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REVIEW

'Socializing' sustainability: a critical review on current development status of social life cycle impact assessment method

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Abstract Social life cycle assessment (S-LCA) is a technique to assess the potential social impacts of a product or service caused by its life cycle. The aim of this paper is to critically review the methodologies applied in S-LCIA and establish its current development status by highlighting areas for improvement. The UNEP/SETAC Guidelines published in 2009 provided general procedures for conducting S-LCA, but lack S-LCIA methods. Many new S-LCIA methods have been proposed but these are inherently different, indicating a scientific and well-accepted S-LCIA method is yet to be developed. Broadly, two types of S-LCIA methods, i.e. performance reference point and impact pathways methods are in use. A direction for future research could be the refinement of the social hotspots database and the social hotspot index calculation method. Moreover, the S-LCIA method could be developed by combining the performance reference point and impact pathways methods.

Keywords Social life cycle assessment · Life cycle sustainability assessment · Social impact assessment · Social hotspots

Introduction

Sustainable development and sustainability are ideas that have been widely used since the 1980s in response to the negative impacts of development, policies, and strategies on the environment and society (UNEP/SETAC 2011; Turcu 2013; Fiksel et al. 2014). Sustainability has three main pillars, namely environment, economic and social (Valdivia et al. 2011), which are referred to as the triple-bottom-line (TBL) (Sikdar 2007; Vinodh et al. 2012). Integrating life cycle thinking in product or process development with the TBL approach challenges the conventional waste management and pollution prevention mindset that mainly focuses on the factory site (UNEP/SETAC 2011). This new perspective avoids shifting the problem from one phase to another and from one geography to another (UNEP/SETAC 2009). This integrated approach is referred to as life cycle sustainability assessment (LCSA) (UNEP/SETAC 2011). LCSA is "the evaluation of all environmental, social, and economic negative impacts and benefits in decision-making processes towards more sustainable products throughout their life cycle" (UNEP/SETAC 2011). It has three components: environmental life cycle assessment (E-LCA), economic life cycle assessment (i.e. life cycle costing, LCC), and social life cycle assessment (S-LCA) (Klopffer 2003; UNEP/SETAC 2011). Among these three aspects of LCSA, S-LCA is newer and is the least developed (Klopffer 2003; Jørgensen et al. 2008; Macombe et al. 2013). S-LCA gives an additional value to sustainability assessment by measuring its social dimension (UNEP/SETAC 2009).

A social and socio-economic life cycle assessment, or simply social LCA, is a technique that assesses the potential social impacts of a product or service caused by its life cycle. The life cycle includes the phases from material extraction and manufacturing to end-of-life phases. The social impacts are mainly on human capital, human well-being, cultural heritage, socio-economy and social behaviour (Weidema 2006; UNEP/SETAC 2009). Social LCA refers to the assessment of the real and

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potential social and socio-economic impacts of products or services including positive and negative impacts along their life cycle (UNEP/SETAC 2009; Dreyer et al. 2010a; Feschet et al. 2012). Historically, the LCA approach was introduced in the late 1960s (Paragahawewa et al. 2009), whereas the S-LCA was introduced in 1993 with the initiation of the Society of Environmental Toxicology and Chemistry (SETAC) Workshop (Benoît et al. 2010). Therefore, S-LCA is relatively young as compared to LCA.

S-LCA complements both E-LCA and LCC in terms of sustainability assessment (UNEP/SETAC 2009). S-LCA has similar applications to E-LCA, such as sustainability labelling, sustainability management and assessment of technology alternatives considering social aspects. In S-LCA, the Area of Protection (AOP) is human dignity and well-being (Hauschild et al. 2008). More specifically, the AOP is autonomy, well-being-freedom, and fairness based on a capability approach (Reitinger et al. 2011). The ultimate goal of S-LCA is the well-being of stakeholders over a product's life cycle (UNEP/SETAC 2009). Jørgensen (2012) argues that S-LCA should support decision making that improves social impacts in a product's life and should give alternatives. This article aims to review the methods applied in social LCIA and establish its current development status by highlighting general shortcomings.

Social life cycle assessment framework

Similar to E-LCA, the general framework for S-LCA consists of four steps, i.e. goal and scope definition, inventory analysis, impact assessment and interpretation as indicated by ISO 14040/14044 (ISO 2006a, b). The framework is also endorsed by UNEP/SETAC Life Cycle Initiative taskforce (Grießhammer et al. 2006) and UNEP/SETAC Guidelines (UNEP/SETAC 2009). The UNEP/SETAC Guidelines for conducting the social LCA of products were published after a five-year effort, including several stakeholder consultations and review (Benoît et al. 2010). The Guidelines are a methodological guide for practitioners conducting S-LCA. The UNEP/SETAC Guidelines are supported by the methodological sheets comprised of indicators for guiding data collection (Benoît-Norris et al. 2011; Parent et al. 2010; UNEP/SETAC 2013). The steps for conducting S-LCA are as follows (UNEP/SETAC 2009):

(a) *Goal and scope definition* The objectives and scope of the study include functional unit, system boundary, activity variables, unit processes, impact categories, subcategories, stakeholders' identification, social life cycle impact assessment methods and assumptions.

(b) *Life cycle inventory analysis* This step includes life cycle data collection on activity variables and used for prioritization, hotspots assessment, site-specific evaluation and impact assessment. Occasionally, new issues may be identified that could require the modification of the goal and scope of the study.

(c) *Life cycle impact assessment* The life cycle inventory results are first classified into social impact categories and subcategories (referred to as classification) and then calculated for the subcategory indicators or endpoints (referred to as characterization). Data validation and characterization are important components of S-LCIA. Both the positive and negative impacts of a product life cycle are included.

(d) *Life cycle interpretation* The results of life cycle impact assessment and life cycle inventory analysis are evaluated together in order to identify significant issues. Finally, conclusions are drawn in relation to the defined goal and scope.

Methodology

This comprehensive review is mainly based on peer-reviewed journal articles; however, to some extent it also encompasses important conference proceedings and reports. S-LCIA methodologies and case studies were critically reviewed. The relevant literature was searched using keywords, through online databases, web-based scientific search engines and an electronic library till October 2013. Several researchers have used keywords for searching the literature for critical reviews (Jørgensen et al. 2008; Jørgensen 2012; Yi and Chan 2013; Kabir et al. 2013). The appropriate documents were selected based on the following methods:

(i) *Journal articles* The majority of the scholarly articles were obtained through Web of Knowledge (WOK) databases. WOK has indexed 18,711 journal titles including the areas of the sciences, the social sciences and the arts and humanities (Reuters, 2013). This range of subject areas suits the interdisciplinary nature of S-LCA. The keywords "social life cycle assessment", "social LCA", "societal life cycle assessment", and "SLCA" were used alternatively in "topic" and "title" field for the search. When the keyword "social life cycle assessment" was used as the topic, 38 articles were found but only 28 were related to S-LCA; "social LCA" resulted in 26 articles, of which 17 were related to S-LCA; "societal life cycle assessment" resulted in 4

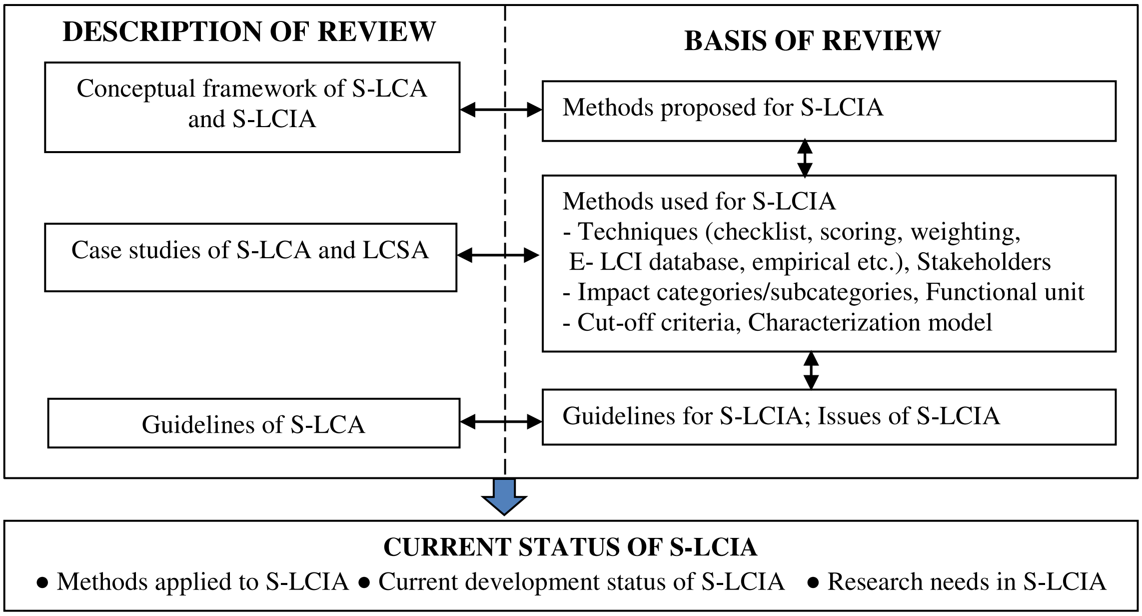

Fig. 1 Basis of critical review of S-LCIA literature (modified from Haider et al. 2013)

articles, of which 2 were related to S-LCA. In addition, using the same keywords in "title" field returned mostly the same articles but reduced the number of articles. Similar keywords were used for the search in SCOPUS and "Compendex Engineering Village" databases. The resulting articles were mostly similar. Moreover, because the S-LCA may be conducted as a part of LCSA (UNEP/SETAC 2011), an additional search with a keyword "life cycle sustainability assessment" was performed, which resulted in 22 articles in WOK. Among these articles, 7 had a content related to S-LCA. Also, the websites http://www.sciencedirect.com and http://www.springer.com were used for an additional search. The selected articles were further screened based on the information taken from the abstract in order to select the articles having the identified key areas.

(ii) *Web-based search engine and electronic library* The web-based search engine http://scholar.google.ca/ and the electronic library of the University of British Columbia, Canada were searched using the following keywords: "social life cycle assessment," "social LCA", "societal life cycle assessment", "SLCA", "life cycle sustainability assessment", and "Guidelines for social LCA". Conference proceedings, reports and books related to S-LCA were obtained from these searches.

The literature selected by above procedures were reviewed based on the methods used for S-LCIA that incudes techniques for assessing social impacts (checklist, scoring, weighting, E-LCI database, empirical etc.), impact categories/subcategories, stakeholders considered, functional unit, and cut-off criteria as shown in Fig. 1. These documents were reviewed in order to identify the S-LCIA methods applied, current development status and research needs.

Social life cycle impact assessment

Although studies of S-LCA started in the early 1990s, there was very limited published literature on this subject prior to the publication of the UNEP/SETAC Guidelines in 2009. The S-LCA framework given by UNEP/SETAC Guidelines included five stakeholder categories (*workers, local community, society, consumers* and *value chain actors*), six impact categories with 31 subcategories; inventory analysis; and impact assessment (UNEP/SETAC 2009). The categories identified were *human rights, working conditions, health and safety, cultural heritage, governance* and *socio-economic repercussions*. The stakeholder categories workers, local community, society, value chain actors and consumers have 8, 11, 3, 4 and 5 subcategories, respectively (UNEP/SETAC 2009). These subcategories are characterized using a more than 100 inventory indicators identified in a separate publication "The methodological sheets for subcategories in social life cycle assessment" (UNEP/SETAC 2013). Many S-LCA researchers used these Guidelines after their publication. However, because the Guidelines lack specific impact assessment methodology, the researchers have used various methods for

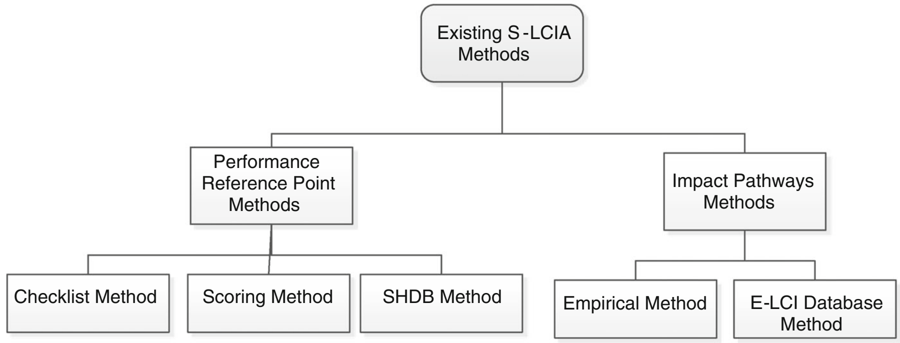

Fig. 2 Existing S-LCIA methods

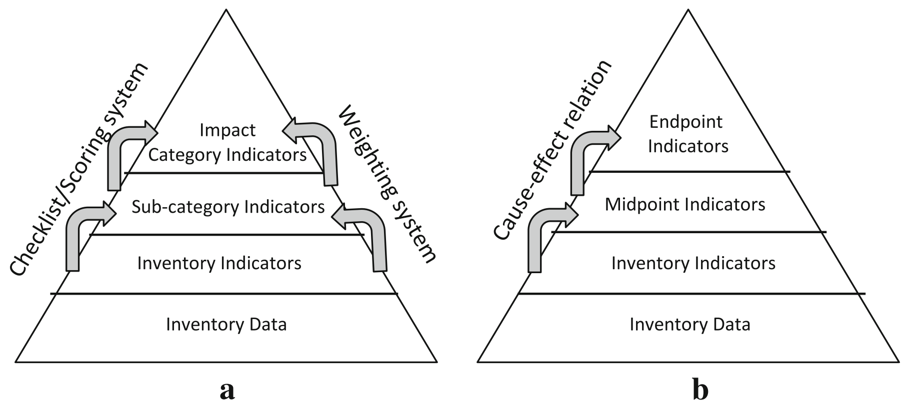

Fig. 3 **a** Performance reference point based. **b** Impact pathways-based S-LCIA mechanism (modified from UNEP/SETAC 2009)

S-LCIA. The existing S-LCIA methods can be classified into two broad categories: performance reference point and impact pathways methods. These categories can be further divided into subcategories as shown in Fig. 2 and described below.

Performance reference point methods

Performance reference point methods assess social impacts using performance reference points based on internationally accepted minimum performance levels such as ILO[1] conventions, the ISO 26000 guidelines, and OECD[2] Guidelines for Multinational Enterprises (Parent et al. 2010). The methods use colour coding, scoring and a weighting system for aggregating the inventory indicator data to impact categories (e.g. human rights). They can aggregate qualitative and quantitative indicators. These methods do not use cause-effect chains because the authors believe that "cause-effect relationships are not simple enough or not known with enough precision to allow quantitative cause-effect modelling" (UNEP/SETAC 2009). These methods are included as Type 1 impact assessment by UNEP/SETAC Guidelines (Parent et al. 2010). The mechanism of impact assessment in these methods is shown in Fig. 3a.

Impact pathways methods

Impact pathways methods assess the social impacts of a product system using impact pathways as characterization models comprised of midpoint[3] indicators and/or endpoint[4] indicators similar to environmental LCA (Parent et al. 2010). These methods are based on social effects and use cause-effect chains to estimate the impacts. These methods are mostly based on quantitative indicators. They are included in Type 2 impact assessment by UNEP/SETAC Guidelines (Parent et al. 2010). The mechanism of impact assessment in these methods is shown in Fig. 3b.

The S-LCIA methods reviewed are explained in the following sections—performance reference point and impact pathways methods.

[1] International Labour Organisation.

[2] Organisation for Economic Co-operation and Development.

[3] The point that lies somewhere on the impact pathway as an intermediate point between the LCI results and the damage or end of the pathways.

[4] The attribute or aspect of natural environment, human health, or resources, identifying an environmental issue giving cause for concern or damage categories.

Performance reference point methods

Many S-LCA researchers have applied performance reference point methods in assessing social impacts as a part of S-LCA. However, they followed different techniques for impact assessment, which are broadly classified as checklist, scoring and Social Hotspots Database (SHDB) methods. The SHDB method also uses scores, but these scores are predefined as a part of a larger SHDB system.

Checklist method

The checklist based impact assessment method uses the tick (√) sign against the presence of an impact. It assesses an impact in terms of the presence or absence only. For instance, Franze and Ciroth (2011) compared the social life cycle impacts of roses from Ecuador and the Netherlands. They developed a new checklist method for impact assessment, although in general it followed the UNEP/SETAC Guidelines for S-LCA. At first, the influence of the stakeholder subcategory on the impact category was assessed using a tick (√) if it influenced the impact category, a dash (-) if it did not influence the impact category or left blank if it was not applicable. Then, the overall social impact for each subcategory was assessed using a simple colour system composed of five different colours (green to red or varying shades), representing positive, indifferent, lightly negative, negative and very negative effects. However, the applied method does not have a feature to express the overall social impacts of a stakeholder category by combining their subcategories.

Scoring methods

The scoring based impact assessment methods use scores to assess an impact. These methods allow a researcher to indicate a level of impact. Several researchers have developed their own scoring methods. The major studies that used the scoring system for S-LCIA are discussed below.

(Dreyer et al. 2010a, b) developed a scoring based characterization model using multi-criteria indicators for S-LCIA and this model was applied to six companies. They modelled labour rights covering the following impact categories (i.e. subcategories in the terminology of the UNEP/SETAC Guidelines): forced labour, child labour, discrimination and freedom of association and collective bargaining. Their model was based on a scorecard that contained several social impact categories. The management efforts of companies were scored and then translated into an aggregated performance score. The performance score was multiplied by a contextual adjustment score resulting in a company risk score, which represents the risk of labour rights violations occurring. The contextual adjustment score reflects the risk of violation in terms of geographical location and industrial sector/branch. The company risk score was interpreted as very high, high, high to medium, medium and low risk, respectively, for >0.9–1.0; >0.6–0.9; >0.4–0.6; >0.2–0.4; and >0–0.2 (Dreyer et al. 2010a). In addition, the risk of a particular product of a company, referred to as the *product risk score*, can also be calculated by multiplying the company risk (CR) score and product relation factor.[5] The inclusion of the geographical setting and industrial sector context in impact assessment is an important social dimension and is new in the model. However, the methodology proposed is mostly suitable for large traditional industries mainly employing blue-collar workers (Dreyer et al. 2010b) and considered only workers. Similarly, Traverso et al. (2012) assessed the social impacts of photovoltaic (PV) modules on the workers stakeholder category, considering discrimination, child labour, wages, working hours, social benefits, and health conditions as a part of LCSA. The study simply compared these subcategories (impact) among three PV modules based on the number of male and female workers, disabled workers, holidays, work shift, working hours, family benefits, average wage for male and female workers and minimum wage for a worker. However, the study considered social impacts of PV modules only at the manufacturing stage and only on the workers stakeholder category in the supply chain.

On the other hand, Ciroth and Franze (2011) considered many stakeholder categories and developed their own scoring based method for S-LCIA. They applied their method to a complex product, an Ecolabeled Notebook namely an ASUSTeK laptop. In their approach, they used a colour code that was transferred into the numerical values using the assigned factors. They used six performance levels: very good, good, satisfactory, inadequate, poor and very poor performance levels and six impact levels: positive, lightly positive, indifferent, lightly negative, negative and very negative effect levels. Each of these six levels was assigned a colour dark green, light green, bluish green, yellow, orange and red and a factor 1, 2, 3, 4, 5 and 6, respectively. Each subcategory of a stakeholder was assessed twice, i.e. for the performance of a company and the impacts of the company. The resulting score for each stakeholder category was the average of the assigned values of its subcategories (Ciroth and Franze 2011). In this method, all subcategories are given equal importance, although all subcategories and stakeholders may not be equal in relevance.

Ekener-Petersen and Finnveden (2013a) included the quantity of production (activity) in impact assessment

[5] Refer to (Dreyer et al. 2010a, b) for detailed calculation steps.

based on a laptop case study. In this method, the total activity in every phase of a product's life cycle was distributed among different participating countries, which were then categorized into the groups: *very large activity, large activity, moderate activity*, and *other countries* based on the degree of activity. On the other hand, the values of each indicator of the subcategories lying in the highest quartile range and second highest quartile range among the countries were marked as *severe impacts* and *quite severe impacts,* respectively. Whenever the larger activity coincided with severe impacts, hotspots occurred. In addition, Ekener-Petersen and Finnveden (2013b) revealed the lack of data as well as the low quality of data in some instances as a challenge of S-LCA. Although they claimed the method as applicable, it is at a generic level. It requires refinement particularly in the precise definition of relevant indicators, stakeholder context, activity variables, and inclusion of use phase.

Foolmaun and Ramjeeawon (2013) measured company performance quantitatively and proposed a new scoring method to assess the impacts of the company on stakeholders (e.g. workers, society etc.) with respect to the selected subcategories (e.g. child labour). This method converted the inventory data collected for predefined subcategory indicators into percentages and assigned the scores 0 to 4 to the indicators within 0–20, 21–40, 41–60, 61–80, and 81–100 %, respectively. A higher score indicates better conditions. Then, the scores obtained in each subcategory were totalled to get a single score that allowed for comparison with different scenarios. They have applied this method to the social life cycle assessment of selected waste disposal alternatives for PET bottles and claimed the impact assessment method as a better methodology. However, this method gives an equal weight to all subcategories. Also, all indicators such as transparency, freedom of association, human rights etc. may not be expressed in percentages. In addition, they calculated a single score for the combined scenarios based on weighted sum of scores of each scenario, which may not represent the real scenario. Also, the researchers have suggested further research in their newly developed impact assessment method.

Manik et al. (2013) used the gaps between stakeholders' expectation and perception in impact assessment. They assessed the social implications of palm oil biodiesel by considering four stakeholder categories: value chain actors, workers, local community and society. The social impacts of the palm oil production in Jambi Province, Indonesia were assessed by combining the stakeholders' survey and expert evaluation. The stakeholders' survey determined the gaps between the stakeholders' expected and perceived quality of each social criterion (subcategory) using Likert scaled questionnaires. Similarly, an expert panel weighted the impact categories and their subcategories (criteria). The gap of each criterion was multiplied by criteria weight. The weighted sum gave a final score for the product indicating its social impacts. The method seems applicable; however, the result depends on the responses of the experts and stakeholders. Therefore, the survey needs to be representative with a large sample size in order to avoid the samples having a conflict of interest. Obtaining a sufficiently large sample is a challenge.

(Aparcana and Salhofer 2013a, b) used a yes/no type of response for scoring in order to assess social impacts of waste recycling systems. They proposed a methodology by scoring 1 for fulfilment and 0 for non-fulfilment of social criteria. Based on stakeholders' interviews, scores were assigned to each social indicator of subcategories. Since many individuals were interviewed within each stakeholder, the average score for each indicator was calculated. The stakeholder rated the degree of satisfaction on a scale of 1 (very bad), 2 (bad), 3 (medium), 4 (good) and 5 (very good). These ratings were assigned scores of 0, 0.25, 0.5, 0.75 and 1 ,respectively. An average score higher than medium (0.5) indicated the fulfilment of social criterion and received a final score of 1, otherwise it received a final score of 0. After computing average scores for each of 26 indicators, the score of each subcategory was calculated. The authors mentioned this method as a feasible methodology to assess the social impacts of waste recycling systems based on formalization approaches. However, the linkage between functional unit and social impacts in the methodology is not stronger. Therefore, its applicability to other systems needs to be validated.

In summary, the variety of scoring systems proposed by different researchers for S-LCIA methods indicates the lack of a common, well-accepted system. The assigned scores vary with 0/1 for yes/no questions to four scoring classes or more for grading the levels of impacts. Another issue is the use of weights. Clearly, all the impact categories and subcategories are not of equal significance. So, a proper weighting scheme for impact categories and subcategories is needed. In addition, scientific cut-off criteria that distinguish the important stakeholders and impact categories are lacking. Moreover, as far as possible, specific social impacts rather than generic social impacts should be assessed. As one method, Dreyer et al. (2010a) included geographical setting and industrial sector factor using contextual adjustment score for assessing social impacts. In addition, data unavailability and the low quality of data in some cases is an important issue for S-LCIA.

Social hotspots database method

The Social Hotspots Database (SHDB) system was developed under Social Hotspots Database project (www.socialhotspot.org). It has 22 social theme tables with 133 indicators in five categories in March 2013 version (Benoît-Norris et al. 2013). The five categories are *labour rights and decent work; health and safety; human rights; governance; and community infrastructure*. The social theme tables have a list of indicator data with risk levels low, medium, high and very high for 191 countries and 57 sectors. In addition, the SHDB has a feature of Workers Hours Model. The SHDB ranks a country-specific sector (CSS) in supply chains based on labour intensity. The worker hours' model is generated using a Global Input-Out (IO) model obtained from the Global Trade Analysis Project (GTAP) database. By the GTAP model, 113 countries and regions can be modelled for 57 sectors, i.e. 6441 CSS (Benoît-Norris et al. 2012a). Similarly, the social hotspot index (SHI) is calculated to clearly show the large amount of social impact information for each CSS. At first, the risk level identified in each social issue is assigned with a weight of zero to low risk, 1 to medium risk, 2 to high risk and 3 to very high risk. The weight-scores of all the social issues in a CSS are summed. These issues are considered risk or negative impacts. Then, the information of worker hours ranking is incorporated in the index by increasing the weighted sum of social issues based on respective worker hours. The final total score is divided by the highest score possible (a condition if all issues have very high risk levels) for a particular CSS and finally multiplied by 100 in order to calculate the SHI (Benoît-Norris et al. 2012b).

The S-LCA researchers have begun to use the SHDB. (Benoit-Norris et al. 2012a, b) identified social hotspots in product supply chains using the SHDB system as mentioned above. They conducted a pilot test of the SHDB with social scoping assessments of seven products, namely strawberry yogurt, shampoo, orange juice, laptops, wheat cereal, hard surface cleaners and laundry detergent. Moreover, (Benoît-Norris et al. 2013) applied the SHDB system to about 100 product categories to identify social hotspots. The results can also be shown in a graph for easy visualization. However, this procedure results only in the generic hotspot, and specificity is still lacking.

Lehmann et al. (2013) also used the SHDB for identifying social risks in assessing the social aspects of sustainability assessment of two technologies: water supply and wastewater treatment in Indonesia and a design option for new technology of fuel production (microreactor). They found a majority of the social issues included in the methodological sheets describes only the conduct of organisations. Social issues directly related to a process/product are less covered. Therefore, they proposed several social indicators for assessing social sustainability of technologies particularly for developing countries such as reported trust in social institutions, fluctuation of personnel, requirement of skill and knowledge in operating and maintaining technology.

In summary, the SHDB can serve as a database for S-LCIA in much the same way as the environmental LCI database (e.g. ecoinvent) serves for environmental LCIA. However, the SHDB uses GTAP databases which are at the country level and broad economic sectors that lack specificity. In addition, the SHDB should include more positive impacts, uncertainty analysis of the data, and improved characterization model and prioritization method in the SHI (Benoît-Norris et al. 2012a). Moreover, the local conditions and individual company behaviour highly affect social impacts. These issues should be addressed by the S-LCA researchers making a global or regional social database for impact assessment.

The major case studies that used performance reference point methods for S-LCIA are summarized in Table 1. Table 1 shows that S-LCAs were applied to a variety of products in different geographies (countries). The life cycle phases included in the studies varied from single phase studies to the studies of entire life cycle phases. Similarly, there was a high variability in the number of stakeholder categories, subcategories and indicators considered from study to study although the stakeholders and subcategories depend on the objectives of an individual study. The number of stakeholder categories, subcategories and indicators varied from 1 to 5, 4 to 30 and 10 to 138, respectively as shown in Table 1. Above all, the cut-off criteria were not specified in most studies. These case studies show that the performance reference point methods being practised are not standardized. For instance, the selection of a cut-off point that delineates the system boundary may alter the results significantly. These weaknesses indicate that performance reference point methods still need to be improved to be acceptable to the scientific community.

Impact pathways methods

Generally, impact pathways methods involve quantitative indicators characterizing midpoints and endpoints. Researchers have used different techniques, which can be classified as the empirical method and the environmental LCI database method. The empirical method uses the data obtained from secondary sources such as literature, archive data or primary sources such as the data obtained from the field for use in empirical relations. However, environmental LCI database method uses the data from environmental LCI database which has been primarily prepared for E-LCA.

Empirical method

The empirical method involves the use of empirical formulas or rules in order to assess social impacts. There are a variety of empirical methods applied to S-LCIA as discussed below.

Table 1 Summary of major case studies using performance reference point methods for S-LCIA

Author, year	Product, country	Objectives	Functional unit	S-LCA phase	Cut-off point[a]	Stakeholders	No. of subcategories	No. of indicators	Characterization method	Major contribution
Dreyer et al. (2010a, b)	5 manufacturing companies (Malaysia, Brazil, Croatia, Hungary, Israel) & 1 knowledge company (Denmark)	Develop framework for modelling SLCIA with case study on labour rights	NS	Gate to gate[b]	NS	Workers	4 subcategories related to labour rights	NA	Multi-criteria model (proposed)	Inclusion of geographical setting and industrial sector context in S-LCIA
Franze and Ciroth (2011)	Roses, Ecuador and Netherlands	See applicability of UNEP/SETAC Guidelines	A bouquet of roses with 20 caulis per spray	Gate to gate	NS	Workers	8	9	5 impact levels: positive, indifferent, lightly negative, negative, very negative. No scores assigned and aggregate impact for a subcategory/category cannot be assessed	Developed checklist method for impact assessment
						Company	2	2		
						Local Comm.	3	5		
						Society	4	4		
						Consumers	2	1		
						Total	19	21		
Ciroth and Franze (2011)	Notebook (Laptop), Belgium	Identify social hotspots in entire life cycle	1 Notebook	Cradle to grave[c]	NS	Workers	8	25	6 performance levels based on international reference points & 6 impact levels; scores assigned 1 -6; aggregate impact is average of scores	Proposed scoring based impact assessment method
						Local Comm.	9	25		
						Society	5	15		
						Val. chain actors	4	8		
						Consumers	4	15		
						Total	30	88		
Ekener-Petersen and Finnveden (2013a, b)	Laptop, Sweden	Generic social hotspot assessment	1 laptop	Cradle to grave	NS	Workers	8	13	4 impact levels assigned based on quartiles; 4 activity levels; social indicator with higher impact and larger activity together is hotspot	Inclusion of quantity of production (activity) in impact assessment
						Local Comm.	9	26		
						Society	5	10		
						Val. chain actors	4	1		
						Consumers	4	11		
						Total	30	61		
Foolmaun and Ramjeeawon (2013)	PET bottles disposal technique, Mauritius	Compare social impacts of disposal alternatives	1 tonne of used PET bottles	Gate to grave	NS	Workers	6	9	5 levels of impact with score 0–4	Proposed a new scoring method to assess impacts of company on stakeholders quantitatively
						Society	1	1		
						Local Comm.	1	1		
						Total	8	11		
Benoît-Norris et al. (2012a, b)	7 product categories, US	Identify social hotspots	1 million USD purchase in each	Cradle to grave	CSS > 0.1 % worker hours share	Workers	22 social themes	138 indicators, 112 issues	Use of SHDB system; 4 risk levels are assigned with score resp. 0–3; SHI is calculated	Identification of social hotspots in product supply chains using the SHDB system
						Local Comm.				
						Society				
						Val. chain actors				

Table 1 continued

Author, year	Product, country	Objectives	Functional unit	S-LCA phase	Cut-off point[a]	Stakeholders	No. of subcategories	No. of indicators	Characterization method	Major contribution
Traverso et al. (2012)	PV modules (Italy & Germany)	Conduct LCSA including S-LCA	1 m^2 PV module	Gate to gate	NS	Workers	6	10	Comparison of numerical values of social indicators	Inclusion of S-LCA in life cycle sustainability dashboard or LCSA
Benoît-Norris et al. (2013)	100 product categories, US	Identify social hotspots	1 million USD purchase in each	NS	CSS > 0.1 % worker hours share	Workers, local community, society, value chain actors	22 social themes	133 indicators, 89 issues	Use of SHDB system; 4 risk levels are assigned with score resp. 0–3; SHI is calculated	Identification of social hotspots in product supply chains using the SHDB system
Manik et al. (2013)	Palm oil biodiesel, Indonesia	Investigate social implications	NS	Cradle to gate[d]	NS	Workers	8	NA	5 impact categories and weights to impact categories and subcategories by expert evaluation	Impact assessment using gaps between stakeholders' expectation and perception
						Local Comm.	8			
						Society	5			
						Val. chain actors	3			
						Total	24			
Aparcana and Salhofer (2013a, b)	Waste recycling system, Peru	Assess social impacts of formalised recycling systems	Recyclable waste collected/house/yr (i.e. 60 kg)	Gate to grave[e]	NS	Workers & value chain actors	9 in total	24	3 impact categories; Based on scoring system assigning 1 for fulfilment and 0 for non-fulfilment	Proposed scoring method using 1 for fulfilment and 0 for non-fulfilment of social criteria
Lehmann et al. (2013)	Water supply/wastewater treatment and fuel production (microreactor), Indonesia	Asses social sustainability of two technologies	Fixed amount of water and fuel (NS)	Cradle to grave	NS	Local comm.	6	6	Use of SHDB system	Proposed several social indicators as a majority of social issues included in the methodological sheets describes only the conduct of organisation
						Workers	3	2		
						Consumers	1	1		
						Society	2	2		
						Total	12	11		

NS not specified, *com*. community, *Val. chain actors* value chain actors, *resp*. respectively

[a] Cut-off point delineates system boundary of an S-LCA study

[b] Gate to gate is a partial life cycle phase looking at a single added process or material in the product chain

[c] Cradle to grave is an entire life cycle phase of a product from material extraction to disposal after the use phase

[d] Cradle to gate includes material acquisition to manufacturing (factory gate) phases but excludes product uses and end-of-life

[e] Gate to grave includes production gate to disposal (end-of-life) phases

In one of the earlier works on S-LCA, Dreyer et al. (2006) proposed a conceptual S-LCA framework using ILO conventions. The pathway model (framework), from top to down, included an area of protection (human dignity and well-being) and midpoints (impacts of companies on employees). As a new concept, they included a two-layer social LCA method containing an optional and obligatory set of impact categories. In the obligatory set, a minimum requirement based on universal norms and local or country norms was included. In the optional set some self-determined context-specific parameters were included. Although some impact categories and their indicators have been developed, the framework is still at an early stage and lacks a systematic framework for normalisation, weighting and aggregation. On the other hand, Weidema (2006) proposed QALYs (Quality Adjusted Life Years) as a unit of impact measurement for human well-being analogous to DALYs (Disability Adjusted Life Years) being used as a measurement unit for damage to human health in environmental LCA. He used six damage categories for human life: health; life and longevity; autonomy; safety, security and tranquillity; equal opportunities; and participation and influence.

Brent and Labuschagne (2005) and Labuschagne and Brent (2006) proposed a quantitative method, Social Impact Indicators (SII) for social impact assessment for S-LCA. This method was developed based on the Resource Impact Indicator approach of the South African context. The $\mathrm{SII_G}$ (SII for a main social resource group) was calculated as follows (Brent and Labuschagne 2005, Labuschagne and Brent 2006):

$$\mathrm{SII_G} = \sum_{\mathrm{C}} \sum_{\mathrm{X}} Q_{\mathrm{X}}.C_{\mathrm{C}}.N_{\mathrm{C}}.S_{\mathrm{C}} \quad (1)$$

where Q_{X} represents the quantifiable social intervention (X) of a life cycle system in a midpoint impact category C; C_{C} represents a characterization factor for an impact category (of intervention X) within the pathway (no characterisation factors are assumed as a first approximation);

N_{C} represents the normalisation factor for the impact category based on the social objectives in the region of assessment, i.e. the inverse of the target state of the impact category (obtained from social footprint data in the region of the assessment);

$S_{\mathrm{c}} = C_{\mathrm{s}}/T_{\mathrm{s}}$ represents the significance of the impact category in a social group based on *distance-to-target* method; C_{s} represents the current social state; T_{s} represents the target social state

The SII impact assessment method was applied by Labuschagne and Brent (2006) to assess the social dimension of the sustainability of projects and technologies in three process industries: an open cast mine, a chemical facility and a fibre manufacturing plant. They found that information on the social footprint or the project is not available for all midpoint categories and concluded "a quantitative assessment of social life cycle impacts cannot be applied for project and technology life cycle management purposes in industry at present". Social footprint is necessary for S-LCIA. The authors reached the same conclusion with additional case studies (Labuschagne and Brent 2008). Moreover, Labuschagne et al. (2005) and Labuschagne and Brent (2006, 2008) identified the social area of protection (AOP) as internal human resources, external population, macro social performance and stakeholder participation with each having several midpoint categories. Labuschagne and Brent (2006) urge the development of practical guidelines and a checklist for assessing the social dimension of the sustainability of a project and technology life cycle. In addition, subjective weighting is also needed for four main social category groups based on the expert judgement (Brent and Labuschagne 2005).

However, Paragahawewa et al. (2009) proposed modified SII impact assessment. The authors recommended using the SII of Labuschagne and Brent (2006) by substituting 'significance of the impact category' (Sc) by a severity ratio (SR) defined as follows:

$$\mathrm{SR} = L_{\mathrm{f}}/L_{\mathrm{CR}} \quad (2)$$

where L_{f} represents the level of sustainability issue of concern in the future time (T_{F}) and L_{CR} represents Critical level of sustainability issue

L_{f} is further estimated as:

$$L_{\mathrm{f}} = L\mathrm{cu}_i \pm \int_{T_{\mathrm{c}}}^{T_{\mathrm{f}}} \mathrm{d}t \quad (3)$$

for a sustainability issue having continuous functions for many environmental issues

$$L_{\mathrm{f}} = L\mathrm{cu}_i \pm \sum_{T_{\mathrm{c}}}^{T_{\mathrm{f}}} \Delta \quad (4)$$

for a sustainability issue having discrete functions for many social issues

where Lcu represents the current level of a sustainability issue, T_{C} represents the current time, and T_{F} represents the future time

This method also needs weighting among impact categories as well as among social category groups. The authors proposed six subgroups: company, employees, national and international community, future generations, and consumers. The inclusion of future generations as a subgroup (or stakeholder) characterized by the indicators resource use and environmental impacts is a newer concept.

Jørgensen et al. (2008) compared several methods applied to S-LCIA before 2008 and found an inconsistency in researchers' understanding of social impacts. Some researchers used midpoint level impacts while others used endpoint level impacts. At the midpoint level, the major impact categories used were human rights; labour practices and decent work conditions; society; and product responsibility including several quantitative and descriptive indicators which varied among the authors. At the endpoint level, Norris (2006) used a human health/human well-being impact category with two indicators: mortality and morbidity.

A single social impact indicator, specifically health impact, was assessed empirically by some researchers. Feschet et al. (2012) assessed the social impact of a product using Preston pathway (curve), an empirical relationship, between real life expectancy at birth and real per capita income. The study has presented the health impact due to economic activity of the banana industry in Cameroon. Interestingly, they found that the activity of the banana industry would increase the life expectancy at birth in the country by five days over 20 years considering 200,000 tons export of bananas annually. In addition, Feschet et al. (2012) have suggested that the Preston curve is applicable when the four conditions are met: GDP per capita is less than 10,000 dollars; the given activity has a significant contribution to national GDP; the duration of the given activity is regular and long; and the added value generated by the activity is shared within the entire country. Although the authors mentioned it as a valid method for comparative purpose, it needs further research for its validity and refinement. Indeed, health is affected by many factors such as environmental quality, education, employment, access and quality of health care, and health behaviours (smoking, diet, and alcohol) in addition to income (Senterfitt et al. 2013).

In another study, Basurko and Mesbahi (2012) considered health and safety as the social AOP and have proposed a newer methodology for impact assessment using a water treatment system as a case study. The authors used the BAMES tool (sustainability assessment tool for social dimension) similar to Myers-Briggs Type Indicator (MBTI) psychometric personality tests, which expressed social impacts in four-letter codes with each code representing the health impacts of users. They considered four health aspects such as physical impact (musculoskeletal), psychological impact (mental disorder), impact on state of mind (cognitive sate), and impact on health (biological health i.e. illness) each defined by two alternatives resulting in 16 impact types. These social impacts were ranked based on the health aspects in a decreasing priority as illness, psychological impact, physical impact, and impact on state of mind. The authors considered this method helpful in designing and operating the marine technologies. However, the boundaries between happy and unhappy; apathy and energetic; degenerative and good; and ill and healthy states are usually fuzzy, which could produce uncertain results.

Some authors have assessed country-level social LCA. For instance, Stamford and Azapagic (2012) assessed the social dimension of the sustainability of electricity options for the UK at the country level as a part of LCSA by considering the full life cycle. Five electricity options (gas power, nuclear, offshore wind, photovoltaics, and coal) were compared. They assessed social impacts on workers, local community, society, and future generation by considering eight impact subcategories (social issues) comprising 19 social indicators. However, the study is at the country level and generic and assessed social impacts mainly based on the estimation from historical data and in some cases the estimation from LCIA results. In addition, only a few social issues were considered and the basis of social issues selection or cut-off criteria is not discussed in the study.

Social impacts under competition may be different than usual. Lagarde and Macombe (2013) assessed social impacts in the context of competition using a new method – the systematic competitive model. They compared social impacts i.e. change in rural jobs created due to the implementation of a pig farming plan in the Republic of Croatia in two different assessment systems. They used the same cut-off criterion (significant dependency), i.e. inclusion of those whose behaviour with social effects was significantly affected by the changes. The assessment systems used a value chain method and a systematic competitive model. The value chain method is a classical method as suggested by the UNEP/SETAC Guidelines (2009), whereas the systematic competitive model is a new model proposed by the authors. The new model includes the short term effects of market competition evolved due to the new production. However, the two assessment systems produced very different results for the same real system. The new model is applicable in the context of intense competition in the supply chain and valid for about one year as competition in business changes rapidly. Also, the proposed cut-off criterion of significant dependency has subjectivity.

An empirical method can also be applied using the data directly collected from the field. The collected data are site specific, and so impact assessment is also site specific. This method increases the certainty of impacts assessed with respect to the location. Few researchers have used the field based method for impact assessment. For instance, Moriizumi et al. (2010) assessed the social dimension of the sustainability of mangroves planted on wastelands in Thailand as a part of LCSA considering a complete biological lifecycle of a mangrove from seed collection to mangrove use phase. The study considered employment as an indicator for assessing the social dimension of sustainability. It compared two mangrove management systems based on the amount of local employment generated in different phases of the mangrove life cycle (including the mangrove-charcoal use phase). The study involved site-specific data collection and analysis from the plantation site, the mangrove forest area, mangrove study centres, and charcoal factories. However, it considered only one social indicator for assessing the social dimension of sustainability.

In conclusion, there is a wide variation in the empirical method applied in assessing social impacts. Cut-off criterion is an important issue, which has not yet been defined in S-LCIA methodology. On the other hand, Feschet et al. (2012) and Weidema (2006) proposed methods of modelling impact pathways quantitatively; however, their application has limited use and requires further development. So, there is a lack of a characterization model for impact pathways or cause-effect modelling in social impact assessment. This situation can lead to subjectivity in the results and can cause a higher uncertainty. On the other hand, Moriizumi et al. (2010) demonstrated the use of field based data to assess the social dimension of sustainability. The use of field based data has the benefit of higher specificity in social impacts with respect to location. However, it is time and resource consuming. This method is mostly suitable for assessing social impacts only on one or very few stakeholders considering a fewer issues in one or two phases of life cycle. The field based S-LCA of the *entire* life cycle of a product that has life cycle phases in more than one country is difficult and impractical.

Environmental LCI database method

In environmental LCI database method, the environmental LCI database is used for estimating social impacts. This approach is similar to environmental life cycle impact assessment. Hunkeler (2006) used an LCI database of E-LCA to compare the social impacts of two types of detergents. The methodology was based on midpoints and used labour hours as an intermediate variable. By the same system boundaries and a functional unit as of E-LCA, the existing LCI was transformed to a geographically specific LCI for each unit process. Then, the employment hours were calculated for each unit process and an overall employment table was computed. Finally, the social impacts were assessed using estimated regional characterization factors. However, the author mentioned this method as preliminary model. Although this method attempts to connect S-LCA with E-LCA by including a geographic specificity in S-LCA, it is a process based model and does not account for the behaviour of a company, which is also an important aspect of S-LCA. In another example, Menikpura et al. (2012) used the results of E-LCIA to assess the social dimension of the sustainability of municipal solid waste management systems in Thailand. The human health impacts were estimated based on the disability adjusted life years (DALYs) resulted from LCIA, whereas the income based community well-being i.e. potential generation of employment opportunities at each hierarchal position was estimated using Eq. 5 based on Hunkeler's (2006) theoretical concept.

$$\text{Uplifting living standard (no.of individuals per tonne)} = \frac{\sum_i (\text{PEO}_i * \text{TW}_i) + I_{\text{informal}}}{\text{COL}} \quad (5)$$

where PEO_i = potential employment opportunities for ith level (labour h/tonne), TW_i = rate of wages ($/h) of ith level, I_{informal} = income generation from indirect activities ($/tonne), COL = cost of living ($/person)

The researchers found this approach to be applicable for evaluating the social dimension of the sustainability of municipal solid waste management. However, human health impacts assessed through life cycle emissions (LCIA results) give an average impact for the general population. This method does not include the health impacts to waste handlers, which are more severe. In addition, only two social issues are captured in the framework.

Baumann et al. (2013) also used DALY as an indicator of health impacts and compared the health impacts of automobile airbag production and the lives saved by its use. The DALY lost due to metals mining and the production of electricity and pyrotechnic materials were estimated using their statistical records on accidents, whereas DALY lost due to toxic emissions along the life cycle of an airbag system was estimated using the USE-LCA[6] model used in the Eco-indicator'99 impact assessment method. Similarly, DALY saved by the use of airbags is the sum of Years of Life Lost (YLL) saved and Years of Life Disabled (YLD) saved by the airbag system as follows:

$$S_{\text{airbag}} = \text{No .of lives saved by airbag alone} = (S \times e_{\text{airbag}}) / (e_{\text{airbag}} + e_{\text{seatbelt}}) \quad (6)$$

$$\text{YLL} = (S_{\text{airbag}}/\text{No. of airbags produced per year}) \times \text{Average life years saved per accident}$$

$$\text{YLD} = (P_{\text{airbag}}/\text{No. of airbags produced per year}) \times \text{Duration of nonfatal accidents prevented} \times \text{severity of nonfatal (spinal cord) injury prevented}$$

where S represents total number of lives saved by airbag and seatbelt systems together; e represents life-saving effectiveness; P denotes injuries prevented analogous to S and f (injury-preventing effectiveness) is analogous to e as of Eq. 6. Moreover, as mentioned in the previous section, Stamford and Azapagic (2012) also assessed some social

[6] Uniform System for the Evaluation of Substances Adapted for LCA Purposes (USE-LCA).

impacts of electricity options for the UK using E-LCIA results particularly for human toxicity, total human health impacts, and abiotic resources depletion. However, these methods lack cut-off criteria. In addition, they give generic results lacking location specific impacts.

From these case studies, it can be said that the use of the E-LCIA database for S-LCIA is the bridge for linking S-LCA and E-LCA and also maintains uniformity in functional unit, system boundary, and base data as far as possible. However, only a few social impacts such as health impact and employment are assessed by this method. In addition, it is mostly generic assessment. The many social effects caused by company behaviour cannot be captured by this method.

The major case studies mentioned above that used impact pathways methods for S-LCIA are summarized in Table 2. Table 2 shows that S-LCAs were applied to a variety of products across the world. Similar to performance reference point methods, the life cycle phases included in different studies were variable. The number of stakeholder categories, subcategories, and indicators included was also highly variable although the stakeholders and subcategories depend on the objectives of an individual study. There were 1–5 stakeholder categories, 1–18 subcategories, and 1–43 indicators considered in the studies as depicted in Table 2 Compared to performance reference point methods as mentioned in Table 1, impact pathways methods include fewer subcategories and indicators. The reason might be that impact pathways methods require quantitative indicators to establish cause and effect quantitatively in order to estimate social impacts. Also, it is noteworthy that the cut-off criteria were specified in very few studies. The cut-off criteria were given in qualitative terms such as "significant" process. As a result of these limitations, these methods must be scientifically improved.

Discussion and future direction

The issues associated with the social life cycle impact assessment method and the researches needed to overcome these issues are discussed below.

Issues of social life cycle impact assessment method

There is a great variation in the application of social life cycle impact assessment methods. Several researchers have proposed their own S-LCIA methods that need additional scientific justification. The main issues related to the S-LCIA method are discussed below.

(i) The social dimension of sustainability is difficult to measure (Clift 2003). There is no international consensus formed yet on the social life cycle impact assessment method. The approaches proposed by different researchers for S-LCIA are highly innovative and experimental (Macombe et al. 2013). Development of a standardized method for impact assessment is required.

(ii) There is no complete set of social (significant) issues yet prepared for conducting S-LCIA. The methodological sheets of the UNEP/SETAC Guidelines identified more than one hundred issues. These issues are highly ideological and ambiguous and may be interpreted differently depending on political, ethical, and cultural backgrounds (Baumann et al. 2013). Often, only a few issues are directly related to a process or a product (Lehmann et al. 2013). Therefore, the list of social issues needs to expand in scope to include the issues related to a product or process, making it as crisp as possible.

(iii) The social issue is highly dynamic with respect to space, time and institutions (companies). In addition, there are other phenomena such as market competition associated with products, which may produce different social impacts besides those that may result from the conventional S-LCA method (Lagarde and Macombe 2013). The competitiveness features are generally difficult to quantify (Dos Santos and Brandi 2014). These dynamic impacts are yet to be modelled in S-LCA studies.

(iv) There is no consensus among S-LCA community on cut-off criteria for identifying the socially significant processes, system boundary (Benoît et al. 2010) and weighting system. These are great challenges to be addressed in order to develop a scientifically accepted impact assessment method.

(v) The recently developed social hotspot index 'SHI' identifies social hotspots using performance levels (social theme tables) as well as labour intensity (workers hour model); however, it is more generic, i.e. applicable geographically at the country level and economically at the broad sector level.

(vi) A majority of S-LCA studies have not included the use phase of a product, which in fact, is necessary to be assessed.

Research needs

The social LCA is still a newer area for research. In order, to develop this research area, the followings can be considered.

(i) Research is needed to refine S-LCIA method to be acceptable for the scientific community. The acceptable impact categories, scoring, weighting,

Table 2 Summary of major case studies using impact pathways methods for S-LCIA

Author, year	Product, country	Objectives	Functional unit	S-LCA phase	Cut-off point[a]	Stakeholders	No. of subcategory	No. of indicators	Characterization method	Major contribution
Labuschagne and Brent (2006)	3 (Mine, chem. facility, fibre manuf. plant), South Africa	Develop social LCIA method	NS	Gate to gate[b]	NS	Internal hum. resource	3	3	$SII_G = \sum_C \sum_X Q_X.C_C.N_C.S_C$	Revealed social footprint information required for quantitative S-LCIA
						External popln	12	14		
						Macro soc.perform.	2	2		
						Stakhld. particip.	1	1		
						Total	18	20		
Paragahawewa et al. (2009)	Cheese production, New Zealand	Develop SLCA framework for cheese production	1 kg cheese	Cradle to grave[c]	Socially significant process	Company	2	5	$SII_G = \sum_C \sum_X Q_X.C_C.N_C.SR$	Inclusion of future generations as a stakeholder
						Employees	5	15		
						National/Intel. Comm.	5	8		
						Future generation	2	5		
						Consumers	4	10		
						Total	18	43		
Moriizumi et al. (2010)	Mangrove plantation, Thailand	Compare sustainability (+ social) of two mangrove systems	1 ha plantation land	Mangrove seed collection to use	NS	Local comm.	1 (local employment)	1 (no. of employment)	Comparison of no. of employment	Social sustainability assessment using site specific data
Menikpura et al. (2012)	Municipal solid waste (MWS) management, Thailand	Develop LSCA framework (including social) & apply to MSWM	1 tonne MSW	Cradle to grave	NS	Local comm.	1 (Community well-being)	1 (no. of employment)	For community well-being: Uplifting living standard $= \frac{\sum_i (PEO_i * TW_i) + I_{informal}}{COL}$	Estimation of human health impacts using DALYs; estimation of income based community well-being
							1 (Human health)	–	Human health impacts estimated from DALYs resulted from LCIA result	
Feschet et al. (2012)	Banana industry, Cameroon	Apply 'Preston pathway' for SLCIA	Annual export of 200,000 t bananas	Gate to gate	NS	People	1 (Health)	1 (life expectancy)	Based on regression equation	Application of Preston pathway to assess social impact
Basurko and Mesbahi (2012)	Ballast water treatment unit, UK	Compare social impacts of 3 alternative treatments	Treatment of 125,000 m3 of ballast water (25 yrs use)	Cradle to grave	Not specific	Consumers (Technology users)	1 (Health and safety)	20	BAMES tool characterizing health and safety issues of technology users into 16 types with letter code	Application of BAMES tool for assessing health impacts
Stamford and Azapagic (2012)	Electricity, UK	Compare electricity options of gas, nuclear, offshore wind, PV and coal	Per unit electricity produced	Cradle to grave	NS	Workers	3	7	Estimation from historical data (mostly) and LCIA results (in some cases)	Assessed social sustainability of electricity options as part of LCSA at country level
						Local community	1	3		
						Society	3	5		
						Future generation	1	4		
						Total	8	19		

Table 2 continued

Author, year	Product, country	Objectives	Functional unit	S-LCA phase	Cut-off point[a]	Stakeholders	No. of subcategory	No. of indicators	Characterization method	Major contribution
Baumann et al. (2013)	Automobile airbag, Sweden	Compare injuries and live lost by airbag production with lives saved by its use	1-driver airbag system	Cradle to use[d]	Same as ELCA	Workers Consumers Society	1 (Health)	1 (DALY)	YLL = (S_{airbag}/No. of airbags produced per year) × Average life years saved per accident YLD = (P_{airbag}/No. of airbags produced per year) × Duration of nonfatal accidents prevented x severity of nonfatal injury prevented	Estimation of health impacts using DALY
Lagarde and Macombe (2013)	Pig farming, Croatia	Compare social impacts i.e. change in rural jobs due to pig farming plan in two assessment methods	Annual pork prodn by new single Pig Plan farm; 165 tons/yr	Production gate to market gate	*Significant dependency* criterion	Workers	1 (Rural employment)	1 (Rural job)	Estimation from historical employment statistics	Revealed social impacts are different during intense competition in market than usual; proposed systematic competitive model to assess social impacts

NS not specified, *chem.* chemical, *manuf.* manufacturing, *Intel.* International, *hum.* human, *popln* population, *soc. perform.*: social performance, *stakhld. particip.* Stakeholder participation, *com.* community

[a] Cut-off point delineates system boundary of an S-LCA study

[b] Gate to gate is a partial life cycle phase looking at a single added process or material in the product chain

[c] Cradle to grave is an entire life cycle phase of a product from material extraction to disposal after the use phase

[d] Cradle to use includes material extraction to use phases

cut-off criteria, allocation method, and area of protection are to be included.

(ii) As social impacts within a supply chain mostly depend on the behaviour of an individual company, site-specific data collection is the key. However, it is practically very difficult to visit and collect site-specific data from all the organizations within the supply chain of an S-LCA study. It requires prioritization or cut-off criteria for identifying socially significant organizations/companies for site-specific data collection, for which a global social database is needed. The recently developed SHDB system might serve for this purpose. However, this database can be made specific for a more realistic result by further breaking down its sectors. Each sector/industry can further be classified as large, medium and small industries as many social issues depend also on company size. Innovative research is needed to make the SHDB more specific.

(iii) The present methodology of the SHI needs further improvement to make it more objective, and one alternative could be the inclusion of multi-criteria decision analysis in the SHI (Benoît-Norris et al. 2012a, 2013).

(iv) Since the financial conditions change rapidly in the global business environment, it affects the social database. A regular update of the database and further research is needed to capture the dynamic behaviour of social data.

(v) Research is also needed in elaborating social and socio-economic mechanism (UNEP/SETAC 2009) and in identifying and reducing the sources of uncertainties associated with S-LCIA methods (Meyer and Upadhyayula 2014).

(vi) In contrast to E-LCA, the mechanisms and indicators linking inventory data to potential social impacts may not always be quantitative in S-LCA. Some impacts may be captured by qualitative and semi-quantitative indicators (UNEP/SETAC 2009). This shows that the S-LCIA method can include performance reference points-based impact assessment methods. For instance, many S-LCA case studies conducted to date have used these methods although there is a great variation in their study methods. These methods require development of a common scoring system.

(vii) In addition, impact pathways-based impact assessment method is objective and able to quantitatively link a functional unit and life cycle inventory data to social impacts. Some social impacts like human health, employment, salary etc. can be assessed using quantitative indicators showing the applicability of impact pathways-based methods. This implies that the S-LCIA method can be developed further by combining performance reference point-based and impact pathways-based methods, for which a further research is needed.

Conclusions

Social LCA is conducted to improve the well-being of stakeholders throughout a product's life cycle. S-LCA, along with already developed E-LCA and LCC, completes the sustainability analysis of a product. This article aimed to provide the current development status of S-LCIA. S-LCIA is still developing in terms of depth and breadth of research, applications, and method development. In particular, a scientific and widely accepted impact assessment method is yet to be developed. Diverse S-LCIA methods have been proposed that might produce varying results. Moreover, future research direction could include the formation of global social database, the refinement of the SHDB and improvement of the SHI calculation method. The SHI can be made more objective by including multi-criteria decision analysis. The improved SHI can be used for prioritizing site-specific data collection. On the other hand, the S-LCIA method can be further developed by combining performance reference point and impact pathways methods. The method needs to be capable of assessing positive and negative social impacts. Also, precisely defined cut-off criteria must be included in order to objectively identify socially significant processes.

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