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## **Social life cycle assessment of biodiesel production at three levels: A literature review and development needs**

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### **Abstract**

Assessment of social impacts of products and services has gained increasing interest in society. Life cycle assessment (LCA) is a tool developed to estimate the impacts of products and services from cradle to grave. Traditionally LCA has focused on environmental impacts, but recently approaches for social life cycle assessment (SLCA) have also been developed. Most of them fairly address **social performances** of business, but the aim of this paper is to analyse the possibilities and development needs in the complementary approach, which is the evaluation of **social impacts** in LCA. We review the field in general and take a closer look at the empirical case of biodiesel production, which is a timely topic globally in view of the climate change mitigation objectives. The analysis is carried out at three levels – company, regional, and state level. Despite active development in the field of SLCA, we conclude that in many cases it is not yet possible to carry out a comprehensive SLCA. Finally, we outline lines of research that would further improve the methodological and empirical basis of SLCA at various levels of decision-making.

### **Keywords**

biodiesel production; company, region, and state levels; decision support; life cycle assessment; social impacts

## 1. Introduction

Society is taking increasing interest in assessing social impacts of various human activities. According to UNEP–SETAC (2009), great variety in methods and approaches exists in the field, depending on the object of interest. If the focus is on a project, intervention, or facility, one can utilise social impact assessment or health impact assessment, for example. In the case of organisations, tools such as value network assessment or social footprint can be applied. For communities, one can apply such methods as participatory action research or focus groups. The approach involving products or services is called social life cycle assessment (SCLA). In SLCA, most methods address social performances of business. In this paper, we focus on complementary methods concerning social impacts.

As the paper is about the assessment of impacts, the first question to address is what social impacts are. Here we refer to the narrow definition of impacts. We draw many ideas from the Impact Assessment principles (Vanclay, 2003) devoted to project assessment. Social impacts (Vanclay, 2002) are caused by changes (e.g., setting up a new facility), which entail effects (more traffic). Some of these effects directly cause phenomena that are experienced by people or by groups of people (e.g., death or injuries in traffic). The experienced phenomena are ‘social impacts’. The list cannot be fixed, but some examples can be found in impact assessment (Becker and Vanclay, 2003) or SLCA literature. They are related to changes in life expectancy, health, social status etc. Reitingger and colleagues (2011) suggest the first list of social impacts from the capability theory of Sen (2003) to operationalize the phenomena. Well-being and health are generally agreed upon as social impacts, cited by many authors (Weidema, 2006), but consensus has not yet been reached on other impact categories. For this reason, the rest of this text will focus on the **well-being and health impacts**, which are the only consensual impact categories to date.

Often, researchers do not have at their disposal the full chain of calculations needed for the assessment of the target social impact. Because of this limitation, they stop the calculation at an intermediate point, such as the change in elimination of jobs, which could lead to further important social impacts (see Jeorgensen et al., 2010). To acknowledge our inability to calculate the true social impact when this concern is relevant, we will use the term ‘social effect’ instead of ‘social impact’.

‘Social performances’ are neither social effects nor social impacts of changes. Social performances are difficult to link with social impacts of changes, because they are features of a situation in a relevant organisation (or features of the value chain of organisations shaping the life cycle), referring more or less to social issues. The state of gender issues in the workplace, child labour, trade-union freedom etc. are typical social performances of organisations. Table 1 describes the distinction between performances, effects, and impacts.

Table 1: Distinguishing between performances, effects, and impacts

Context	This is a <b>performance</b>	This is an <b>effect</b>	This is an <b>impact</b>
One situation (within one company)	Feature of the situation		
One change (driven by one company)		Social phenomena caused by the change that could have impacts	Consequence of the change that is felt by people directly in life
Examples	Gender issue, child work, or freedom to organise within the company	Loss of jobs, creation of jobs, or creation of new networks	Changes in health status, or changes in sense of confidence

Processing the assessment of social performances is always feasible by asking stakeholders which performance and indicator they deem important to assess. Many examples have already been published, addressing decision levels from company (Schmidt et al., 2004) to nation (Labuschagne and Brent, 2006). In this paper, **we deal not with the social performance**

## **assessment of organisations but with methodologies for the calculation of social impacts**

(or social effects by default) caused by one change affecting these organisations.

The paper addresses the case of three different raw materials – palm oil, forest biomass, and algae – in biodiesel production. The comparison of three distinct raw materials is considered as an opportunity for challenging SLCA methods. The production chains selected are the same as in the work on pages **XXX–YYY** of this issue, in which the analysis concentrates on environmental impacts. We are interested in biodiesel in general, not in any specific country, region, or company. However, Finland, Sweden, Germany, and France are the European Union member states, which have the greatest potential for forest biomass supply for energy (Ericsson and Nilsson, 2006).

In real-life decision-making, it is necessary to deal with economic, environmental, and social impacts (see e.g., Leskinen et al., 2012), but here we consider **only the social effects** caused by the functioning of the product chain, and only routine functioning at that. Indeed, neither possible accidents nor construction of facilities is taken into account.

Social impacts are important, because employing biomass for energy provides opportunities also for supporting welfare and employment. So far, most of the empirical research examining the bioenergy industry has only touched on the social aspects of energy production, though one should see the work of Leskinen et al. (ibid.). In addition, previous research has not approached the different levels (i.e. company, region, and state) of concern in the impacts of bioenergy production. In fact, the individual hierarchical levels (Dreyer et al., 2010) of concern must be examined separately, because differing and potentially competing concerns at different levels may be involved in the same project of one bioenergy plant (Elghali et al., 2007). Also, not all levels of decision-making demand the same types of information. Domac et al. (2005) recall that, while reduction of carbon emissions and security of energy supply are headline issues at national level, local communities are likely to consider job creation, income

improvements, the local environment, and regional development at least as important when considering supporting or opposing any new bioenergy plant. Indeed, it proceeds from Vanclay's (2002) definition that reducing carbon emissions, securing resource supply, or getting the approval of people **is not a social impact**. Here we make the assumption that some conditions (such as public approval) are met by the scenario before the implementation of the assessment via SLCA. Hence, we deal only with how to calculate the well-being and health social impacts **thanks to the methods developed within the LCA field**.

We borrow methods either from social or environmental LCA. Indeed, environmental LCA practitioners performed some estimation of potential harm to human health long before developing a comprehensive SLCA methodology.

The scenarios presented here are based on the production of bioenergy from palm oil, from forests, or from algae, and they are addressed at the company, region, and state levels.

First, we check the approaches available for assessing social impacts/effects or performances in the LCA framework (Section 2). Then we discuss the possibilities offered by this review, assuming the social assessment of biodiesel projects is applied at each of the company, region, and state levels (Section 3). The main purpose of this exercise is to highlight current knowledge gaps and development needs for SLCA (Section 4). Section 5 presents conclusions of the review.

## **2. Social impacts and performances in LCA literature**

Different types of approaches are available, depending on the scope. They involve different descriptions of the systems under scrutiny.

Social LCA is defined in the work of UNEP–SETAC (2009) as ‘a systematic process using best available science to collect best available data on and report about social impacts (positive and negative) in product life cycles from extraction to final disposal’. We do not

deal with the entire history of the methods, which can be found in the work of Benoît et al. (2010), and we make only a brief mention of two families of methods stemming from the environmental LCA framework, which address harm to health people might experience due to environmental issues. For instance, the Eco-Indicator 99 method (Spriensma and Goedkoop, 2001) belongs to the first family, dealing with the impact on ‘human health’. The second family brings together methods related to ‘LCA of work environment’ and the determination of possible harm to workers’ health caused by their exposure to pollutants (Kim and Hur, 2009; Antonsson and Carlsson, 1995).

We focus here on the main approaches aimed at the assessment of either social performances or social impacts of product chains, quoting representative authors only. We extract them from a corpus of about 50 papers. This corpus is the result of our four years of collection of all literature on social LCA. Only one part may be retrieved from “Scopus” (15 results) or “Web of Science” (14 results) databases with the keywords “social life cycle assessment” in the article title.

All the approaches are highly innovative and experimental, but not yet comprehensive. Nevertheless, they obviously describe and analyse the examined system at a different level, e.g., a chain of unit processes or a chain of companies. We will refer to these SLCA methods in light of the opportunity they offer for the assessment of social impacts of bioenergy product chains. When methods for the assessment of social impacts are not already available, we turn to authors’ suggestions for methods to assess social performances, also quoting their work.

### 2.1. The system described as a chain of unit processes

In the Hunkeler study (2006), the functional unit and the system boundaries are the same as in the environmental LCA (ELCA) inventory. Accordingly, the systems are described as chains of unit processes. Hunkeler calculates the effects of the product’s life cycle on regional (part

of a continent) employment, but for the ‘societal’ impact categories, he designs ‘key societal indicators, such as housing, health care, education and necessities’ that he considers to be regionally dependent and linked with regional employment. The study calculates the number of work hours required for ‘extraction, transport to the production site, production, transport to the consumer, use and ultimate disposal’ (ibid., p. 372). The number of employment hours involved within each unit process, in each of the relevant geographical regions, is calculated mainly through an allocation process at the level of the organisation. The suppliers’ work hours are either included or not, in line with the ELCA system description. Considering the number of work hours required by region and by unit process highlights the distribution of work along the life cycle. Usually, one product life cycle affects several countries. To take into account ‘regional’ differences, Hunkeler suggests moving from work hours to the ability to acquire necessities such as housing, education, and health care. The comparison unit becomes the time required to acquire, marginally, one unit of such a necessity, in each country. Hunkeler’s approach may be used for the calculation of the number of hours required per unit process and per functional unit, for the product system classically described in ELCA. The method, or one part of it, may aid in the social assessment of the bioenergy chains when differences in purchase power are relevant in the cycle – such as when the product chain crosses regions whose development stages differ greatly.

## 2.2. The system described as a chain of organisations

In the approach of Andrews et al. (2009) and more generally in the approaches dealing with **social performances** of companies, the system is described as akin to a supply chain of organisations. Andrews and colleagues compile the number of work hours per organisation and several attributes for each organisation (e.g., is it locally produced, is it ISO-certified, ...?). Then, they calculate the number of work hours involved in a functional unit for each



organisation. Doing so, they come to this result: ‘this study reveals that 81% of the tomato company’s supply chain (measured in worker hours) is local, 3% is not local, and we do not know whether 16% of the supply chain is local or not’ (Andrews et al., 2009, page 572). One can choose any attribute. The authors set the boundaries of the system in line with ‘hot spots’. The interest of this approach stems from the potential variety of the guiding leads (e.g., number of work hours is a guiding lead). The guiding lead could be any of the so-called additive indicators<sup>1</sup> (Kruse et al., 2009). Indeed, for biofuels studies, several guiding leads (like hectares of forest or land-use) might be of the utmost interest for backers. The result is a comparison of several scenarios given the same guiding lead and set of attributes.

L.C. Dreyer and colleagues (2010) describe the system in terms of a chain of companies, too. Instead of direct but vague indicators, they collect information about the measures taken to ensure a safe and healthy work environment. Therefore, they calculate an indirect indicator of the quality of the work environment, which reflects the company’s efforts (will and ability) to prevent a risk of violation of workers’ rights. This may be of relevance when some suppliers are liable to be at risk: companies always run the risk of being chastised by non-governmental organisations (NGOs) for their foreign suppliers' behaviour.

### 2.3. The system described in terms of sectors of the economy

The question raised by Hofstetter and Norris (2003) is ‘[C]ould we introduce occupational health impacts into the US integrated product policy?’ They present an example of what could be done to assess the impacts of work conditions on the health of workers, with a comparison of two given sectors. The two systems under scrutiny are described in terms of the links between sectors, i.e., the usual 491 sectors of the Accounts of the Nation in the US. The first system gathers the links between the steel fuel tank industry (for cars) and its suppliers

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<sup>1</sup> They may be related to the functional unit, they may be quantified at each step in the chain, and they are additive along the chain.

(other sectors in the US input–output tables, 1999), while the second system gathers the links between the plastic fuel tank industry and the other sectors. The comparison excludes elements that are common to the two alternatives. The boundaries are those of the national economy. The authors use disability-adjusted life years (DALY) as the unit for health, for the state of occupational health and deaths, for all suppliers of the two systems. Thus they obtain the DALY score for making a million fuel tanks from either steel or plastic.

If the compared scenarios of the production of bioenergy are set in the same country, this method highlights the comparative human costs of work for different sectors of activity, provided that reliable data are available.

#### 2.4. The system described in terms of several countries in comparison

When the aim is to compare social impacts between countries at different levels of development, authors calculate pathways that are obviously linked with human well-being, such as changes in longevity, changes in health, or infant mortality rates. The purpose of Bo Weidema's (2006) seminal work<sup>2</sup> is to demonstrate that world data are available for the calculation of the impacts of human activities in six 'damage categories', all linked with health. He suggests indicators, units of measurement, and an initial estimate of worldwide normalisation values for 'life and longevity' or 'health'. The approach has not been adapted to the scale of product chains in nations, but it probably could be.

The studies by Norris (2006) and by Hutchins and Sutherland (2008) elaborate upon one common idea. When a company chooses a supplier from a very poor country, the economic activity generated in the poor country entails a change in life expectancy or in infant mortality. When a Dutch electricity company (Norris, 2006) generates economic activity (even less than 10% of the economic activity of its supply chain) in non-OECD countries, the

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<sup>2</sup> Alongside longevity and non-fatal impacts on human health, Weidema (2006) suggests the following end-point impacts: 'autonomy', 'safety, security, tranquillity', 'equal opportunity', and 'participation and influence'.

socio-economic health gains exceed abundantly (x 1,000) the harm to health caused by pollution (calculated here with Eco-Indicator 99) in the poor countries. Regardless of all their limitations, these studies pave the way toward the calculation of effects whose importance can hardly be challenged. They could be used to address health impacts at state and supranational levels.

### **3. Assessment of social effects of biodiesel production at different levels in LCA**

This section of the paper briefly introduces our three alternative processes of biodiesel production (Subsection 3.1) and discusses how to assess social effects in LCA (subsections 3.2 to 3.4) by applying the findings of the literature reviewed in Section 2 to the case of biodiesel production at the three levels. For each level, different kinds of affected actors are involved. Moreover, each entity is likely to require the assessment of **both social impacts and performances**, as described in the introductory section above. Therefore, in Section 3 we focus on the assessment of **social impacts** in line with Vanclay, and more specifically on impacts related to health or well-being, via quantitative LCA methods. For each level, we suggest the main needs in relation to the assessment of health or well-being impacts, and then describe the LCA methods (if any) available for responding to the need.

#### **3.1. Examples of biodiesel production processes**

The examples of production processes are connected to Finland, but it is emphasised that the examples are hypothetical scenarios and not directly related to the actual situation in Finland. The raw materials considered in the biodiesel production are palm oil, forest biomass, and algae. Biodiesel production based on palm oil is taken as a reference scenario (scenario A), and the latter two options represent alternatives that could replace palm oil in biodiesel production in the future. The general idea is to consider the change from the reference

scenario to two distinct alternative scenarios (as in Impact Assessment, Vanclay, 2003). Other raw materials such as algae (cultivated<sup>3</sup> in artificial ponds, co-located with a production plant; scenario B) and forest biomass (scenario C) could be used in biodiesel production. Here, we do not address the social performance **per se** of a certain production system (as it could be done for benchmarking purposes, for instance).

The biodiesel production scenario based on palm oil is described in Figure 1.

Figure 1. An example of a production process based on palm oil.

The cultivation, processing, and production of palm oil are considered as a global process involving suppliers outside of Finland. In addition, the infrastructure, auxiliary materials, electricity, heat, and diesel inputs are assumed to be global for the same reasons. After production of the palm oil, it is transported to Finland by ship. The Finnish biodiesel refining process is local, the biodiesel factory being located in southern Finland near the sea. The phases of storage, distribution, and combustion are also assumed to be local; i.e., the produced biodiesel is assumed to be consumed in Finnish markets as transportation fuel. However, as can be observed from the subsequent processes based on algae and forest chips, the storage, distribution, and combustion processes for biodiesel are identical, regardless of the origin of the raw material. Therefore the last part of the chain can be excluded from the analysis, since the same component is included in both the reference and the alternative scenarios. Figure 2 represents the process based on forest residues.

Figure 2. An example of a production process based on forest chips.

A key difference in comparison to Figure 1 is that the raw material's production is based on forest biomass harvested in Finland instead of imported raw material. Since it is assumed that

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<sup>3</sup> Description of the cultivation of algae and other steps may be found in this issue, on pages **XX-YY**.

the biodiesel production factory is located in southern Finland, and since a hypothetical biodiesel production plant is likely to be large-sized, it is assumed that the biomass production area consists of the whole of southern and eastern Finland, implying regional scale. Although the biomass production is regional, energy and material inputs are assumed to be global. The biodiesel is processed in southern Finland in an area analogous to that in Figure 1. The storage, distribution, and combustion processes are identical to those in the case of palm oil, as presented above.

Finally, Figure 3 describes the production scenario based on algae biomass. In contrast to the first two cases, algae production in Finland is at the level of laboratory testing, but algae may become a realistic large-scale option in the future. In the case of algae, it is assumed that the production is a local process with respect to a biodiesel factory located in southern Finland. Certain inputs are global and others local. Again, the end use of algae biodiesel is assumed to occur in Finnish markets.

Figure 3. An example of a production process based on algae.

In the sections below, we show examples of the three above-mentioned scenarios for the bioenergy supply in Finland. They will help us to distinguish i) which target populations the entity (company, region, or state) claims to address and ii) in which way each entity represents the bioenergy systems within its scope.

The functional unit for comparison of the three scenarios is the same in each one (e.g., 1,000 megawatts of biodiesel available at the output of the factory).

### 3.2. Company level

We consider the case wherein a central large company or a group of smaller companies in Europe forms an informal network, a co-operative group, or a joint venture processing

biomass for biodiesel. The three scenarios under scrutiny have already been deemed relevant from the technical, political, and economic point of view. Next we view the social impacts caused by changing from scenario A to scenario B or C. The reasoning related to the target populations facing the social impacts, comes from the comparison of value chains, as in Figure 4, between biodiesel made from palm oil (top) and algae (bottom). The arrows stand for flows of either the processed product or services, materials, and energy. Each organisation (or group of similar organisations) is represented by a rectangle. White rectangles are for companies operating mainly in Europe, while coloured rectangles indicate organisations operating mainly in non-European countries. Despite the use stage being the same in the two scenarios, the process and use of side-product glycerine becomes a Finnish issue in scenarios B and C, while it does not in scenario A.

#### Figure 4. Comparison of two value chains at company level

Which kind of target populations is the company interested in? Based on Figure 4, we hypothesise that the company cares about its effects on 1) the health of the Finnish population, which is affected by a change in the product chains. The general population is in contact with the product chain mainly during the use phase, but we will not tackle this issue, since the use phase is identical for all alternatives studied. We will take into account only the rest of the chain. However, the company especially cares about 2) the occupational health in Finland, which may produce differences between alternative production chains. For example, the fertilisers used for the cultivation of algae may be harmful and logging wood with modern machines may be less dangerous than shipping palm oil in precarious conditions.

The company might worry about social performances such as choosing suppliers that respect the human rights of their workers. Algae cultivation requires regular purchases of glass from China, so NGOs could demand accounts of the respect for workers' rights. Dreyer et al.'s

(2006) approach aids in choosing a less risky supplier. On the contrary, the choice of certain suppliers may present an opportunity for the company to have positive social impacts. For instance, purchasing palm oil in large quantities from certain developing countries could assist in their development and result in the improvement of their inhabitants' health, which would make it worthwhile to include these countries in the calculations. 3) The change in the health of foreign populations is especially important in the cases of large multinational companies, whose size allow them to influence people's lives nearly to the extent that the state does.

Table 2 shows suggestions of methods or tools in the LCA field available for addressing the social impact assessment of the change between scenario A and scenario B or C.

Table 2: Summary of the social impacts that companies claim to calculate

Nature of the assessed social impact	Target experiencing the impact	Suggestions for main tool or method (examples)
(1) Changes in the health of the population	Population exposed to the effects of the change	Calculation of the end-point value 'human health' by ELCA for each life cycle
(2) Changes in the health of the workers	Workers involved in the life cycle chains in Finland	Methods for assessing the work environment (e.g., Kim and Hur, 2009)
(3) Changes in health in foreign countries	General population in developing partner countries	see table 4

Potential harm to 1) the general population's health may be assessed via an element of environmental LCA methods for the calculation of the 'human health' impact (for instance, calculated thanks to Eco-Indicator 99). This tool takes into account the respiratory and carcinogenic effects, global warming, ozone layer depletion, and the effects of ionising radiation. The ELCA method (e.g., Kim and Hur, 2009) allows calculation of potential harm to 2) occupational health on account of environmental issues in factories. But this answers only one part of the question. Issue 3 will be dealt with at the state level.

### 3.3. Regional level

Regions may invest in a production plant and hire out the facilities to a private entrepreneur, or the plant may be controlled by the region and maintained by employees at regional level. We establish the hypothesis that a region is wondering about the advantages and drawbacks of changing its main source of biomass from palm oil to forest or algae biomass. After preliminary assessment, the region deems scenarios B and C worthy of being socially assessed.

Regions and municipalities examine social impacts mostly on the scale of the region they have the most direct responsibility in, so the focus is on the inhabitants of the region. There is natural antagonism between the LCA spirit that considers the whole life cycle (Heiskanen, 2002), and the interests of regions, which are local. The contribution of LCA spirit to regions is to make them see the problems from a new perspective, taking into account what could happen somewhere else. Nevertheless, the detailed studies integrate within their boundaries only the foreground processes and the suppliers that are located in the region (Figure 5). Often, impacts occurring outside the region are not measured with details nor taken into full consideration.

Figure 5. Representation of territorial value chains to be compared at regional level.

We make the assumption that the companies performing logging, processing biomass from wood, and transporting it to the refinery plant are within the delimited region. The figure compares two territorial value chains, in which each square stands for one organisation (or group of similar organisations).

Usually, regions and municipalities worry about the number of jobs created or destroyed in the different scenarios within their boundaries. As noted above, this is not social impact but one social effect that could lead to future impacts (Jeorgensen et al., 2010a). It may be



calculated as in Hunkeler’s work (2006), provided that parts of the chain are found in poor regions or countries.

As to target populations, we make the assumption that regions consider first 1) the health changes for workers within the boundaries, 2) the health changes in the region’s population, and 3) the changes in the well-being of said population. Table 3 presents suggestions of methods or tools for meeting these demands.

Table 3: Summary of the social impacts that regions claim to calculate

Nature of the assessed social impact	Target experiencing the impact	Suggestions for main tool or method (examples)
(1) Changes in the health of the workers in the region	Workers located in the region	Occupational health data by sector scaled down to region (Hofstetter and Norris, 2003)
(2) Changes in the health of the population in the region	The population of the region	Calculation of the ‘human health’ end-point value by ELCA for each life cycle
(3) Changes in the well-being of the region’s population	The population of the region	No tool

The work published by Hofstetter and Norris (2003) is of the greatest interest for the anticipation of potential issues of 1) the occupational health of Finnish workers, in comparison of the three scenarios. As we have discussed above, potential harm to 2) the population’s health is likely to be assessed via ELCA methods that calculate ‘human health’ impact, but this has not been done for local populations yet. No tool is available for the assessment of issue 3 yet.

### 3.4. State level

Biodiesel production at state level is of concern not only for company-level choices within various industries and for the solutions developed in municipalities in different regions, but also for decisions on the use of energy based on imported sources and the consequences for foreign countries.

We consider one European state that is contemplating favouring the production of biodiesel from its own forests or algae instead of palm oil. Before any social study is envisioned, the projects have been deemed technically and economically feasible, and capable of reducing carbon emissions and securing supply. Assessing biodiesel projects requires depicting the links between the sectors involved at national level, as illustrated in Figure 6. The schema represents the economic sectors directly involved in delivering energy from biomass, either from palm oil (top) or from forests (bottom). The size of each rectangle stands for the added value. Because of the magnitude of purchases of palm oil, the rectangle ‘Exchanges with foreign sectors’ is bigger for the first scenario than for the other. Because steel and machines would be processed in Finland, the sub-sectors ‘steel industry’ and ‘wood harvest machines’ are supposed to create more added value in case 2 than in the first case. Obviously, it is the same for ‘heating and electricity from wood’. Of course, these pictures are only examples and are not expected to correspond to reality.

Figure 6. Schema of the economic sectors involved at state level in a comparison of scenarios A and C.

Regarding the target populations, the state level is involved with more general topics. We suggest that policymakers deal with the 1) health and 2) welfare of the society, and especially status improvement (e.g., reduction of poverty) for the most vulnerable persons – regarding not only immediate but also long-term consequences. Harm to the 3) occupational health of a nation could lead a country to dangerous hazards in 30 years. It is possible that algae cultivation on a large scale could create a new chronic occupational health issue. Outside Finland, too, the new chain could entail harm to occupational health. This could be included in the assessments. Moreover, EU member states have committed to a common strategy for sustainable development (COM, 2001, 2002, 2006). Therefore, they are accountable for 4) the

welfare of the populations of the countries affected by the immediate consequences of their decisions. Table 4 displays ideas about the tools and methods available in LCA to meet the needs for social assessment at state level.

Table 4: Summary of the social impacts states claim to calculate

Nature of the assessed social impact	Target experiencing the impact	Suggestions for main tool or method (examples)
(1) Changes in health	National population	Calculation of the end-point impact "Human Health" by ELCA
(2) Changes in welfare (e.g. changes in poverty)	National population	No tool
(3) Changes in occupational health	Workers who are part of the life cycle	Changes revealed by occupational health data, by sector of the economy, as in the work of Hofstetter and Norris (2003)
(4) Changes in the welfare of foreign populations	The national population of each foreign partner, if it is a non-OECD country	Relationships between change in economic activity per capita and change in life expectancy, as in Norris's work (2006)

Changes in 1) the health of the national population caused by environmental issues can be assessed via ELCA again. Nothing has been done yet within the SLCA framework for 2) welfare or poverty in rich countries. Unfortunately, the conditions for the use of the Preston relationship first suggested by Norris (2006) (see 4.4.1.) forbid us to use it for rich countries like Finland (Pritchett and Viarengo, 2010; Feschet et al., 2012).

The changes in 3) occupational health could be assessed either via top-down methods, as in Hofstetter and Norris's work (2003) in terms of the human cost of work delivered, depending on the sector (palm oil versus forest material or algae oils), or via cumulative methods detailing several sources of potential harm entering the work environment (Antonsson and Carlsson, 1995; Kim and Hur, 2009), which use data at sector level.

As for changes in health within foreign populations 4), the relationship between changes in economic activities and life expectancy **in poor countries** may be predicted in line with Norris (2006) and followers.

The state is the richest level for SLCA methods, because it is the level where economic data (changes in the activity of product chains, recorded through changes in economic data) and social data cross. The main reason is historical: the recording of data has been organised at state level for many years. Nevertheless, there is no method available yet in LCA to assess the important issues of welfare changes, or changes in social status, caused by economics changes. Whilst all of the methods developed in social LCA should contribute to the assessment of the ‘human well-being’, no-one has fully reached this goal to date.

#### **4. Knowledge gaps and development needs of social LCA**

First we consider the gaps that are common to all levels, then specific gaps for each level.

##### **4.1: Knowledge gaps common to all levels**

Researchers assign life cycle thinking the purpose of preserving ‘areas of protection’, which are clearly defined in ELCA (Udo de Haes and Lindeijer, 2002; Jolliet et al., 2004; Bare and Gloria, 2008). In SLCA, Dreyer and colleagues (2006) suggest that the area to be protected is ‘human well-being and dignity’ and Weidema (2006) proposes ‘human well-being’, but the next theoretical or operational steps have not been addressed yet (Jeorgensen et al., 2008). The framework published by Reitingier and colleagues (2011) is noticeable progress. Nevertheless, it is worth suggesting alternative frameworks. Without a coherent framework of the theoretical roots of SLCA, each researcher is working on small pieces of the puzzle without a clear understanding of the place and importance of this piece in the global design.

Which people and groups are affected the most? It is quite impossible to consider the full catalogue of actors affected by a change, but we call for progress in how to identify those persons/groups most affected for each impact. So far, this has been done through hot-spot assessment (UNEP–SETAC, 2009); however, so-called hot spots identify only the cultural and institutional situations that are obviously different from the ones agreed upon by

occidental norms. We stress that “impacts on the worst-off members of the society should be a major consideration in all assessment.”(Vanclay, 2003, page 9). A great deal is still to be done.

In SLCA, the **use phase** has been acknowledged as so specific (Dreyer et al., 2006) that it demands a special approach that is still not clearly defined. Recent work (Wangel, 2012) has given new insights, but the task is not completed yet.

**How to define the system’s boundaries** in SLCA, and how to integrate ELCA and SLCA within the same framework are questions that need more attention (Reap et al., 2008). The UNEP–SETAC report (2009) expects more scientific evidence about whether boundaries in SLCA can be delineated as in ELCA. Recent work builds on the management science perspective (Lagarde and Macombe, 2012) in suggesting that the boundaries are not identical. Little attention has been paid to the **impact assessment step** (Jeorgensen et al., 2008). As we have noted above, Weidema (2006) suggests several relationships allowing prediction of the potential social effects of changes in value chains. To our knowledge, outputs from these ideas have not been published yet.

We have suggested several times the use of the impact pathway “human health” from ELCA. Nevertheless, the current tools available in LCA deliver results on the scale of a global world. No health impact affecting a target population (within one specific location) can be addressed. Several efforts are under way to improve the USEtox<sup>TM</sup> modelling by developing regional versions (Henderson et al., 2011). Indeed, the first purpose of USEtox<sup>TM</sup> was to gather and flesh out other models predicting intake fractions and human exposure (Bennett et al., 2002; Pennington et al., 2005) – but addressing human population as a whole.

We are missing direct access to well-ordered data for the use of SLCA. Furthermore, the three levels are not affected similarly.

#### 4.2. Knowledge gaps specific to the company level

Calculation of the health impacts on the relevant target – such as the local population affected by the company activity – is a new field of research.

Companies gather versatile datasets, monitoring elements that contribute directly to their performance. As noted above, adopting a life cycle spirit fits in with the angle of a ‘social planner’ (Heiskanen, 2002). It means paying attention to the changes **through the eyes of the society as a whole**. Monitoring what is happening inside the company is often done by monitoring social performances. But addressing impact is what assesses the contribution of the company’s activity for the society. One important part of companies’ social effects comes from the distribution of the new income. Indeed, two pathways for addressing this issue have already been suggested (Norris, 2006; Hutchins and Sutherland, 2008), starting with the added value created by the company. The same trend is seen in the most recent work (Feschet et al., 2012).

Beyond the health impacts directly caused by pollution, workers are liable to experience changes in health effects because of changes in workplace conditions (e.g., stress) in the bioenergy industries. Weidema (2006) suggests building on the scientific work done by Siegrist (1996). Doing so would provide new assessment methods at company scale, taking as their starting point identified groups of workers at risk of health detriments caused by the work organisation. This work is in progress and not yet published.

#### 4.3. Knowledge gaps specific to the regional level

There is a fundamental lack of organised social data at regional level. Often, official data refer only to the national domain, but finer spatial granularity would be required. Many social data are available at regional level. For instance, local government agencies often monitor social

exclusion or deprivation. Developing models to use and to articulate these data<sup>4</sup> would aid in the filling of the gaps.

Changes in the well-being of the population at regional level have not been addressed in SLCA yet. Scientific work (Wilkinson and Pickett, 2010) argues that most social issues depend on income inequality, especially in wealthy countries. On this assumption, one could assess the effects of the changes in biomass supply based on the decreases or increases in income inequality within the region. For all three scenarios, one could compare the changes in terms of inequality effect. To our knowledge, this has not been done within LCA framework yet.

Workers are not exposed to the same health risks when working in the forest as opposed to algae ponds. We have suggested using occupational health data, but this may turn out to be infeasible because of lack of accurate data. Another method could be built thanks to data from the European Agency for Safety and Health at Work (2009). They highlight that different sectors (e.g., agriculture or forestry) run different risks of stress, and thereby harm to workers' health, because of the features specific to the work. It would be possible to downscale these national data to the region. Moreover, one can predict risk for still unknown sectors by using the data from a sector wherein the work conditions are quite similar (applying data from market gardening to algae cultivation, for instance).

#### 4.4. Knowledge gaps specific to state level

The state level has been the most advanced in collection of official data. Nevertheless, each country develops its national accounts on its own. Designing a dynamic world input–output database<sup>5</sup> is of the utmost importance for the analysis of international interactions.

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<sup>4</sup> As in the European project SAMPLE; see <http://www.sample-project.eu/>.

<sup>5</sup> This is the purpose of the ongoing European project WIOD, funded by the 7th Framework Programme.

We separate our discussion of knowledge gaps into existing methods that should be improved (4.4.1.) and methods that must be built from scratch (4.4.2.).

#### 4.4.1. Existing methods for improvement

Work conditions are not the same for the workers in the three value chains corresponding to the three scenarios. Indonesian farmers or agricultural labourers on palm plantations are not exposed to the same conditions as Finnish wood workers, or future Finnish algae-growers. Hofstetter and Norris's (2003) method could be developed to assess the human cost of choosing one scenario instead of another. The method presented at the end of the paragraph 4.3. would be of great value at the state level.

We have referred several times to Norris's (2006) idea of accounting the improvement in the average life expectancy of foreign poor populations based on the incomes generated locally. Generalisation of this work to all poor countries is under way (Feschet et al., 2012), but it can not be used for rich countries. There are many tools to account for the past evolution of welfare or poverty within one given rich country. In general, each country designs its own set of indicators, and monitors their evolution. Nevertheless, to our knowledge, there is no model for predicting the changes in health caused by the economic activity generated by life cycles in rich countries. Recent work is under way, but not published yet.

#### 4.4.2. Methods to be built

Weidema's paper (2006) suggests some ways of calculating the differences among the three scenarios in terms of occupational health, but these have not been implemented at state level yet.

As previously shown, a major impact of interest is the change in welfare of the national population caused by the changes in biomass supply. The use phase would be technically the



same whatever the source of biomass, but transition to wood or algae biomass could be harmful for inhabitants' real income in the short term (due to price rises). The issue of poverty is especially relevant at state level when biomass supply choice is concerned. Indeed, on one hand, the basic price of biodiesel generated from a wood or algae supply, instead of imported palm oil, would likely increase. On the other hand, creating numerous local jobs in wood and/or algae industries would probably improve the status of the most vulnerable people. The transition to domestically handled biomass supplies could be an opportunity for partially redistributing wealth through the population.

Moreover, other changes in well-being may occur in areas such as sense of security (because the supply of wood or algae would be localised within the country itself) or pride (in mastery of new green technologies). So far, these impacts have been predicted in qualitative assessment only.

#### 4.5. Dealing with the combinations of levels

Studies conducted along SLCA lines are obviously different at the three levels considered, in both the boundaries of the system under scrutiny and the way of calculating the impacts taken into consideration. Even if interest in health and well-being is expressed at every level, the target groups are different.

Moreover, each level of entity may demand other specific assessment of the social impacts of changes. Indeed, a company might speak for the result of changes made in the biomass supply in terms of literacy or empowerment of local people. Regions might be sensitive to one particular local concern such as the social link between inhabitants. States are often willing to increase feelings of confidence among their residents. Nevertheless, these levels may overlap. Regions and states may share the same attention to social issues linked with governance. Some multinational companies reach the same power, and have the same preoccupations as certain states. Even if the levels overlap because they share interest in a certain impact, the

data and the methods available are still level-specific. They must be carefully scaled up or down in order to be useful at different levels.

## 5. Discussion

Proceeding from the findings in the literature review, we conclude that performing a comprehensive SLCA in the sense defined here is not possible yet. Only the part of SLCA stemming from social performance assessment is correctly addressed to date. The best that researchers can do is to suggest and deliver conceptual parts of the method, such as the general theoretical framework, the rules for setting the boundaries, or the definition of one impact pathway associated with partial case studies. We need five or ten years before having a full impact assessment method. In the meantime, practitioners implement other techniques (addressed in Subsection 5.1). Expert knowledge may be useful for the designing of pathways when no other source is available (explored in Subsection 5.2). Even when fully developed, SLCA will not fill all the gaps (an issue covered in Subsection 5.3). We return, in conclusion, to the implementation of the bioenergy case and to what we have learnt about it (Subsection 5.4).

### 5.1. What to do now, before the full social LCA method is completed?

With respect to the part of social LCA methods estimating potential consequences of changes, work is still in its early stages. Because **logos** (science) is so weak here, companies, regions, and states are often forced to resort to **ethos** (guiding beliefs) or **nomos** (elaborating law). Because of the demand in societies, it is not possible to wait for scientifically comprehensive SLCA impact assessment methods to be fully developed. In general, practitioners use other approaches, gathering information from some stakeholders involved in the product chain. Such methods are close to “life cycle attribute assessment” (Norris, 2006; Andrews et al.,

2009; Parent, 2010). They may help companies, regions, and states to make more informed choices, especially when implemented within genuine participatory approaches. For instance, they could be useful if one is 'on the fence' between algae and forest shares in the supply. They do not calculate social impacts, they describe 'social performances'. Obviously, decision-makers must be very cautious when interpreting the results, and when implementing related measures. For instance, Jeorgensen et al. (2010b) highlighted that eradicating child labour (in order to improve the corresponding social performance indicators) might lead to a worse situation for children and their families.

### 5.2. How to use expert knowledge to design new pathways?

**Nomos** may be a source of valuable knowledge for designing new pathways. For any given case study, the idea is to use modelling of expertise (see, for example, the work of Kangas and Leskinen (2005) for an example of modelling of ecological expertise). In this approach, the rationale would be to ask experts to assess the difference in social merits between certain production chains in cases wherein no well-established databases are available. Experts may have substantial knowledge of the impacts. Also, the methodological approaches discussed by Kangas and Leskinen (ibid.) enable elicitation and assessment of the uncertainties involved (see also Mattila et al., 2012), which would be important in view of the nature of the information. The next stage is to generalise the new pathway, designed by experts, to as many cases as possible.

### 5.3. The knowledge gaps social LCA can never close

Even after all of these knowledge gaps are closed, numerous limits of social LCA tools will remain. First, SLCA can never deal with **all** the social effects of changes within product life cycles. We will end up with only a few of the methods we would need for a comprehensive assessment. Moreover, there are always unpredictable effects at different points in time. The

purpose of SLCA lies in considering the most important effects at short and mid-term horizons, while it is impossible to tackle the whole. Second, some effects (such as the above-mentioned feeling of security) seem unpredictable by quantitative assessment. Indeed, impact is the result of one effect meeting one fertile breeding ground for it. Quantitative assessment requires generalisation, which seems difficult when the social impacts resulting from the same change vary hugely from one country to another (e.g., feeling of security, confidence etc.). In contrast, the health status of a population improves when people's income rises, regardless of the country, provided that it is a poor one (Pritchett and Viarengo, 2010). That is why the first focus in the search for pathways should be on relationships whose potential for generalisation is high. Third, welfare often has more to do with state action and culture's evolution than with product chains. Predicting the absolute improvement in real welfare status as a whole seems beyond the reach of SLCA. SLCA can predict the differences in potential welfare status caused by changes in value chains, **ceteris paribus**. Fourth, the quality of data is often low or unknown. In SLCA, data provide clues about the order of magnitude and about trends in evolution. We would be going too far if claiming that the SLCA outputs might be 'the truth'. In fact, SLCA will help us to rank alternative scenarios set in the same general context from worst to best, but it will never be able to assess how 'good' one scenario is per se.

## 6. Conclusion

Our examples of production chains involve biodiesel production based on different raw materials. One important observation about the raw materials is that algae is mono-functional as a raw material but forests are essentially multifunctional. In other words, algae in ponds is produced for oil but forest resources can be used for pulp/paper, sawn timber, heating and electricity, recreation, mushroom- and berry-picking etc., in addition to biodiesel production. When comparing the social impacts of algae to those of forest-biomass-based production, we

could also argue for a much larger set of social indicators than was discussed in this paper, for proper measurement of the multifunctionality elements related to forest-biomass-based biodiesel production. For example, Leskinen and colleagues (2012) use diverse criteria to address social (as well as cultural, economic, and environmental) performances of certain forest-biomass-based production chains. Their work was based on appropriate indicators defined by experts, stakeholders, and local citizens. In fact, comparing single- and multi-function systems would require looking at the list of services provided in parallel with the list of impacts, as in the emergent life cycle assessment of territories (Loiseau et al., 2012).

Also, the combination of SLCA and ELCA results may create some scientific problems. In general, multi-criteria decision analysis techniques (e.g., Myllyviita et al., 2012) can provide a methodological framework for combination of SLCA with ELCA, but, for instance, the role of the functional unit should be still clarified.

This paper has outlined several issues of methodological development that SLCA researchers are handling today or could tackle in the future. Because of the sheer breadth of the topic at hand, we have presented only a rough draft-level design for this new knowledge field. Nonetheless, we expect it to be of help to researchers for positioning themselves in the field and being aware of the recent scientific work in this area.

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## References

- Andrews, E., Lesage, P., Benoît, C., Parent, J., Norris, G., Revéret, J.-P., 2009. Life cycle attribute assessment: Case study of Quebec greenhouse tomatoes. *J. Ind. Ecol.* 13 (4), 565–578.
- Antonsson, A.-B., Carlsson, H., 1995. The basis for a method to integrate work environment in life cycle assessments. *J. Clean. Prod.* 3 (4), 215–220.
- Bare, J.C., Gloria, T.P., 2008. Environmental impact assessment taxonomy providing comprehensive coverage of midpoints, endpoints, damages, and areas of protection. *J. Clean. Prod.* 16 (10), 1021–1035.
- Becker, H.A., Vanclay, F., 2003. *The International Handbook of Social Impact Assessment: Conceptual and Methodological Advances*. Edward Elgar Publishing, Sheltenham (UK).
- Bennett, D.H., Margni, M.D., McKone, T.E., Jolliet, O., 2002. Intake fraction for multimedia pollutants: A tool for life cycle analysis and comparative risk assessment. *Risk Anal.* 22, 905–918.
- Benoît, C., Norris, G.A., Valdivia, S., Citroth, A., Moberg, A., Bos, U., Prakash, S., Ugaya, C., Beck, T., 2010. The guidelines for social life cycle assessment of products: Just in time! *Int. J. Life Cycle Assess.* 15, 156–163.
- COM European Strategy for sustainable development (COM/2001/064). Towards a global partnership for sustainable development (COM/2002/82). Review of the EU Sustainable Development Strategy (EU SDS) – Renewed Strategy (10917/06).
- Domac, J., Richards, K., Risovic, S., 2005. Socio-economic drivers in implementing bioenergy projects. *Biomass Bioenerg.* 28 (2), 97–106.
- Dreyer, L.C., Hauschild, M.Z., Schierbeck, J., 2006. A framework for social life cycle impact assessment. *Int. J. Life Cycle Assess.* 11 (2), 88–97.
- Dreyer, L.C., Hauschild, M.Z., Schierbeck, J., 2010. Characterisation of social impacts in LCA Part 1: Development of indicators for labour rights. *Int. J. Life Cycle Assess.* 15, 247–259.
- Heiskanen, E., 2002. The institutional logic of life cycle thinking. *J. Clean. Prod.* 10, 427–437.
- Elghali, L., Clift, R., Sinclair, P., Panoutsou, C., Bauen, A., 2007. Developing a sustainability framework for the assessment of bioenergy systems. *Energ. Policy* 35, 6075–6083.
- Ericsson, K., Nilsson, L.J., 2006. Assessment of the potential biomass supply in Europe using a resource-focused approach. *Biomass Bioenerg.* 30, 1–15.
- European Agency for Safety and Health at Work, 2009. OSH in figures: Stress at work – facts and figures. European Risk Observatory Report no. 9. Office for Official Publications of the European Community, Luxembourg.

Feschet, P., Macombe, C., Garrabé, M., Loeillet, D., Benhmad, F., Rolo Saez, A., 2012. Social impact assessment in LCA using the Preston Pathway- The case of banana industry in Cameroon, *Int. J. Life Cycle Assess.* 2012, DOI: 10.1007/s11367-012-0490-z

Henderson, A.D., Hauschild, M.Z., van de Meent, D., Huijbregts, M.A.J., Larsen, H.F., Margni, M., McKone, T.E., Payet, J., Rosenbaum, K., Jolliet, O., 2011. USEtox fate and ecotoxicity factors for comparative assessment of toxic emissions in life cycle analysis: Sensitivity to key chemical properties. *Int. J. Life Cycle Assess.* 16, 701–709.

Hofstetter, P., Norris, G.A., 2003. Why and how should we assess occupational health impacts in integrated product policy? *Environ. Sci. Tech.* 37 (10), 2025–2035.

Hunkeler, D., 2006. Societal LCA methodology and case study. *Int. J. Life Cycle Assess.* 11 (6), 371–382.

Hutchins, M.J., Sutherland, J.W., 2008. An exploration of measures of social sustainability and their application to supply chain decisions. *J. Clean. Prod.* 16 (15), 1688–1698.

Jeorgensen, A., Finkbeiner, M., Jeorgensen, M., Hauschild, M.Z., 2010a. Defining the baseline in social life cycle assessment. *Int. J. Life Cycle Assess.* 15, 376–384.

Jørgensen A., Lai L.C.H., Hauschild M.Z. 2010b, Assessing the validity of impact pathways for child labour and well-being in social life cycle assessment *Int J Life Cycle Assess* (2010) 15:5–16

Jeorgensen, A., Le Bocq, A., Nazarkina, L., Hauschild, M., 2008. Methodologies for social life cycle assessment. *Int. J. Life Cycle Assess.* 13 (2), 96–103.

Jolliet, O., Müller-Wenk, R., Bare, J., Brent, A., Goedkoop, M., Heijungs, R., Itsubo, N., Pena, C., Pennington, D., Potting, J., Rebitzer, G., Stewart, M., Udo de Haes, H., Weidema, B., 2004. The LCIA midpoint-damage framework of the UNEP/SETAC Life Cycle Initiative. *Int. J. Life Cycle Assess.* 9 (6), 394–404.

Kangas, J., Leskinen, P., 2005. Modelling ecological expertise for forest planning calculations – rationale, examples, and pitfalls. *J. Environ. Manag.* 76, 125–133.

Kim, I., Hur, T., 2009. Integration of working environment into life cycle assessment framework. *Int. J. Life Cycle Assess.* 14, 290–301.

Kruse, S.A., Flysjö, A., Kasperczyk, N., 2009. Socioeconomic indicators as a complement to life cycle assessment – an application to salmon production systems. *Int. J. Life Cycle Assess.* 14, 8–18.

Labuschagne, C., Brent, A.C., 2006. Social indicators for sustainable project and technology life cycle management in the process industry. *Int. J. Life Cycle Assess.* 11 (1), 3–15.

Lagarde, V., Macombe, C., 2012. Designing the social life cycle of products from the systematic competitive model, *Int. J. Life Cycle Assess.* DOI 10.1007/s11367-012-0448-1.



Leskinen, P., Kähkönen, T., Lähtinen, K., Pasanen, K., Pitkänen, S., Sironen, S., Myllyviita, T., Sikanen, L., Asikainen, A., 2012. Moniulotteinen kestävyuden arviointikehikko puuenergian tuotannolle. *Suomen Ympäristö* 9. 145 p.

Loiseau, E., Junqua, G., Roux, P., Bellon-Maurel, V., 2012. Environmental assessment of a territory – an overview of existing tools and methods. *J. Environ. Manag.* DOI 10.1016/j.jenvman.2012.07.024

Mattila, T., Leskinen, P., Soimakallio, S., Sironen, S., 2012. Uncertainty in environmentally conscious decision-making: Beer or wine? *Int. J. Life Cycle Assess.* 17: 696-705.

Myllyviita, T., Holma, A., Antikainen, R., Lähtinen, K., Leskinen, P., 2012. Assessing environmental impacts of biomass production chains – application of life cycle assessment (LCA) and multi-criteria decision analysis (MCDA). *J. Clean. Prod.* 29–30, 238–245.

Norris, G.A., 2006. Social impacts in product life cycles: Towards life cycle attribute assessment. *Int. J. Life Cycle Assess.* special issue 1, 97–104.

Parent, J., Cucuzzella, C., Revéret, J.-P., 2010. Impact assessment in SLCA: Sorting the sLCIA methods according to their outcomes. *Int. J. Life Cycle Assess.* 15, 164–171.

Pennington, D.W., Margni, M., Ammann, C., Jolliet, O., 2005. Multimedia fate and human intake modelling: Spatial versus non-spatial insights for chemical emissions in Western Europe. *Environ. Sci. Technol.* 39 (4), 1119–1128.

Pritchett, L., Viarengo, M., 2010. Explaining the cross-national time series variation in life expectancy: Income, women's education, shifts and what else? UNDP, Human Development Research Paper 2010/31.

Reap, J., Roman, F., Duncan, S., Bras, B., 2008. A survey of unresolved problems in life cycle assessment. *Int. J. Life Cycle Assess.* 13, 290–300.

Reitinger, C., Dumke, M., Barosevcic, M., Hillerbrand, R., 2011. A conceptual framework for impact assessment within SLCA. *Int. J. Life Cycle Assess.* 16, 380–388.

Schmidt, I., Meurer, M., Saling, P., Kicherer, A., Reuter, W., Gensch, C.-O., 2004. SEEbalance<sup>®</sup> – managing sustainability of products and processes with the socio-eco-efficiency analysis by BASF. Greener Management International, BASF.

Sen, A., 2003. *Un nouveau modèle économique: Développement, Justice, Liberté.* Odile Jacob, Paris.

Siegrist, J., 1996. Adverse health effects of high effort – low reward conditions at work. *J. Occup. Health Psychol.* 1, 27–43.

Spriensma, R., Goedkoop, M., 2001. *The Eco-Indicator 99: A damage oriented method for life cycle impact assessment, methodology report.* Ministerie van Volkshuisvesting, report 1999/36A, PRé Consultants, Amersfoort, Netherlands.



Udo de Haes, H.A., Lindeijer, E., 2002. The conceptual structure of life cycle impact assessment. In: Udo de Haes et al. (eds), *Life Cycle Impact Assessment: Striving Towards Best Practice*. Society of Environmental Toxicology and Chemistry (SETAC), Pensacola, Florida (US), pp. 103–119.

UNEP–SETAC 2009. *Guidelines for Social Life Cycle Assessment of Products*. UNEP, Paris.

Vanclay, F., 2002. Conceptualising social impacts. *Environ. Impact Assess. Rev.* 22, 183–211.

Vanclay, F., 2003. International Principles For Social Impact Assessment, *Impact Assessment and Project Appraisal*, 21:1, 5-12

Wangel A. , 2012. Identifying social impacts in use phase scenarios: The school lunch, SETAC 18<sup>th</sup> Life Cycle Assessment Case Study Symposium & 4<sup>th</sup> NorLCA Symposium, 26<sup>th</sup>-28<sup>th</sup> November 2012, Copenhagen

Weidema, B., 2006. The integration of economic and social aspects in life cycle impact assessment. *Int. J. Life Cycle Assess.* 11, special issue 1, 89–96.

Wilkinson, R., Pickett, K., 2010. *The Spirit Level :Why Equality is Better for Everyone*. Penguin Books, London (UK)

#### Table of footnotes

<sup>1</sup> <i>They may be related to the functional unit, they may be quantified at each step in the chain, and they are additive along the chain.</i>
<sup>2</sup> <i>Alongside longevity and non-fatal impacts on human health, Weidema (2006) suggests the following end-point impacts: ‘autonomy’, ‘safety, security, tranquillity’, ‘equal opportunity’, and ‘participation and influence’.</i>
<sup>3</sup> <i>Description of the cultivation of algae and other steps may be found in this issue, on pages <del>XX–YY</del>.</i>
<sup>4</sup> <i>As in the European project SAMPLE; see <a href="http://www.sample-project.eu/">http://www.sample-project.eu/</a>.</i>
<sup>5</sup> <i>This is the purpose of the ongoing European project WIOD, funded by the 7th Framework Programme.</i>