The discussion of chapter 2.4 pointed out that the identification of suitable social indicators is by itself a big challenge, let alone the adaptation to the concept of biorefineries. While in LCA the same indicators can be used throughout the entire production chain, when assessing social impacts there might be differences among stages (following examples are oriented on the UNEP guidelines classifications, see chapter 2.4.2 and Annex A.1): For instance, different stages may influence different stakeholder categories (e.g. the use and/or recycling stage of a bioplastic influences consumers as group more than workers). Or an impact category/indicator that might be of importance in one stage may not be relevant in another (e.g. complaints over consumer privacy are in principle more relevant for the biomass processing stage than for biomass production). On the other side, there are indeed indicators that are applicable to the entire chain, like conditions in the working environment (e.g. hours, forced and child labour, right to form unions). So, the challenge is not only to identify suitable indicators, but also to find a way to integrate (and take into account in an equal or relative manner) indicators that are relevant for different parts of the chain and to different social groups. Tab. 4 presents a non-exhaustive list of indicators that could be relevant in the case of biorefineries.

Tab. 4 List of social indicators that could be relevant in the case of biorefineries (based on Annex A.1)

Indicator
Absence of working children under the legal age
Workers are free to join unions of their choosing
Lowest paid worker, compared to the minimum wage

Percentage (estimate) of forced labour by region
Women in the labour force participation rate by country
Numbers of incidents of discrimination and actions taken
Number/ percentage of injuries or fatal accidents
Presence of policy concerning health and safety
Number of consumer complaints
Communication of results of social and environmental life cycle impact assessment
Organisational support for community initiatives
Development of project-related infrastructure with mutual community access and benefit
Forced evictions stemming from economic development
Prevalence of racial discrimination
Organization efforts to strengthen community health
Percentage of workforce hired locally
Existence of (legal) obligation on public sustainability reporting
Contribution of the product/service/organization to economic progress (revenue, gain, paid wages)

As mentioned in chapter 2.4, the integration of quantitative and qualitative indicators under a unified reporting way is until now the main challenge, not only for biorefineries but in general. This could be achieved, for instance, by a form of matrix where all results could be translated through grade-scales into quantifiable values and then summed up. The link to the respective functional unit and how exactly these scales are identified is however, subject to research /53/.

Limitations

Contrary to LCA which, under circumstances, could be a valuable tool for comparison between products or concepts, SLCA has the particularity of assessing social impacts, which have a strongly regional character and render comparison a very sensitive issue. As is the case for biomass processing in general, biorefineries may be parts of a production chain that is scattered over different locations. And while this can be tolerated in LCA that uses universal and quantified indicators, it is a very crucial aspect in SLCA. Certain social impacts (especially those that relate to the impacts on the local community) could be perceived very differently from region to region and even if they could be quantified their results could not be placed against and compared to those of another biorefinery that belongs to a different production chain somewhere else (even if the products are the same). For that reason, SLA seems appropriate for general assessment of products or concepts, but for comparison only of those alternatives that are in the same region or have the same geographical pathway (e.g. two alternatives for the construction of a biorefinery concept in the same location that uses biomass produced in the same region)

Another factor that renders comparison attempts of questionable usefulness is that some social impacts can't be subject to comparison, where a certain concept is "better" than another one, because relativity can't be established. For example two biorefinery concepts that are proven to violate obligations concerning racial discrimination can't be compared in that respect, because such a behaviour/performance is in any case unacceptable and no biorefinery can be better than the other. /16/

3.4 Integration

Apart from the challenges associated with each separate component of sustainability assessment, a major challenge that emerges is how to bring those components together for an integrated reporting of the results. Klöpfer et al discuss two options /53/:

- Three distinct individual assessments that would be equally important and would keep as much as possible the same system boundaries
- One “new” LCA that would incorporate SLCA and LCC as impact categories and would thus use the same LCI

What is the best solution is too early to be determined and further research is needed on that respect.

Cunningham et al also deal with this issue by proposing a matrix that consists of various environmental, economic and social indicators, based on which **single** products – in their case a biolubricant – are compared. The values of the indicators are converted to grades based on a scale from 0 (more sustainable) to 5 (less sustainable) and the sum of all the grades reveals which product is “more sustainable”. This approach is intended to provide a quick aid for decision-makers on the sustainability of products to be marketed. Although it follows the life cycle concept, the scaling procedure is used to avoid issues such as functional unit or by-product consideration. Furthermore, the inherent uncertainty and subjectivity when assigning grades to values is a topic that should be taken into account /54/. *Janssen et al* also suggest a multi-criteria decision analysis (MCDA) to help integrate the results of LCA, techno-economic analysis and social LCA from a biorefinery assessment and provide assistance to decision makers /55/. *Perimenis et al* also suggest a MCDA for the incorporation of economic, environmental and social criteria for the assessment of biofuels /56/.

Caution however should be paid to the scope of the comparison, in case a matrix is used. *Schaidle et al* use the same logic of assigning points to criteria based on their values. Three types of biorefineries are assessed based on a number of criteria and compared with each other by means of a final score (i.e. Analytic Hierarchy Process). These biorefinery systems are in fact biofuel production processes with one by-product (i.e. lignocellulosic ethanol and power, starch ethanol and DDGS, FT diesel and power) so the issue of multi-product consideration is not discussed. *Schaidle et al* follow the life cycle concept, but do not discuss the goal of such a comparison between three systems that use different feedstock, have different process configurations and different biofuel output. /49/

4 Initiatives on sustainability assessment of bioproducts and bioenergy

While individual aspects of sustainability assessment for various bioproducts have often been investigated (e.g. mainly LCA), there is scarce information that deal with the topic by examining all aspects. The following entries focus mainly on those initiatives that look at sustainability assessment as a whole (if not specifically bioproduct-oriented then potentially applicable also for bioproducts).

4.1 Projects

PROSUITE (Prospective Sustainability Assessment of Technologies) is a four-year project (2010-2014), partly funded by the 7th Framework Programme of the EC. It gathers 26 scientific, SME and industry partners. The aim of the project is to develop a coherent, scientifically sound methodology for the sustainability assessment of current and future technologies, taking into account their entire life cycle.

PROSUITE will provide tools to assess the economic, environmental and social dimensions of technologies in a standardized and comprehensive way. These tools will be shared freely to help SMEs, industry and decision makers to make sustainable choices. One specific case study that will be examined within the project is “Biorefineries” (*visit: www.prosuite.org*).

SUPRABIO (Sustainable Products from economic processing of biomass in highly integrated biorefineries) is a four-year project (2010-2014) with 17 partner organizations, financially supported by the 7th Framework Programme of the EC. The aim of the project is to develop and demonstrate a toolkit of new generic processes together with advanced intensification and integration methodologies that can be applied to a range of biorefinery scenarios based on sustainable biomass feedstock. A work package focuses on sustainability issues. It will provide a multi-criteria evaluation of the sustainability of the entire value chain by taking into account technological, environmental, economic, social, political and legal aspects. The aim is to identify the most sustainable biorefinery pathways for the simultaneous production of biofuels, biomaterials and biochemicals (*visit: www.suprabio.eu*).

The IEA Bioenergy Task 42 - Biorefinery aims to assess the worldwide position and potential for biorefineries. The framework of the task is the sustainable processing of biomass into a spectrum of biobased products and bioenergy. Task 42 is dealing with raw materials, conversion processes and products within a Full Sustainable Value Chain Approach. A specific activity focuses on sustainability aspects of biorefineries (acceptable social conditions, affordable production chains, environmental protection) and will result in the production of a guidance document by the end of 2011 (*visit: www.iea-bioenergy.task42-biorefineries.com/*).

BIOCORE (Biocommodity Refinery) is a four-year project (2010-2014) involving 24 partners and partly funded by the 7th Framework Programme of the EC. The project will investigate the industrial feasibility of a biorefinery concept that will convert lignocellulosic resources (e.g. straw, forestry residues) into a wide spectrum of products including second generation biofuels, chemical intermediates, polymers and materials. A specific task force aims to identify the most sustainable biorefinery pathway among the ones compared. For that, a thorough sustainability assessment is envisaged with the integration of necessary specific technological and economical data, as well as multi-parameter environmental, social and legal aspects (*visit: www.biocore-europe.org/*).

CATCHBIO (Catalysis for sustainable chemicals from biomass) is an eight-year project (2007-2015) involving 21 partners and funded by the Dutch Government and the partners of the consortium. CATCHBIO aims to develop clean and efficient processes for biomass conversion into low-cost and sustainable biofuels, chemicals and pharmaceuticals. To tackle the different scientific and technological issues involved in biomass conversion, CATCHBIO is divided in five research clusters. One of the clusters is focused on the socio-economic and ethical aspects of the processes and products (*visit: www.catchbio.com/*).

BIOLYFE (Demonstrating large-scale bioethanol production from lignocellulosic feedstocks) is a three-year project (2010-2013) involving 10 partners and co-funded by the 7th Framework Programme of the EC. Main result of the project will be the construction of an efficient second generation industrial demonstration ethanol facility. BIOLYFE aims at improving critical process steps and demonstrating the whole supply chain, from feedstock sourcing via fuel production to product utilisation. One of the focus points concerns sustainability and BIOLYFE will provide a multi-criteria evaluation of the sustainability of the technology by taking into account technological, environmental, economic and social aspects (*visit: www.biolyfe.eu/*).

4.2 Standards, Codes of Practice, Guidelines

CEN (European Committee for Standardisation) & ISO (International Organisation for Standardisation)

The working group **CEN BT/WG/209** was established in an effort to explore the potential of EU-wide bio-based product standards. The group has identified stakeholders in the area of biobased products and has recommended a research roadmap to achieve the goal of development of standards. The Task Group 2, explains the focus points of the research roadmap, i.e. issues like terminology, biobased content, biobased carbon content, sustainability criteria, life cycle analysis guidance and certification tools. Specifically for sustainability criteria, they are formulated within six themes, following NTA 8080 (/57/):

- GHG emissions
- Competition for land use and other uses of biomass (food/non-food)
- Biodiversity
- Environment
- Prosperity and
- Social well being.

Research is focus among others on identifying suitable indicators that qualify sustainability of biobased products, on investigating how these indicators could be quantified, on examining durability aspects of biobased products and their impact on sustainability criteria and on comparing biobased products to their fossil-based alternatives. /58/

Moreover, the technical committee **CEN/TC 383** is working on the development of standards for the verification of compliance with the sustainability criteria for biofuels and bioliquids as they are presented in the RED Directive ⁶. First results are expected by 2013. The six working groups are focusing on:

- Economic and social aspects
- Verification and auditing
- Terminology, consistency of evaluation methods and other cross-cutting issues
- GHG emission balances from a life cycle perspective and
- Biodiversity and environmental aspects

Similarly to CEN, ISO has established a Technical Committee, the **ISO TC/248**, with the purpose of developing standards in the field of sustainability criteria for production, supply chain and application of bioenergy. The four working groups of the TC/248 are focusing on cross:

- Cross-cutting issues (including terminology and verification and audit)
- GHG emissions
- Environmental, economic and social aspects
- Indirect effects

Roundtable on Sustainable Biofuels

The Roundtable on Sustainable Biofuels (RSB) is an international initiative that brings together various stakeholders, in an effort to establish standards that would ensure sustainability of biofuel production. The second version of RSB Principles & Criteria has been released November 2011, accompanied with documentation on guidance and compliance indicators. RSB establishes twelve main principles (each

⁶ 2009/28/EC Directive on the promotion of the use of energy from renewable sources

including various criteria) that determine and affect sustainability along the entire biofuel production (Tab. 5). Furthermore, RSB is currently testing a certification system that would certify biofuel production under the criteria developed. /59/

Tab. 5 Principles & criteria of the RSB version 2.0, /59/

Legality (1 criterion)	Planning, monitoring and continuous improvement (3 criteria)
Greenhouse gas emissions (3 criteria)	Human and labour rights (7 criteria)
Rural and social development (2 criteria)	Local food security (2 criteria)
Conservation (5 criteria)	Soil (1 criterion)
Water (4 criteria)	Air (2 criteria)
Land rights (2 criteria)	Use of technology, inputs, and management of waste (5 criteria)

Other similar roundtables and initiatives working on the development of sustainability standards and certification schemes also exist. They are either investigating biomass use overall or focusing on specific biomass feedstock or specific products:

- Roundtable on sustainable palm oil (RSPO, *visit: www.rspo.org*)
- Roundtable on responsible soy (RTRS, *visit: www.responsiblesoy.org*)
- Better Sugarcane Initiative (BSI, *visit: www.bonsucro.com*)
- Programme for the Endorsement of Forest Certification (PEFC, *visit: www.pefc.org*)
- Forest Stewardship Council (FSC, *visit: www.fsc.org*)
- International Sustainability and Carbon Certification (ISCC, *visit: www.iscc-system.org*)
- Council on Sustainable Biomass Production (CSBP, *visit: www.csbp.org*)
- Verified Sustainable Ethanol Initiative (VSE, *visit: www.sustainableethanolinitiative.com*)
- The Global Bioenergy Programme (GBEP) has formed a Taskforce for Sustainability that will develop a set of criteria and indicators concerning sustainability of bioenergy. The second draft contains a list of 44 environmental, economic and social indicators. The initial report regarding GBEP indicators is expected in May2011 /60/ (*visit: <http://www.globalbioenergy.org/>*)

International Social and Environmental Accreditation and Labelling (ISEAL)

ISEAL has developed a “Code of Good Practice for Setting Social and Environmental Standards”. It is not a proposal for sustainability standards, rather than guidelines on appropriate procedures that should be followed in order to develop such standards (including among others points like stakeholder mapping, balance of interests, review and revision, etc.). Complementary to that, ISEAL has developed a “Code of Good Practice for Assessing the Impacts of Social and Environmental Standard Systems”. Those Codes of Practice could provide a basis for the development of biorefinery-oriented sustainability standards. ISEAL codes of practice have been consulted for the development of existing standards, for example by the Roundtable for Sustainable Biofuels and the Forest Stewardship Council (*visit: www.isealalliance.org*). /61/, /62/

Global Reporting Initiative (GRI)

The GRI-G3 guidelines are intended to serve as a generally accepted framework for reporting on an organization’s economic, environmental, and social performance. They are designed for use by organizations of any size, sector, or location. In this sense, they could provide a basis for the reporting of organisation involved in biorefinery operation. Sustainability performance is classified under economic, environmental, and social categories, the latter being further categorized by labour, human rights,

society, and product responsibility. Each category includes a corresponding set of core and additional performance Indicators (visit: www.globalreporting.org). /63/

4.3 Workshops

Towards Harmonisation for biofuel sustainability standards, London, UK, 17-18 February 2010

Under the initiative of the International Union for Nature Conservation (IUCN), Shell and the Packard Foundation, the workshop has gathered 44 stakeholders along the entire biofuel chain and focused specifically on collaboration and the identification of those factors that would permit the harmonisation of sustainability standards for biofuels. Two main discussion groups were identified: (i) standards-related group and (ii) certification-related groups.

In the first group, the current status and further work to be done has been discussed for the areas of:

- Environmental and Social Impact Assessment
- Expansion and conversion of land resources for biomass production
- Greenhouse gas calculation methodologies
- Indirect land use change (ILUC)

In the second group, the current status and further research needs has been discussed for:

- Chain of custody
- Capacity building
- Benchmarking and recognition. /64/

Organisation for the Economic Co-operation and Development (OECD): Workshop on Best Practices in Assessing the Environmental and Economic Sustainability of Bio-based Products, 23-24 July, 2009, Montreal, Canada.

The workshop pointed out that, despite the numerous efforts on the topic, there are no internationally agreed best practices/instruments for assessing the sustainability of bio-based products and processes and highlighted the importance of interdisciplinary work to achieve this goal. This would also help to minimise the risk of loss of consumer confidence, as a result of the lack of consistency and comparability between different frameworks. Due to differences of the key target audiences (i.e. policy makers and practitioners), there appeared to be a preference for a dual type of framework: a detailed guide for practitioners and a high level guidance document for policy makers.

Among core outcomes of the OECD workshop was that:

- A high level of agreement is needed at least for core indicators (e.g. conservation of water),
- The primary purpose of assessments should be to make comparisons rather than absolute judgments
- Sensitivity and uncertainty analyses are important to raise the level of confidence
- Operational methods should incorporate different types of approaches, including environmental impact assessment (EIA), strategic environmental assessment (SEA) and risk assessment (RA)
- There is significant variation in (LCA) results resulting from the purpose of the assessment, system boundaries, data limitations, software use and interpretation of the results

It was also suggested that biofuels could be considered as simpler biobased product systems. Use and end-of-life are essentially one and the same for biofuels. Other bio-based products, depending on the product, can sometimes be decomposed and other times recycled, reprocessed and reused. At a

minimum, it could be said that biobased product assessment shares “biomass feedstock processing” with biofuels, but that it involves more life cycle stages. This would broaden the scope in assessment methods like LCA and more data will be required. /5/, /65/

Lighthouses of Sustainability - European Concepts for Competitive Bio-based Chemicals, 3-4 February, 2010, Brussels, Belgium

The workshop focused on the various initiatives under way for the promotion of sustainable bio-based production. Among the topics discussed were:

- The promotion of sustainable bio-based production from the policy side with initiatives like the Lead Market Initiative (LMI), the Knowledge-based Bio-economy (KBBE) and the Joint Biorefinery Call
- Technical aspects including innovative processes and integration approaches
- Sustainability issues including competitiveness, sustainability assessment and certification schemes. /66/

The workshop produced a document with recommendations for action for the promotion of the bio-based economy with focus on funding of pilot and demonstration projects, increase of publicity, integration of disciplines, system-oriented investigations and better understanding of the scope of sustainability /67/.

International Workshop on Assessing the Sustainability of Bio-based Products, 26-27 June, 2003, Oklahoma, USA

This workshop also pointed out the importance of the goal and purpose of the sustainability assessment. The way one views the sustainability of bio-based products depends, in part, on how one frames the question of sustainability and the methods of assessment adopted. We always have to consider the whole life cycle and material quantities are crucial especially in mobile applications. Careful checking of data and consistency in allocation procedures, substituted products and end-of-life treatments are required to ensure the quality and comparability of studies. The top six indicators of bio-based product sustainability identified were:

- Land use / soil conservation
- Energy flows (density, intensity, quality)
- Social Issues / Vulnerability
- Economic Viability / System Profitability
- Climate Change/ Greenhouse Gases
- Nutrient Cycles

Assessment techniques include: involvement of stakeholders first and throughout, benefit cost analysis and risk assessment, back-casting, dynamic system analysis and the use of geographical information systems. One important step towards a consistent assessment would be to set a research project with a common case study (e.g. a composite product involving transport and heat production) and have experts using different assessment techniques work in parallel on the same case to identify the critical sustainability issues, with a comparison workshop in the end. /39/

Workshop on the Economic and Environmental Impacts of Biobased Production, Chicago, Illinois, 8-9 June, 2004, Chicago, Illinois, USA

The workshop examined a macroeconomic perspective of biobased products with questions, for instance, on how current import tariffs, regulations, and subsidies might the innovation the innovation and

development of bio-product technology and markets or what the global market might look like if energy and product needs were to be supplied not from OPEC countries but from agriculturally strong nations.

On sustainability issues, it was pointed out that LCA-type tools and assessments should be expanded, and uncertainty and variability should be incorporated into the analysis. Moreover, the spatial and temporal scale of the analysis is very important to consider. /68/

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A.1 Subcategories and indicators of the UNEP framework for SLCA

Tab. 6 Classification of sub-categories and indicators, /28/

Stakeholder categories	Subcategories	Indicators (examples)
Workers	Freedom of association and collective bargaining	Evidence of restriction to Freedom of association and Collective bargaining (g, sqn) Operations where the right to exercise freedom of association and collective bargaining may be at significant risk (g, ql-sqn) Employment is not conditioned by any restrictions on the right to collective bargaining (s, ql-sqn) Workers are free to join unions of their choosing (s, ql-sqn) Employee/union representatives are invited to contribute to planning of larger changes in the company, which will affect the working conditions (s, sqn)
	Child labour	Percentage of children working by country and sector (g, qn-ql-sqn) Absence of working children under the legal age (s, qn-ql-sqn) Records on all workers stating names and ages or dates of birth are kept on file (s, sqn)
	Fair salary	Minimum wage by country (g, qn) Non poverty wage by country (g, qn) Lowest paid worker, compared to the minimum wage (s, qn-sqn) Regular and documented payment of workers (weekly, bi-weekly) (s, ql-sqn)
	Working hours	Excessive Hours of work (g, qn-ql-sqn) Respect of contractual agreements concerning overtime (s, sqn) Clear communication of working hours and overtime arrangements (s, sqn)
	Forced labour	Commodities that are at high risk of having been produced using forced labour (g, qn-sqn) Percentage (estimate) of forced labour by region (g, qn) Workers are free to terminate their employment within the prevailing limits (s, sqn) Workers voluntarily agree upon employment terms; employment contracts are comprehensible to the workers and are kept on file (s, ql-sqn)
	Equal opportunities / Discrimination	Women in the labour force participation rate by country (g, qn-ql-sqn) Country gender index ranking (g, sqn) Presence of formal policies on equal opportunities (s, ql-sqn) Total numbers of incidents of discrimination and actions taken (s, ql-qn) Ratio of basic salary of men to women by employee category (s, qn-sqn)
	Health and safety	Occupational accident rate by country (g, qn) Presence of a formal policy concerning health and safety (s, sqn) Number/ percentage of injuries or fatal accidents in the organisation by occupation (s, qn) Adequate general occupational safety measures are taken (s, ql-sqn) Education, training, counselling, prevention and risk control programs in place to assist workforce members, their families, or community members regarding serious diseases (s, ql-sqn).

	Social benefits / Social security	Social security expenditure by country and branches of social security (e.g. healthcare, sickness, maternity) (g, qn-sqn) List and provide short description of social benefits provided to the workers (e.g. health insurance, pension fund, child care, education, accommodation etc.) (s, ql) Evidence of violations of obligations to workers under labour or social security laws and employment regulations (s, qn-ql-sqn)
Consumers	Health & safety	Presence of consumer complaints (at national, sector, organizational level) (g, ql-sqn) Total number of incidents of non-compliance with regulations and voluntary codes (g, qn-ql-sqn) Number of consumer complaints (s, ql) Quality of labels of health and safety requirements (s, ql-sqn)
	Feedback mechanism	Presence of feedback mechanisms (e.g. after sale services) (g, qn-ql-sqn) Management measures to improve feedback mechanisms (s, qn-ql-sqn) Practices related to customer satisfaction (s, qn-ql-sqn)
	Consumer privacy	Country ranking related to regulations on data-sharing (g, sqn) Country ranking related to the strength of regulatory powers to investigate privacy-related complaints (g, sqn) Number of consumer complaints related to breach of privacy or loss of data within the last year (s, qn)
	Transparency	Presence of a law or norm regarding transparency (by country and/or sector) (g, ql-sqn) Consumer complaints regarding transparency (s, ql-sqn) Non-compliance with regulations regarding transparency (s, ql-sqn) Communication of the results of social and environmental life cycle impact assessment (s, ql-sqn) Certification/label the organization obtained for the product/site (s, ql-sqn)
	End of life responsibility	Strength of national legislation covering product disposal and recycling (g, sqn) Level of management attention to end-of-life impacts (s, ql-sqn) Annual incidents of non-compliance with regulatory labelling requirements (s, qn)
	Access to material resources	Changes in Land Ownership (g, qn) Extraction of Material Resources (g, qn) Percent of Population (Urban, Rural, Total) with Access to Improved Sanitation Facilities (g, qn) Development of project-related infrastructure with mutual community access and benefit (s, ql-sqn) Does the organization have a certified environmental management system (s, sqn)
Local community	Access to immaterial resources	Patent Filings (g, qn) Levels of Technology Transfer (g, sqn) Annual arrests connected to protests of organization actions (s, qn) Presence/strength of community education initiatives (s, ql-sqn)
	Delocalisation and migration	Forced evictions stemming from economic development (g, qn) International migrants a percentage of the population (g, qn) Strength of organisational policies related to resettlement (e.g. due diligence) (s, qn) Number of individuals who resettle (voluntarily or not) that can be attributed to organisation (s, ql-sqn)
	Cultural heritage	Cultural heritage in urgent need of safeguarding (g, ql)

	Prevalence of racial discrimination (g, ql-sqn) Strength of policies in place to protect cultural heritage (s, ql-sqn)	
Safe & healthy living conditions	Burden of Disease by Country (g, qn) Pollution Levels by Country (g, qn) Organization efforts to strengthen community health (s, ql-sqn) Management effort to minimize use of hazardous substances (s, ql-sqn)	
Respect of indigenous rights	Human rights issues faced by indigenous people (g, ql-sqn) Indigenous land right conflicts/land claims (g, ql-sqn) Organization Operates in a Region where there is Land Rights Conflict with Indigenous Groups (s, sqn) Response to Charges of Discrimination against Indigenous Community Members (s, ql-sqn)	
Community engagement	Freedom of peaceful assembly and association (g, ql) Transparency of Government policymaking (g, sqn) Diversity of the community stakeholder groups that engage with the organisation (s, ql-sqn) Organisational support for community initiatives (s, qn)	
Local employment	Unemployment Statistics by Country (g, qn) Poverty and Working Poverty by Country (g, qn) Percentage of workforce hired locally (s, qn) Strength of policies on local hiring preferences (s, ql-sqn)	
Secure living conditions	State of Security and Human Rights in Country of Operation (g, ql) Strength of Public Security in Country of Operation (g, sqn) Number of casualties and injuries per year ascribed to the organization (s, qn) Number of legal complaints per year against the organization with regard to security concerns (s, qn)	
Society	Public commitments to sustainability issues	Existence of (legal) obligation on public sustainability reporting (g, sqn) Presence of publicly available documents as promises or agreements on sustainability issues (s, ql-sqn) The organization has pledged to comply with the Global Compact principles (s, sqn) Presence of mechanisms to follow-up the realisation of promises (s, ql-sqn)
	Contribution to economic development	Economic situation of the country/region (GDP, economic growth, unemployment, wage level, etc.) (g, qn-ql) Relevance of the considered sector for the (local) economy (g, qn-ql) Contribution of the product/service/organization to economic progress (revenue, gain, paid wages, R+D costs in relation to revenue, etc.) (s, ql-qn)
	Prevention and mitigation or armed conflicts	Is the organization doing business in a region with ongoing conflicts? (g, ql-sqn) Organization's role in the development of armed conflicts (s, ql-sqn) Disputed products (s, ql-sqn)
	Technology development	Research and development costs for the sector (g, qn) Involvement in technology transfer program or projects (s, ql-sqn) Partnerships in research and development (s, ql-sqn)
	Corruption	Risk of corruption in the country and/or sub-region (g, sqn)

Subcategories and indicators of the UNEP framework for SLCA

		Formalised commitment of the organization to prevent corruption, referring to recognised standards (s, ql-sqn) Financial damages (s, qn)
	Fair competition	National law and regulation (g, ql-sqn) Sectoral regulation (g, ql-sqn) Membership in alliances that behave in an anti-competitive way (s, ql-sqn) Legal actions regarding anti-competitive behaviour, violations of anti-trust and monopoly legislation (s, qn-ql-sqn) Employee awareness of the importance of compliance with competition legislation and fair competition (s, ql-sqn)
Value chain actors	Promoting social responsibility	Industry code of conduct in the sector (g, sqn) Presence of explicit code of conduct that protect human rights of workers among suppliers (s, sqn) Membership in an initiative that promotes social responsibility along the supply chain (s, sqn)
	Supplier relationships	Reasonable volume fluctuations (s, ql-sqn) Absence of coercive communication with suppliers (s, ql-sqn) Payments on time to suppliers (s, sqn)
	Respect of intellectual property rights	General Intellectual Property Rights and related issues associated with the economic sector (g, ql-sqn) Organization's policy and practice (s, ql-sqn) Use of local intellectual property (s, ql-sqn)

Legend → g: generic; s: specific; qn: quantitative; ql: qualitative; sqn: semi-quantitative