Different paths in social life cycle impact assessment (S-LCIA) – a classification of Type II impact pathway approaches

Solène Sureau[1*], Sabrina Neugebauer[2], Wouter M.J. Achten[1]

[1]Institute for Environmental Management and Land-use Planning (IGEAT), Université Libre de Bruxelles (ULB), Avenue F. D. Roosevelt 50 – C.P. 130/02, B-1050 Brussels, Belgium; [2]Institut für Nachhaltigkeit im Bauwesen (INaB), RWTH Aachen University, Mies-van-der-Rohe-Straße 1, 52074 Aachen, Germany

[*]Corresponding author: Solène Sureau, +32 (0)2 650 43 26, Fax: +32 (0)2 650 43 24, ssureau@ulb.ac.be

Abstract

Purpose: In Social Life Cycle Assessment (S-LCA), we can distinguish two main types of impact assessment (LCIA): Type I can be seen as a reporting approach with the use of performance reference points; and Type II aims at including cause-effect chains or impact pathways in the analysis. Given the heterogeneity of those Type II approaches, this review provides a classification of existing Type II approaches. **Methods:** We reviewed a total of 28 articles against the background of their main purpose, the method used, the issues covered and the origin of data (observation/characterization/ measurement). We checked the articles against: i) the reflection of an impact pathway, ii) the availability of so-called inventory and impact indicators, iii) the presence of characterization models or factors translating correlations or causality. **Results and discussion:** The analysis reveals three main paths to include impact pathways in S-LCA, which differ in authors' intentions: 1) Some studies *identify and propose* variables composing impact pathways, or frameworks gathering several pathways; 2) other studies *investigate or test* known pathways empirically, and until now seek mainly to link income data with health impacts at a macro scale, and 3) a last batch *applies* known and already quantified characterization models or factors from other research works in case studies. Until now these case studies focus mainly on income-related social effects, or on health impacts. Further, each path is further characterized and classified under nine approaches. Our findings highlight the heterogeneous nature of approaches, but also their common denominator which is to not consider phenomena or impacts in isolation but to consider them in relation to their sources or further impacts. It should be noted that Type II studies are not limited to quantitative approaches and variables, but can also use more qualitative variables and methods. **Conclusion & Outlook:** The here presented classification may be used as a guidance tool for authors to make their methodological choices. Also, our findings indicate the opportunity of extending future Type II S-LCA research to variables tackled in Type I studies (e.g. safe and fair employment and working conditions), beyond pathways including incomes and health impacts. This can be done by using theories from social sciences for the identification of impact pathways. Those could then further be investigated through statistical approaches or in the framework of S-LCA case studies, with specific data and potentially more qualitative methods to analyze causality or social mechanisms.

Keywords: S-LCA, SLCA, Social Life Cycle Analysis, Social Life Cycle Assessment, Impact pathway, Type II, S-LCIA, social and socioeconomic impacts, literature review

1 Introduction and background

In Social life cycle assessment or analysis (S-LCA), the way to carry out the third phase of the analysis, the impact assessment (or LCIA), is not streamlined, and there are two main approaches that are called Type I and Type II (Benoît and Mazijn, 2009). The definitions of these two approaches are not set in stone and vary according to S-LCA researchers and practitioners.

However, we highlight two main differences. The first one is the use of impact pathways or cause-effect chains in the analysis, which is typical for Type II LCIA. In type II LCIA, researchers or practitioners consider the link between two or more phenomena or events in the assessment (e.g. the use of an input or the exposure to certain working conditions in a production process and health impacts on workers). In Type I LCIA, such link is not considered. Rather, Type I LCIA assesses performances, and collected data is compared with performance reference points (e.g. the number of hours worked per worker weekly is compared with the statutory working time) (Parent et al., 2010).

At the beginning of the research on S-LCA, a number of studies investigated the inclusion of impact pathways (Hutchins and Sutherland, 2008; Norris, 2006; Weidema, 2006). Then, from 2009 onwards, studies that we can classify as Type I have been developed, mainly boosted by the publication of the Guidelines for S-LCA (Benoît and Mazijn, 2009) and its list of subcategories or criteria to be assessed. One reason for this development might be that impact pathways in S-LCA cannot be described the same way as in environmental LCA (E-LCA), as the E-LCA LCIA approach of underlying physical and natural science cannot be directly transposed. Indeed, impact assessment in E-LCA and S-LCA call partly upon different disciplines and methods. While practitioners in E-LCA deal with physical phenomena and quantitative data, in S-LCA they deal mainly with social and socioeconomic phenomena and partly with qualitative data.

Type I S-LCIA has a close linkage to social reporting approach, such as Corporate Social Responsibility standards (ISO, n.d.) (Feschet, 2014). Yet, when impact pathways are considered and impacts are assessed, S-LCA can be used as a tool to predict impacts stemming from product life cycles or from changes in product life cycles, and thus as a decision-support tool (Macombe, 2013a) or as a tool that can help understand practices of life cycle organizations (Sureau et al., 2017). Indeed, when phenomena are linked through variables, then it becomes possible to look for explanations of negative impacts, and thus for levers that can foster the improvement of impacts.

Parallel to this boom in Type I S-LCA publications (Wu et al., 2014), Type II or impact pathway approaches continued developing in many directions. A number of literature reviews listed and proposed broad classifications of various studies into Type I or Type II (Chhipi-Shrestha et al., 2014; Feschet, 2014; Neugebauer, 2016; Parent et al., 2010; Wu et al., 2014). These works of characterization and classification are very useful, all the more so because the terminology used by researchers reflects quite often different views and realities (e.g. researchers use the terms "characterization", "impact assessment" or "social impacts" whether they adopt a Type I or a Type II approaches, while what they actually assess and do is quite different). Some of these reviews provide a broad classification of Type II studies, into two main branches mainly, which are different according to each author. (Wu et al., 2014) distinguish between 'multiple qualitatively constructed pathways with expert knowledge' and 'single and quantitative pathways', (Chhipi-Shrestha et al., 2014) distinguish between E-LCI Database Method and Empirical method, whereas (Neugebauer, 2016) distinguishes between type II/impact pathways and type III/economic modelling. These classification studies will be discussed and compared to the classification we propose in this article (cf. Discussion).

Next to the publication of the above-mentioned literature reviews, other studies were published proposing, applying or discussing different approaches within the Type II impact pathway methodology (Arvidsson et al., 2016; Di Cesare, 2016; Iofrida et al., 2019; Neugebauer et al., 2016; Silveri, 2016; Sureau and Achten, 2018; Touceda et al., 2016; Weidema, 2018a, 2018b; Wu et al., 2015). These studies and the previous ones are very different from each other, in their purposes, scopes and methods. However, there is as yet no detailed review and characterization of their common features and differences, while this work has already been achieved for Type I studies (Russo Garrido et al., 2016). (Russo Garrido et al., 2016) further add on the earlier review papers and highlight what additionally distinguishes Type I and Type II studies. Thus, in Type I, the inventory data and the "characterized", or referenced result[1] are at the same point along the impact pathway, and in type II, they are at different points along the impact pathway (cf. **Figure 1**). We will use this distinction between Type I and Type II S-LCIA as a reference for our review. Adding further to the work of (Russo Garrido et al., 2016), this study will highlight the diversity of Type II S-LCIA approaches by providing a comprehensive classification.

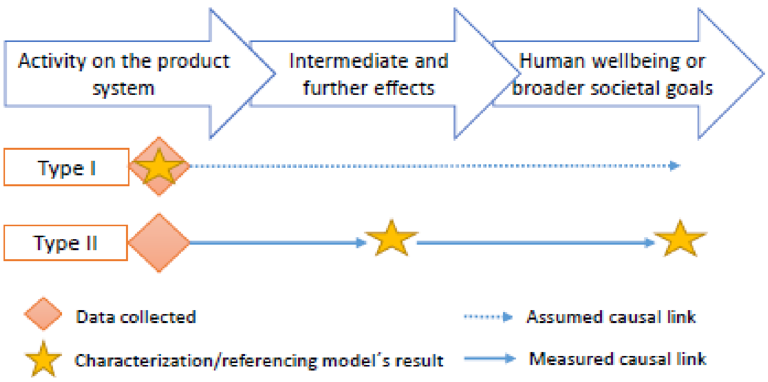

Figure 1: Positioning of Type I and II inventory data and characterization/referencing results on the impact pathway in the framework of S-LCA (adapted from Russo Garrido et al. (2016))

[1] In type I studies, referring to characterization is not correct since there is no characterization per se (as in E-LCA), but rather a referencing with performance reference points (i.e. generally a translation from qualitative to semi-quantitative variables)

After introducing the materials and methods used, we present the results providing detailed classification and description of the various Type II approaches. Then, we discuss these results through a comparison with other (earlier) classifications. Finally, we give recommendations for future research on impact pathways in S-LCA.

2 Materials and method

2.1 Materials

As a basis of our review, we list the studies identified as Type II/impact pathway approaches by other literature reviews, complemented by further and more recent studies which we judge to be corresponding to Type II. Focus is set on peer-reviewed articles published in international journals; however, for the sake of completeness, recent articles published on the topic in e.g. conference proceedings are as well included. In the end, our literature review covers 28 studies or research works (cf. ***Table 1***).

Table 1 **:** List of reviewed studies (listed in the order of publication date)

Author(s) and year	Title of study
(Hoffstetter and Norris 2003)	Why and How Should We Assess Occupational Health Impacts in Integrated Product Policy?
(Weidema, 2006)	The Integration of Economic and Social Aspects in Life Cycle Impact Assessment
(Brent and Labuschagne 2006)	Social Indicators for Sustainable Project and Technology Life Cycle Management in the Process Industry
(Dreyer et al. 2006)	A Framework for Social Life Cycle Impact Assessment
(Norris 2006)	Social Impacts in Product Life Cycles - Towards Life Cycle Attribute Assessment
(Hunkeler 2006)	Societal LCA Methodology and Case Study (12 pp)
(Hutchins and Sutherland 2008)	An exploration of measures of social sustainability and their application to supply chain decisions
(Jørgensen et al. 2009)	Assessing the validity of impact pathways for child labour and well-being in social life cycle assessment
(Jørgensen et al. 2010)	Defining the baseline in social life cycle assessment
(Moriizumi et al. 2010)	Simplified life cycle sustainability assessment of mangrove management: a case of plantation on wastelands in Thailand
(Feschet et al. 2012)	Social impact assessment in LCA using the Preston pathway
(Menikpura, et al. 2012)	Framework for life cycle sustainability assessment of municipal solid waste management systems with an application to a case study in Thailand
(Lagarde and Macombe 2012)	Designing the social life cycle of products from the systematic competitive model
(Baumann et al. 2013)	Does the Production of an Airbag Injure more People than the Airbag Saves in Traffic?
(Arvidsson et al. 2014)	On the scientific justification of the use of working hours, child labour and property rights in social life cycle assessment: three topical reviews
(Neugebauer et al. 2014)	Impact Pathways to Address Social Well-Being and Social Justice in S-LCA—Fair Wage and Level of Education
(Bocoum et al. 2015)	Anticipating impacts on health based on changes in income inequality caused by life cycles
(Wu et al. 2015)	Causality in social life cycle impact assessment (SLCIA)
(Musaazi et al. 2015)	Quantification of social equity in life cycle assessment for increased sustainable production of sanitary products in Uganda
(Weidema 2016)	The social footprint—a practical approach to comprehensive and consistent social LCA
(Silveri 2016)	Anticipating Psychosocial Factors Effects in the agri-food sector: the Siegrist's Pathway
(Di Cesare et al. 2016)	Farmworkers' pesticides exposition assessment: the Wesseling pathway
(Arvidsson et al. 2016)	A method for human health impact assessment in social LCA: lessons from three case studies
(Touceda Gomez 2016)	Implementation of socioeconomic criteria in a Life cycle sustainability assessment framework applied to housing retrofitting - The Brussels-capital region case study
(Neugebauer et al. 2016)	Calculation of Fair wage potentials along products' life cycle – Introduction of a new midpoint impact category for social life cycle assessment
(Weidema, 2018b)	Towards a taxonomy for social impact pathway indicators
(Sureau and Achten, 2018)	Including chain governance and economic aspects to assess and explain social impacts: a methodological proposal for S-LCA
(Iofrida et al., 2019)	Psychosocial risk factors' impact pathway for social life cycle assessment: an application to citrus life cycles in South Italy

2.2 Method

For the evaluation we analyze and characterize the 28 studies under consideration against the following criteria:

i. Purpose of the article/the research on impact pathways: e.g. is the article proposing impact pathways, investigating an impact pathway, implementing a case study;
ii. Method used to deal with impact pathways: e.g. is a statistical approach, or literature review applied;
iii. Issues/variables used/investigated: e.g. number of variables and aspects/topics covered (such as health impacts, economic aspects, other aspects);
iv. Data collection/origin of the result: how are the data/result obtained, i.e. measurement with observed data (statistics or on-site collection) or calculation (implying a characterization).

On this basis, we analyze common features within the approaches as well as the main differences, considering the first criterion *i. Purpose of the research* as a main entry point, as it seemed to determine several other characteristics included in the approaches. In addition, to determine whether the selected articles correspond indeed to Type II S-LCA, we check against the three following characteristics:

i. the reflection of an impact pathway;
i. the availability of so-called inventory and impact indicators;
ii. the presence of characterization models or factors translating correlations or causality.

3 Results

Through the criteria and defined characteristics, we identify three (3) main paths of Type II S-LCA studies (see ***Figure 2***). In the first path we summarize studies targeting the identification or proposition of impact pathways (e.g. impact pathways relating to unemployment in (Jørgensen et al., 2010)) or frameworks (e.g. the general one of Weidema 2006); the second path displays studies investigating impact pathways (e.g. the Preston pathway in Feschet et al. 2012); and the third path includes approaches applying existing and known impact pathways, characterization models or factors from other research works or calculating impacts at a midpoint or endpoint level (e.g. the three case studies of Arvidsson et al. 2016).[2] A more detailed description of all reviewed studies and approaches can be taken from electronic **Supplementary material 1**). Within each path we can distinguish nine (9) general approaches, which are detailed below.

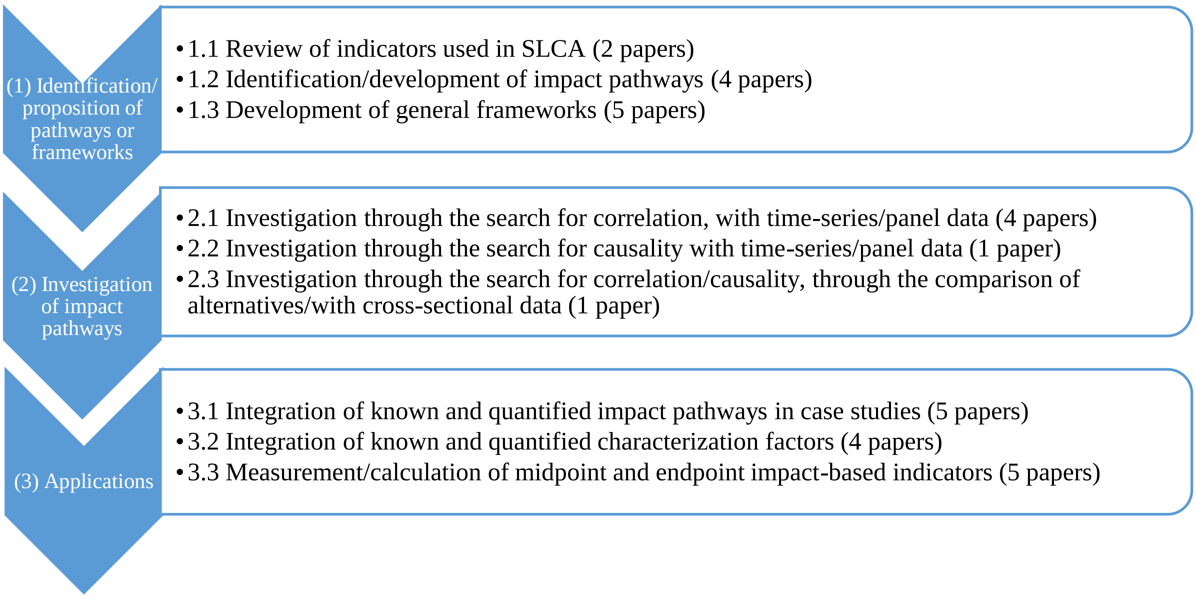

Figure 2 **:** Illustration of the 3 main paths and nine general approaches identified in Type II studies (some studies apply to more than one approach)

[2] These 3 paths (identification of variables, testing and applications) are not to be understood as subsequent steps, but rather as a way to highlight the authors´ intentions within their studies. However, the studies relating to the different paths may benefit from each other and one may be used as the basis for further studies.

Identification or proposition of pathways or frameworks

Studies classified under the first path strive to identify/develop/propose impact pathways and/or frameworks for S-LCA. Some of the studies also implement a case study (e.g. Neugebauer et al. 2016), which however does not constitute the core of the article, but is rather meant as a justification of the preliminary work undertaken. One of the studies investigates impact pathways as well (Weidema, 2006), but it seems that the core of the work is to provide a comprehensive and coherent framework rather than to test it.

Among this first path, we distinguish three different approaches. Studies gathered under **Approach 1.1** review assessment criteria used in Type I S-LCA (e.g. Guidelines' subcategories) and check whether these criteria are relevant/suitable in relation to impact pathways to be investigated. (Jørgensen et al., 2009) investigate the impacts of child labor on the basis of an extensive literature review including various research fields (e.g. social science), and (Arvidsson et al., 2014) undertake a similar approach extending child labor to working hours and property rights. Both studies highlight how research done in these different fields may benefit and feed S-LCA. Although the research undertaken does not target a specific application, it seems to be a prerequisite for developing and applying (concrete) impact pathways. It may further be useful to justify the use of indicators in Type I S-LCA.

Studies classified under **Approach 1.2** use similar methods as studies from the first approach, but aim to define/build single/specific impact pathways, rather than solely checking the relevance of used assessment criteria. They build on existing research, e.g. by using literature reviews (Jørgensen et al. 2010, who look at the various impacts of unemployment), by integrating specific theoretical frameworks (Sureau and Achten 2018, who link product chain governance, profitability and working conditions along the chain), by using external sources such as expert knowledge on the pathway to be documented (Di Cesare, 2016 who looks at how the exposure to pesticides impacts health of farm workers, or by combining several ways (Silveri, 2016, who looks at the factors influencing occupational health).

While studies of the 1.2 approach define single impact pathways, studies listed under **Approach 1.3** propose general frameworks to conduct S-LCA that include several impact pathways linking inventory indicators, midpoint, endpoint impacts and/or areas of protection. Frameworks can equate to a taxonomy, which purpose is "to provide structure and conceptual clarity to a scientific domain through clear definitions of hierarchically organized concepts" (Weidema, 2018b, p. 1). Most of these works (Brent and Labuschagne, 2006; Dreyer et al., 2005; Weidema, 2018b, 2006) adopt a top-down approach, propose areas of protection and endpoint categories that are to be linked to inventory indicators and seek to provide a comprehensive picture. As an example, Weidema (2006) proposes 14 quantitative social pressure inventory indicators to be linked to six damage areas including life and longevity, health, autonomy, safety, security and tranquility, equal opportunities, participation and influence. The study of (Neugebauer et al., 2014) on the other hand focuses on two specific midpoint categories (fair wage and education) and proposes specific impact pathways related to these two categories, linking inventory indicators to the included AOPs (i.e. social well-being and social justice). In approaches 1.1, 1.2 and 1.3, variables composing impact pathways are *identified and proposed*.

Investigation of impact pathways

In this second path, researchers investigate impact pathways that have already been identified by researchers in other disciplines. The idea is to prove empirically their existence or even to quantify the relationship between two or more variables, in order to be able to use the characterization factor in case studies. Most of the time, the model is then applied to a case study. To achieve this, authors look for correlations or causality between two or more variables with time series and/or panel econometric modeling. Once the correlation or causality has been proven, it can be used to predict a change in the impact variable (e.g. health impacts) if the explanatory variable changes (e.g. income) or to compare alternatives (Hutchins and Sutherland, 2008). For now, studies using econometric modeling focus on the relation between incomes or income inequality linked to the product life cycle and health impacts (life expectancy or child mortality rate).

At a methodological level, a distinction has been made by (Neugebauer et al. (2016) and Bonacina De Auraujo and Ugaya (2018) between studies inferring correlation (**approach 2.1**) and those inferring causality (**approach 2.2**): simple and multiple regression modelling makes it possible to prove a correlation (as in Norris 2006; Hutchins and Sutherland 2008; Feschet et al. 2012; Bocoum, Macombe, and Revéret 2015), while Structural Equation Modelling (SEM, as used in only one study, Wu et al., 2015); makes it possible to establish causality. Indeed, "in SEM, it is possible to analyze several dependency relations simultaneously", with several explanatory and explained variables (Bonacina De Auraujo and Ugaya, 2018, p. 69). Rather, simple and multiple regression analyze the relationship between several explanatory variables and a single explained variable, and “do not allow the identification of factors” or latent variables, but “the prediction of the [explained] variables, through the determination of coefficients” (Bonacina De Auraujo and Ugaya, 2018, p. 69). What brings together approaches 2.1 and 2.2 is the use of what Neugebauer, (2016) call “consequential modelling” to investigate impact pathways: researchers compare two situations, before and after a change in the product life cycle, and they look for co-variations of two or more indicators during a time period. The study of Feschet et al., (2012) illustrates what is done in approach 2.1: the characterization factor linking GDP per capita and life expectancy is calculated with a simple regression, on the basis of panel data from 107 countries, as well as its conditions for use. The study of Wu et al. (2015) extends the work of Feschet et al. (2012) and provides an example of the approach 2.2 by identifying with SEM two latent variables, health expenditures and health access, that mediate the impact pathway from GDP to life expectancy.

(Hofstetter and Norris, 2003) take a different approach to investigate impact pathways: they compare alternatives (**approach 2.3**). The idea is to compare the S-LCA results of product life cycles which differ on one (or more) parameter(s) and to determine from this whether this changing parameter is decisive and can be considered as an explanatory factor, as well as to potentially identify other explanatory parameters. In their study, (Hofstetter and Norris, 2003) investigate the pathway “differences in worker health according to sectors" (Feschet, 2014) by comparing the number of occupational injuries and illness in two sectors (steel and plastic) producing the same product (fuel tank systems for cars). However, the type of data used is the same as in 2.1, 2.2 and 2.3 since they use generic data/statistics at a sectoral level.

In approaches 2.1, 2.2 and 2.3, so-called inventory and impacts data are *observed* through statistics and from these impact pathways are investigated or tested.

Applications

Studies of the third path are applications. These applications include three approaches, for which the use of impact pathways vary: some studies apply existing and already quantified impact pathways (3.1), some others apply characterization factors (3.2) and some others calculate impacts at midpoint or endpoint levels (3.3). While some of the studies adopt the same approach for all indicators (approach 3.1 for Iofrida et al. 2019), other studies adopt different approaches according to indicators (approaches 3.1 and 3.3 for Arvidsson et al. 2016; Touceda, Neila, and Degrez 2016, approaches 3.1 and 3.2 for Menikpura, Gheewala, and Bonnet 2012); these latter studies are therefore found in different approaches.

In the approach (3.1), practitioners apply already known and already quantified impact pathways (meaning that a characterization factor has already been calculated) and calculate impact indicators. Arvidsson et al., (2016), Baumann et al. (2013),and Touceda et al., (2016) use the inventory made in the framework of an Environmental LCA (i.e. E-LCI, physical inputs and outputs linked to a product life cycle) to calculate health impacts. These studies include health impacts related to human toxicity only (e.g. Baumann et al. 2013) or to other E-LCA impact categories as well (Arvidsson et al., 2016). While (Touceda et al., 2016) include impacts from near-field environment for the product use phase (as opposed to impacts from far-field environment, see (Huang et al., 2017)), it is not clear whether these impacts are taken into account in other studies of 3.1 group. (Iofrida et al., 2019) use existing researches in medical sciences mainly to assess health impacts on workers exposed to specific working conditions. Instead of using the composite indicator DALY, (Iofrida et al., 2019) keep results disaggregated and highlight links between specific working conditions (e.g. long working hours) and specific diseases (e.g. metabolic syndrom). In this approach, impact results are calculated, since they are obtained after applying a characterization factor linking two distinct variables or phenomena.

In approach (3.2), characterization factors are also used to calculate impacts. However, these characterization factors link variables or phenomena which, on the impact pathway, are closer to each other or are less distinct than the ones described in (3.1) approaches. Hunkeler (2006); Menikpura et al. (2012); Musaazi et al. (2015) and Weidema (2016) calculate the impact of incomes generated by the product life cycle on access for stakeholders to basic needs or utility with respectively cost of living in various countries and elasticity of marginal utility of income (i.e. characterization factors). The idea behind these approaches is that a same monetary flow will have a different impact if earned and spent in a poor country or in a rich country. In this sense, rather than to calculate impacts from an inventory indicator with the support of a characterization factor, studies of the 3.2 approach put inventory data in perspective (e.g. income generated by the product life cycle), with the support of specific data (e.g. cost of living in the country) .In the **approach (3.3)** practitioners assess midpoint or endpoint impact-based indicators but without the explicit use of impact pathways. It means that indicators are assessed alone and are not linked to a stressor or an inventory indicator. It means that features of impact pathways (predicting or explaining impacts) cannot be used since no link is established between two phenomena. This approach seems rather a reporting approach. However, these approaches are included in this review since the used indicators do not reflect an activity on the product system, i.e. behavior of life cycle organizations or consumers, but rather (measure) effects located further on the impact pathway. In addition, for these impacts no referencing is made (as would happen in type I). Finally, these impacts are assessed together with other impacts, which on the contrary are calculated with the use of impact pathways. Therefore, these studies are considered type II studies and are on the radar of this review. Indicators concerned with this approach are mainly of three kinds: DALY (Arvidsson et al., 2016; Baumann et al., 2013; Touceda et al., 2016), number of jobs (Lagarde and Macombe, 2012), and other composite indicators (Touceda et al., 2016). In the case of (Touceda et al., 2016), indicators are composite and gather various collected data. (Lagarde and Macombe, 2012) use a single indicator summing up job creations and destructions resulting from of a change in a product life cycle which has impact on demand for competitors. Thus, in this latter study, we find again a consequential modelling, however, in this case, the link between two indicators is not done as it is done by e.g. (Feschet et al., 2012), who investigate the link between GDP per capita and life expectancy. For the rest of studies classified in (3.3), impacts are actually *observed and measured* (including in statistics) and are not the result of a characterization.

4 Discussion

4.1 About other classifications

Our classification shares common characteristics with previous classifications, but also differences, as detailed in **Table 2**.

Table 2: Classification proposed in this study compared to other existing classifications

Our classification		Macombe (2013) – Pathways:	Wu et al. (2014) - Pathways:	Chhipi-Shrestha et al. (2014) – Methods:	(Neuge bauer, 2016)	(Bonacina De Auraujo and Ugaya, 2018)
Identification/ proposition of pathways/ frameworks	Review of indicators used in type I S-LCA (1.1)		Multiple qualitative			
	Identification/building of impact pathways (1.2)	Pathway 2			Type II/III	
	Development of theoretical frameworks (1.3)		Multiple qualitative	Empirical	Type II	
Investigation of impact pathways	Investigation through the search for correlation (2.1)	Pathway 1	Single and quantitative	Empirical	Type III	Simple and multiple regression
	Investigation through the search for causal inference (2.2)				Type II	Structural equations modelling
	Investigation through the comparison of alternatives (2.3)					
Applications	Application of impact pathways (3.1)	Pathway 2		E-LCI database	Type II	
	Application of characterization factors (3.2)			E-LCI database	Type II	
	Application of impact-based indicators (3.3)	Pathway 3		Empirical/E-LCI database	Type II	

With the here proposed classification we add detail on the currently existing classifications regarding Type II SLCA. Wu et al. (2014) distinguish single and multiple impact pathways, while Wu et al (2015) distinguishes between quantitative and qualitatively constructed impact pathway with expert knowledge (Wu et al., 2015). Qualitatively constructed impact pathways correspond to studies identifying or proposing pathways or frameworks (1). Single quantitative impact pathways correspond to studies investigating pathways either through the search for correlation (2.1) or the search for causal inference (2.2). Chhipi-Shrestha et al. (2014) simply distinguish the method which uses environmental LCI databases to estimate social impacts and the empirical methods. However, the "empirical method" which is defined as involving "the use of empirical formulas or rules in order to assess social impacts" appears to encompass very different methods. We found that studies under that category can be either grouped under 1.3 (*development of theoretical frameworks*), 2.1 (*investigation of impact pathways*), or 3.3 (*measurement of impact indicators*). Studies using environmental LCI databases correspond to two types: *applications of impact pathways* (3.1), but also *to measurements of impact-based indicators* (3.3). As regards the classification of (Macombe, 2013a): Pathway 1 that is based on a formalized mathematical relation can be classified under *investigation of impact pathways through the search for correlations* (2.1), Pathway 2 that presents a matrix of known results on relations can be classified under *identification/building of impact pathways (1.2)*, and Pathway 3 which assesses social effects corresponds to *measurement of impact-based indicators (*3.3).

More recently, (Neugebauer, 2016) and (Bonacina De Auraujo and Ugaya, 2018) put apart Type II studies looking for correlation between variables (Feschet et al., 2012; Hutchins and Sutherland, 2008; Norris, 2006) from those looking for causal inference (Wu et al., 2015), with a new dedicated category (Type III) as proposed in (Neugebauer, 2016). We consider that approaches investigating impact pathways through the search for correlation classified in (2.1) (or in Type III S-LCA according to (Neugebauer, 2016), which use simple and multiple regressions, are consistent with the impact pathway approach. The objective of these is to reveal/highlight empirical causal relations between phenomena and to quantify them, through the search for correlations. Simple and multiple regressions are one of the methods used by social scientists to analyze causal relations. It does not allow to infer causality, but so are most almost all methods in social sciences which are not experiments. Experiments are in fact the only effective way to infer causality, since it is the only way to isolate the effect from a specific cause, but they can rarely be used in social sciences (Behaghel, 2006). S-LCA being partly based on findings from social sciences, investigation of impact pathways through the search for correlation can be regarded as type II.

4.2 About a definition for Type II S-LCA

Coming from the distinction made by (Russo Garrido et al., 2016) between Type I and Type II, our findings underline the differences between the two approaches (Type I and II) for social life cycle impact assessment. Furthermore, our investigation allows to encompass the diversity of approaches in studies stamped as Type II. Purposes, covered impacts, data collection, result obtaining methods and identification/investigation methods differ greatly. However, what gathers all those Type II studies is to not consider phenomena or impacts in isolation but the search to link them to the source(s) of the impacts, or to further impacts or social aspects. According to this definition, we believe that Type II S-LCIA is not only about quantitative indicators, nor about measuring endpoint impacts, but about using impact pathways i.e. pathways linking interconnected phenomena, also with rather qualitative approaches.

Thus, we judge qualitative approaches described and studies classified in the first path (Identification/proposition of pathways or frameworks) consistent with Type II S-LCA. Even though not quantitative, these studies consider existing research from different fields, often social sciences, to review or build pathways for relevant social phenomena considered within the S-LCA framework. They further expand the coverage of the topics that are commonly covered in S-LCA impact pathway approaches.

Studies using quantitative variables, such as studies measuring impact indicators at a midpoint or endpoint level (e.g. DALY that we classify under the approach 3.3) are not necessarily studies using the impact pathway approach. For example, some studies provide results on the number of deaths occurring in a product process, thanks to company's reporting on occupational accidents. However, this number of death is not related to specific inputs or tasks in the process. Using impact pathways implies investigating the connection between two phenomena or events: in the S-LCA field, connecting a company's practice to its effect on people or to its source. This feature for a long time was seen as one of the main strengths of the E-LCA approach since it allows to be aware of problem's sources and consequently derive improvement potentials from it. This is a key reason for continuing research on Type II S-LCA approaches targeting the further development and integration of impact pathways. However, in the study of (Arvidsson et al., 2016), in the impact assessment for the use life cycle phase the underlying impact pathway is not mentioned. This may lead to inconsistent results, as they are obtained in different ways (observed data versus data obtained after a characterization). It may on the one hand increase the scope of these studies (by including further issues or life cycle phases), but may at the same time be a source of unclarity.

4.3 Recommendations

4.3.1 On the use of the proposed classification

Starting from the within, this study presented a clearer picture on the different approaches in Type II S-LCA. Our results can be used to identify or prioritize future research fields of Type II S-LCA or S-LCA in general. The classification can also help in clarifying the intention and/or objective of researchers or practitioners before they start with their work in the context of Type II S-LCIA. For instance, do they seek to identify or propose variables composing impact pathways, to investigate or test proposed impact pathways or to apply known pathways or characterization factors? Examples on the different approaches can be read in the **Supplementary material 1** in accordance with our classification, which may serve as a good starting point for further investigations.

Once the purpose of the research work is set, it could be interesting to specify the method used, the way that data/result is obtained (at the start and at the end of the impact pathway) and the investigated phenomena composing the impact pathway. The present review can lead the practitioner to relevant studies that pursued the same research purpose and can thus inspire/guide the researchers in the development of their approach. We summarize the findings of our review in the decision tree representing the various possible approaches and methods (cf. **Figure 3**).

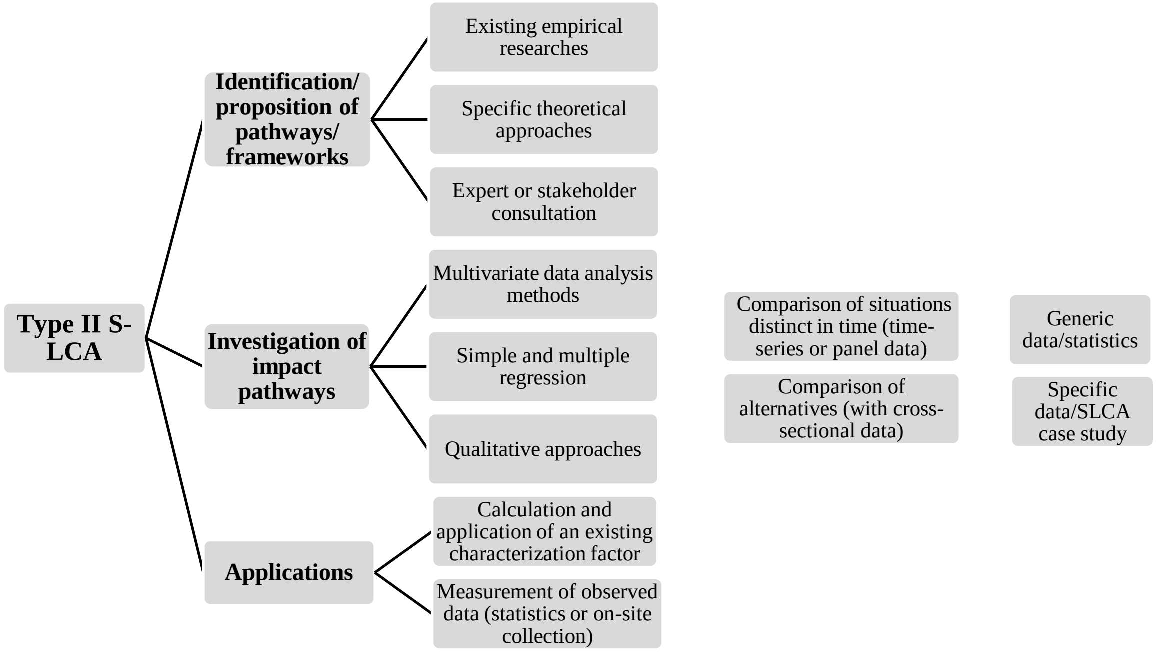

***Figure 3**: Decision tree for S-LCA type II research*

- If the purpose is to identify variables composing impact pathways (1st path), the means used could be: existing empirical researches, including in social sciences, specific theoretical approach, expert or stakeholder consultation;
- If the purpose is to investigate pathways (2nd path): the approach used could be a method to infer causality (e.g. SEM), to quantify a correlation (e.g. simple and multiple regression), or another more qualitative approach. If the purpose is to apply impact pathways, characterization factors, or to measure midpoint or endpoint impact indicators (3rd path): the two linked phenomena and the way that data or result is obtained could more clearly be specified. For the latter, it can be through a calculation and the application of an existing characterization factor or through a simple measurement of observed data (statistics or on-site collection).In that former case, the specification of the origin of the characterization factor should be required in any S-LCA study, in order to ensure transparency.

4.3.2 For future Type II research

Using existing theoretical frameworks to identify pathways

We have seen that several ways are used to identify impact pathways or general frameworks for S-LCA (expert and stakeholder consultation, existing scientific knowledge). To identify impact pathways, we recommend **using existing theoretical frameworks**, including in social sciences (e.g. economics, sociology, management studies, development studies), which are themselves drawn from empirical observations. This recommendation is in accordance with previous calls to draw on existing researches in social sciences (Arvidsson et al., 2014; Grubert, 2016; Iofrida et al., 2016) and to reinforce theoretical grounds for S-LCA, especially when it comes to impact pathways (Feschet, 2014; Iofrida et al., 2016; Jørgensen et al., 2009). To select impact pathways we argue more precisely to use theories that seek to explain or understand phenomena relevant for S-LCA (e.g. health impacts of workers and users, poor employment and working conditions, or inequalities within supply chains).

Using multivariate data analysis methods to investigate impact pathways (Bonacina De Auraujo and Ugaya, 2018; Neugebauer, 2016; Wu et al., 2015)

If identified impact pathways have been investigated enough, validated or even quantified, these can be directly integrated in S-LCA case studies (as 3.1 approaches do). Otherwise, identified impact pathways might be empirically investigated and/or tested, before being integrated in SLCA case studies. The investigation of impact pathways has been done mostly with econometric modelling, and simple and multiple regression through the search for correlation between two indicators (e.g. Bocoum et al., 2015; Feschet et al., 2012; Norris, 2006) (Neugebauer, 2016). In the same vein, (Wu et al., 2015) used structural equation modelling in order to infer causality. We support the call of (Bonacina De Auraujo and Ugaya, 2018) to expand this by existing **multivariate data analysis methods** in order to identify latent variables in impact pathways (e.g. principle component analysis, exploratory factor analysis), or even in order to confirm these latent variables (incl. with structural equations modelling).

While these studies look at the co-variations of two or more indicators during a time period, another and less used way to investigate causality is **to look for variations of indicators among individuals** as done by (Hofstetter and Norris, 2003) (cf. **Supplementary material 1**). It appears that it would be worth using this latter approach also in order to investigate impact pathways.

Using S-LCA to build knowledge on cause-effect chains relating to product life cycles

These studies using statistical methods are implemented with generic data, often at macro level. Possibly, the investigation of impact pathways could also be done through **the carrying out of a S-LCA case study based on specific data, collected on-site** (cf. **Figure 3**). This would then suppose that all investigated variables be observable, and would thus exclude certain non-observable variables on e.g. health impacts which are rarely observable at the time that the study is carried out. But a number of variables and impact pathways could be investigated this way.

Obviously, when using specific data (and thus small samples) it is not possible to call upon statistical methods to investigate impact pathways. Other methods in social sciences to analyze cause-effect chains might be usefully explored and potentially imported into S-LCA methodological development works, e.g. **more qualitative methods such as mechanism analysis/identification** (Gorton, 2019; Knight and Winship, 2013).

Impact pathways may be investigated with smaller sample of specific data, but those should then be applied to other cases in order to check their general applicability. The approach envisaged in (Sureau and Achten 2018) corresponds to the investigation of an impact pathway through the carrying out of a S-LCA case study using specific data and comparing various alternatives for the same product (cf. **Figure 3**). These alternatives are chosen on the basis of their differences, corresponding to parameters which are set as explanatory variables of other impacts variables. The objective of (Sureau and Achten, 2018) is to analyze the causality between product chain governance models, transaction modalities, value chain actors profitability and provided employment conditions. Such approach could be used to analyze other causal relations (e.g. working conditions and worker wellbeing). **In this way, S-LCA can be used as an empirical tool to build knowledge on cause-effect chains relating to product life cycle**

Looking at the root causes of main social issues

The discussion above brings us to the key issue of what is to be assessed. When looking at impact pathways included in current Type II approaches investigating (2) and applying pathways (3), we can conclude that these are limited to E-LCI, income and health variables, i.e. mainly quantitative variables, for which there is an easy access to data at macro level for the latter ones (one notable exception is the recent study of (Iofrida et al., 2019) linking exposure to certain working conditions and health impacts). This is however not the case of approaches identifying impact pathways (1), which include much more diverse variables that get close to what is being assessed in Type I S-LCA. Together with the use of more qualitative approaches to investigate impact pathways (cf. recommendations), other impact pathways and **qualitative variables** relevant to S-LCA (e.g. including the issue of employment and working conditions in the supply chain) could be addressed. The approaches using quantitative model and variables has clear advantages and merits, and also deserve further research. However, we consider that we should not limit ourselves to quantitative models and variables, because such a limitation will necessarily hamper the coverage and potential comprehensiveness of S-LCA. We argue that S-LCA should not be adapted to fit the E-LCA format, but S-LCA should be tailored to explain social mechanisms by considering the (social) nature of assessed impacts or phenomena, implying other variables and methods.

Such a shift to other variables and impact pathways could be a way to align Type I and Type II S-LCA. In fact, putting in perspective Type II studies with what is done in Type I S-LCA, we observe few connections between these two fields in terms of assessed aspects or variables. Type I studies focus mainly on employment and working conditions in supply chains, highlighting the presence of "hotspots" or unfavorable practices of suppliers regarding workers, in the context of contemporary global value chains. While S-LCA is developed with the aim to improve social impacts linked to product life cycles, few Type II studies focus on the investigation of sources or causes of main social issues, such as poor employment and working conditions on supplier side. Indeed, current approaches focus on the downstream side of impact pathways (assessing health impacts of certain working conditions or income), rather than **the upstream side of impact pathways (looking for the root causes of indecent employment and working conditions or income)**. Thus, we see a need to investigate impact pathways linking main problems in product life cycles. We foresee interesting areas of potential research investigating the root causes of inequalities within product chains, and of poor employment and working conditions at level of suppliers or upstream nodes of value chains, which are the main hotspots highlighted in type I S-LCA studies. Such research could help identify levers that could be activated to improve the social sustainability of product chains.

Acknowledgments

This research is funded by a Mini-ARC PhD scholarship of the Université libre de Bruxelles.

5 References

Arvidsson, R., Baumann, H., Hildenbrand, J., 2014. On the scientific justification of the use of working hours, child labour and property rights in social life cycle assessment: three topical reviews. Int. J. Life Cycle Assess. 20, 161–173. https://doi.org/10.1007/s11367-014-0821-3

Arvidsson, R., Hildenbrand, J., Baumann, H., Islam, K.M.N., Parsmo, R., 2016. A method for human health impact assessment in social LCA: lessons from three case studies. Int. J. Life Cycle Assess. 1–10. https://doi.org/10.1007/s11367-016-1116-7

Baumann, H., Arvidsson, R., Tong, H., Wang, Y., 2013. Does the Production of an Airbag Injure more People than the Airbag Saves in Traffic? J. Ind. Ecol. 17, 517–527. https://doi.org/10.1111/jiec.12016

Behaghel, L., 2006. Lire l'économétrie, Collection Repères. Economie ; 460. La Découverte, Paris.

Benoît, C., Mazijn, B., 2009. Guidelines for social life cycle assessment of products. UNEP/SETAC, Paris.

Bocoum, I., Macombe, C., Revéret, J.-P., 2015. Anticipating impacts on health based on changes in income inequality caused by life cycles. Int. J. Life Cycle Assess. 20, 405–417. https://doi.org/10.1007/s11367-014-0835-x

Bonacina De Auraujo, J., Ugaya, C.M.L., 2018. Development of S-LCIA models: a review of multivariate data analysis methods, in: Pre-Proceedings, Fruitrop Thema. Presented at the 6th Social LCA conference - People and places for partnerships, CIRAD, Pescara, Italy.

Brent, A., Labuschagne, C., 2006. Social Indicators for Sustainable Project and Technology Life Cycle Management in the Process Industry (13 pp + 4). Int. J. Life Cycle Assess. 11, 3–15. https://doi.org/10.1065/lca2006.01.233

Chhipi-Shrestha, G.K., Hewage, K., Sadiq, R., 2014. 'Socializing' sustainability: a critical review on current development status of social life cycle impact assessment method. Clean Technol. Environ. Policy 17, 579–596. https://doi.org/10.1007/s10098-014-0841-5

Di Cesare, S., 2016. Farmworkers' pesticides exposition assessment: the Wesseling pathway.

Di Cesare, S., Macombe, C., Petti, L., Loeillet, D., 2016. Necessity of including the evaluation of pesticides impacts on farmworkers health in social LCA, in: Book of Abstracts SLCA 2016. Presented at the 5th International S-LCA conference, Harvard, Cambridge, USA.

Dreyer, L., Hauschild, M., Schierbeck, J., 2005. A Framework for Social Life Cycle Impact Assessment (10 pp). Int. J. Life Cycle Assess. 11, 88–97. https://doi.org/10.1065/lca2005.08.223

Feschet, P., 2014. Analyse du Cycle de Vie Sociale. Pour un nouveau cadre conceptuel et théorique (PhD Thesis). Université de Montpellier 1, Montpellier, France.

Feschet, P., Macombe, C., Garrabé, M., Loeillet, D., Saez, A.R., Benhmad, F., 2012. Social impact assessment in LCA using the Preston pathway. Int. J. Life Cycle Assess. 18, 490–503. https://doi.org/10.1007/s11367-012-0490-z

Gorton, W., A., 2019. The Philosophy of Social Science. Internet Encycl. Philos.

Grubert, E., 2016. Rigor in social life cycle assessment: improving the scientific grounding of SLCA. Int. J. Life Cycle Assess. 1–11. https://doi.org/10.1007/s11367-016-1117-6

Hofstetter, P., Norris, G.A., 2003. Why and How Should We Assess Occupational Health Impacts in Integrated Product Policy? Environ. Sci. Technol. 37, 2025–2035. https://doi.org/10.1021/es025838w

Huang, L., Ernstoff, A., Fantke, P., Csiszar, S.A., Jolliet, O., 2017. A review of models for near-field exposure pathways of chemicals in consumer products. Sci. Total Environ. 574, 1182–1208. https://doi.org/10.1016/j.scitotenv.2016.06.118

Hunkeler, D., 2006. Societal LCA Methodology and Case Study (12 pp). Int. J. Life Cycle Assess. 11, 371–382. https://doi.org/10.1065/lca2006.08.261

Hutchins, M.J., Sutherland, J.W., 2008. An exploration of measures of social sustainability and their application to supply chain decisions. J. Clean. Prod., Sustainability and Supply Chain Management 16, 1688–1698. https://doi.org/10.1016/j.jclepro.2008.06.001

Iofrida, N., De Luca, A.I., Silveri, F., Falcone, G., Stillitano, T., Gulisano, G., Strano, A., 2019. Psychosocial risk factors' impact pathway for social life cycle assessment: an application to citrus life cycles in South Italy. Int. J. Life Cycle Assess. 24, 767–780. https://doi.org/10.1007/s11367-018-1482-4

Iofrida, N., Luca, A.I.D., Strano, A., Gulisano, G., 2016. Can social research paradigms justify the diversity of approaches to social life cycle assessment? Int. J. Life Cycle Assess. 1–17. https://doi.org/10.1007/s11367-016-1206-6

ISO, n.d. ISO 26000 Social responsibility [WWW Document]. ISO. URL http://www.iso.org/cms/render/live/en/sites/isoorg/home/standards/popular-standards/iso-26000-social-responsibility.html (accessed 4.29.19).

Jørgensen, A., Jørgensen, M.S., Finkbeiner, M., Hauschild, M.Z., 2010. Defining the baseline in social life cycle assessment. Int. J. Life Cycle Assess. 15, 376–384. https://doi.org/10.1007/s11367-010-0176-3

Jørgensen, A., Lai, L.C.H., Hauschild, M.Z., 2009. Assessing the validity of impact pathways for child labour and well-being in social life cycle assessment. Int. J. Life Cycle Assess. 15, 5–16. https://doi.org/10.1007/s11367-009-0131-3

Knight, C.R., Winship, C., 2013. The Causal Implications of Mechanistic Thinking: Identification Using Directed Acyclic Graphs (DAGs), in: Morgan, S.L. (Ed.), Handbook of Causal Analysis for Social Research, Handbooks of Sociology and Social Research. Springer Netherlands, Dordrecht, pp. 275–299. https://doi.org/10.1007/978-94-007-6094-3_14

Lagarde, V., Macombe, C., 2012. Designing the social life cycle of products from the systematic competitive model. Int. J. Life Cycle Assess. 18, 172–184. https://doi.org/10.1007/s11367-012-0448-1

Macombe, C., 2013a. How can one predict social effects and impacts?, in: Social LCAs - Socio-Economic Effects in Value Chains, Fruitrop Thema. CIRAD/IRSTEA.

Macombe, C., 2013b. ACV sociales, Effets socio-économiques des chaines de valeurs, Fruitrop Thema. CIRAD, Montpellier, France.

Menikpura, S.N.M., Gheewala, S.H., Bonnet, S., 2012. Framework for life cycle sustainability assessment of municipal solid waste management systems with an application to a case study in Thailand. Waste Manag. Res. https://doi.org/10.1177/0734242X12444896

Musaazi, M.K., Mechtenberg, A.R., Nakibuule, J., Sensenig, R., Miyingo, E., Makanda, J.V., Hakimian, A., Eckelman, M.J., 2015. Quantification of social equity in life cycle assessment for increased sustainable production of sanitary products in Uganda. J. Clean. Prod., Integrating Cleaner Production into Sustainability Strategies 96, 569–579. https://doi.org/10.1016/j.jclepro.2013.10.026

Neugebauer, S., 2016. Enhancing Life Cycle Sustainability Assessment Tiered Approach and new Characterization Models for Social Life Cycle Assessment and Life Cycle Costing. Technischen Universität Berlin, Berlin, Germany.

Neugebauer, S., Emara, Y., Hellerström, C., Finkbeiner, M., 2016. Calculation of Fair wage potentials along products' life cycle – Introduction of a new midpoint impact category for social life cycle assessment. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2016.11.172

Neugebauer, S., Traverso, M., Scheumann, R., Chang, Y.-J., Wolf, K., Finkbeiner, M., 2014. Impact Pathways to Address Social Well-Being and Social Justice in SLCA—Fair Wage and Level of Education. Sustainability 6, 4839–4857. https://doi.org/10.3390/su6084839

Norris, G.A., 2006. Social Impacts in Product Life Cycles - Towards Life Cycle Attribute Assessment. Int. J. Life Cycle Assess. 11, 97–104. https://doi.org/10.1065/lca2006.04.017

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. https://doi.org/10.1007/s11367-009-0146-9

Russo Garrido, S., Parent, J., Beaulieu, L., Revéret, J.-P., 2016. A literature review of type I SLCA—making the logic underlying methodological choices explicit. Int. J. Life Cycle Assess. 1–13. https://doi.org/10.1007/s11367-016-1067-z

Silveri, F., 2016. Anticipating Psychosocial Factors Effects in the Agri-food sector: the Siegrist's Pathway.

Sureau, S., Achten, W.M.J., 2018. Including governance and economic aspects to assess and explain social impacts: a methodological proposal for S-LCA, in: Social LCA, People and Places for Partnership - 6th Social LCA Conference, Fruitrop Thema. Presented at the 6th Social LCA conference - People and places for partnerships, Pescara, Italy.

Sureau, S., Mazijn, B., Garrido, S.R., Achten, W.M.J., 2017. Social life-cycle assessment frameworks: a review of criteria and indicators proposed to assess social and socioeconomic impacts. Int. J. Life Cycle Assess. 1–17. https://doi.org/10.1007/s11367-017-1336-5

Touceda, M.I., Neila, F.J., Degrez, M., 2016. Modeling socioeconomic pathways to assess sustainability: a tailored development for housing retrofit. Int. J. Life Cycle Assess. 1–16. https://doi.org/10.1007/s11367-016-1194-6

Weidema, B.P., 2018a. The social footprint—a practical approach to comprehensive and consistent social LCA. Int. J. Life Cycle Assess. 23, 700–709. https://doi.org/10.1007/s11367-016-1172-z

Weidema, B.P., 2018b. Towards a taxonomy for social impact pathway indicators, in: Pre-Proceedings, Fruitrop Thema. Presented at the 6th Social LCA conference - People and places for partnerships, CIRAD, Pescara, Italy.

Weidema, B.P., 2006. The Integration of Economic and Social Aspects in Life Cycle Impact Assessment. Int. J. Life Cycle Assess. 11, 89–96. https://doi.org/10.1065/lca2006.04.016

Wu, R., Yang, D., Chen, J., 2014. Social Life Cycle Assessment Revisited. Sustainability 6, 4200–4226. https://doi.org/10.3390/su6074200

Wu, S.R., Chen, J., Apul, D., Fan, P., Yan, Y., Fan, Y., Zhou, P., 2015. Causality in social life cycle impact assessment (SLCIA). Int. J. Life Cycle Assess. 20, 1312–1323. https://doi.org/10.1007/s11367-015-0915-6

Supplementary material 1: Description and characterization of Type II approaches – first path: Identification/proposition of pathways or frameworks

Title of study and author(s)	Purpose of the study and details of the method	Start of impact pathway	End of impact pathway
(1.1) REVIEW OF INDICATORS used in S-LCA through literature review in the light of impact pathways			
Assessing the validity of impact pathways for child labour […] (Jørgensen et al. 2009)	Through a review of literature of relevant research fields, investigation/discussion over the validity of an inventory indicator usually used in S-LCA.	Incidence of child labour	Various, incl. health risks, schooling outcomes, wage
On the scientific justification of the use of working hours, child labour and property rights […] (Arvidsson et al. 2014)	Through a literature review of non-S-LCA scientific articles, investigation of the scientific justification of the use of topics usually included in S-LCA. For each of the analysed topic, impacts were identified and classified according to whether the topics facilitated or obstructed beneficial social values/impacts, and whether they facilitated or obstructed adverse social values/impacts	Working hours, child labour and property rights	Various
(1.2) IDENTIFICATION/BUILDING OF SPECIFIC IMPACT PATHWAYS on the basis of existing research, theoretical approaches or external sources (consultation of stakeholders or experts)			
Defining the baseline in social life cycle assessment (Jørgensen et al., 2010)	On the basis of the statement that the "consequence of a decision to implement a life cycle of a product can be seen as the difference between the decision being implemented and 'non-implemented' product life cycle", identification of impacts relating to the non-implemented product life cycle on the basis of theories and empirical findings from relevant fields of research, and proposition of indicators. For workers, the study looks at impacts of unemployment and four impact categories are proposed, in addition to "modifying factors" (factors that influence the impacts).	Unemployment	Physical health and mental health, poverty, family tension, violence and crime
Anticipating Psychosocial Factors Effects in the agri-food sector: the Siegrist's Pathway (Silveri, 2016)	Silveri bases her work on the Job demands/resources model (Demerouti et al. 2001, 2004 in (Silveri, 2016)) in order to build a pathway linking working conditions and well-being at work (Siegrist pathway). The task is to identify most relevant job resources and demands that influence well-being at work. Variables and relations between them are identified through literature review and with the use of data from two sites of a French company bottling and selling wine (company social documents and interviews with workers). Next to that work, data were collected through a literature review to build a matrix relating factors "to the probability of a specific disease to occur". This pathway is called the Matrix pathway (Macombe, 2013b) in which all known results (qualitative and quantitative) for interesting relations are gathered from existing studies.	Job resources and demands (including psychosocial risk factors)	Risk of occupational health
Necessity of including the evaluation of pesticides impacts on farmworkers health in social LCA (Di Cesare et al., 2016)	In order to build the impact pathway linking pesticides exposure with health impacts on farm workers (Wesseling pathway), Di Cesare et al. use expert knowledge with expert elicitation/Delphi expert consensus method and interviews (systematic approach that synthesize subjective judgments of experts about one issue). From interviews, knowledge trees are designed. Then "human cost" equations are designed, with the use of this expert knowledge, especially on the degree of operators' exposure. The model can be used to compare different cropping systems for the same crop.	Pesticides exposure way	Health impacts on farm workers
Including chain governance and economic aspects to assess and explain social impacts […] (Sureau and Achten, 2018)	Proposition of an impact pathway linking product chain governance, inequalities within the product chain and working conditions on the basis of the theoretical approach of value chain and global supply chain analysis. The latter analyze the way that product chains are organized and governed and the power relations embedded in supply chains, which potentially explain inequalities within supply chains. Impact pathway to be investigated by comparing employment and working conditions in chains differing in terms of governance.	Chain governance and transaction modalities between value chain actors	Profitability, employment and working conditions

Title of study and author(s)	Purpose of the study and details of the method	Start of impact pathway	End of impact pathway
(1.3) DEVELOPMENT OF THEORETICAL FRAMEWORKS including several pathways/midpoint and endpoint categories			
The Integration of Economic and Social Aspects in Life Cycle Impact Assessment (Weidema, 2006)	Development of a framework including six damage categories that are to be aggregated to a comprehensive indicator (Quality Adjusted Life Years) and a set of inventory indicators. Provision of examples of impact pathways linking inventory indicators to impacts on wellbeing and productivity: child labour and autonomy infrangement and productivity (through lack of education), health impacts of unemployment, etc. In addition, an estimate of global normalization values is proposed.	14 quantitative social pressure inventory indicators measuring midpoint impacts	Damages incl. life and longevity, health, autonomy, safety, security and tranquility, equal opportunities, participation and influence, to be translated in QALY
Social Indicators for Sustainable Project and Technology Life Cycle Management in the Process Industry (Brent and Labuschagne, 2006)	Proposition of a theoretical framework to assess social sustainability of projects and technologies and of a quantitative method to calculate impacts. The framework includes four AOP) linked to 18 midpoint categories and to interventions of life cycle system. The method was then applied to projects and technologies in three process industries: an open cast mine, a chemical facility and a fibre manufacturing plant but not completely given the lack of data for each midpoint category.	Various	Internal human resources, external population, macro social performance and stakeholder participation
A Framework for Social Life Cycle Impact Assessment (Dreyer et al. 2005)	Proposition of a theoretical framework to conduct S-LCA. Dreyer proposes Human dignity and well-being as AoPs and a two-layer set of impact categories: an obligatory, normative, predetermined set of categories expressing minimum expectations to conducting responsible business (based on UN conventions and on local and national norms), and an optional, self-determined set of categories expressing interests specific to the product manufacturer. According to this framework, "Impacts on people are naturally related to the conduct of the companies engaged in the life cycle rather than to the individual industrial processes."	Conduct of companies	Two layer set of impact categories with obligatory and optional categories, under two AOPs
Impact Pathways to Address Social Well-Being and Social Justice in S-LCA—Fair Wage and Level of Education (Neugebauer et al., 2014) and Calculation of Fair wage potentials along products' life cycle – Introduction of a new midpoint impact category for social life cycle assessment (Neugebauer et al., 2016)	Development of qualitative pathways from life cycle inventory to endpoint impacts for two midpoint categories: **(1)** level of education and **(2)** fair wage. Definition of inventory indicators, of areas of protection (social well-being and social justice) and of three endpoint (economic welfare, environmental stability and damage to human health), that are to be linked to midpoint impacts. For the latter midpoint category (2), in a further article, proposition of a quantitative indicator "fair wage potential": real wage and working time are compared to minimum living wage and contracted working time. In addition, an inequality factor describing income inequalities at organizational, sectoral or country levels (according to data availability) is included. This approach is "comparable to the classical distance-to-target method that sets "the actual state in relation with the targeted situation" which is expressed by the characterization factor defined, thus this approach gets close to the Type I approach comparing life cycle inventory data with a performance reference point. Database to calculate the indicator and linkages with endpoints proposed. Model applied on case study on tomatoes produced in Germany.	**(1)** Indicators on education and discrimination	Type of jobs, working conditions, public and private education and information access as direct impacts, to be linked to level of education
		(2) Indicators on income, other benefits for employees and worker expenses	Access to needs as direct impacts to be linked to fair wage
Towards a taxonomy for social impact pathway indicators (Weidema, 2018b)	Development of a conceptually complete taxonomy for social impact pathway indicators, with elementary flows, midpoint impacts and endpoint impacts. Basis for this taxonomy includes Jolliet et al. (2009) for areas of protection, Simões (2014) for elementary flows, Bare et Gloria (2008) and UNECE (2014) (as cited in (Weidema 2018)).	Various	Equity-weighted welfare or utility

Description and characterization of Type II approaches – second path: investigation of impact pathways

Title of study and author(s)	Purpose of the study and details of the method	Start of impact pathway	End of impact pathway
(2.1) INVESTIGATION OF IMPACT PATHWAYS by searching for correlations with simple and multiple regression			
Social Impacts in Product Life Cycles – Towards Life Cycle Attribute Assessment (Norris 2006)	Reconstruction of the relation between economic activity and health with the support of World Bank data from 2002 and calculation of country-specific characterization factors. Norris applied these factors to calculate the impact on life expectancy of an increased economic activity in the (global) supply chain of Dutch electricity (with the help of a multiregional input/output LCI database) and to compare it to the impact of related pollution. He finds that "economic growth is much more powerful at achieving health benefits when it occurs in the lower-income countries". In the discussion part, Norris questions this approach given its limitations, including the uncertainties relating to the use of national-average impacts.	Incomes related to economic activity and pollution	Life expectancy
An exploration of measures of social sustainability and their application to […] (Hutchins and Sutherland 2008)	Use of the "UN's Human Development Report of 2005 to establish a non-linear regression model to describe the impact pathway from the GDP per capita in the purchasing power parity (PPP) to the infant mortality rate" (Wu, 2014). The model is then applied to a case where a company has to choose between two suppliers, in the US and in Mexico.	GDP per capita in PPA	child mortality rate
Social impact assessment in LCA using the Preston pathway (Feschet et al. 2012)	Calculation of the Preston pathway linking GDP per capita with life expectancy based on panel data from 107 countries, from [1950-2009] and definition of its conditions for use. Feschet et al. then apply the pathway to the bananas industry in Cameroon to calculate the health impacts resulting from the export of 200.000 tons of bananas annually over the 2010-2030 period.	GDP per capita	Life expectancy
Anticipating impacts on health based on changes in income inequality caused by life cycles (Bocoum et al., 2015)	Calculation of the relationship between income inequality and infant mortality (Wilkinson pathway) in member and non-member OECD countries with an empirical regression model based on the generalized method of moments (GMM). Data includes 46 countries over the period 1960-2006, that come from various sources. Then, Bocoum et al. propose "a method to calculate the change in income distribution in a population (hence the variation in the Gini coefficient) based on changes in the life cycle (expressed in variation in turnover)" and present a fictional case study.	Change in income distribution (GINI)	infant mortality rate
(2.2) INVESTIGATION OF IMPACT PATHWAYS by searching for causal inference between variables			
Causality in social life cycle impact assessment (SLCIA) (Wu et al. 2015)	Development of an approach to identify impact pathways with multiple impact categories simultaneously and intermediary variables for Type II characterization models through SEM (Structural equations modelling). Quantification of an example impact pathway at macro-scale.	GDP per capita, through health expenditures and access	Life expectancy
(2.3) INVESTIGATION OF IMPACT PATHWAYS through the comparison of alternatives			
Why and How Should We Assess Occupational Health Impacts in Integrated Product Policy? (Hofstetter and Norris 2003)	Investigation of the pathway linking working conditions per sector and health impacts. Comparison of two alternatives to produce fuel tank systems for cars (plastic or steel) in terms of number of death of workers, on the basis of information on occupational injuries and illnesses provided by companies to the U.S. Bureau of Labor Statistics. "Because of data uncertainties, they could not establish a pathway differences in worker health according to sectors" (Feschet 2014).	Sectors	Human health with the number of death

Description and characterization of Type II approaches – third path: applications

Title of study and author(s)	Purpose of the study and details of the method	Start of impact pathway	End of impact pathway
3.1 APPLICATIONS of existing and already quantified impact pathways			
E-LCI and/or exposure to substances => health impacts on society and/or on users (health impacts related and/or not related to environmental impacts)			
[…] LCSA of municipal solid waste management systems […] (Menikpura et al. 2012)	Assessment of impacts from municipal solid waste management in Thailand: income-based community well-being **(2)** and **(1)** societal health impacts linked to environmental issues with "relevant characterization factors for mortality, severe morbidity and morbidity, that were retrieved from the [Swedish environmental priority strategies] model [Steen, 2000]".	**(1)** E-LCI	Disability-adjusted life years (DALY)
Does the Production of an Airbag Injure more People than the Airbag Saves in Traffic? (Baumann et al., 2013)	Comparison of lives saved by the use of airbags **(3)** with DALY lost due to airbag production, incl. 4 process areas: human toxicity along the life cycle, excl. waste handling **(1)**, accidents during the mining of metals, the production of electricity and of inflators **(2)**. **(1)** DALY lost due to toxic emissions (metals, organic pollutants and air pollutants), along the airbag life cycle calculated using the Uniform System for the Evaluation of Substances Adapted for LCA Purposes (USES-LCA) model used in the Eco-indicator '99 method. It does not include health damages due to emissions to the environment.	**(1)** Human toxicity emissions	DALY
A method for human health impact assessment in social LCA: lessons from three case studies (Arvidsson et al., 2016)	Comparison of health impacts of production of catalytic converters and gold jewellery (human toxicity impacts and health impacts stemming from emissions contributing to environmental problems **(1),** work environment impacts for all processes **(2))** and for the latter only, the lives saved by their use (conflict-related DALY **(3)).** **(1)** For both products: health damages due to emissions to the environment and human toxicity impacts with ReCiPe method. For 1st product only: DALY avoided in use phase similarly quantified by assessing avoided health impacts from the reduced emissions.	**(1)** E-LCI + human toxicity emissions	DALY
Implementation of socioeconomic criteria in a Life cycle sustainability assessment framework applied to housing retrofitting […] (Touceda et al., 2016)	Definition of models to assess social and socioeconomic impacts of two housing retrofitting options. In addition to health impacts stemming from emissions to the environment **(1),** health impacts for households stemming from indoor air quality **(2)** and from inadequate indoor temperature and mold **(3)** (see below). Other assessed impacts include: damages to workers **(4),** fair employment, fuel poverty of households, and contribution to growth **(5)** (see 3.2). **(1)** Health damages due to emissions to the environment with the RECIPE method (outdoor air quality)	**(1)** E-LCI	DALY
	(2) Health impacts for households of retrofitting options assessed, including direct impacts of substances (NO2, VOC, Formald; PM10 and PM2,5) with the USETOX method (indoor air quality)	**(2)** Human toxicity emissions	DALY
Exposure to certain use conditions => health impacts on users			
(Touceda et al,2016) See study detail above	**(3)** Health impacts of specific retrofitting options regarding inadequate housing: impact of insulation and ventilation on the presence of mold and on indoor cold, which in turn influence respectively asthma and cardiovascular diseases.	**(3)** Exposure to indoor cold and mold	Relative risk of car-diovascular diseases and asthma in DALY
Exposure to certain working conditions => health impacts			
Psychosocial risk factors' impact pathway for S-LCA : an application to citrus life cycles in South Italy (Iofrida et al., 2019)	Building the work of (Silveri, 2016) on the psychosocial risk factor's impact pathway, calculation of risk to develop health troubles stemming from the working conditions (i.e. psychosocial risk factors) of the cultivation of two citrus (orange and mandarin). As a first step, the number of hours of working exposed to specific working conditions (e.g. vibration, stress, cold temperatures, high physical demand, use of chemicals, temporary employment etc.). Then, these hours are translated into risks of developing certain diseases (physical and psychological), with the support of odds ratios (i.e. statistical measure of the intensity of the association between two variables) that were retrieved from previously published empirical studies in medical sciences.	Exposure to certain working conditions	Relative risk to develop certain health troubles

Title of study and author(s)	Purpose of the study and details of the method	Start of impact pathway	End of impact pathway
(3.2) APPLICATIONS of characterization factors			
Income => access to basic needs or utility			
Societal LCA Methodology and Case Study (Hunkeler, 2006)	Measurement of the working hours necessary for each unit process of the product life cycle and of their geographical localization. These hours act as an activity variable, which is linked to the functional unit. Alongside, a characterization table is built which determines the number of working hours necessary to access a serie of needs (housing, health care or education) in each country. From the working hours calculated for each unit process, calculation of the increased access to housing, education and health care generated through employment. Application of the method to a case study of 2 detergents; the one which uses more working hours in countries where e.g. housing is more affordable will generate more benefits in terms of access to housing.	Working hours/employment and generated income	Access to social needs, considering specific national cost of living
(Menikpura et al., 2012), see study details above	**(2)** Use of Hunkeler approach to calculate the uplifting living standard resulting from employment and income, considering the cost of living in the country where income is generated. Application to municipal solid waste management systems in Thailand.	(2) Employment and income generation from indirect activities	Income-based community well-being considering cost of living
Quantification of social equity in LCA for increased sustainable production of sanitary products in Uganda (Musaazi et al., 2015)	Based on the principle of the economic multiplier effect, comparative analysis of the social equitability of a product according to where it is produced and consumed (Uganda/OECD country), through two impacts, "quantified as a function of income level": **(1)** Affordability: cost of sanitary pads as a % of annual income, multiplied by an estimated world income distribution function; **(2)** Manufacturing wage impacts: difference in a specific manufacturing plants' laborers' wages minus income, multiplied by the distribution function. Due to countries' income differences, impacts of producing pads in Uganda is greater than importing pads.	(1) Costs of products as a % of annual income	Affordability impacts
		(2) Wages	Manufacturing wage impact
The social footprint—a practical approach to comprehensive and consistent social LCA (Weidema, 2018a)	Combination of a top-down approach using input-output data to focus the data collection effort on processes with high value added or number of work hours, with an impact assessment that limits the inventory data requirement and the need for detailed impact pathway descriptions, by focusing on: impacts **(1)** of income redistribution on utility and **(2)** of missing governance on productivity. Application to Nestlé's milk production in Pakistan, to tomato sauce production in Spain and to clothing industry. **(1)** For the 1st pathway, the idea behind is that productive activities imply an income transfer between e.g. workers, consumers. The distributional impact is calculated as the increase/loss in utility caused by the transfer, by weighting the spending and income for each group by their relative marginal utility of income (with related elasticity) and by applying a purchase-power correction.	**(1)** Added value distribution by country-sector	Increase (or loss) in utility
Various factors => productivity			
(Weidema, 2018a), see study details above	**(2)** Productivity impacts of missing governance is viewed as an "overall summary measure" incl.: missing education, corruption, underemployment, trade barriers and lacking physical infrastructure, with no details on the specific causal factors. "Additional data sources are […] required to disaggregate the summary indicator according to these causal factors." Productivity impact measured by the difference between the actual and potential value added when all productivity impacts are internalized (corresponding to the value added per work hour in the US, corrected with a coefficient to consider impacts from e.g. unemployment).	**(2)** Missing governance	Productivity impact

Title of study and author(s)	Purpose of the study and details of the method	Start of impact pathway	End of impact pathway
(3.3) APPLICATIONS through the measurement of midpoint and endpoint impact-based indicators, without the use of impact pathways			
Measurement of health indicators (work environment and users)			
(Baumann et al., 2013) See study detail above	**(2)** The DALY lost due to metals mining and the production of electricity and pyrotechnic materials were estimated using their statistical records on accidents.		Number of fatal accidents and diseases in DALY
	(3) DALY saved by their use was estimated with the support of statistics provided by the producing company.		Lives saved by the product use in DALY
(Arvidsson et al., 2016) See study detail above	**(2)** For catalytic converter and gold jewellery: work environment impacts for all processes based on work of Scanlon et al. (2015), which developed industry-level work environment characterization factors, incl. both injuries (e.g. bruises, wounds and traumatic injuries) and workplace exposure to chemicals. These factors are ratios of work-related fatal and nonfatal injuries and illnesses occurring in the U.S. worker population to the amount of physical output from U.S. industries.		Number of fatal accidents and diseases in DALY
	(3) For gold jewellery only: the conflict-related DALY caused by gold estimated as work environment health impacts: number of DALY calculated by dividing the DALY caused in the conflict with gold production from 1998 to 2006 and allocated to gold by economic value".		Number of deaths linked to conflicts
(Touceda et al., 2016), see study detail above	**(4)** Work environment health impacts assessed based on the number of fatal, non-fatal and occupational diseases in the supply chain from local statistics (as the total number of hours worked per profession) and translated into DALY with the use of the WHO Global burden of disease method: calculations of YLL and YLD from the number of fatal accidents and diseases. For background processes: SHDB		Number of fatal, non-fatal accidents and occupational diseases in DALY
Calculation of other simple indicators			
Designing the social life cycle of products […] (Lagarde and Macombe, 2012)	Presentation of the systematic competitive model which aims at setting system boundaries and includes the short term effects of competition with the planned activities. Application to a case study assessing rural job creation/destruction effects of a plan of the government of Croatia to install industrial pig production farms. Assessment of the effects on an event that is external to the product life cycle on demand and then on employment creation/destruction		Employment creation/ destruction
Measurement of other composite indicators			
(Touceda et al., 2016) See study details above	**(5)** Socioeconomic impacts for workers: indicator "fair employment", combining "the quantification of worker hours and their qualification in relation to the associated risks, which are assessed through a combination of SHDB indicators (e.g. wage, child labor)		**(5)** Fair employment
	(5) Socioeconomic impacts on households: indicator "fuel poverty", measuring "the amounts by which the assessed energy needs of fuel poor households exceed the reasonable cost threshold". Data: various costs at household level and household disposable income.		**(5)** Fuel poverty
	(5) At the state level, calculation of "Net present cost": it sums up public investment, return and avoided expenses (cost of works and rehousing costs for social housing, loss and gain of VAT, contribution to social security and avoided aids to unemployment)		**(5)** Net present cost