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Social sustainability assessments in the biobased economy: Towards a systemic approach

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Social sustainability assessments in the biobased economy: Towards a systemic approach

Abstract

The majority of impact assessments for the biobased economy are primarily focused on the environmental and (techno-)economic aspects, while social aspects are rarely considered. This study proposes a modified systemic approach for a social sustainability impact assessment of the biobased economy, based on a review on the common methodologies for assessing social impacts. Accordingly, the proposed approach follows the four general iterative steps of social life cycle analysis (SLCA) as it considers all life cycle phases of the biobased economy. The systemic approach considers the potential social impacts on local communities, workers, and consumers as the main three groups of the stakeholders. The review showed that the most common social indicators for inventory analysis within the biobased economy include health and safety, food security, income, employment, land- and worker-related concerns, energy security, profitability, and gender issues. Multi-criteria decision analysis (MCDA) was also highlighted as the broadly utilized methodology for aggregating the results of impact assessments within the biobased economy. Taking a life cycle perspective, this study provides a holistic view of the full sustainability of research, design, and innovation in the biobased economy by suggesting the integration of the social aspects with techno-economic and an environmental life cycle assessment. Our proposed systemic approach makes possible to integrate the social impacts that are highly valued by the affected stakeholders into the existing sustainability models that focus only on environmental and techno-economic aspects. We discuss the steps of the proposed systemic approach in order to identify the challenges of applying them within the biobased economy. These challenges refer mainly to the definition of the functional unit and system boundaries, the selection and the analysis of social indicators (inventory analysis), the aggregation of the inventory to impact categories, and the uncertainties associated with the social sustainability evaluation. The result of this review and the proposed systemic approach serve as a foundation for industry and policy makers to gain a better insight into the importance of social sustainability impacts assessment within the biobased economy.

Keywords: Social impacts, social life cycle, systemic approach, environmental techno-economic assessment.

1. Introduction

The biobased economy is one that utilizes 'green' materials instead of fossil-based materials to generate energy, chemicals, transport fuels, and other biobased products [1]. Within such an economy, sustainability and the efficient use of resources are the key components of social and industrial implementations [2]. In this regard, production of bioenergy and biobased products and services is expected to increase. Also, the European Commission identified the biobased economy as a sector that has the potential to bring benefits for both the private sector and society [3]. In the present study, biobased products are defined as those that are entirely or partly extracted from biomass and converted using chemical, physical, and/or biological processes [4]. Biobased products may vary from high-value-added specialty chemicals used in cosmetics, pharmaceuticals, or food additives, to high-volume substances like bulk chemicals or fertilizers [5]. The biobased economy has helped Europe meet its target of an actual sustainable economy by creating a total of 520,000 direct and indirect jobs and a yearly turnover of around €78 billion [6]. If we want to further change a fossil-based economy into a biobased economy, we must take into account that production location, storage, refining, and transportation need to be restructured [1]. This restructuring implies that new investments in infrastructure will have to take place. In order to convince the society that these costs are justified, we should assess the sustainability of the biobased economy.

Sustainability is comprised of environmental, economic, and social aspects [7, 8]; all three aspects should be taken into account when assessing the sustainability of the biobased economy. There are numerous concerns with regard to the social (such as labor and human rights, health issues, and food safety), economic (such as local welfare and job creation), and environmental (such as biodiversity, global warming, and water quality) impacts of producing biomass on large scales [9]. Therefore, a suitable sustainability impact assessment approach is required. However, most existing sustainability impact assessments assess only the environmental [10, 11, 12, 13] or economic impacts [14, 15, 16] of the biobased economy. Although some efforts have been made to integrate social aspects into the sustainability impact assessment of the biobased economy [17, 18, 19, 20, 21], there is no consensus on a standardized approach with which to evaluate the social impacts at different scales [22]. Also, social issues are not always measurable in quantitative terms, so they have been dropped from many sustainability evaluation studies. Importantly, there is a lack of social data regarding the use of biomass in comparison with data available for the environmental aspect of sustainability [23, 24]. A precise sustainability evaluation calls for an evaluation of the balance between biomass usage in, for example, biorefineries and the need for safe food and feed, along with the conservation of natural resources, mainly water, soil, and biodiversity [25]. Furthermore, the indicators that are considered in some existing social sustainability impact assessments of the biobased economy vary along with the goal and scale of the study. For example, Elghali et al. [26] developed a sustainability approach for evaluating the life cycles of bioenergy systems at the system level, only taking into account social acceptance as an indicator of social impact. Assefa and Frostell [27] considered only three social indicators (acceptance, fear, and knowledge) in their evaluation of the sustainability of energy technology systems. An example at the local level is Foolmaun and Ramjeeawon’s [28] study of four disposal alternatives of PET bottles in Mauritius, with seven social indicators for the analysis and comparison of its life cycle social and environmental impact.

Based on the above, we can conclude that there is a need to develop a general social sustainability impact assessment approach that allows integration with existing economic and environmental assessment approaches in order to result in an overall sustainability impact assessment approach (that is, one that includes economic, environmental and social aspects). Therefore, as a first step, we developed such a general social sustainability impact assessment approach for future research in different scales, whether internationally, nationally, locally or company-focused. The intention is to integrate this approach with an environmental techno-economic assessment (ETEA), which is based on the integration of a techno-economic assessment and an environmental life cycle assessment as proposed by Thomassen et al. [29]. Integrating the social aspects with an ETEA provides a holistic insight into the full sustainability related to research, design, and innovation in the biobased economy. Accordingly, the main goal of this study is to provide a modified systemic approach for evaluating the social impacts, in order to incorporate them into the ETEA. A comprehensive review process to achieve this goal is explained further in the following section.

There are three main goals for this study, which also reflect the structure of this paper: (i) provide an overview of the main methodologies for assessing social impacts and identify which of them has the most promising methodological features to be applied in the biobased economy, (ii) define a modified systemic approach for evaluating the social impacts in order to incorporate them into the ETEA, and (iii) identify the challenges for each step of the proposed systemic approach in the context of the biobased economy. The main focus for these challenges is on the inventory analysis. We consider a range of frameworks that have already been applied in order to identify and classify the main social indicators along the entire life cycle for the assessment of the social impacts in the biobased economy. We then compare some recent empirical studies that have applied these frameworks within the biobased economy in order to identify the main elements that need to be taken into account throughout data collection for inventory analysis of the biobased economy. We conclude with recommendations for future research.

2. Methodology for constructing the literature review process

To address the goals of the study, we searched a number of databases, including the ISI Web of Knowledge, Web of Science, Google Scholar, and Science Direct, to identify review papers and original publications between 1990 and 2016 on social impacts evaluation, and sustainability assessment frameworks for the biobased economy. The searching process also included grey literature such as academic theses and dissertations, and official reports on (social) sustainability impact evaluation methodologies, both on a general level and specifically within the biobased economy. We identified a total of 103 studies and reports from the databases. The topics and abstracts of the papers and documents were first reviewed to exclude the duplicates and to identify whether they are suitable for meeting the mentioned goals of this review paper. The decision for including papers was based on two criteria: (i) the focus on 'social aspects' of the biobased economy and (ii) the focus on sustainability assessment frameworks and methodologies. Accordingly, 44 studies were identified as relevant and included for further analysis. Afterwards, we also screened the reference lists of the selected publications for additional suitable publications, based on which 15 peer-reviewed articles were included in the review study. Finally, we included 59 papers and documents to conduct a comprehensive review on the social sustainability assessment within the biobased economy.

3. Review of the main methodologies for assessing social impacts

This section starts by discussing the social sustainability concerns within the biobased economy, highlighting the need to develop methodologies for monitoring the potential social impacts to help decision-makers evaluate their industry's performance. We then compare different methodologies applied for evaluating social sustainability impacts in order to identify a suitable approach for conducting social sustainability assessment within a biobased economy.

3.1. Social sustainability within a biobased economy

There is no universally accepted definition of social sustainability. As Valente et al. [30] stated, it is quite challenging to define social sustainability since its meaning is not obvious. According to Black [31], social sustainability is "the extent to which social values, social identities, social relationships and social institutions can continue into the future". Social aspects of a sustainable biobased economy consist of issues associated with livelihoods and food safety, the energy supply reliability, the security of people and regions [32], respecting human rights, and establishing a long-term sustainability plan with continuous monitoring of social aspects [33].

For example, different biofuel supply chains can be defined based on various feedstocks (such as sugarcane, eucalyptus, corn, wheat, palm oil, or macauba), which might affect the security of people and regions involved. Previous research has indicated that higher rates of deforestation and soil erosion, biodiversity loss, and increased pressure on water resources have been observed by adopting biofuels [34, 35]. Although such impacts are mostly observable in developing countries and regions that already face higher land and water scarcity risks [36], many of them can be the consequence of the Europe's biofuels policy [37], resulting mainly in two major social phenomena: (i) intensifying food price fluctuations and hunger, and (ii) land acquisitions. For instance, according to a report by FAO [38], 65 percent of Europe's rapeseeds are utilized for biodiesel generation. By increasing the demand for biodiesel production in Europe, more plant oils (mainly palm oil) need to be imported. This requires more rainforest clearing to provide enough space for cultivating palm seeds [38]. There are also various arguments concerning the relationship between biofuel production and deforestation, and related positive social impacts, especially on human welfare [39]. For example, expansion of agricultural areas for biofuel production can help induce rural improvements by creating jobs by using more labor for forest clearing [40]. However, it has been reported that the income generated during the forest-clearing stage does not meet the needs of all the local population [41]. In general, the relationship between biofuels and deforestation depends on the institutional and political frameworks and socioeconomic context of each country [42]. Moreover, there will be a significant impact on the price of seeds globally; by 2020 Europe's biofuels policy will have increased prices for plant oils and oilseeds by 16 percent and 10 percent, respectively [43]. Such issues may force vulnerable groups of people to lose their homes and move to other places.

Another range of social impacts in a biofuel supply chain are related to the stress on water resources, as a significant volume of water might be used in different steps of the supply chain, including extraction of the resource, feedstock crops' irrigation, fuel processing and refining, and transportation. For instance, 3726 kg of freshwater (without recycling) is required to produce 1 kg of biodiesel from microalgae [44]. Due to the fact that the water intensity of producing biofuels from irrigated feedstock crops is higher than that of fossil fuel resources [45,46], the development of biofuel supply chains can cause water security issues for people through nutrient loading (for example, contamination by fluids that contain pollutants), which influences the availability and quality of surface water and groundwater [45]. According to the prediction by the International Energy Agency [46], water withdrawals for biofuels are expected to rise in accordance with world supply, from 25 billion m^3 to 110 billion m^3 between 2010 and 2035, whereas consumption might increase from 12 billion m^3 to approximately 50 billion m^3 over the same period. However, it has been argued that there are some opportunities to enhance the water resources issues related to the biofuels production, such as adopting advanced biofuels with less water-intensive feedstock crops, as well as selecting biomass crops and locations with the greatest water efficiency [46].

Given the potential social impacts associated with biofuel production and increased demand for EU biofuels' production [47], not enough attention has been given to the full sustainability issues, including social concepts in the biofuel supply chains [48]. Therefore, it is important to develop methodologies for monitoring such impacts in order to help decision-makers assess the competency of continuing with their industry or strategies and ex-post assessments of their performances. Accordingly, different methodologies already exist and are applied to evaluate the social sustainability impacts. A review of these methodologies is provided in the following section.

3.2.Methodological comparison for the social sustainability assessment

According to the literature [49], the commonly applied methodologies for the social sustainability impact assessment in the context of the biobased economy include *Social Impact Assessment (SIA), Socio-Economic Impact Assessment (SEIA),* and *Social Life Cycle Analysis (SLCA).* SIA is the process of evaluating, monitoring, and managing the planned and unplanned social outcomes of proposed action including policies, programs, plans, and projects [49]. SEIA is the systematic methodology for determining and assessing the potential social and economic impacts of a proposed development on local wellbeing, the life of people's families, and their communities as a whole [50]. Finally, SLCA is defined as a methodology that evaluates the social and socio-economic aspects of an industry, product, or process and the potential positive and negative impacts of these aspects throughout their life cycle [51]. Table 1 summarizes the main characteristics and challenges of the three common methodologies for social impact evaluations. As the table shows, the three mentioned methodologies more or less follow the same steps for social sustainability assessments, including goal and scoping identification, determining the social issues, analyzing impacts, and, in the interpretation step, suggesting mitigation, management, and monitoring actions.

[insert Table 1]

The main difference among the methodologies is related to impact categories and indicator identification as well as evaluation techniques. SIA and SEIA have a lot in common, although a clear difference is that, in a suitable SEIA, both economic and social impacts are investigated. With regard to identifying social topics, SIA and SEIA mostly assess the social impacts on the community structure and demographic effects of a planned intervention. They also consider protection of cultural resources and sufficient services and infrastructure while there are more 'behavioral' changes considered in SIA than in SEIA. In contrast to these two methodologies, SLCA differentiates between the impacts on various stakeholders (that is, workers, society, consumers, local community, and value chain actors) while considering the full life cycle. With regard to the evaluation techniques, SIA is a principally qualitative approach, which does not make it easy to be completely precise or predictive because it depends on the fairness of the practitioner and the experience and knowledge or commitment of the involved stakeholders to telling the truth [52]. Common evaluation techniques include assessing the results of qualitative data through matrices, expert opinion, carrying capacity analysis and modeling. SEIA applies separate evaluation techniques for social and economic impact assessment, with fiscal impact analysis, cost-benefit analysis, and input-output (I/O) analysis as the common economic techniques. For the social impacts, SEIA also uses surveys and questionnaires comparable to the scoping methods of SIA. Similarly, SLCA is also based on stakeholder involvement. Compared to SIA and SEIA, SLCA presents a more comprehensive picture of the product life cycle, encompassing multiple value chains in its evaluation.

3.3.Social Life Cycle Analysis

The SLCA methodology has been carried out in different case studies from various industries, but only a few case studies can be found for the biobased economy (e.g., Ekener-Petersen et al. [53]; Manik et al. [54]; Aparcana and Salhofer [55]; Foolmaun and Ramjeeawon [28]; Prosuite [56]; Halog and Manik [19]; Macombe [57]; and German and Schoneveld [58]). There is growing interest in expanding the use of SLCA approaches in research about the biobased economy [59, 60, 61]. An important reason for that is related to the difference in the scope and level of the social impacts addressed by SLCA compared to SIA or SEIA. SLCA uses data collected at the company and process levels by considering the entire product life cycle [62], while a SIA, for example, "only covers a glimpse of some phases of a product's life cycle at a particular time" [51, p.32]. According to a recent review conducted by IUCN [63], more in-depth information about social impacts is required in order to understand the rights of different groups with regard to the production of biofuels, especially workers, local communities, and women. Furthermore, social sustainability assessment methodologies are usually carried out under the request of a community group, regional or local government, or an industry developer. Each of these stakeholders has different interests and priorities that they are willing to enhance or protect. As a result, several potential impacts might be excluded from the assessment process since they are not considered major issues at the time of the assessment procedure. Moreover, the selection of the related social impacts will differ based on the goals to be achieved [64]. In fact, SIA and SLCA can be complementary techniques that concentrate on various scopes and goals for research [65].

The biobased economy involves all activities of the organizations contributing in different life cycle stages of the biobased product and processes, such as biomass production, transport, or material production [59]. Therefore, the whole life cycle should be considered when assessing the sustainability impact of the biobased economy. According to Lehmann et al. [66], the SLCA approach is the only social assessment methodology that takes the social pillar from a life cycle viewpoint and considers the possible shift of impacts along the life cycle phases. Thus, the SLCA provides a more comprehensive evaluation to make decisions between alternatives and to determine hotspots throughout the life cycle that must be considered to enhance the social sustainability performance of a company [67]. For this reason, we focus primarily on the SLCA as the preferred methodology for a social sustainability impact assessment.

SLCA is about impacts on people, so the focus must be on the life cycle stages activities that influence the involved stakeholders [68]. Hence, it is important to have clear definitions of the goal and scope of the study, as well as the subcategories and indicators and their evaluation. Accordingly, following the four main iterative stages of the environmental life cycle assessment (LCA) procedure (definition of the goal and scope; life cycle inventory analysis; impact assessment; and interpretation) can help fulfill the above-mentioned requirements for SLCA. Furthermore, since SLCA requires both qualitative and quantitative data [69], two recently developed LCA-based approaches that cover both qualitative and quantitative types of evaluation processes are taken into account. These two approaches are: (i) the Prospective Sustainability Assessment of Technologies, or Prosuite for short [56]; and (ii) the Product Social Impact Assessment [70]. Prosuite was a four-year European Union project intended to provide a sustainability assessment approach for new technologies [56]. The project proposes a common structure for impact categories for all three sustainability perspectives within a life cycle framework defined as impact on human health and social wellbeing (social perspective), prosperity (economic perspective), natural environment, and exhaustible resources (environmental perspectives) [106]. The Prosuite approach has been applied on four important technologies: biorefineries, nanotechnology, multifunctional mobile devices, and carbon storage and sequestration. The Product Social Impact Assessment is an SLCA-based quantitative approach designed to evaluate the social impacts of a product on stakeholder groups involved throughout the life cycle of a product. It is designed to address three main objectives: (i) to make it possible to measure positive and negative impacts of products, (ii) to assist communication procedures and decision making at the product level, and (iii) engagement in overall assessment of sustainability.

In the following section we propose a modified systemic approach that can be used to evaluate social impacts over the entire life cycle at different scales. We will use the four general steps of SLCA, the UNEP-SETAC Guidelines for SLCA of Products [51], and the two mentioned LCA and SLCA-based approaches as a basis for our assessment of social impacts.

4. Defining a modified systemic approach for assessing social impacts

The term 'systemic approach' implies that the whole approach needs the capacity to understand the nature of a system's parts and the relationships between them. Therefore, a systemic assessment must include technological, economic, social, and environmental aspects. Currently, these aspects are often separated in different assessments, which may lead to different system boundaries and confusing interpretations. Integrating technological with economic or environmental information can clearly show the effects of a change in one aspect (such as a technological variable) on another aspect (such as profitability). As a consequence, time-consuming and costly research that may focus on parameters that only have a marginal effect on the sustainability outcome can be avoided. As mentioned above, a methodological approach for the integration of a techno-economic assessment with the environmental aspect (ETEA) has already developed [29], although it does not yet have any integration of the social pillar. Therefore, there is a need to develop a comprehensive approach that considers the social aspect in such a way that it can be incorporated into sustainability impact assessment. Fig. 1 shows our proposed modified systemic approach for assessing social impacts. This approach is developed based on the four general stages of SLCA and taking into consideration the UNEP SETAC Guidelines for SLCA of Products [51] and the two SLCA-based approaches (that is, Product Social Impact Assessment [70] and Prosuite [56]). The UNEP-SETAC Guidelines for SLCA of Products [51] form the basis for many SLCA case studies and/or for choosing suitable social topics and indicators [69].

[insert Fig. 1]

4.1. Goal and scope definition

The aim and the scope of the study affect the suitability of the various methodologies applied in the following steps of the SLCA [59]. Therefore, it is important to highlight the main issues that need to be defined within this first step. In total, the results of a SLCA study can be useful for a broad range of decision makers, including producers, consumers, organizations, and industry management and policy makers [71]. Therefore, first, the targeted decision makers of the study need to be identified. According to Siebert et al. [59], the main issues that need to be taken into account during the first step of the SLCA are: (i) defining the production system and system boundaries; (ii) identifying stakeholder categories affected by the activities throughout different life cycle stages; and (iii) defining a functional unit. All three of these issues are discussed in detail in the following sections.

4.2. Inventory analysis

As Fig. 1 shows, after the first step, goal and scope definition, the main part of the second step of the systemic approach includes identifying the social impact categories and indicators associated with particular stakeholder groups involved in the life cycle of a specific industry or process under consideration [72]. ESMAP et al. [73] presents a complete list of potential stakeholders in the biobased economy. The stakeholder groups are representatives of the different groups of individuals that are potentially influenced by the industry's activities [51]. In general, three main stakeholder groups are usually identified: local communities, workers, and consumers. The goal of the second step is to come up with a final list of social impact categories and indicators that need to be assessed. The selection of these categories and indictors is possible by questioning experts about the social indicators that they consider most important for the evaluation. For this assessment, a comprehensive set of indicators that already exists in literature can be presented to the experts. A complete list of potential social impact categories and related indicators for each stakeholder group is suggested by the UNEP-SETAC [74] guidelines, which also comprise the measurement methodologies including inventory indicators, measurement units, and potential data sources. The experts involved for social impact (sub)categories and indicator identification consist of experts who are familiar with social sustainability assessment and SLCA, managers from the sustainability departments of the case study under consideration, and experts in the field of social responsibility for the specific case study. For the qualitative approach, we suggest using the materiality analysis to assess the relevance of the indicators [75]. This analysis is composed of the following four main steps: (i) identification of social impact and respective performance indicators, (ii) their prioritization, (iii) their alignment with available time and resources, and (iv) checking their validation to see whether the social impacts and indicators selections made in the prior steps are stable and reliable, and if not, modify [70]. In case of the quantitative/semi-quantitative approach, the quality of the data will be examined using the Prosuite matrix [56].

4.3.Impact assessment

The third step is the impact assessment, which includes a characterization model for aggregating the inventory data to the impact categories. Generally, there are two types of characterization models: type I and type II [51]. Type I aggregates the results for the subcategories according to the stakeholders' interest and the aggregation of the indicators' values is performed using a scoring system. In contrast, type II models incorporate causal relationships whereby the inventory is related to midpoint and endpoint impact categories along the impact pathways [76]. Multi-criteria decision analysis (MCDA) can be used to weigh the selected social impact categories and indicators via experts' scores (using a Likert scaling) as proposed by Macombe et al. [4]. This MCDA is performed for both qualitative and quantitative/semi-quantitative approaches. Prosuite [77] provides a comprehensive review on the application of MCDA techniques for sustainability assessment. MCDA has also been broadly utilized in the biobased-economy-associated fields over the past 15 years [78]. For example, Elghali et al. [26] conducted a case study on UK bioenergy systems using the multi-attribute utility method. Other studies on technology assessment of clean biobased energy technologies applied the analytic hierarchy process (AHP) [79, 80]. The AHP has also been combined with other methods, such as with social multi-criteria analysis in Antunes et al. [81], in order to compare irrigation technologies in Portugal. Moreover, Halog and Manik [19] suggested AHP and dynamic system modeling, amongst others, for sustainable assessment of biofuels supply chain. Wang et al. [69] developed a modified ranking method based on the ranking scale of AHP for a pairwise comparison matrix and the consistent fuzzy preference relations method. However, their modified AHP can be very challenging and time-consuming if the impacts along the whole life cycle phases need to be taken into account. This is supported by Kuo and Lu [82], who concluded that assessment of the associated impacts between two subcategories is difficult and not very efficient when a large number of pairwise comparisons are needed or when incoherencies in the gathered information are occurred. The technique for order of preference by similarity to ideal solution (TOPSIS) is another MCDA that tackles such difficulties to a great extent. Nevertheless, this technique is rarely applied (e.g., Karklina et al. [83]) for the assessment of social performances within the biobased economy. There are some advantages that TOPSIS an efficient MCDA technique for SLCA compared to other associated techniques such as AHP. The basic element of TOPSIS analysis is a data matrix that is simple to use and easily understood since (i) it represents the logical basis of human selection, (ii) it has a scalar value taking into account all types of indicators (subjective and objective), (iii) the computation processes are easy and can be simply programmed within a spreadsheet, and (iv) the values of all alternatives (indicators) on attributes (impact subcategories) can be pictured on at least a two-dimensional polyhedron [84]. The outcomes can be used to inform the producers about the most and least important social impacts (subcategories) so that the potential social impacts caused by their production activities can be improved or prevented [59].

4.4. Interpretation and integration with environmental and economic aspects

In the fourth step, the results need to be interpreted. A sensitivity analysis should be performed to provide a better insight about the significance of the impact categories. This step also includes highlighting the major results, assessing the overall study on consistency and completeness, engaging with stakeholders, and providing conclusions, suggestions and reporting.

The social score can later be integrated into the sustainability approach of ETEA. Since it is not possible to collect quantitative data for all social aspects, by the systemic approach it is suggested to collect the inventory data for the highly valued social impacts (positive and negative) identified through a MCDA-based technique in the previous step. In doing so, according to the goal and scope of the ETEA, the practitioner can incorporate the most important social impact values along the life cycle phases into the ETEA model in order to observe the changes in the outcome of the ETEA model derived from the social impact values.

The next section provides a discussion of the potential challenges for applying each step of the proposed approach in the context of the biobased economy.

5. Challenges in applying the steps of the proposed systemic approach for the biobased economy

The challenges in conducting the proposed systemic approach mainly refer to the definition of the functional unit and the system boundaries, the selection and the analysis of the social indicators (inventory analysis), the impact assessment, and the uncertainty evaluation [85]. For each step of the proposed approach, some examples from the real case studies on the biofuel supply chains are provided in order to make the challenges of the proposed framework more understandable.

5.1. Goal and scope definition

The first step for the assessment of the social impact using the proposed systemic approach is to highlight the goal and scope of the study. The definition of the goal and scope also influences which stakeholder groups are affected along the life cycle phases. There are two different approaches for defining the goal; that is, the “process” and “company conduct” approach. Examples of the process approach can be found in, for example, Schmidt et al. [86] and examples of the company conduct approach can be found in, for example, Dreyer et al. [68], and UNEP-SETAC [51]. It is believed that both are important to provide a complete insight in the social impact [87]. Table 2 provides the four recent case studies from different biofuel supply chains (including biodiesel, biomethane, and bioethanol) applying the social life cycle analysis. To the best of our knowledge and based on a literature review conducted by Martínez-Blanco et al. [88], there are very few specific studies on the SLCA for the biofuel supply chains, while there are several theoretical discussions in academia. As Table 2 shows, all these studies applied process approaches, mainly through a comparison with normal fuel supply chains, to highlight the differences in potential social impacts through a life cycle perspective. In all of the analyzed cases, the biofuel supply chains showed more positive social impacts, especially with regard to the job creation and income generation [e.g., 89].

For identifying the affected stakeholders, it is imperative to define the system boundaries where the main activities throughout the life cycle occur. Defining the system boundaries influences the next steps of the assessment process for developing the social indicators and characterization methods, as well as collecting the inventory data [59]. Similar to the goal definition, there are also two different approaches for defining system boundaries. One is to limit the system boundaries to certain parts of the life cycle that are directly affected by the performance of the company. The other approach (e.g., [90]) is to consider the full life cycle, but to ignore processes that do not substantially influence the overall outcomes of the study. According to Schmidt et al. [86], impacts could be located in all steps of the supply chain, which means that a full life cycle assessment is required instead of just considering some parts of a life cycle. This is recommended in the case of a biobased economy because biomass has the potential for degradability and can be recycled back to nature [91]. In general, a biobased supply chain exists involving the following steps: (i) the production of local feedstock (such as sugarcane), (ii) transportation of the feedstock from the production site to the collecting equipment, (iii) transportation to the production facility for pre-treatment and processing to generate end products (such as bio-ethanol), and (iv) additional production equipment for upgrading the product to higher value goods (such as ethylene). It is important to note that this is a general description of the supply chain and the order of the steps could vary depending on the raw material and feedstock [1]. Fig. 2 illustrates the possible system boundaries for the products in the biobased economy. As in the case of environmental LCA, the system boundaries in the biobased economy are mainly defined on three main scales: cradle to gate [e.g., 92], cradle to grave [e.g., 93], and cradle to cradle [e.g.,94]. In the four biofuel case studies illustrated in Table 2, depending on the goal of the study, all phases of the supply chain are usually taken into account except the use and disposal phases [e.g., 54; 89]. It is also worth mentioning that, in the life cycle of some products in the biobased economy such as biobased plastics, researchers may also define boundaries from the cradle to resin [e.g., 95; 96] and pellet [e.g.,129] where the analysis ends at the stage of resin pellets creation, and eliminates subsequent phases encompassing product manufacture, utilization, and end-of-life [91]. However, according to Essel [97], in most of the literature on biobased plastics impacts analysis, the authors considered “cradle to gate” scales excluding the use phase and disposal phase.

[insert Fig. 2]

[insert Table 2]

Another challenge in this step is related to the identification of the functional unit. As Table 2 shows, for social impact evaluation of biofuel supply chains in most cases it was not possible to define the functional units mainly due to the fact that the social evaluation is based on descriptive data about the process’s attributes and characteristics [54; 83]. Nevertheless, it is argued that, depending on the system’s boundaries, in a conventional LCA a functional unit must be defined to make it possible to equally compare various systems levels, such as unit-process level, company level, and country comparison level [76; 98]. However, this is not the case in SLCA, and therefore not in our systemic approach, since the social impacts are rather associated to a company's behavior in place of the product function [68]. Martínez-Blanco et al. [88] emphasized that reliability and comparability of the SLCA outcomes are major challenges given the methodological basis for defining the functional unit. A recent review conducted by Petti et al. [99] showed that, out of 35 SLCA studies, 12 cases considered a numerical functional unit, while 18 case studies applied a non-numerical functional unit, five of which cited no functional unit at all. They further discussed that among the analyzed case studies, a non-functional unit- based SLCA approach needs to be considered according to Zamagni et al. [100]. Moreover, some researchers, such as Umair et al. [101], have considered qualitative data, emphasizing that it is not possible to express the impacts in a FU; in two other studies [54; 102], the functional unit was not specified. Indeed, SLCA often deals with information about the features of processes and/or their correlated companies, which is not summarized per functional unit when aggregating data along the life cycle [62]. However, if the aim is to combine SLCA results with conventional LCA, functional units are required, which can be defined with regard to corresponding performance reference points, for each company in the production system [59]. Performance reference points (such as average working hours, mass, and value added per activity) show benchmarks, thresholds or objectives [62] developed in relation to a geographic location of the production site and its industrial sector.

5.2.Inventory analysis

In the second step, a challenge is related to the lack of databases for social issues. Some general databases already exist, such as the product social impact life cycle assessment (PSILCA) and the Social Hotspots Database (SHDB), which has been established as the superior resource for social inventory data for 57 economic sectors throughout 113 geographic regions [103]. According to Table 2, Ekener-Petersen et al. [53] used the SHDB to identify the potential hotspots for major social impacts of four vehicle fuels, including biodiesel bioethanol, diesel and petrol at a generic level (that is, country/sector level). They found that the evaluation was due to the prioritized set of social impacts within the SHDB. Therefore, they had to consider a limited range of social impacts categories because the database only included those categories identified as important. Therefore, data needs to be collected using all the available databases and one should identify the correctness and reliability (that is, the quality) of the available data. In a later step, the impact of the uncertainty ranges in the data needs to be taken into account in order to identify the primary data that should be focused on when collecting information. The main uncertainties in biofuel supply chains, for example, encompass uncertainties in the supply of raw materials, transporting and logistics, operation and production, price and demand, and other uncertainties mainly related to sustainability, policies, tax and regulations. These kinds of uncertainties can directly and/or indirectly affect the social performance of the biofuel supply chains and should be taken into consideration in the decision making processes to bridge the gap among the economic pillars of biofuel, and the social concepts [48].

5.2.1. Identification and classification of social impact categories and indicators for the biobased economy

Having a transparent, generally accepted set of social indicators can allow policy makers and planners to make a comprehensive and unbiased judgment about the sustainability of the biobased economy [104]. To date, researchers have often used an existing set of social indicators and no new social indicators have been developed. With regard to biofuel supply chains, for instance, literature has shown that there are no SLCA databases on biodiesel production. This may present an obstacle for identifying hotspots and, as a result, desk screening procedure is usually suggested by researchers as a basis for inventory analysis [102]. Among the case studies from biofuel supply chains in (Table 2), working conditions, health and safety issues are mostly considered as the main social impact categories. A primary list of social concerns mainly related to the community level was provided by Mackenzie [50]. Carrera and Mack [104] also considered literature from the last two decades and looked for applicable indicators for the social impact assessment of energy systems. Furthermore, van Dam [105] presented a list of socioeconomic impacts associated with biomass production, categorized under the following themes: (i) working conditions and rights, (ii) economic aspects, (iii) competition and availability of natural resources, (iv) social aspects and welfare, (v) health impacts, (vi) food security, (vii) smallholder aspects, (viii) policy and governance aspects, (ix) land tenure and rights, and (x) participatory aspects. Labuschagne et al. [106] also suggested four main social sustainability topics at company levels, including internal human, external population, stakeholder participation, and macro social performance, and then provided a list of subcategories for each main category.

The following frameworks are the most commonly applied frameworks in the biobased economy: (i) the Global Assessment of Biomass and Bio-product Impacts on Socioeconomics and Sustainability Project (Global-Bio-Pact) [23], (ii) the Global Bioenergy Partnership (GBEP) by FAO [107], (iii) BioSTEP by Hasenheit et al. [61], (iv) Oak Ridge National Laboratory (ORNL) by Dale et al. [108], and (v) UNEP-SETAC [51]. The latter is the mostly applied framework for SLCA on biofuel supply chains (Table 2).Recently, the UNEP-SETAC [74] provided the methodological sheets for the indicators and subcategories for various affected stakeholders along the life cycle phases. An overview of these frameworks is provided in Table 3. This overview provides a set of main indicators to help determine relevant indicators that should be considered when assessing the sustainability of a biobased economy from a social perspective. According to this table, common social indicators applied in the biobased economy include health and safety, food security, income, employment, land- and worker-related concerns, energy security, profitability, and gender issues (Fig. 3).

[insert Table 3]
[insert Fig. 3]

5.2.2. Main steps for collecting data on indicators

After the set of indicators is determined, it is important to target data collection in order to maintain the feasible level of work and to ensure that essential issues are not neglected by paying more attention to irrelevant information [70]. Therefore, as Fig. 4 shows, before collecting the data, the following three aspects must be taken into account: (i) data scales, (ii) data types, and (iii) the impact pathway.

[insert Fig. 4]

5.2.2.1.Data scales

Depending on the objectives pursued, the scale of the data can be either generic or site-specific. With regard to a generic study, international, national, and/or sector information is usually collected; for a specific study, a researcher might collect general data using interviews as the key source of information next to site-level data [109]. Although Weidema [21] and Manhart and Grießhammer [110] confirmed that site-specific data will result in more accurate assessments overall, they also argued that already available generic data from databases at national, regional, and global levels can provide a rough estimation on a number of social impacts. Also, Barthel et al. [111] suggested using generic information from country and specific databases of an industry. For example, in recent years, it has been possible to access the SHDB for hotspot evaluation [109], as mentioned above. In this regard, Ekener-Petersen et al., [53] considered the generic socioeconomic impacts of different bio/fossil fuels using data from SHDB. Another database called PSILCA was developed to illustrate how social data can be set, evaluated, and eventually utilized for social impact assessment [112]. The new database encompasses the indicators suggested in the UNEP-SETAC guidelines for SLCA for 187 countries and for 15,909 sectors overall. However, there is no data specifically for the biobased economy. Generic and/or site-specific data availability of the biobased economy is a major challenge for social sustainability assessment. This is mainly because the biobased industries and processes are in the early stage of development and it is not possible to collect data through the entire steps of the life cycle. This challenge relates to the Technology Readiness Level (TRL), which is a classification scale for the level of enhancement of a particular technology [113]. Most biobased industries and processes are in an early TRL stage at which data for the whole process does not yet exist [29]. Moreover, site-specific data collection for the biobased economy throughout the life cycle of a product or a process is very time-consuming and not generally feasible [8, 71, 98]. It can be eased through stakeholder involvement in identifying key social impact categories and indicators along the life cycle.

5.2.2.2.Data types

With regard to the type of data, a social indicator can be either quantitative or qualitative. A common discussion regards whether to utilize mainly quantitative inventory information or to concentrate more on qualitative indicators and data for assessing the social impacts along the value chain [114]. Quantitative indicators can be based on calculation in semi-quantitative scores, physical units, or yes/no scales. Besides, there is no limitation on the type of data that can be incorporated in the assessment using qualitative indicators, which means the data can be applied in a more exploratory context than the quantitative and/or semi-quantitative elements [6]. However, it has been suggested that quantitative and qualitative data, indicators, and measurements should be combined, as quantitative data alone are not enough to represent all dimensions of social impacts [115]. On the other hand, there is a possibility to convert qualitative outcomes into (semi-)quantitative results, as proposed by Benoit et al. [62] and Dreyer et al. [68]. In order to consider semi-quantitative indicators, Wang et al. [69] developed a new method based on the UNEP-SETAC guidelines, taking into account five factors (measure, policy, response, communication and record) to evaluate the social performance of the companies. The social impact for all quantitative and semi-quantitative indicators is finally converted into the social impact score. Although the proposed framework provides a solution for considering not only quantitative but also semi-quantitative indicators for social impacts assessment of companies, it has been only applied to one stakeholder category (workers) in the Taiwanese electronics sector [69]. Therefore, one of the main shortcomings of this new framework can be the difficulty of applying the framework for all stakeholder groups involved in an industry.

5.2.2.3. Impact pathways

Finally, several social impact assessment methodologies utilize midpoint indicators, while others take endpoint indicators into consideration. The two types of indicators are essentially connected by an impact pathway [71] defining the cause-effect relationship among midpoint and endpoint; however, this relationship is usually not easy to reveal. Since midpoint indicators are very close to the source of impact and also more comprehensible for stakeholders involved and decision makers, Dreyer [68] and Flysjö [116] stated that these are the preferred ones. The midpoint impact is taken as a spot in the cause-and-effect chain of the impact pathway before the endpoint [117]. Anyhow, the midpoint indicator can be an indicator for a specific subject under a social impact, whereas the endpoint indicator is an indicator for a social impact itself, which might be more desirable for the decision makers. Some recent references that applied the main frameworks for identifying impact categories and indicators in the biobased economy are presented in Table 4. As the table shows, quantitative, midpoint, and site-specific data are the main characteristics that need to be taken into account when collecting the data for the inventory analysis step. Considering stakeholder and experts' view is the common aspect of all current analytical framework for social impact assessment of industries. This is due to the difficulty of quantifying all social impacts along the life cycles. Therefore, all social impact assessments rely on experts' view to transfer qualitative information into semi-quantitative values.

[insert Table 4]

5.3.Impact assessment

Another challenge is related to the characterization step for aggregating the inventory data to the impact categories. As stated before, there are two types of characterization models: type I involving stakeholders and type II involving causal relationships [51]. With regard to type I, a wide range of MCDA approaches have been conducted in the biobased economy, such as those based on outranking [132] and value trees [133]. With regard to biofuel supply chains considered in Table 2, the MCDA was the main aggregation method and/or a part of the evaluation process [54; 83]. Enzensberger et al. [134] discussed the important role of involving all stakeholder groups in the impact assessment process and emphasized that engaging various perspectives can help policy makers forecast potential problems at an early stage. In relation to type II, it may be challenging to link the activities in the process chain to some endpoint indicators. Furthermore, current emphases on methodology developments highlight the importance of adequate consideration of uncertainty (and ignorance) at all life cycle stages and of using different stakeholders of the community to involve multiple viewpoints of the assessment topic [135]. There are different ways to deal with data and model uncertainties [136], which are caused by the assumptions of the study, and the temporal and spatial variability in data resources and variables. Uncertainty analysis helps demonstrate whether the model's pattern is considerably affected by any shift in key parameters. For biofuels supply chains, for instance, there is no literature on modeling the uncertainties in biofuel supply chain management. However, according to a review carried out by Awudu and Zhang [48], uncertainty in the biofuel supply chain can be evaluated by applying distribution or scenario-based approaches. In the scenario-based approach, the uncertainty is described through a range of discrete scenarios, predicting future uncertainties. Each scenario is based on the probability level of expectations from the decision makers' viewpoints. The other approach can be applied when the discrete scenarios cannot be determined, and only a continuous set of possible values can be forecasted. Nevertheless, as proposed in the systemic approach, the most commonly used method is to conduct a sensitivity analysis of the model through which a set of simulated experiments are performed. Sensitivity analyses can be applied for a broad range of purposes including decision making and understanding the relationship among input/output data [137]. A sensitivity analysis is important to ensure the outcomes do not rely on a single assumption, particularly when the assumption is according to the stakeholders' behavior [91]. This is the case in our proposed social sustainability assessment approach, where multi-social indicators are a multi-criteria decision-making problem. This creates a need for sensitivity analysis through which changes in the results of the problem can be determined through changes in the weight of each attribute. Such sensitivity analysis can perform differently. For example, in MCDA research, sensitivity analysis is frequently done using Monte Carlo simulations for initial data generation and the results are presented graphically along with the associated standard deviations to each alternative [138].

5.4.Interpretation

The interpretation step should involve checking the completeness and consistency of the outcomes to see whether they address the study goal and boundaries. In the biofuel case studies analyzed in Table 2, the results mainly revealed the higher advantages of applying biofuel supply chains in comparison to conventional fuels highlighting the importance of the social concerns incorporation in designing policies and regulations for biofuel productions. In addition, during the interpretation phase, engagement of stakeholders should be taken into account in a way that makes it possible to formulate suggestions and options for future actions. The target of a social sustainability impact assessment is not to provide final decisions, but instead to highlight trade-offs and provide support to policy [115]. When the third pillar of sustainability is accompanied with the other two pillars of sustainability, more choices will be available to make a balance in the link between sustainability and policy. In other words, integrating social impacts into the sustainability approaches can provide an enlightened response to the stakeholders involved in the biobased economy by comparing different possible operations from social as well as environmental and techno-economic perspectives. In order to achieve the overarching sustainability aims that the experts within the biobased economy seek, more collaboration among the experts in the integrated sustainability assessment is valuable for incorporating the concepts of systemic approach into early stages of innovative technology sustainability assessment within the context of the biobased economy.

6. Conclusion

This study has provided an overview of the present frameworks and methodologies for performing a social sustainability assessment in order to develop a modified systemic approach for the biobased economy and its incorporation into an overall sustainability assessment approach. Our review has shown that there is not yet one best methodology that covers all social aspects, as it really depends on the scope of the study, data availability, and the priorities of the stakeholders involved in the biobased economy under consideration. Given that, the suitable choice and development of social topics remains one of the critical challenges in social sustainability assessment. Based on our review, common social indicators applied in the biobased economy are provided, which it would be useful to take into account for the social sustainability assessment of a biobased economy.

By providing some results of the case studies from biofuel supply chains, this review has shown that, although growing, there is still a lack of research on the social impacts of innovative technologies within the biobased economy. This calls for more attention to the need of future direction of research and investments into the social concepts of the biofuel supply chains. Our proposed approach provides a foundation that will help future researchers identify the social issues based on the engagement of the experts' view for determining the value of the social issues for sustainability assessment of the biobased economy. Studies will have to adjust according to the difficulties and complications of sustainability challenges, and the availability of data and approaches to identify the main indicators and impact categories. Following the suggested systemic approach enables practitioners to obtain the scores for different social topics based on their positive and negative values of importance along the life cycle stages. This makes it possible to incorporate such values into an environmental techno-economic assessment model in such a way that all aspects of sustainability assessment can be considered through underlying values that are most important from the experts' view for the sustainable performance of the biobased industries and processes. Despite the remaining challenges, considering the proposed approach for social impact evaluation can be a starting point for assessing the social sustainability in the biobased economy in order to inform decision makers about enhancing or preventing social impacts resulted from their production activities. Future studies should further specify the proposed systemic approach in order to determine how it can be applied through real-world case studies to facilitate the development of a sustainability database, particularly for the biobased economy.

References

[1] Haer T. Environmental, Social and Economic Sustainability of Biobased Plastics; Bio-polyethylene from Brazil and polylactic acid from the U.S. Master thesis, CIO, Center for Isotope Research IVEM, Center for Energy and Environmental Studies. University of Groningen, 2012. http://www.rug.nl/research/portal/files/14446149/EES-2012-128T_ToonHaer.pdf

[2] Morone P, Tartiu VE, Falcone P. Assessing the potential of biowaste for bioplastics production through social network analysis. Journal of Cleaner Production 2015;90:43-54.

[3] European Bioplastics. Relevant EU Strategies; 2013. http://en. european-bioplastics.org/policy/general-strategies/

[4] CEN (The European Committee for Standardization). European standards supporting the market for bio-based products. CEN – European Committee for Standardization, Brussels, Belgium; 2014.

[5] European Commission. Report on the Assessment of the Bio-based Products Market Potential for Innovation, The BIOCHEM project activities; 2010.

[6] Salimbeni A. Half a million jobs, €78 billion per year: The socio-economic impact of the European Bio-based Industry. EUBIA, Belgium; 2015, http://bioenergy-nw.eu/socio-economic-impact-of-european-bio-based-industry/#.Vr2oZDa_Nok, Viewed March 2016.

[7] Jeswani HK, Azapagic A, Schepelmann P, Ritthoff M. Options for broadening and deepening the LCA approaches. J. Clean. Prod. 2010; 18:120–127.

[8] Kloepffer W. Life cycle sustainability assessment of products. Int. J. LCA 2008;13:89-95.

[9] Marten GG, Babor D, Kasturi P, Lewis DA, Mulcock C, Christanty Widagda L, Willington IP. Environmental Considerations for Biomass Energy Development: Hawaii Case Study. East-West Environment and Policy Institute Research Report No. 9, 58 p., 1981.

[10] Mu D, Min M, Krohn B, Mullins KA, Ruan R, Hill J. Life cycle environmental impacts of wastewater-based algal biofuels. Environmental science & technology 2014; 48:11696–704.

[11] Grierson S, Strezov V. Life Cycle Assessment of the Microalgae Biofuel Value Chain: A critical review of existing studies. The Third International Conference on Bioenvironment, Biodiversity and Renewable Energies 2012;6.

[12] Clarens AF, Nassau H, Resurreccion EP, White MA, Colosi LM. Environmental impacts of algae-derived biodiesel and bioelectricity for transportation. Environmental science & technology 2011;45:7554–60.

[13] Agusdinata DB, Zhao F, Ileleji K, DeLaurentis D. Life cycle assessment of potential biojet fuel production in the United States. Environmental science & technology 2011; 45:9133–43.
[14] Bowling IM, Maria Ponce-Ortega J, El-Halwagi MM. Facility location and supply chain optimization for a biorefinery. Industrial & Engineering Chemistry Research 2011; 50:10:6276- 6286.
[15] Krishnahumar P, Ileleji KE. A comparative analysis of the economics and logistics requirements of different biomass feedstock types and forms for ethanol production. Applied Eng. in Agric 2010;26:5:899-907.
[16] Carolan JE, Joshi SV, Dale BE. Technical and financial feasibility analysis of distributed bioprocessing using regional biomass pre-processing centers. Journal of Agricultural and Food Industrial Organization 2007; 5,2.
[17] Raman S, Mohr A, Helliwell R, Ribeiro B, Shortall O, Smith R, Millar K. Integrating social and value dimensions into sustainability assessment of lignocellulosic biofuels. Biomass and Bioenergy 2015;82:49–62.
[18] Santoyo-Castelazo E, Azapagic A. Sustainability assessment of energy systems: integrating environmental, economic and social aspects. Journal of Cleaner Production 2014; 80: 1:119–138.
[19] Halog A, Manik Y. Advancing integrated systems modelling framework for life cycle sustainability assessment. Sustainability 2011; 3:12:469–499.
[20] Zhang Y, White MA, Colosi LM. Environmental and economic assessment of integrated systems for dairy manure treatment coupled with algae bioenergy production. Bioresource technology 2013; 130:486–94.
[21] Weidema B. The integration of economic and social aspects in life cycle impact assessment. Int J Life Cycle Assess 11 2006; Special Issue:1:89–96.
[22] Geibler JV, Walbaum H, Liedke C. Development of Sustainable Bioprocesses: Modelling and Assessment. John Wiley & Sons, Ltd: Chichester, UK 2006;82–113.
[23] Global-Bio-Pact. Global-Bio-Pact Global Assessment of Biomass and Bioproduct Impacts on Socio-economics and Sustainability. FP7 EU funded project; 2012. http://www.globalbiopact.eu/.
[24] European Union. Final Report-Global-Bio-Pact (Global Assessment of Biomass and Bioproduct Impacts on Socio-economics and Sustainability); 2016. http://cordis.europa.eu/publication/rcn/16662_en.html.
[25] European Commission. Joint Technology Initiative in the field of Bio-based industries. RTD.DDG3.E.2. 11/2012. http://ec.europa.eu/smartregulation/impact/planned_ia/docs/2013_rtd_007_biobased_industries_en.pdf.
[26] Elghali L, Clift R, Sinclair P, Panoutsou C, Bauen A. Developing a sustainability framework for the assessment of bioenergy systems. Energy Policy 2007;35:6075–6083.
[27] Assefa G, Frostell B. Social sustainability and social acceptance in technology assessment: a case study on energy technologies. Technol. Soc., 2007;29(1):63–78
[28] Foolmaun RK, Ramjeeawon T. Comparative life cycle assessment and social life cycle assessment of used polyethylene terephthalate (PET) bottles in Mauritius. Int J Life Cycle Assess 2013;18:1:155–171.
[29] Thomassen G, Van Dael M, Lemmens B, Steven Van Passel. A review of the sustainability of algal-based biorefineries: Towards an integrated assessment framework, Renewable and Sustainable Energy Reviews 2016. doi:10.1016/j.rser.2016.
[30] Valente C, Saur Modahl I, Askham C. Method development for Life Cycle Sustainability Assessment (LCSA) of New Norwegian Biorefinery. Project title: Nytt Norsk

Bioraffineri, Report no.: OR.39.13; 2013. 62p. http://ostfoldforskning.no/uploads/dokumenter/publikasjoner/715.pdf.
[31] Black A. The quest for sustainable, healthy communities. Effective Sustainability Education Conference, NSW Council on Environmental Education, UNSW, Sydney, 18–20, February; 2004.
[32] European Commission. HORIZON 2020 - Work Programme 2016 - 2017 Food security, sustainable agriculture and forestry, marine and maritime and inland water research and the bioeconomy. (European Commission Decision C(2016)4614 of 25 July 2016). https://ec.europa.eu/research/participants/data/ref/h2020/wp/2016_2017/main/h2020-wp1617-food_en.pdf.
[33] Vanclay F, Esteves AM, Aucamp I, Franks DM. Social Impact Assessment: Guidance for assessing and managing the social impacts of projects. International Association for Impact Assessment (IAIA), 2015. http://www.iaia.org/uploads/pdf/SIA_Guidance_Document_IAIA.pdf.
[34] Dias de Oliveira ME, Vaughan BE, Rykiel EJ. Ethanol as fuel: Energy, carbon dioxide balances, and ecological footprint. BioScience 2005; 55:593–602.
[35] Pimentel D, Patzek T, Cecil G. Ethanol production: Energy, economic, and environmental losses. In Reviews of Environmental Contamination and Toxicology; Whitacre D, Ware G, Nigg H, Doerge D, Albert L, Voogt P, Gerba C, Hutzinger O, Knaak J, Mayer F., et al., Eds.; Springer: New York, NY, USA 2007; 189:25–41.
[36] HlPe (High level Panel of experts on food security and nutrition). Biofuels and food security: A report by The High Level Panel of Experts on Food Security and Nutrition. HlPe report 5. rome, HlPe; 2013.
[37] Grethe G, dePPermann A, Marquardt S. Biofuels: Effects on Global Agricultural Prices and Climate Change, OXFAM; December 2013. https://www.oxfam.org/sites/www.oxfam.org/files/biofuels_disk_papier2.pdf
[38] FAO, IFAD, IMF,OECD, UNCTAD, WFP, the World Bank, the WTO, IFPRI and the UN HLTF. Price Volatility in Food and Agricultural Markets: Policy Responses; 2 June 2011. http://www.oecd.org/tad/agricultural-trade/48152638.pdf
[39] Rodrigues AS, Ewers RM, Parry L, Souza C Jr, Veríssimo A, Balmford A. Boom-and-bust development patterns across the Amazon deforestation frontier. *Science* 2009;324: 5933:1435-1437.
[40] Gasparatos A, Stromberg P (Eds.). Socioeconomic and Environmental Impacts of Biofuels: Evidence from Developing Nations. Cambridge: Cambridge University Press; 2012. Doi:10.1017/CBO9780511920899.004.
[41] Mulyoutami E, Rismawan R, Joshi L. Local knowledge and management of simpukng (forest gardens) among the Dayak people in East Kalimantan, Indonesia**.** For. Ecol. Manag., 2009; 257:2054–2061
[42] Gao Y, Skutsch M, Masera O, Pacheco P. A global analysis of deforestation due to biofuel development. Working Paper 68. CIFOR, Bogor, Indonesia; 2011.
[43] Bourguignon D. EU biofuels policy; Dealing with indirect land use change. EPRS (European Parliamentary Research Service). PE 545.726; Briefing, January 2015.
http://www.europarl.europa.eu/RegData/etudes/BRIE/2015/545726/EPRS_BRI(2015)545726_REV1_EN.pdf
[44] Yang J, Xu M, Zhang X, Hu O, Sommerfeld M, Chen Y. Life-cycle analysis on biodiesel production from microalgae. Water footprint and nutrients balance, Bioresource Technology 2011;102:159-165.
[45] WWAP (United Nations World Water Assessment Programme). The United Nations World Water Development Report 2015: Water for a Sustainable World. Paris, UNESCO;

2015. http://unesdoc.unesco.org/images/0023/002318/231823E.pdf
[46] OECD/IEA. Water for energy; Is energy becoming a thirstier resource? Chapter 17 of the World Energy Outlook 2012. International Energy Agency, Paris, France; 2012. http://www.worldenergyoutlook.org/media/weowebsite/2012/WEO_2012_Water_Excerpt.pdf.
[47] European Commission. EU agricultural outlook. Prospects for EU agricultural markets and income 2016-2026. European Commission; December 2016. https://ec.europa.eu/agriculture/sites/agriculture/files/markets-and-prices/medium-term-outlook/2016/2016-fullrep_en.pdf
[48] Awudu I, Zhang J. Uncertainties and sustainability concepts in biofuel supply chain management: A review. Renewable and Sustainable Energy Reviews 2012; 16:1359–1368.
[49] Vis M, Dörnbrack A-S, Haye S. Chapter 1; Socio-Economic Impact Assessment Tools. In D. Rutz, R. Janssen (eds.), Socio-Economic Impacts of Bioenergy Production. Springer International Publishing, Switzerland' 2014 ;17. DOI 10.1007/978-3-319-03829-2_2.
[50] Mackenzie. Issues and recommendations for social and economic impact assessment in the Mackanzie Valley. Yellowknife, Canada, Mackenzie Valley Environmental Impact Review Board; 2007.
[51] UNEP-SETAC. Guidelines for social Life Cycle Assessment of products. United Nations Environmental Programme. Belgium: Druk in der weer; 2009. http://www.unep.fr/shared/publications/pdf/dtix1164xpa-guidelines_slca.pdf.
[52] Tiwari S, Harrison JA, von Maltiz G. Chapter 6 Assessing Social Impacts of Bioenergy Projects. pp. 119-147. In Amezaga, J. M., G. von Maltitz and S. Boyes (edits.). 2010, Assessing the Sustainability of Bioenergy Projects in Developing Countries: A framework for policy evaluation, Newcastle University, 179 p; 2010.
[53] Ekener-Petersen E, Höglund J, Finnveden G. Screening potential social impacts of fossil fuels and biofuels for vehicles. Energy Policy 2014; 73:416–426.
[54] Manik Y, Leahy J, Halog A. Social life cycle assessment of palm oil biodiesel: a case study in Jambi Province of Indonesia. Int J Life Cycle Assess 2013;18:1386–1392.
[55] Aparcana S, Salhofer S. Application of a methodology for the social life cycle assessment of recycling systems in low income countries: three Peruvian case studies. Int. J. Life Cycle Assess 2013; 18:5:1116–1128.
[56] Prosuite. Handbook on a novel methodology for the sustainability impact assessment of new technologies; 2013. www.prosuite.org.
[57] Macombe C (eds.). Social LCAs: socio-economic effects in value chains. FruiTrop, Montpellier; 2013.
[58] German L, Schoneveld G. A review of social sustainability considerations among EU-approved voluntary schemes for biofuel, with implications for rural livelihood. Energy Policy 2012;51:765-778.
[59] Siebert A, Sinéad O'Keeffe AB, Thrän D. Social life cycle assessment: in pursuit of a framework for assessing wood-based products from bioeconomy regions in Germany. Int J Life Cycle Assess 2016. DOI 10.1007/s11367-016-1066-0.
[60] Myaka CMN. Social Life Cycle Assessment of Biodiesel in South Africa: An Initial Assessment. The 9 International Conference on EcoBalance, November 9-12, Tokyo, Japan; 2010.
[61] Hasenheit M, Gerdes H, Kiresiewa Z, Beekman V. Summary report on the social, economic and environmental impacts of the bioeconomy; 2016. http://bio-step.eu/fileadmin/BioSTEP/Bio_documents/BioSTEP_D2.2_Impacts_of_the_bioeconomy.pdf.

[62] Benoit C, Norris GA, Valdivia S, Ciroth A, Moberg A, Bos U, Prakash S, Ugaya C, Beck T. The guidelines for social life cycle assessment of products: Just in time! International Journal of Life Cycle Assessment, 2010;15:2:156-163.
[63] IUCN. A Global Assessment of the Environmental and Social Impacts Caused by the Production and Use of Biofuels. Gland, Switzerland: IUCN. 42pp; 2014.
[64] Diaz-Chavez RA, Rettenmaier N, Rutz D, Janssen R. Global-Bio-Pact set of selected socio-economic sustainability criteria and indicators. WP8 – Task 8.2 – D8.2; October 2012. www.globalbiopact.eu, viewed March 2016.
[65] Lehmann A, Russi D, Bala A, Finkbeiner M, Fullana-i-Palmer P. Integration of social aspects in decision support. Based Life Cycle Think Sustain 2011;3:4:562–577.
[66] Lehmann A, Zschieschang E, Traverso M, Finkbeiner M, Schebek L. Social aspects for sustainability assessment of technolo- gies—challenges for social life cycle assessment (SLCA). Int J Life Cycle Assess; 2013:18(8):1–12.
[67] Norris CB. Data for social LCA. Int J Life Cycle Assess; 2014:19:261–265. doi: 10.1007/s11367-013-0644-7.
[68] Dreyer LC, Hauschild M, Schierbeck J. A Framework for Social Life Cycle Impact Assessment. International Journal of Life Cycle Assessment 2006;11:2:88-97.
[69] Wang S-W, Hsu C-W, Hu AH. An analytic framework for social life cycle impact assessment—part 1: methodology. Int J Life Cycle Assess 2016;21:1514–1528.
[70] Fontes J, et al. Handbook for product social impact assessment, Version 2.0. PRé Sustainability Stationsplein, The Netherlands; 2014, www.product-social-impact-assessment.com/handbook.
[71] Jørgensen A, Le Bocq A, Nazarkina L, Hauschild M. Methodologies for Social Life Cycle Assessment. Int J LCA. 2008;13:2:96 –103.
[72] Palme U. Social aspects in work towards sustainable supply chains, TOSCA report; April 2011.
[73] ESMAP. The World Bank., and ICMM., Community Development Toolkit. ISBN: 0-9549954- 3-0; 2005.
[74] UNEP-SETAC. The methodological sheets for sub-categories in social life cycle assessment (S-lca). 2013. UNEP DTIE Sustainable Consumption and Production Branch, Paris, France. www.unep.org.
[75] GRI. G4 Sustainability Reporting Guidelines Implementation Manual; 2013. https://g4.globalreporting.org/introduction/how-to-use-guidelines/Pages/default.aspx.
[76] Wu R, Yang D, Chen J. Social Life Cycle Assessment Revisited. Sustainability 2014;6: 4200-4226. doi:10.3390/su6074200.
[77] Prosuite. Approaches to integration in sustainability assessment of technologies. Report prepared within the EC 7th framework project. Lisbon, 01 February 2012. http://www.prosuite.org/c/document_library/get_file?uuid=c378cd69-f785-40f2-b23e-ae676b939212&groupId=12772.
[78] Buchholz T, Rametsteiner, E, et al. Multi Criteria Analysis for bioenergy systems assessment. Energy Policy 2009;37: 484-495.
[79] Daim T, Yates D, Peng Y, Jimenez B. Technology assessment for clean energy technologies: The case of the Pacific Northwest. Technology in Society 2009; 31:232–4-243.
[80] Nigim K, Munier N, Green J. Pre-feasibility MCDM tools to aid communities in prioritizing local viable renewable energy sources. Renewable Energy 2004;29:1775–1791.
[81] Antunes P, Karadzic V, Santos R, Beça P, Osann A. Participatory multi-criteria analysis of irrigation management alternatives: The case of Caia irrigation district, Portugal. International Journal of Agricultural Sustainability 2011; 9:2: 334-349.
[82] Kuo YC, Lu ST. Using fuzzy multiple criteria decision making approach to enhance risk

assessment for metropolitan construction projects. Int J Project Manage; 2013:31:602–614
[83] Karklina K, Slisane D, Romagnoli F, Blumberga D. Social life cycle assessment of biomethane production and distribution in Latvia. Environment. Technology. Resources, Rezekne, Latvia Proceedings of the 10th International Scientific and Practical Conference, 2015:II:128-132.
[84] Shih H-S, Shyur H-J, Lee ES. An extension of TOPSIS for group decision making, Mathematical and Computer Modelling; 2007::45(7–8):801-813.
[85] Baumgartner R. Dealing with uncertainty—integrated sustainability assessment based on Fuzzy Logic Sustainable Development and Planning II; WIT Press: Billerica, MA, USA; 2006:1, 2.
[86] Schmidt I, Meurer M, Saling P, Kicherer A, Reuter W, Gensch C. SEE balance: managing sustainability of products and process with the socio eco efficiency analysis by BASF. Greener Management International 2004; 45:79-94.
[87] Paragahawewa U, Blackett P, Small B. Social Life Cycle Analysis (S-LCA): Some Methodological Issues and Potential Application to Cheese Production in New Zealand. AgResearch Ltd.; June 2009. http://www.saiplatform.org/uploads/Library/SocialLCA-FinalReport_July2009.pdf
[88] Martínez-Blanco J, Lehmann A, Muñoz P, Antón A, Traverso M, Rieradevall J, Finkbeiner M. Application challenges for the social LCA of fertilizers within Life Cycle Sustainability Assessment. J. Clean. Prod. 2014;69:34–48.
[89] Papong S, Rewlay-ngoen C, Itsubo N, Malakul P. Environmental life cycle assessment and social impacts of bioethanol production in Thailand. Journal of Cleaner Production 2017; 157:254-266.
[90] Spillemaeckers S, Vanhoutte G, Taverniers L, Lavrysen L, van Braeckel D, Mazijn B, Rivera JD (2004): Integrated Product Assessment – The De- velopment of the Label 'Sustainable Development' for Products Ecologi- cal, Social and Economical Aspects of Integrated Product Policy. Belgian Science Policy, Belgium.
[91] Hottle TA, Bilec MM, Landis AE. Sustainability assessments of bio-based polymers. Polymer Degradation and Stability 2013;98:1898-1907.
[92] Piemonte V, Gironi F. Land-use change emissions: how green are the bio- plastics? Environmental Progress & Sustainable Energy 2011;30:685-91.
[93] Madival S, Auras R, Singh SP, Narayan R. Assessment of the environmental profile of PLA, PET and PS clamshell containers using LCA methodology. Journal of Cleaner Production 2009;17:1183-94.
[94] James K, Grant T. LCA of degradable plastic bags. Melbourne, Australia: RMIT (Royal Melbourne Institute of Technology) University; 2005.
[95] Gerngross TU. How green are green plastics? Scientific American, 283: 36e41
[96] Kijchavengkul T, Auras R. Compostability of polymers. Polymer International 2008;57:793-804.
[97] Essel R. Meta analysis of life cycle assessments for bio-based polymers (PLA & PHA). 5th International Congress on Bio-based Plastics and Composites, Cologne, March 15th; 2012.
[98] Swarr TE. Societal life cycle assessment—could you repeat the question? Int J Life Cycle Assess 2009;14:4:285–289.
[99] Petti L, Serreli M, Di Cesare S. Systematic literature review in social life cycle assessment. Int J Life Cycle Assess 2016. DOI 10.1007/s11367-016-1135-4.
[100] Zamagni A, Amerighi O, Buttol P, Strengths or bias in social LCA? Int J Life Cycle Assess 2011;16:596–598.

[101] Umair S, Björklund A, Ekener-Petersen E. Social impact assessment of informal recycling of electronic ICT waste in Pakistan using SETAC SETAC guidelines. Resour Conserv Recycl 2015; 95:46–57.
[102] Nemarumane T, Mbohwa C. Social Life Cycle Assessment in the South African Sugar Industry: Issues and Views. In: Muthu SS (eds.) Social life cycle assessment—an insight. Springer, Singapore 2015;71–113.
[103] Blakelindley. Social Life Cycle Assessment: Recognising the challenges ahead. The IES Blog. July 21; 2014. https://iesinternships.wordpress.com/2014/07/21/social-life-cycle-assessment-recognising-the-challenges-ahead/
[104] Carrera DG, Mack A. Sustainability assessment of energy technologies via social indicators: Results of a survey among European energy experts. Energy Policy 2010:38: 1030–1039.
[105] Van Dam J, Faaij A, Rutz D, Janssen R. Socio-economic impacts of biomass feed-stock production, Global BioPact project. Utrecht: Utrecht University; 2010.
[106] Labuschagne C, Brent AC, van Erck RPG. Assessing the sustainability performances of industries. Journal of Cleaner Production 2005;13:373-385.
[107] FAO. The Global Bioenergy Partnership (GBEP) Sustainability Indicators for Bioenergy. First edition, 223p; 2011.
[108] Dale VH, Efroymson RA, Kline KL, Langholtz MH, Leiby PN, Oladosu GA, Davis MR, Downing ME, Hilliard RE. Indicators for assessing socioeconomic sustainability of bioenergy systems: A short list of practical measures. Ecological Indicators 2013;26:87–102.
[109] Benoit-Norris C, Vickery-Niederman G, Valdivia S, Franze J, Traverso M, Ciroth A, Mazijn B., Introducing the UNEP/SETAC methodological sheets for subcategories of social LCA. Int J Life Cycle Assess 2011;16:7: 682-690.
[110] Manhart A, Grießhammer R. Social impacts of the production of notebook PCs – Contribution to the development of a Product Sustain- ability Assessment (PROSA). Öko-Institut e.V., Freiburg, Germany; 2006.
[111] Barthel L, Wolf MA, Eyerer P. Methodology of Life Cycle Sus- tainability for Sustainability Assessments. Presentation on the 11th Annual International Sustainable Development Research Conference (AISDRC), 6th–8th of June 2005, Helsinki, Finland.
[112] Ciroth A, Eisfeldt F. PSILCA – A Product Social Impact Life Cycle Assessment database, Database version 1.0; 2016. http://www.openlca.org/wp-content/uploads/2016/08/PSILCA_documentation_v1.1.pdf
[113] Mankins JC. Technology readiness assessments: a retrospective. Acta Astro- naut 2009;65:1216–23. [114] Interorganizational Committee on Guidelines and Principles (IGCP). Guidelines and principles for social impact assessment. US. Dep. Commerce., NOAA Tech. Memo 1994; 29p.
[115] Grießhammer R, Benoît C, Dreyer LC, Flysjö A, Manhart A, Mazijn B, Méthot A, Weidema BP. Feasibility Study: Integration of social aspects into LCA. Discussion paper from UNEP-SETAC Task Force. Freiburg, Germany; 2006.
[116] Flysjö A. Indicators as a Complement to Life Cycle Assessment – A Case Study of Salmon. Presentation held 17th of June 2006 , Lausanne; 2006.
[117] Bare JC, P Hofstetter D. Pennington and H.A. Udo de Haes., Life Cycle Impact Assessment Workshop Summary: Midpoints vs Endpoints – The Sacrifices and Benefits. International journal of life cycle assessment 2000; 5:6:319-326.
[118] Efroymson RA, Dale VH, Langholtz MH. Socioeconomic indicators for sustainable design and commercial development of algal biofuel systems. GCB Bioenergy; 2016. doi: 10.1111/gcbb.12359.

[119] Sbarra R, Hilbert J. Socio-economic impacts of the Soy chain in Argentina. Case study within the Global-Bio-Pact project 'Global Assessment of Biomass and Bioproduct impacts on socio-economics and sustainability'. Buenos Aires, Argentina, INT A; 2011.
[120] Wright A. Socio-Economic Impacts of the Palm oil chain in Indonesia. Case study within the Global-Bio-Pact project 'Global Assessment of Biomass and Bioproduct impacts on socio-economics and sustainability. Jakarta, Green Light Biofuels; 2011.
[121] Gerber Machado P, Walter A. Socio-economic impacts of the Sugarcane chain in Brazil. Case study within the Global-Bio-Pact project 'Global Assessment of Biomass and Bioproduct impacts on socio-economics and sustainability'. Campinas, UNICAMP; 2011.
[122] Cárdenas A, Fallot A. Socio-economic impacts of the sugarcane-to-ethanol production chain in Costa Rica. Case study within the Global-Bio-Pact project 'Global Assessment of Biomass and Bioproduct impacts on socio-economics and sustainability'. Turrialba Cartago, Costa Rica, CATIE; 2011.
[123] Sawe EN, Shuma J, et al. Socio-economic impacts of the Jatropha chain in Tanzania. Case study within in the Global-Bio-Pact project 'Global Assessment of Biomass and Bioproduct impacts on socio-economics and sustainability. Dar-es- Salaam, TATEDO; 2011.
[124] Burrel T, Ouattara O, et al. Socio-economic impacts of Jatropha production and its conversion routes in Mali. Case study within the Global-Bio-Pact project 'Global Assessment of Biomass and Bioproduct impacts on socio-economics and sustainability'. Bamako, Mali, Mali-Folkecenter Nyetaa; 2011.
[125] Sleen PV, Vis M, et al. Socio-economic impacts of lignocellulosic biomass in Canada. Case study within the Global-Bio-Pact project 'Global assessment of biomass and bioproduct impacts on socio-economics and sustainability. Enschede (the Netherlands), Oxford (UK), BTG, Proforest; 2011.
[126] Köppen S, Fehrenbach H, Markwardt S, Hennecke S. Implementing the GBEP Indicators for Sustainable Bioenergy in Germany. Final Report, ifeu - Institut für Energie- und Umweltforschung gGmbH and IINAS - International Institute for Sustainability Analysis and Strategy GmbH, Heidelberg, Darmstadt, Berlin; October 2014. http://www.iinas.org/tl_files/iinas/downloads/bio/IFEU_IINAS_2014_GBEP_Application_indicators_in_Germany.pdf
[127] Hayashi T, van Ierland EC, Zhu X. A holistic sustainability assessment tool for bioenergy using the Global Bioenergy Partnership (GBEP) sustainability indicators. Biomass and Bioenergy 2014;66:70–80.
[128] FAO. Pilot Testing of GBEP Sustainability Indicators for Bioenergy in Colombia. Rome, Italy; 2014. http://www.fao.org/3/a-i4058e.pdf
[129] Blom M, Solmar C. How to socially assess biofuels: a case study of the UNEP/SETAC code of practice for social-economical LCA – University Publication - Master's thesis in cooperation with the Division of Quality and Environmental Management at Luleå University of Technology, commissioned by Enact; 2009.
[130] Myaka CMN. Social Life Cycle Assessment of Biodiesel in South Africa: An Initial Assessment, The 9 International Conference on EcoBalance, November 9-12, Tokyo, Japan; 2010.
[131] Chingono TT, Mbohwa C. Social Impacts of Biofuels Production in the Kwa-Zulu Natal and Western Cape Regions of South Africa. Proceedings of the World Congress on Engineering and Computer Science 2015; Vol II WCECS 2015, San Francisco, USA.
[132] Rozakis S, Soldatos P, Kallivroussis L, Nicolaou I. Multiple criteria analysis of bio-energy projects: evaluation of bio-electricity production in Farsala Plain, Greece. Journal of Geographic Information and Decision Analysis 2001;5(1).

[133] Hämäläinen RP, Karjalainen R. Decision support for risk analysis in energy policy. Eur J Oper Res. 1992;56:172–183
[134] Enzensberger N et al. Policy instruments fostering wind energy projects–a multi-perspective evaluation approach. Energy Policy 2002;30:793–801
[135] Stirling A. Precaution, foresight and sustainability: reflection and reflexivity in the governance of technology. J. Voss, R. Kemp (eds.), Sustainability and Reflexive Governance, Edward Elgar, Cheltenham; 2006; 225–272.
[136] Halog A. Models for evaluating energy, environmental and sustainability perform- ance of biofuels value chain. International Journal of Global Energy Issue 2009;32:87-101.
[137] David J. Pannell, Sensitivity analysis of normative economic models: theoretical framework and practical strategies, Agricultural Economics 1997;16(2):139-152.
[138] Simanaviciene R, Ustinovichius L. Sensitivity Analysis for Multiple Criteria Decision Making Methods: TOPSIS and SAW. Procedia-Social and Behavioral Sciences 2010;2(6):7743-7744.

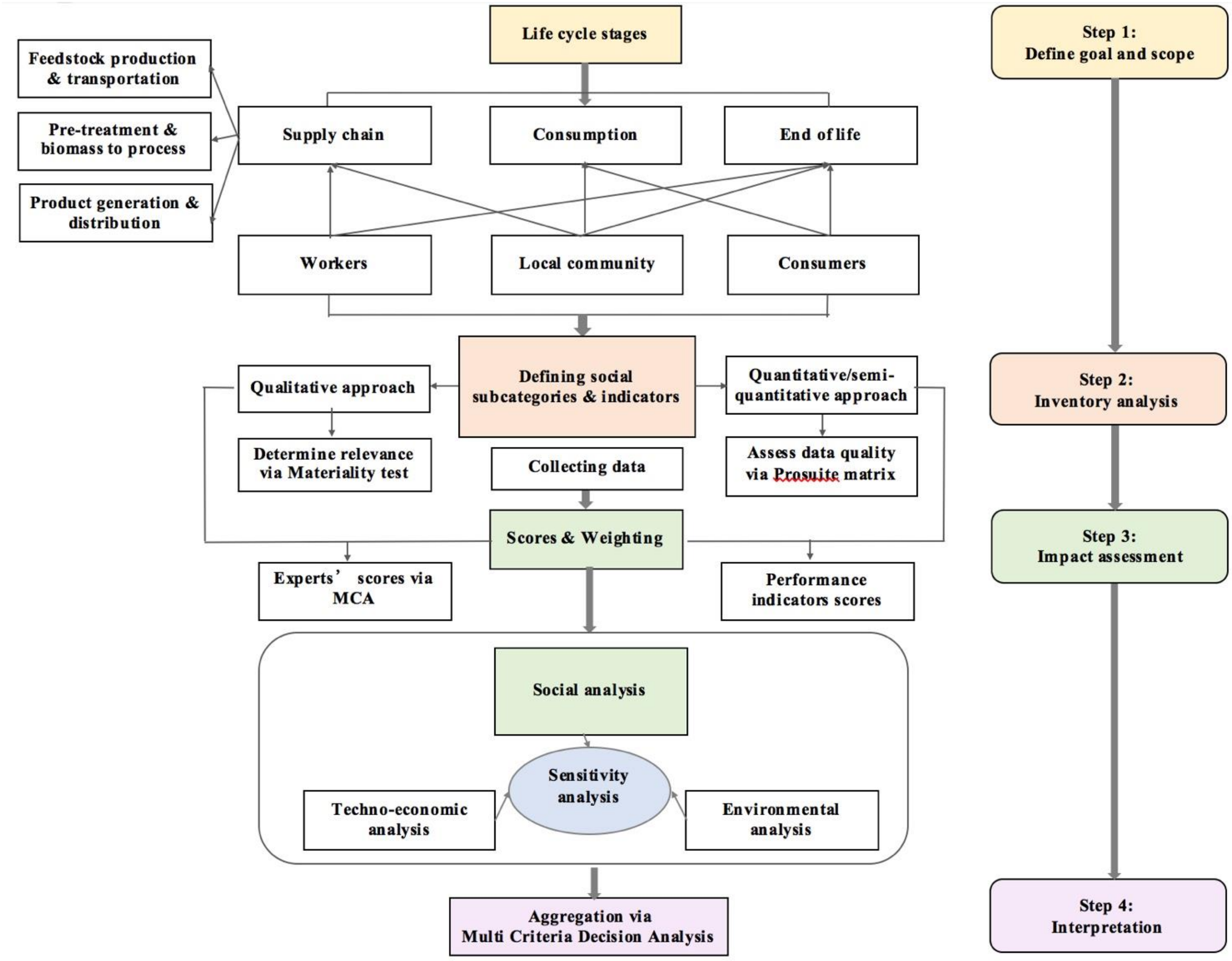
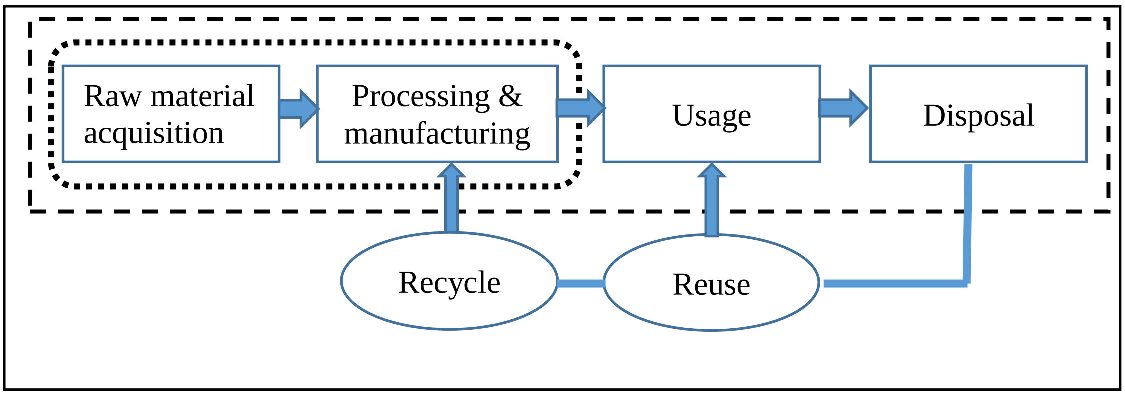


Fig 1. The systemic approach for social sustainability assessment and its integration into an overall sustainability assessment.



...... Cradle to gate: Life cycle assessment includes activities before the use phase

– – – Cradle to grave: Life cycle assessment covers the product's utilization and disposal phases

—— Cradle to cradle: Life cycle assessment covers disposal and/or returning back the product to the environment

Fig. 2. General system boundaries defined based on the life-cycle stages in the biobased economy (adapted from 73).

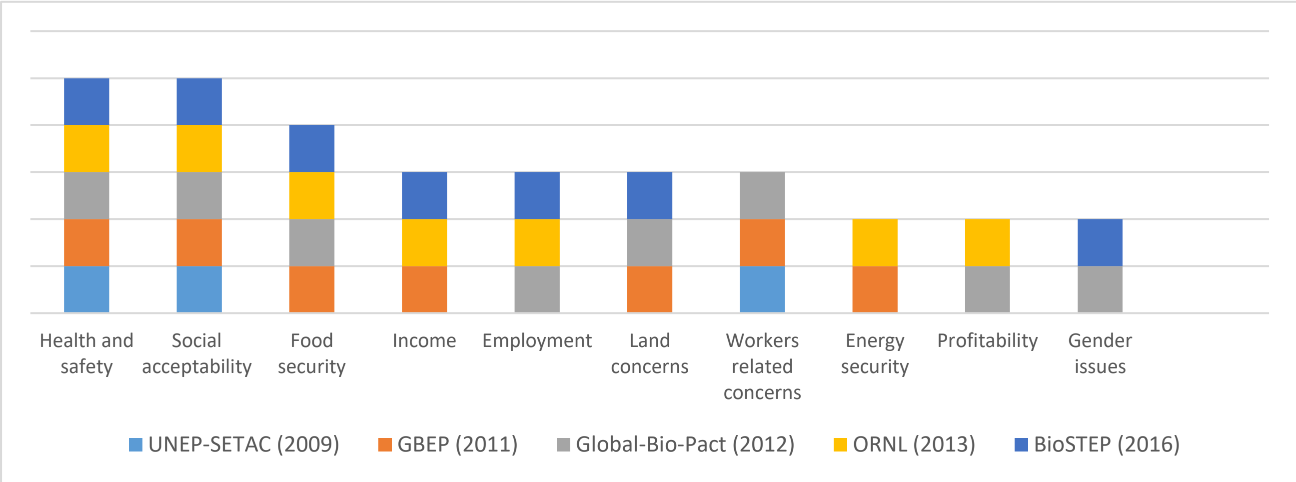


Fig 3. Common social indicators suggested in the main frameworks for the SLCA within the biobased economy (Different colors refer to the frameworks in which the identified indicator mentioned among which food security, income and employment are midpoint and the rest are endpoint indicators).

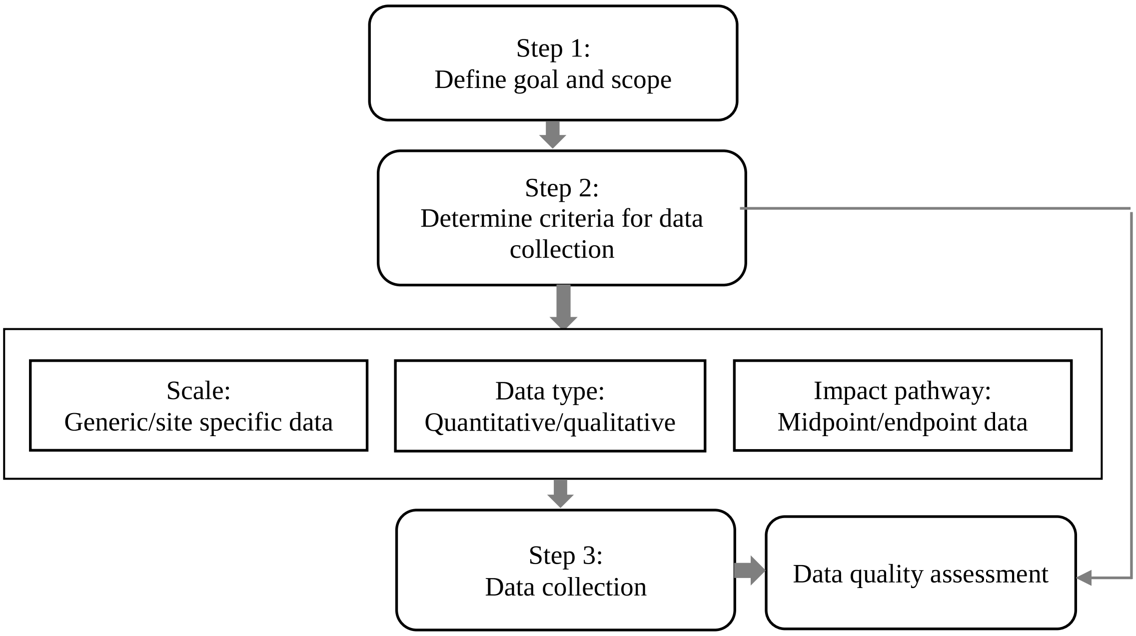


Fig. 4. Main steps for data collection at the inventory analysis step.

Table 1
Summarizing the main characteristics and challenges of three social impact assessment methodologies.

Methodology	Impact category	Step	Evaluation technique	Challenge
SIA (Social Impact Assessment)	1.Community structure, institutions and infrastructure 2.Positive and negative effects on locals, region, developer, urban elites, a company's shareholders 3.Alterations in behaviour of the different groups in a society or societies impacted 4.Changes in behaviour, equity, local values, psychological environment, social procedures and activities 5.Demographic effects 6.Impacts on employment opportunities 7.Changes in mutual support patterns 8.Physical and mental health impacts 9.Gender impacts	1.Public involvement 2.Describe suggested action 3.Scoping 4.Establish baseline 5.Assessment of cumulative social impacts; 6.Formulation of alternatives; 7.Proposed mitigation measures; 8.Monitoring actions	- Scoping methods: 1.Network & Analysis 2.Consultation & Questionnaires 3.Checklists 4.Spatial Analysis -Impact identification and assessment techniques: 1.Matrices 2.Expert Opinion 3.Carrying Capacity Analysis 4.Modelling	1.A soley quantitative approach is generally limiting 2.Politicized process dominated by a broad range of stakeholders with various interests and priorities 3.Community involvements limited because of capacity obstacles 4.Logistical and financial barriers 5.Focus on being a tool for meeting institutionalized requirements rather than minimizing social costs
SEIA (Socio-Economic Impact Assessment)	1.Health and well-being 2.Sustainable wildlife harvesting, land accessibility and utilization 3.Protecting cultural resources 4.Equitable employment and business opportunities 4.Population sustainability 6.Sufficient services and infrastructure 7.Adequate sustainable lifestyle and income	1.Scoping and issues identification 2.Identifying the social and economic baseline 3.Forecasting and analyzing effects 4.Determining mitigation 5.Identifying significance of impacts 6.Applying mitigation and monitoring programs	-Methods for determining economic impacts: 1.Fiscal Impact Analysis 2.A Cost-Benefit Analysis 3.The Input-output (I/O) Analysis -Methods for determining Social Impacts: 1.Surveys/Questionnaires 2.Focus Groups/Workshops 3.Community Meetings 4.Networks/Technical 5.Advisory Committees 6.Checklists 7.Ethnographic/ethno-historic studies	1.Analysis is limited to effects of project 2.Lack of integrated resource management frameworks 3.Developer-driven evaluation 4.Broadening participation and inclusion of different world perspectives 5.Assessing impacts without enough baseline data 6.Determining the magnitude of economic and social effects 7.Lack of tools and techniques for impact evaluation of smaller projects
SLCA (Social Life Cycle Analysis)	1.Stakeholder "worker" 2.Stakeholder "consumer" 3.Stakeholder "local community" 4.Stakeholder "society" 5.Other "value chain" actors	1.Goal and scope definition 2.Inventory analysis 3.Impact assessment 4.Interpretation	Type 1: Using aggregation formulas derived from "Performance Reference Points" as characterization models Type 2: Using impact pathways (midpoint indicators and, potentially, endpoints) as characterization models	1.Determining functional unit and boundaries of the system 2.Linking social pillars to a functional unit and their aggregation throughout the whole life cycle of the product 3.Applicability of SLCA to the social impact evaluation of systems and services, due to the lack of research in this field 4. Data type used for the analysis 5.More researches are needed in terms of methodological, tools and databases development to ease the impact assessment procedure

Table 2

Case studies on social life cycle phases from biofuel supply chains.

Supply chain	Social life cycle steps					
	Goal and scope definition			Inventory analysis	Impact assessment	Interpretation
	Goal	Scope/System boundary	Functional unit			
Palm oil biodiesel (Manik et al., [54]/Indonesia)	-Assessing social implications of the production system. -Hotspot identification -Policy and strategy design.	-All phases of the supply chain including land clearing; plantation; milling; and transportation.	No functional unit was defined since the analysis is based on the qualitative data about the process's attributes.	-Based on the UNEP-SETAC 2009); an expert panel survey. -24 social indicators were identified and aggregated into five social impact categories including "human rights", "working condition", "cultural heritage", "social–economic repercussion", and "governance".	-Multi-criteria decision analysis; -Determining the gaps between expected and perceived quality of each social indicator. - A final score to be able to compare it with other product systems.	-Major social hotspots are related to the working conditions and cultural heritage impact categories. -General perception on the social impacts of the biodiesel product system is lower than the stakeholders' expectation.
Biomethane (Karklina et al., [83]/ Latvia)	- Assessing the potential social impact associated to the production of biomethane from biomass; -Identifying the importance of biofuels' options for transportation fuels.	-Process phases include; Raw material cultivation (algae and manure); Raw material processing into biomethane, storage and distribution; Proper application of digestate as the process by-product.	No functional unit applied.	-Seven alternative production systems were identified. -Social indicators for making comparison between the alternatives include Employment; Standard of living; Rational use of resources; Environmental protection; and energy security.	Using a Multi-Criteria Analysis approach (TOPSIS), seven alternatives were evaluated by experts' views and the best alternative is identified considering the social impacts indicators**.** The weights for all indicators are considered as equal.	"biomethane directly to transport" and "biomethane with grid injection to transport" identified as the first two best alternatives whereas natural gas is assessed as undesirable option.
Bioethanol (Papong et al., [89]/Thailand)	-Assess the social performances of the bioethanol production system from cassava and molasses through a life cycle perspective. -Comparing the results with conventional gasoline supply chains.	-Cradle to gate including the feedstock cultivation/harvesting, raw material processing, ethanol production, and transportation.	The functional unit of the study was 1 GJ (gigajoule) of ethanol produced.	-The social impacts include the wages, total employment and fatal occupational injury. - The data were collected from the primary sources in the working environment of the industrial and the agricultural stages.	-A combined approach using the site specific data and input-output analysis.	The bioethanol production has higher benefits with regard to total employment and income generation compared to gasoline whereas for the fatal occupational injuries, bioethanol systems are identified to have higher impacts than gasoline.
Biodiesel and bioethanol **(**Ekener-Petersen et al., [53]/Global level	-Assessing social and socio-economic impacts of four vehicle fuels; biodiesel bioethanol, diesel and petrol. -Identifying the potential hotspots with a risk of major social impacts.	-Generic level, i.e. country and/or sector levels restricted to fuels used within the EU, with particular focus on northern Europe and Sweden. -Life cycle phases include in the study: production/cultivation; refining/processing; and transport.	Not specified in the study.	Data were collected for 57 pre-defined sectors by the Social Hotspots Database on available categories including "Human rights", "Labour", "Health and safety", "Community" and "Governance".	For each of the three life cycle phases the risks were listed for each fuel and the outcomes were aggregated by calculating the number of indicators with high and very high risk for each product system.	-Country showed higher importance for potential risks comparing to the type of fuels. -Regarding the most important phase for potential social impacts, all three phases evaluated to be equal. -Results suggest that in designing policies, it is crucial to develop strong regulations for social performance for both biofuels and fossil fuels.

Table 3
Overview of the main frameworks and socio(economic) indicators applied in biobased industries.

Framework	Main indicators																					
	Health & safety	stakeholder participation	Income	Human Rights	Work days lost due to injury	Workplace	Employment	Quality of life	External trade	Profitability	Resource conservation	Social acceptability	Value chain actors	Workers	Local community	Transparency	Environment	Corruption	Access to land, water and other natural resources	Food security	Energy security	Gender issues
Global-Bio-Pact (2012)	*			*		*	*			*		*		*	*		*		*	*		*
GBEP (2011)	*		*									*		*					*	*	*	
BioSTEP (2016)	*		*		*		*	*				*					*		*	*		*
ORNL (2013)	*	*	*		*		*	*	*	*	*	*				*				*	*	
UNEP-SETAC (2009)	*	*		*		*						*	*	*	*	*		*				*

Table 4
Recent literature applied in biobased industries based on the main frameworks and data collection elements.

Reference	Guidelines and frameworks					Element					
						Data type [a]		Impact pathway [b]		Data scale [c]	
	UNEP-SETAC (2009)	The GBEP (2011)	Global-Bio-Pact (2012)	ORNL (2013)	BioSTEP (2016)	Quantitative	Qualitative	Midpoint	Endpoint	Generic	Site specific
Hasenheit et al.[61]: Social, economic and environmental impacts of bio-economy					✓	✓	✓	✓	✓	✓	
Dale et al. [108]*:* Socioeconomic indicators for bioenergy sustainability as applied to Eucalyptus				✓		✓					✓
Efroymson et al. [118]*:* Socioeconomic indicators of sustainability of algal biofuels				✓		✓		✓			✓
Sbarra and Hilbert [119]: Biodiesel from soy in Argentina - *Wright* [120]: Palm oil and biodiesel in Indonesia - *Machado and Walter* [121]: Bioethanol from sugarcane in Brazil - *Cárdenas and Fallot* [122]: Bioethanol from sugarcane in Costa Rica - *Sawe et al.* [123]: Jatropha oil and biodiesel in Tanzania - *Burrel et al.* [124]: Jatropha oil and biodiesel in Mali - *Sleen et al.* [125]: 2nd generation biofuels and products from lignocellulosic material in Europe - North- America			✓			✓		✓	✓	✓	✓
Köppen et al. [126]*:* Implementing the GBEP indicators for sustainable bioenergy in Germany		✓				✓		✓		✓	
van Dam et al. [105]*:* Using the GBEP indicators in the Netherlands bioenergy sector		✓				✓		✓		✓	
Hayashi et al. [127]*:* site-specific data from case study of Kyoto		✓				✓		✓			✓
FAO [128]*:* A Pilot Testing of GBEP Sustainability Indicators for Bioenergy in Colombia		✓				✓		✓			✓
Siebert et al. [59]*:* Social life cycle assessment of wood-based products from bioeconomy regions in Germany.	✓					✓	✓	✓	✓	✓	
Blom and Solmar [129]*:* Social assessment of biofuels: a case study from Stockholm, Sweden using the UNEP/SETAC.	✓					✓	✓	✓	✓	✓	
Mbohwa and Myaka [130]*:* SLCA of Biodiesel in South Africa.	✓					✓	✓	✓	✓		✓
Chingono and Mbohwa [131]*:* Social Impacts of biofuels production in the Kwa-Zulu Natal and Western Cape Regions of South Africa.	✓					✓	✓	✓	✓		✓
Valente et al. [30]*:* Social Life Cycle Sustainability Assessment (LCSA) of New Norwegian Biorefinery.	✓					✓	✓	✓	✓		✓
Manik et al. [54]: SLCA of palm oil biodiesel.	✓					✓	✓	✓	✓		✓

[a] **Data type** = The type of data to incorporate in the assessment can be qualitative and/or quantitative.
[b] **Impact pathway** = Difference between midpoint and endpoint indicators is related to their location throughout the impact pathway. Midpoint indicators are defined as a factor in a cause–effect chain for a certain impact category prior to the endpoint where characterization parameters can be measured to show the relevant importance of an impact category.
[c] **Scale of data collection** = Generic data are usually collected at country, region and/or sector level whereas site specific data gather information through interviews and site level.