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Modeling Social Life Cycle Assessment framework for an electronic screen product – A case study of an integrated desktop computer

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A R T I C L E I N F O

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A B S T R A C T

Large scientific literature addresses the environmental impacts of computers, while society is less considered. Although a couple of studies have analyzed laptops based on Social Life Cycle Assessment (SLCA), a quantitative weighting step is missing. Against this background, this paper aims at integrating a weighting approach from literature and proposes a comprehensive model to assess social impacts along a product's life cycle. The model uses an inventory majorly tailored on generic data, focusing on simplified list of components obtained from dismantling the product. Quantitative and semi-quantitative indicators are normalized based on a three-level scale and a weighting factor is applied to enable aggregation of results at stakeholder level and compare different life cycle stages. The model was tested in a cradle to grave case study on an integrated desktop as a first-time application. Results indicate potentially negative social impacts on workers, local community and society. In contrast, low impacts resulted for the value chain actors and consumers. Raw material extraction and productions of basic materials were documented as the most impactful phases. The model and the associated weighting step facilitates companies with a practical method to conduct social impact assessment and assess the social performances of their product's life cycle.

1. Introduction

Computers have penetrated all facets of the world (at least the industrialized world) and become inevitable part of our daily lives like home, school, and employment. The devices have advanced over the years tremendously from bulky monitors, huge CPU (central processing unit) and input devices to laptops and now to the all-in-ones with all the computer components integrated behind the monitor panel. All-in-one computers, also called integrated desktops are another style of desktop computer with similar basic functions, but distinctive features in terms of the number and size of the components used (www.lifewire.com/all-in-one-pcs). The All-in-ones save space on and under the desk and avoid the tangle of wires and extra devices like CPU. These also come with wireless keyboards and mouse making it more convenient to boot up and use without plugging in. The all-in-ones have not affected the sales of the laptops much probably be due the portability advantage, but the desktop sales have slid down tremendously in recent years (www.lifewire.com/all-in-one-pcs). The bigger screen size of All-in-ones compared to laptops, touchscreen monitors and their ease in set up increases its ability to be put in kitchen, office, or living room. For these reasons, all-in-one computers are more popular these days than the conventional desktops (www.usatoday.com).

The electronic screen products keep evolving over the years and manufacturers bring in new products to the market. According to the United Nations University (UNU) report the global E-waste has reached 41.8 million in 2014 (https://unu.edu/keyword/e-waste), indicating that more new products are entering the market making the older versions obsolete. The benefits of ICT (information and communication technology) are numerous ranging from telecommunication (media services, voice) to specific applications like banking, education, health care etc. Access to technology and sharing of information is the basic and most important function of ICT which is supported by an all-in-one computer. Considering the kind of advantages ICT products have, its usage is only going to increase in the future with more innovative products. According to census and statistics department of Hong Kong (HK), the overall import percentage of electronic screen products has increased from 35% in 2001 to over 50% in 2010 and continues to increase more

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rapidly (https://www.censtatd.gov.hk). The kind of innovation, manufacturers like APPLE, HP, Lenovo, DELL and many others have made is tremendous. But all these positive technological advances might have some negative side to it. Risks may be identified both at the production and usage level for electronic screen products. The supply chain of electronic products, specifically computers are often criticized for their negative social implications like forced labor, child labor, excessive working hours etc. These practices are found more in developing countries where poverty and absence of strict legal regulations lead people to take up risky jobs that affect their health and safety. According to the employees working in the plant and the company reports published, labor abuse like harsh working conditions, lethal accidents etc. is quite prevalent in many manufacturing and assembling units and factories (www.nytimes.com). Research conducted in developmental psychology and medical sciences suggests, excessive computer usage results in potential health risks and affects the psychological well-being of the end-users (Subrahmanyam K et al., 2008; Arumugam B et al., 2014). The e-report published by the Department of health of Hong Kong (HK) also reflects potential negative impacts on people's health (https://www.studenthealth.gov.hk).

Social issues and their impacts sometimes are deadly safety problems like explosions killing workers, exposure to toxic chemicals, addictive usage etc. It affects the lives and well-being of the stakeholders involved in the life cycle of an electronic product. This can be termed as the human cost/price that one pays for creating a digital technology. The ICT industry is working to address these concerns. For example, most manufacturers publish their sustainability reports online. Many initiatives are taken by World Summit on the Information Society (WSIS) and Global e-Sustainability (GeSI). Many companies have started adapting Electronics Industry Code of Conduct (EICC), Social accountability 8000 and Global Reporting Initiative (GRI) (Wang et al., 2017a, b).

For alleviating negative social impacts associated with an electronic product, firstly a thorough analysis of all the life cycle stages that includes quantification and assessment of social impacts is needed. Hence, Social life cycle assessment(SLCA), a life cycle-based method is used in this work. The United Nations Environment Program/Society of Environmental Toxicology and Chemistry (UNEP/SETAC) guidelines is the basic reference used for Social Life Cycle Impact Assessment (SLCIA). The details of the methodology are described in the guidelines (Benoit et al., 2010; Benoit and Mazjin 2009). Further to the publication of the guidelines, many new SLCIA methods were developed and used for assessing social impacts of various product categories based on the guidelines. The wide range of application of SLCA includes: notebooks (Ciroth and Franze, 2011; Ekener Peterson and Finnveden, 2013; Benoit et al., 2012)), photovoltaic modules (Traverso et al., 2012), PET bottles disposal in Mauritius (Foolmaun and Ramjeeawon, 2012), waste recycling systems (Aparcana and Salhofer, 2013a, b, Umair et al., 2014 and Geyhan et al., 2017), Palm oil diesels (Manik et al., 2013), cooking oil waste (Vinyes et al., 2012), Fertilizers (Martinez Blanc et al., 2014), Building construction Project (Dong and Ng, 2015); IC packaging (Wang et al., 2016a,b), Bamboo cycle frames (Agyekum et al., 2017) and Dairy farms (Reverret et al., 2015; Chen and Holden, 2017).

In this work, a case study on HP All-in-one desktop computer is presented. When we search the Environmental Life Cycle Assessment (ELCA) literature, there are over 50 case studies that focused on laptops and desktops. Within SLCA literature, only three case studies have analyzed a notebook/laptop for its social impacts, previous to this work. This shows a clear insufficiency in the SLCA case studies for this product category. We believe that this work will contribute to case studies on SLCA of electronic screen products, particularly desktops. The present work can be considered as a first attempt for the product category All-in-one PC in terms of assessing social impacts. Also, the SLCIA framework used in this work attempts to overcome the methodology–specific limitations in the previous notebook case studies (Ciroth and Franze, 2011; Benoit et al., 2012 and Ekener Peterson and Finnveden, 2013). The differences between the previous notebook studies and this work are presented below in Table 1.

From Table 1, the differences between the previous studies and this work is clearly evident. The major difference is the functional unit of the study and the weighting step within the impact assessment that leads to aggregation of results eventually. Hence, this study takes on a slightly different impact assessment approach that includes characterization, normalization and weighting of social issues according to their topical importance. This will help identify and aggregate potential social risks, in the various life cycle stages of an all-in-computer. The methodology details of the case study are presented in the next section.

2. Research methodology

2.1. Goal and scope definition

2.1.1. Goal

The main objectives of this study were to identify the potential social risks/hotspots of an integrated desktop (All-in-one PC) and to test and evaluate the methodology proposed. This product was chosen as it is a latest technology fastly diminishing the sales of desktops; a very familiar product with a complex supply chain and finally an opportunity to fully test the existing SLCIA methods on a new product. The results are not intended for any comparison with previous studies but can serve as a baseline for more case studies within this product category.

2.1.2. Scope

2.1.2.1. Functional Unit. The results of SLCA could not be reported or linked to the function unit of the study and this issue has been existing for more than 5 yrs now in this area (Reveret et al., 2015). The difficulties that exist in the correlation between social impacts and the processes causing it, was dealt with by many researchers in their work (Dreyer et al., 2005; Hauschild et al., 2008; Kloppfer, 2008). Hosseinijou et al. (2014), attributed usage of qualitative data as a reason for this drawback. However, according to Kruse et al. (2009), even quantitative data can't solve this issue. Despite the existing problem, identifying and defining a Functional Unit (FU) for a case study is mandatory according to the guidelines (Geyhan et al., 2017). The FU of this study is a HP Omni 120 All-in-one PC (QU249AA#AB5) with a wireless mouse and keyboard, with generalized features.

2.1.2.2. System boundaries. The case study sought to include the studied product system from ‘cradle to grave’ and the social impacts on all the relevant five stakeholder categories: Workers, Local community, Society, Value chain actors and Consumers, according to the Guidelines. The analyzed HP all-in-one desktop, hereafter called ‘the desktop’ is produced and assembled in various locations. The companies in the upstream supply chain of the desktop are listed in Table 2. The desktop is used in HK. After use, it is assumed to be sent to formal recycling of e-waste in HK. HP is one of the founding members of HK computer recycling program partnering with the HK government, a scheme is set up to take back unwanted desktops and other hp products from housing estates to approved electronic recyclers in HK (http://www8.hp.com/hk/en/hp-information/supplies-recycling/hardware.html). The components and their country of origin is listed in Table 2. Some components that weighed less than 5 g like camera, graphic card, W-LAN card

Table 1
Comparison related to the basic approach, methodology and outcome of the four SLCA case studies on computers: Ciroth and Franze (2011); Benoit et al. (2010); Ekener Peterson and Finnveden (2013) and Paper 1(this work).

	Ciroth and Franze (2011)	Benoit et al. (2010)	Ekener Peterson and Finnveden (2013)	Paper 1 (this work)
Goal of the study	Identify social and environmental hotspots in the life cycle of a laptop	Identify hotspots in a laptops lifecycle	Identify hotspots in the product system of a generic laptop	Identify potential social risks in the life cycle of an all-in-one computer
Functional Unit	ASUSTeK notebook	Generic laptop	Generic laptop	HP all-in-one desktop computer
System boundaries	Cradle to grave excluding use phase	Cradle to gate	Cradle to grave	Cradle to grave
Data collection	Disassembly, corporate websites, sustainability reports, questionnaire surveys and interviews with suppliers and workers	Social Hotspots Database (SHDB) based on global sources related to laptop supply chain, literature of certifications, standards and initiatives	Internet based desktop collection from global sources	Disassembly, sustainability reports, literature review of audit non-compliance reports, SHDB, sources, questionnaire surveys from recycling workers (HK) and sustainability experts in electronics sector
Activity variable	No	Worker hours	No	Company behavior
Characterization and Normalization	- Assessment based on norms and best practices in the country/sector - Coloring scale (green to red) assigned to factors 1–6 (very positive to very negative social performance of companies)	Assessment based on positioning a performance among a distribution of performances - Comparing country specific data as low risk; medium risk; high and very high risk based on labor intensity (worker hours)	Assessment based on comparing companies based on their share in world-wide production of a component - Three color coding representing the activities (very large to moderate) of the companies in different countries	Identification of significant issues based on researchers' expert judgment on company activities - Company behavior assessed based on a 3 – level scoring system (1-commitment, 2-compliance and 3-risky behavior)
Weighting	Equal weighting of all subcategories	Not explicitly carried out	Not explicitly carried out	Weighting according to stakeholders and experts' judgement of significance of social issues, use of weighting factors
Aggregation of results	Aggregated into a single score at stakeholder level without weighting	Not carried out	Not carried out	Aggregated into a single score at stakeholder level after weighting
Most Impacting phase	Raw material extraction, disposal	Manufacturing, raw material extraction, disposal	Raw material extraction, processing, manufacturing, assembly	Production of basic materials, raw material extraction, disposal
Most impacted stakeholders	Worker, local community, society	Not presented	Workers, local community	Worker, society, local community
Results presentation and interpretation	Results presented in tables displaying very negative to very positive social impacts using a color-based scheme	Results presented at global level using tables and spider plots highlighting top countries contributing to social issues	Data presented in excel worksheets displaying the hotspots in different colors at global level	Results presented using radar charts and bar graphs displaying risky, committed and compliant company behavior for each life cycle step with involved stakeholders

Note: Packaging and transportation are excluded from the cradle to grave assessments carried out in all the above case studies due to difficulties in data availability; Aggregation of results beyond the individual life cycle stages has not been carried in all the above studies.

Table 2
Companies in the supply chain of HP all-in-one PC.

Component	Company	Site
Motherboard	Quanta	China
Hard disk drive	Seagate	Suzhou, China
Random access memory	Samsung	Philippines
LCD panel	AU Optronics	Taiwan and China
Optical disk drive	TSST Korea	Philippines
Fan	Delta electronics	China
Camera	Chicony	Taiwan
Sound card	Realtek	Taiwan

are not considered in the SLCA.

The SLCA considers the extraction and processing of raw materials, production of basic materials, manufacturing of components, assembly, use and disposal of the desktop. Analogous to previous research in this area, this study does not include social impacts from transportation, packaging, electricity used in production and consumption phases, as they are considered to create minor social impacts (Ciroth and Franze, 2011). The above aspects are partly included in the working hours assessment within SHDB which is used as a data source in this work. These activities might have social impacts but are not fully covered within the framework of this study, as the main focus is on manufacturing and assembly of components of a company specific integrated desktop identified through dismantling. The predominant metals used in a desktop computer include copper, cobalt, nickel, gold, tin, bauxite majorly mined and extracted from countries including China, Indonesia, Congo, and Chile. Non-ferrous metals like aluminum, silver, lithium, palladium and other basic materials like plastics and glass are also majorly produced in China. The types and amount of materials vary from product to product; upgradation and changes are also applicable with technological advancements. Also, the locations involved in the extraction processes of the basic materials are kept confidential by manufacturers and no information is available online. Hence its quite challenging to accurately estimate the exact amount of metals and non-metals used in a specific electronic product like desktop with over 2000 parts. Considering the existing limitations, and to maintain the conciseness of this study, some important components identified as a result of dismantling the desktop; specific mining and manufacturing sectors in the raw material extraction and pre-production stages highlighted as important and to be considered in a computer supply chain according to SHDB are assessed in this work. Countries that mine and extract precious metals and non-ferrous metals were evaluated using SHDB and top countries with greater prevalence of social issues were listed. China topped the list followed by countries like Mozambique, India, Indonesia and Congo. The life cycle stages of the desktop considered for SLCA are presented in Fig. 1.

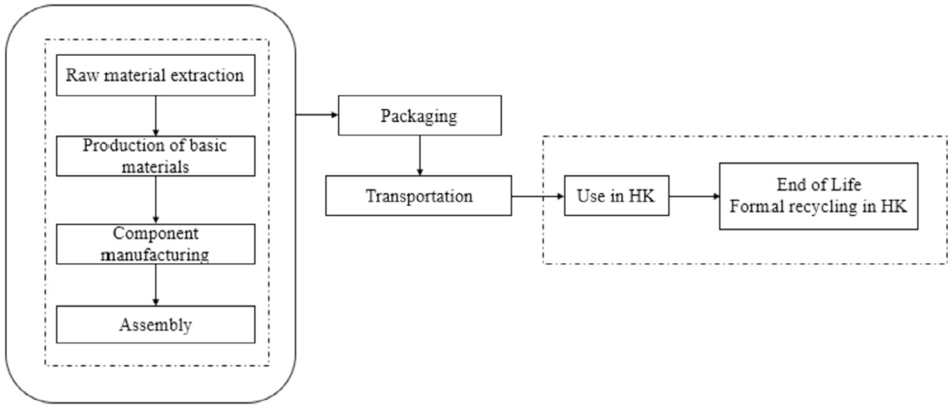

Fig. 1. Product system considered for SLCA (only steps in the dotted lines are considered).

2.2. Social life cycle inventory

In this step, the aim is to collect and analyze relevant data needed to assess the selected impact indicators in the scope section (Jorgenson et al., 2007). It is also the most time consuming and challenging step within SLCA.

2.2.1. Data levels and types

According to Ciroth and Franze (2011), for a reliable SLCA study, organization and site-specific data is the key, which has to be substantiated with country/sector specific statistics as Performance Reference Points (PRPs) for comparison and measurement of a corporate performance. Jorgenson et al., 2007 classified data into 3 types: (1) quantitative (numbers), (2) qualitative (subjective/feelings/judgments) and (3) semi-quantitative (Yes/No type) based on their measurement units. Another apparent distinction within data relates to whether the social indicator directly or indirectly measures the social impacts. Due to the complexity of social impacts, it is difficult to measure most indicators quantitatively, hence qualitative measurement of indicators and later converting them into quantitative comparable scores (scaling system) is the most widely used technique in current practices (Garrido et al., 2016; Geyhan at al., 2017).

In this work, as a starting point for data collection, the desktop was disassembled to identify the components, production locations, suppliers and sites. Bill of materials (BOM) was not available as it was a used product and could not be obtained from company sources due to confidentiality. Both quantitative and semi-quantitative data is used in this work depending on availability.

2.2.2. Data sources

Ideally, according to Ciroth and Juliane (2011), data sources for SLCA should cover governmental organizations, literature (existing studies), involved companies and workers. Contradictions due to the usage of different data sources is natural, when sensitive information is involved, company/organization information could be slightly unreliable. Also, data collected from workers/employees are debatable due to subjectivity and the individual perceptions involved. Sometimes, only the company producing the product can give information and nobody else but it's quite challenging to get it (Benoit et al., 2010). Hence, it is generally concluded that, data is collected according to the availability and objectives of the study.

In this work, site-specific data or information from the employees of HP was not possible. Hence, inventory data was identified through literature review of main audit non-compliance results published by HP. These non-compliance issues assessed by electronic companies are considered to be the most critical issues in the computer supply chain. Previous notebook studies were used as data sources for a few indicators by matching component suppliers that were identified through dismantling. SHDB is also used in this work to identify potential countries/sectors that should be analyzed for social issues in a notebook supply chain, again by matching the component manufacturing locations. The data levels are either company (HP) based or country based (HK and other related production places). For recycling phase, survey results from the respondents of recycling industry collected for an Environment health and safety (EHS) related project carried out by HK polytechnic university was used. Also, government statistics and information form Environment protection department (EPD) of HK were used. More details and relevant data links are provided in Table 3 in the impact assessment section.

2.2.3. Determination of impact categories and inventory indicators

The SLCA guidelines were followed for the selection of stakeholders, subcategories and indicators. All the five impacted stakeholders were assessed, using selected subcategories and indicators (Fig. 2) based on data availability. The impacts on the workers in the component manufacturing and disposal phase, and consumers in the use phase were directly related to the manufacturer of the functional unit, HP. The impacts on workers in the disposal phase were related to the recyclers in HK. Each impact category is characterized based on each corresponding inventory indicator. As it was not possible to link all the indicators and impact categories quantitatively, the subcategories were classified into two types: quantitative and semi-quantitative.

The quantitative data were characterized as percentages (%), semi-quantitative data were characterized in two ways (1) presence or absence of a social issue or (2) on the level of risk as committed, compliant and risky, again based on the nature of the data available. For instance, the social indicator 'access to immaterial sources' in the raw material extraction phase is assessed based on the inventory data from Ciroth and Franze (2011) laptop study, in which all performances were scored from 1 (very positive) to 6 (very negative). In this work, 'access to immaterial sources' is normalized to a scale of 1 (committed-company encourages access to immaterial sources); 2 (compliant -company neither encourages nor restricts; shows an indifferent behavior and 3 (risky-company shows restricted access to resources). Regarding the subcategory of working hours, semi-quantitative scale is applied based on supply chain audit findings of HP, ILO labor standards and EICC. If the weekly occupational hours of work followed in HP and its related supplier locations exceeds the standard 48hrs, the indicator value of the working hours is 3, 2 if it is 45–48hrs and 1 if less than 48hrs. For the subcategory "end of life responsibility" in the disposal

Table 3
Selection of PRPs and normalization details.

Stake holders	Subcategories	Performance reference points	Normalized value range	Data Sources
Workers	Fair salary	Electronic industry code of conduct ILO labor standards	1 Rate of major non-conformances related to wages is < 35% 2 Rate of major non-conformances related to wages is 35 and 70 % 3 Rate of major non-conformances related to wages is > 70%	Wages and benefits non-compliance, HP Global citizenship: Supply chain audit findings 2016 www.hp.com/sustainability www.eiccoalition.org
	Working Hours	Electronic industry code of conduct ILO labor standards	3 Occupational hours of work are > 48hrs 2 Occupational hours of work are between 45 and 48 hrs. 1 Occupational hours of work are < 48hrs	Working hours non-compliance, HP Global citizenship: Supply chain audit findings 2016 www.hp.com/sustainability www.rankabrand.org
	Discrimination	Electronic industry code of conduct ILO labor standards OECD guidelines for multinational enterprises	1 Rate of major non-conformances related to non-discrimination management is < 35% 2 Rate of major non-conformances related to non-discrimination management is 35 and 70 % 3 Rate of major non-conformances related to non-discrimination management is > 70%	Non-discrimination non-compliance, HP Global citizenship: Supply chain audit findings 2016 www.hp.com/sustainability HP Supply Chain Foreign Migrant Worker Standard http://h20195.www2.hp.com
	Health & Safety	Electronic industry code of conduct ILO labor standards	1 Rate of major non-conformances related to H&S is < 35% 2 Rate of major non-conformances related to H&S 35 and 70 % 3 Rate of major non-conformances related to H&S is > 70%	Occupation injury and illness non-compliance, Occupational safety non-compliance, Emergency preparedness non-compliance, HP Global citizenship: Supply chain audit findings 2016 www.hp.com/sustainability
	Social benefits/ Security[a]	Electronic industry code of conduct ILO labor standards	1Rate of major non-conformances related to social benefits is < 35% 2Rate of major non-conformances related to social benefits is 35 and 70 % 3Rate of major non-conformances related to social benefits is > 70%	Wages and benefits non-compliance, HP Global citizenship: Supply chain audit findings 2016 www.hp.com/sustainability
	Freedom of association and collective bargaining[a]	Electronic industry code of conduct ILO labor standards OECD guidelines for multinational enterprises	1 Rate of major non-conformances related to FACB is < 35% 2 Rate of major non-conformances related to FACB is 35 and 70 % 3 Rate of major non-conformances related to FACB is > 70%	Freedom of association non-compliance, HP Global citizenship: Supply chain audit findings 2016 www.hp.com/sustainability
Local Community	Access to immaterial resources[b]	UNEP/SETAC methods sheet	1 Company encourages access to immaterial resources 2 Company neither encourages nor restricts access 3 Company restricts access	Ciroth & Franze (2011)
	Delocalization & Migration[b]	UNEP/SETAC methods sheet	3 Company employs less migrant workers 2 Company employs local and migrant workers equally 1 Company primarily employs migrant workers more than local workers supporting delocalization	Ciroth & Franze (2011)
	Cultural heritage	ILO conventions UNEP/SETAC methods sheet	No data available	
	Safe and healthy living conditions[b]	UNEP/SETAC methods sheet	1 Pollution level is low in local community 2 Pollution level is moderate 3 Pollution level is high	Ciroth & Franze (2011)
	Local employment[b]	ILO conventions UNEP/SETAC methods sheet	1 Promote local employment 2 Neither promote nor restrict local employment 3 Does not promote local employment	Ciroth & Franze (2011)
	Secure living conditions	UNEP/SETAC methods sheet	No data available	
	Access to material resources[b]	UNEP/SETAC methods sheet OECD guidelines for multinational enterprises	1 Company encourages access to material resources 2 Company neither encourages nor restricts access 3 Company restricts access	Ciroth & Franze (2011)

(continued on next page)

Table 3 (*continued*)

Stake holders	Subcategories	Performance reference points	Normalized value range	Data Sources
Society	Public commitment to sustainable issues[b]	OECD guidelines for multinational enterprises UNEP/SETAC methods sheet	1 Company signs code of conduct with the supplier following standards and details summarized in audit reports yearly 2 Company signs code of conduct with the supplier following standards 3 Company does not sign code of conduct with the supplier following standards	Ciroth & Franze (2011)
	Contribution to economic development[b]	OECD guidelines for multinational enterprises UNEP/SETAC methods sheet	1 High contribution of the company to economic development 2 Medium contribution of the company to economic development 3 Low contribution of the company to economic development	Ciroth & Franze (2011)
	Prevention and mitigation of conflicts[b]	UNEP/SETAC methods sheet	1 Low risk of conflicts 2 Moderate risk of conflicts 3 High risk of conflicts	Ciroth & Franze (2011)
	Technology development[b]	OECD guidelines for multinational enterprises UNEP/SETAC methods sheet	1 High efforts by the company in technology development 2 Medium efforts by the company in technology development 3 Low efforts by the company in technology development	Ciroth & Franze (2011)
Value chain actors	Fair competition[a]	OECD guidelines for multinational enterprises UNEP/SETAC methods sheet	1 Rate of major non-conformances related to fair competition is < 35% 2 Rate of major non-conformances related to fair competition is 35 and 70 % 3 Rate of major non-conformances related to fair competition is > 70%	HP enterprise supplier code of conduct HP Supply chain audit findings – 2016 www.hp.com/sustainability www.eiccoalition.org
	Promoting social responsibility[a]	OECD guidelines for multinational enterprises UNEP/SETAC methods sheet	1 Rate of major non-conformances related to social responsibility is < 35% 2 Rate of major non-conformances related to social responsibility is 35 and 70 % 3 Rate of major non-conformances related to social responsibility is > 70%	HP Supply chain responsibility: Our approach HP Supply chain audit findings – 2016 www.hp.com/sustainability www.eiccoalition.org
	Supplier relationship[b]	UNEP/SETAC methods sheet	1 Company publishes report on supplier interaction online 2 Company does not publish but no record of issues with supplier available 3 Company exposed for bad collaboration with its suppliers	HP standards of business conduct-Winning the right way HP Supply chain audit findings – 2016 www.hp.com/sustainability HP living progress report www.rankabrand.org
	`	UNEP/SETAC methods sheet	1 Rate of major non-conformances related to IP rights is < 35% 2 Rate of major non-conformances related to IP rights is 35 and 70 % 3 Rate of major non-conformances related to IP rights is > 70%	HP Supply chain audit findings – 2016 www.hp.com/sustainability www.eiccoalition.org
Consumer	Health & Safety[b]	OECD guidelines for multinational enterprises UNEP/SETAC methods sheet	2 Presence of company policies and standards in place for safe and legal products and handling complaints 3 Absence of company policies and standards in place for safe and legal products and handling complaints	HP standards of business conduct-Winning the right way
	Feedback mechanism[b]	OECD guidelines for multinational enterprises UNEP/SETAC methods sheet	2 Company has provided means to customer to contact them in an uncomplicated on its website 3 Company has not provided means to customer to contact them	www8.hp.com/customer-care-lines.html www8.hp.com/hk/zh/contact/phone assist

Table 3 (*continued*)

Stake holders	Subcategories	Performance reference points	Normalized value range	Data Sources
	Transparency[b]	OECD guidelines for multinational enterprises UNEP/SETAC methods sheet	2 Company provides sustainability report, quality, communication tools on its website with easy access and clarity 3 Company does not provide sustainability report, quality, communication tools on its website	www.rankabrand.org www.hp.com/sustainability
	Privacy[b]	UNEP/SETAC methods sheet	2 Company has policies to ensure data privacy and measures to receive complaints on breaching, with the summary of finding online 3 Company does not have policy and measures	HP living progress report
	End of life responsibility[b]	UNEP/SETAC methods sheet WEEE/ROHS directive	2 Company provides information to customers on product disposal and takeback system in HK and specify clearly in the website; strength of national legislation of HK is high 3 Company does not provide information to customers on product disposal and takeback system in HK	HP planet partners program HP resources for recyclers report HP recyclers vendors report HP Product disassembly information www.wastereduction.gov.hk

[a] Quantitative data.
[b] Semi-quantitative data.

phase, awareness of the customers regarding the take back system of HP computers at its end of life in HK was used as social indicator. Absence or non-availability of information was considered as risky with a value range of 3 and presence or availability of information was considered compliant with a value range of 2. More details on the normalization of quantitative and semi-quantitative indicators based on PRPs can be found in Table 3.

2.3. Social life cycle impact assessment (SLCIA)

This step involves converting the inventory indicators into interpretable and measurable social impacts, compare them against a PRP or benchmark, normalize the results into a comparable range, apply a weighting factor according to the importance of subcategories and calculate the weighting result for each subcategory and aggregate at stakeholder level. According to UNEP guidelines impact assessment (IA) methods are still under development and there is scope for future work. Literature suggests several assessment frameworks — broadly classified as Type 1 (PRP based methods) and Type 2 (impact pathway methods) by Parent et al. (2010). Difference between the two types is in the characterization step. Type 1 models assess inventory data using internationally accepted standards called PRPs, while Type 2 models use quantitative characterization factors based on impact pathways like ELCA. Most studies employed PRP based Type 1 approach and within this type, multiple characterization and weighting approaches are used by researchers for various products/processes (Garrido et al., 2016). This work also uses a PRP based Type1 IA method. Within the characterization and normalization step, scoring systems are employed by researchers predominantly. In these methods, the impacts are assessed using scores which indicate the intensity/level of the impact, few researchers have gone one step ahead and weighed the impacts according to the topical importance of the subcategories.

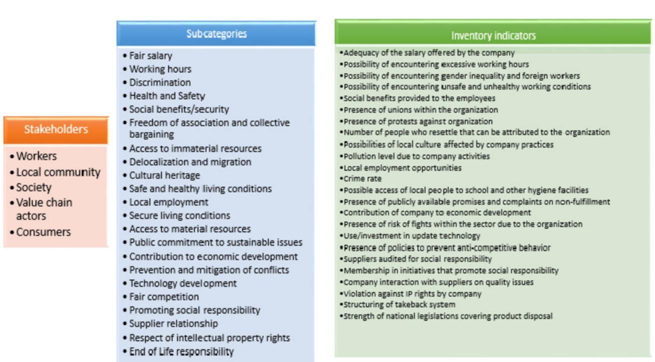

Fig. 2. Selection of stakeholders, subcategories and indicators.

2.3.1. Scoring techniques within type 1 PRP based methods in literature

Dreyer et al. (2010a) measured the management efforts of a company (indicators related to labor rights), scored the indicators based on a 5-level scale ranging from very high risk (>0.9 to 1.0) to low risk (>0–0.2) and finally aggregated into performance scores. Ciroth and Franze (2011) developed a 6-level color-based scoring system ranging from very good to very poor performance and applied them on companies to assess their impacts ranging from very negative to very positive impacts, to evaluate social impacts of a ASUS laptop; Traverso et al. (2012) compared social impacts of 3 photovoltaic modules on workers using quantitative data and linked them to the functional unit. Foolmaun and Ramjeeawon (2012a, b) used yes/no answers from a questionnaire survey responded by stakeholders in PET bottle recycling industry and measured company performance quantitatively by converting those answers into percentages and scaling the percentages using 5 levels (0-20.20-40.40-60,60–80,80-100) and assigned scores of 0–4 respectively. Aparcana and Salhofer (2013a) assessed a formalized recycling system in Peru, in this work indicators were scored as 1 for fulfillment and 0 for non-fulfillment of social criteria based on the answers from the interviews with stakeholders. Umair et al. (2015) proposed a scoring system which indicates data as only positive (+) or (−); Manik et al. (2013) palm oil diesel case study, used a 7 level Likert scale (1-unimportant to 7 − very important) to rank the indicators first and then multiply with corresponding weights and aggregated results at subcategory level. A similar method was adopted by Hosseinijou et al. (2014) for their building construction study that included a two-level weighting step. Sanchez Ramirez (2014a) proposed a sub category assessment method using a 4-level scale (A, B, C and D) based on the compliance of some basic requirements by an organization. Organizations fulfilling the compliance fall under A and B categories, which don't fulfill, fall under C and D categories. Positive and negative context within which a company is working is also considered for level C and D. A scoring system of 0–3 (low risk to very high risk) was employed, to rank the countries involved in a laptop's supply chain, based on working hours by Ekener-Peterson and Finnveden (2013) in their laptop study. Scoring techniques adapted from SHDB were used by Lehmann et al. (2013) and Martinez Blanco et al. (2014) in their fertilizers study. Dong and Ng (2016) in their building construction work normalized the indicator results within a range of −1,0,1 and used weighting factors based on survey results from experts. Reveret et al. (2015) in their dairy farm study, used a four-level scale to measure management efforts of a company (risky, compliant, proactive and committed). Further, companies with risky behavior were evaluated using a 3 level scale (low, moderate high possibility of risk). Wang et al. (2017a, b) in their IC packaging study, used a scoring system of 1–5 after classifying the quantitative indicators into nine scales; semi-quantitative indicators were scored based on a 3-level scale according to full/partial/non-implementation of social criteria by the assessed company. Finally, a weighting step based on 10 experts' opinion using Analytical hierarchy process (AHP) was carried out. The weights were multiplied with normalization results to derive aggregated scores. Agyekum et al. (2017) in their bamboo cycle study, assessed performance of companies and impacts on stakeholders for 3 companies based on a scale of 1 (company don't meet laws, very poor performance and negative impact) to 5 (company meet laws, very good performance and no negative impact); Geyhan et al. (2017) in their packaging study converted indicators into percentages (0–33; 33-66 and 66–100) and assigned scores as 0(low); 0.5 (medium) and 1 (high). Chen et al. (2017) in their Irish dairy farm study normalized the quantitative indicator results based on a three-level scale between −1,0 and 1 and semi-quantitative indicators on a 2-level scale between −1 or 1 for negative and positive social performance respectively.

2.3.2. *Proposed impact assessment method*

It is clearly evident from the above literature analysis that there is no agreed characterization/weighting approach or even a standardized IA method. Hence the primary aim of this study is to set out an SLCA analysis by following the UNEP guidelines and integrating them with the recent methodological advances proposed by scholars in their works. Integrated desktop is chosen as the product for application. The characterization method used in this approach is an assessment-based researchers' expert judgment on companies' activities. The guidelines refer to this approach as ‘simple aggregation’ meaning the researchers firstly unify the qualitative and quantitative data collected into a single summary, based on their expert judgment of importance of social issues. In this work, the quantitative are put into context as ‘percentages’ and semi-quantitative data as ‘level of risk’ based on relevant reference points. This step is consistent with few other studies in literature (Garrido et al., 2016).

A scale-based approach is used in the normalization step; a 3-level scale (risky, compliant and committed) inspired from Reveret et al. (2015) was created. The characterized inventory results for the performance indicators were assigned a score of 1–3. Quantitative data available in the form of percentages were classified as 0–34%, 35–70% and 71–100% and assigned scores of 1,2 and 3 respectively. The company/governmental policies/regulations were compared against a benchmark (PRP) and given a score based on their behavior. A score of 3 is given when the company exhibits a non-compliant or risky behavior by not meeting the PRP norms/expectations; a score of 2 means the company behavior is compliant with the PRP and meets minimum norms; a score 1 indicates committed behavior of the company showing that the company goes beyond meeting the minimum norms of the PRP or is a pioneer in the sector in setting standards. A few indicators are scored either 2 or 3 (compliance or risk) due to data unavailability, but this is a common practice in this area (Reveret et al., 2015; Chen and Holden, 2017). This kind of scoring pattern can help convert qualitative or semi-quantitative data into a comparable range (normalization) and enable aggregation with quantitative data at subcategory level.

This kind of classification is relative as the PRPs might evolve over time and description of the company behavior assessed can be debatable. But it is important to understand that this kind of evaluation majorly depends on data availability which is extremely difficult to obtain. Detailed information is needed to establish PRPs and assess the company behavior also (Reveret et al., 2015). To ensure that the assessment is as clear and transparent as possible, the selected subcategories, PRPs used, scores given, and the data sources are all tabulated below. Few subcategories might have more than one indicator, in that case average of scores is calculated. Also, one indicator can be related to many PRPs. PRPs used are acknowledged standards, norms or practices used as benchmark in the electronics sector, which will help in comparing whether the company meets the minimum expectations.

The characterization and normalization steps are matched with an explicit weighting step to obtain the final results. There are a number of techniques available to weigh the importance of social issues as proposed by scholars in this area. It varies from simple consultation of stakeholders or experts through survey in order to rank the subcategories/indicators according to their importance (Manik et al., 2013; Dong (2015) to multi criteria decision making tools like AHP (Hossinjou et al., 2014; Wang et al. (2017a, b) and Carmo B (2016)). The difference in the techniques lies in the type of people/experts consulted and the statistical tools used to calculate the weighting factors. The weighting approach used in this work is based on experts' judgment on relative importance of social issues. A range of sustainability related experts from academics, NGOs, e-waste recyclers, sustainability consultants and managers from electronic companies were consulted for ranking the social issues/subcategories based on their relative importance. Mean scores derived are used as weighting factors and multiplied with the normalized scores for aggregation at stakeholder level. More details on collection of weighting factors are given in the next section. This weighting step inside a stakeholder category in this work, addresses an important gap in SLCA of electronic products. Indeed, the process of assessing which subcategory among others is most influential on the stakeholder might help to identify the potential social risks/impacts a product might have on human-well-being of the stakeholder (Garrido et al., 2016).

For the quantitative indicators with fair salary within the component manufacturing phase as an example, characterization is to determine percentage of major non-conformance related to wages in HP, normalization is to convert them to scores of 1–3, and weighting factor of 4.14 is applied to calculate the weighting result. For the semi-quantitative indicators with technology development as an example, characterization is to determine level of efforts (high/medium/low) taken by the company towards technology

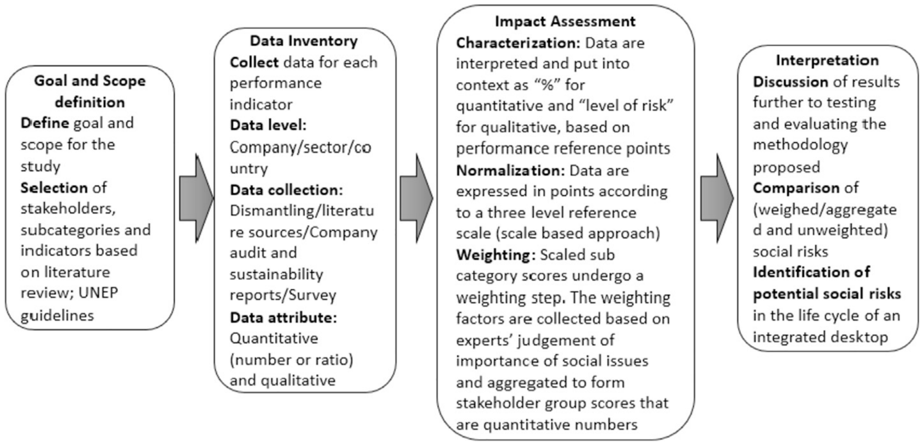

Fig. 3. Proposed impact assessment method.

Table 4
Statistical analysis of the responses of the questionnaire survey.

Subcategories	Mean[a]	Std. Deviation	N	Rank
Fair salary	4.14	0.659	65	6
Working hours	4.18	0.659	65	3
Discrimination	3.83	0.894	65	14
Health and safety	4.6	0.657	65	1
Social benefits/Security	4.15	0.712	65	5
Freedom of association	3.72	0.801	65	15
Access to immaterial resources	3.66	0.906	65	18
Delocalization and migration	3.48	0.903	65	19
Cultural heritage	3.02	1.023	65	22
Safe and healthy living conditions	4.03	1.015	65	9
Local employment	3.45	0.936	65	20
Secure living conditions	3.37	1.039	65	21
Access to material resources	3.71	0.964	65	16
Public commitment to sustainable issues	3.88	0.761	65	13
Contribution to economic development	4.17	0.601	65	4
Prevention and mitigation of conflicts	3.71	0.765	65	17
Technology development	4.05	0.779	65	8
Fair competition	3.97	0.883	65	11
Promoting social responsibility	3.97	0.968	65	12
Supplier relationship	4.08	0.835	65	7
Respect of IP rights	4.02	0.976	65	10
End of life responsibility	4.49	0.59	65	2

[a] Used as weighting factors within impact assessment.

development in their manufacturing sites, normalization is to assign scores of 1, 2 or 3 to the indicator, weighting factor of 4.05 is then applied to calculate the weighting result. The IA method used is depicted in Fig. 3. The PRPs and the risk evaluation scale (normalized value range) used are presented in Table 3.

2.3.3. *Collection of weighting factors*

A questionnaire survey is designed to collect weighting factors of selected sub-categories. The survey included basic details of the respondents in the first 3 questions and final question is a rating question asking the respondents to rate the subcategories in the context of social impacts/sustainability of desktops. The questionnaire was primarily delivered to over 300 local electronics industry related people in a seminar held in HK polytechnic university. The audience included sustainability related people within the electronics industry, officials from environmental protection department of HK, brands like Toshiba, people from the formal e-waste recycling industry, consultants, suppliers, academics and others. Out of this, 47 responses were collected at the end of the seminar. Further, questionnaire was delivered by means of email to around 50 local and overseas electronic industry people related to sustainability (e.g.: sustainability managers of brands like Apple, HP, formal e waste recyclers in HK, sustainability related consultants and others), of which 18 replied.

2.3.3.1. Weighting factors. In the rating question of the survey, the respondents were asked to rate the importance of subcategories according to their experience and expert opinion by means of a five level Likert scale: not important (score-1); somewhat important (score-2); important (score-3); very important (score-4); extremely important (score-5). The reliability of the collected responses was analyzed using Cronbach's alpha analysis. This kind of reliability analysis was carried out in this area by Dong (2015) in their building construction study, in which 51 responses were collected as email responses from building construction related experts, the Cronbach's alpha of that analysis was 0.71. Ideally, the Cronbach's alpha coefficient of a scale should be > 0.7 (Deville's, 2003). In this work, the Cronbach's alpha coefficient is 0.9, which is exceeding the ideal requirement, indicating an extremely good internal consistency and confirming that the sample are consistent and reliable.

The results related to the importance of subcategories are presented in Table 4. Some interesting results were derived from the survey. Health & Safety of the worker was ranked the most important subcategory with a mean score of 4.6 followed by End of Life (EOL) responsibility of the consumers. Few subcategories like technology development, supplier relationship and respect to IP rights were rated as very important. Cultural heritage of the local community was the least scored with the mean score of 3.02. In contrast to a few existing notions, some subcategories like discrimination within workers, freedom of association and secure living conditions of the local community, were not rated so important. The mean scores in Table 4 are adopted as the weighting factors of the corresponding subcategories in the impact assessment.

2.4. *SLCIA results*

The social performance of an HP all-in-one PC was analyzed to provide a preliminary overview of the social risks (potential hotspots) along its life cycle covering raw materials extraction, production of basic materials, component manufacturing, assembly, use and disposal. Table 5 presents the normalized value of each impact indicator, obtained as a score based on the proposed IA method and PRPs described in Table 3. Using the scores, it was possible to assess the social performance of the desktop. The table

Table 5
Normalization results for all the considered life cycle stages.

Stake holders	Subcategories	Raw materials extraction					Production of basic material		Component Manufacturing and assembly					Consumer	Recycling of desktop in HK
		Cu, Co, Ni from **Congo**	Gold from **China**	Tin from **China**	Tin from **Ind** onesia	Bauxite from **Ind** one sia	Non-ferrous metals from China	Plastics from **China**	Seagate (HDD)	Samsung-SEPHIL (RAM)	AU optronics (LCD)	Samsung TSST (ODD)	Delta (Fan)		
Workers	Fair salary[a]	3	3	3	1	3	3	3	1	1	1	1	1	NA	2
	Working Hours[a]	3	1	1	1	1	no data	3	3	3	3	3	3	NA	3
	Discrimination[a]	3	3	3	3	2	no data	no data	1	1	1	1	1	NA	3
	Health & Safety[a]	3	3	2	2	1	2	2	1	1	1	1	1	NA	3
	Social benefits/Security[a]	3	no data	no data	no data	no data	no data	no data	1	1	1	1	1	NA	2
	Freedom of association and collective bargaining[a]	3	3	3	3	2	3	3	1	1	1	1	1	NA	3
Local community	Access to immaterial resources[b]	3	3	3	1	1	3	3	3	3	3	3	3	NA	2
	Delocalization & Migration[b]	3	no data	no data	no data	no data	no data	no data	1	1	1	1	1	NA	1
	Safe and healthy living conditions[b]	3	3	2	3	3	2	2	3	3	3	3	2	NA	3
	Local employment[b]	3	2	2	3	2	2	2	3	2	1	3	3	NA	1
	Access to material resources[b]	3	3	3	3	3	3	3	3	3	3	3	2	NA	2
Society	Public commitment to sustainable issues[b]	1	3	3	2	1	3	3	1	2	3	2	3	NA	3
	Contribution to economic development[b]	1	1	2	1	1	2	2	1	1	1	2	1	NA	2
	Prevention and mitigation of conflicts[b]	3	3	3	2	2	no data	no data	3	no data	no data	no data	3	NA	2
	Technology development[b]	3	3	3	3	no data	3	no data	1	1	no data	2	1	NA	2
Consumer	Fair competition[a]	NA							1	1	1	1	1	NA	NA
Value chain actor	Promoting social responsibility[a]	NA							1	1	1	1	1	NA	NA
	Supplier relationship[b]	NA							2	2	2	2	2	NA	NA
	Respect of IP rights[a]	NA							1	1	1	1	1	NA	NA
	Health and safety	NR												2	NA
	Feedback mechanism													2	NA
	Transparency													2	NA
	End of life responsibility													2	NA

also presents clear list of all the components and life cycle stages considered and analyzed in the study. The various precious metals (raw materials), basic materials, and components in the desktop are mined, extracted, produced and assembled from various locations across the globe. It was impossible to get primary data related to desktop supply chain, dismantling helped identify only the name of the component suppliers, manufacturing locations and nature of the raw materials used. When there is no availability of complete and reliable data from involved companies, SHDB can be used (Carmo B et al., 2017). According to SHDB specific mining and manufacturing sectors in China, Congo, and Indonesia needed more attention as they are locations with the greatest number of social issues in a computer supply chain. Hence in this study, components and life cycle stages that are related to the above locations were analyzed.

2.4.1. Raw material extraction and production of basic materials

The raw materials and basic materials produced at various locations were analyzed for their social performance based on the inventory results presented in Ciroth and Franze (2011). The scale used in Ciroth and Franze (2011) had 6 levels: (1-positive effect, 2-lightly positive, 3- indifferent, 4- lightly negative, 5- negative and 6-very negative effect). We aggregated the “positive and slightly positive”; “indifferent and lightly negative” and “negative and very negative” in order to be consistent with our 3-level evaluation scale. A few subcategories were not included in the assessment due to lack of data or due to its relevance in the considered life cycle stage. For example, within the consumer stakeholder, all life cycle stages become irrelevant except use phase.

2.4.2. Component manufacturing and assembly

The workers category within components manufacturing and assembly were scored based on the non–compliance audit report of HP. The other stakeholders were scored based on Ciroth and Franze (2011) laptop study. Among the desktop components listed in Table 2, three component manufacturers (1) Quanta (motherboard), (2) Chicony (camera) and (3) Realtek (sound card) are not included in the assessment. Chicony and Realtek were ignored as they are in Taiwan, which is not attributed to high level of social risks according to SHDB. The motherboard manufactured by Quanta could not be included in the assessment, as no data was available in the literature review and supply chain contact was kept confidential when approached. Only information available was that the company submits Corporate sustainability report (CSR) using global reporting initiative (GRI) framework according to HP supplier code of conduct. Also, it is understood from one of the company contacts of HP that assembly line keeps changing from time to time and cannot be restricted to one sole source. Hence the component manufacturers assessed above are found as a result of dismantling this particular product under study, however components and assembly can be done through different suppliers also for other HP products.

2.4.3. Use phase

The use phase was assumed to take place in HK. The consumer stakeholder is the only category considered for use phase. Analogous to the previous two notebook case studies, in this work also, the selected subcategories were all related to retailer interaction only i.e. the current set of indicators and subcategories proposed by the UNEP/guidelines relate to the company behavior/general behavior like consumer complaints, quality labels; management measures to improve transparency like publication of sustainability report and privacy of consumer's data in the device. There are no substantiated complaints regarding product safety or breach of consumer privacy or loss of consumer data according to the HP living progress report and close to 20 countries sought and receive advice from HP on data privacy regulations. The HP privacy and data protection board (PDPB) oversee risk management and compliance focusing on cloud computing, big data analytics, government access to information and data security (HP living progress report). Presence of voluntary computer recycling schemes like CRP for which HP is a contributing organization and a structured takeback system by the company for its used product at end of life in over 72 countries including HK indicates a compliant behavior of the company and the government, towards the product in its EOL. However, data related to public commitment towards these programs and monitoring of these take back systems and related reports are not explicitly available.

2.4.4. Recycling of desktop in HK

The computer and communications products recycling programme (CRP) is the recycling management organization for HP products in HK. HP is one of the participating organizations of this programme. It was established in 2008 with 4 methods of collection including pick up from estate/public collections points, recycling day and members take back scheme. 18 designated public collection points are established throughout the region and hotlines are also available for bulk pick up. The collected e-waste is first checked for re-use and those in good condition are donated to needy through Caritas HK and the remaining are dismantled and useful parts are recovered through appointed commercial recyclers (EPD Hongkong). The total recycling rate of HP is 14% and over 1 million tons of hardware are recycled globally according to the sustainability report in 2016. HP has a well-established takeback system in 72 countries including HK. HP does not allow export of e-waste from developed (Organization for Economic Co-Operation and Development and European Union) to developing countries either directly or through intermediaries (http://www8.hp.com/us/en/hp-information/global-citizenship/environment/ewaste-export-policy.html). The hardware recycling (http://h20195.www2.hp.com); reuse standard (http://h20195.www2.hp.com) and product disassembly instructions (http://h22235.www2.hp.com) are all developed by HP and available online for responsible recycling and recovery.

The formal recycling sector in HK is in general not connected to any notable social issues. The recycling companies provide uniform, basic personal protective equipment to the workers such as gloves, masks.etc., but do not carry out regular environmental monitoring on the exposure to hazardous substances in air and water, and also lack noise monitoring exercise (Survey Report on the Project ‘EHS Awareness of the WEEE Recycling Industry in Hong Kong’, 2016). Based on the survey results conducted for an EHS project by HK polytechnic university it is evident that: some of the dismantling steps are handled manually, most companies (around 70%) provide gloves, masks and safety shoes to their workers. General job safety and training is provided to the workers (55%) and recycling instructions/manuals are provided as guideline to workers in most companies (82%). Workers don't have a regular body check-up, in some cases, is done by the workers themselves and not the employer. Only few companies arrange body check-up once in a year for their workers (36%).Exposure to multiple chemicals, pollution level in the workplace, industrial hygiene, are all sources of potential health risks for the worker, termed as occupational hazards. Lighting level, noise level and thermal condition also affect the health and working environment of workers in recycling facilities (Alan HS et al., 2011). According to the survey results, most of the companies (82%) don't have a regular monitoring/testing plan to assess concentration of heavy metals concentration, noise level and dust in air and sewage, which might impact the safety and health of workers. The working hours of the workers is 44.5 h/week which exceeds the ILO conventions of 40 h/week. Since company/sectoral information is not available, country data was used, and it was assumed that recycling sector follows this norm.

A considerable amount ($ 61,631.8 m) is provided by the government for social welfare of the work force in industrial sector. Both the employer and the worker should register for the mandatory provident fund, again sector level data is not available for this indicator. The wage level in the recycling sector is not very high as it does not require a high level of education, however companies in HK should comply with minimum wages requirement of $30 per hour to $32.5 per hour which is sufficient to be above the poverty line. Discrimination especially related to ethnic minority is the major challenge faced by HK. Women and ethnic minority face discrimination in terms of income earned despite the Equal Opportunities Commission (EOC) in place. Though sectoral data is not available, still is an important negative social influence to be addressed. There are no labor unions in the e-waste recycling sector, but there is a HK Recycle Materials & Re-production Business General Association Limited, founded in 2000, with over 300 members, holding above 95% recycling industrial sector share. Workers seem to lack bargaining power against the company and hence fail to express their basic needs and working condition related issues.

There is no notable restriction of access to material and immaterial resources in the areas of recycling facilities. Recycling sector does not attribute much to resource consumption, rare metals are only recovered in this industry. The recycling of e-waste has a positive effect as the production of primary materials is avoided to a certain part. But it will produce emissions of dust, metals, gases, and dioxins, etc., hence might affect air quality and increase pollution levels (http://www.healthyhk.gov,hk). Uncontrolled spillage of pollutants in the form of toxic sewage from a recycling yard was once reported. The number of individuals who relocate to HK to work in this sector is assumed to be low, since this sector does not need a special skill set or physique to carry out the operations, hence local employment opportunities increase more due to this sector and provides more jobs for locals not only as workers in facilities, but also as collectors, importers, exporters, consultants etc.

E-waste recycling is a relatively new industry that's grabbing more attention since last decade, hence presence of publicly available promises/commitments towards sustainability issues and complaints regarding non-fulfillment of the same is weak, government and EPD are focusing to attend these issues. Currently, HK heavily relies on voluntary recycling programs for computer recycling, the number of recovered items seems to be low, public commitment towards this issue should be improved in the future to

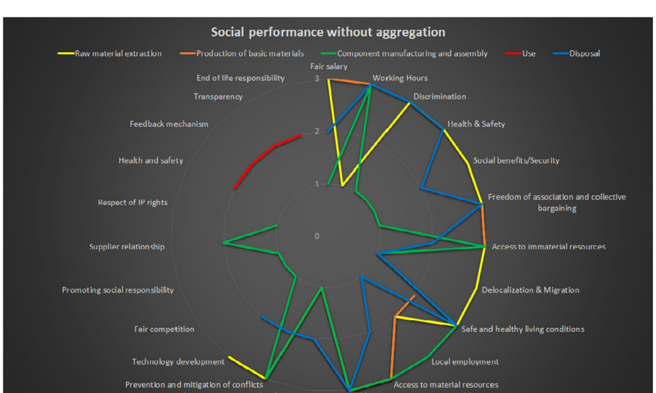

Fig. 4. Results without aggregation.

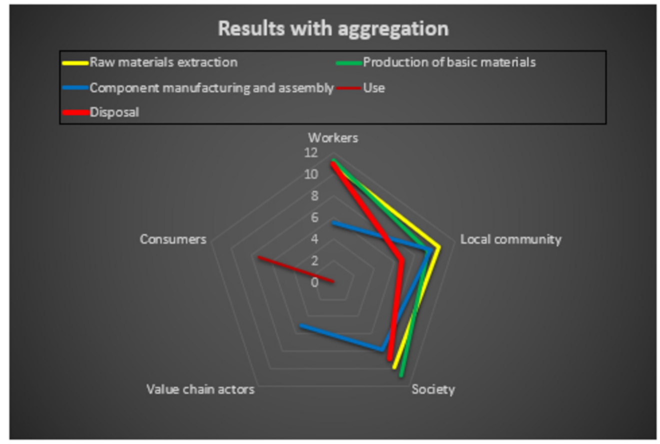

Fig. 5. Social performance after aggregation.

enable effective recovery and recycling. There is some levy in definition of waste regulations, some pre-products (PCB, computer casing etc.) are considered non-hazardous and allowed to be exported to china and other countries for recycling. No notable cases of corruption or conflicts is reported within the sector (https://www.transparency.org/country/#HKG). It is obvious that recycling business brings money and revenue for the locals and consequently contributes to the economic development of the region. Regarding technology development, sectoral efforts in using eco-friendly technologies is compliant but has scope for improvement. Provision of proper treatment procedure at sorting, dismantling level, installation of machines and training for the workers are still weak areas in HK WEEE recycling industry when compared to Korea, Germany and other European countries.

2.4.5. Social performance analysis

The results without aggregation/weighting are presented in Fig. 4. It presents the social performance of the integrated desktop towards its stakeholders, i.e. workers, local community, society, value chain actors and consumers at different life cycle stages. The raw materials extraction, production of basic materials and component manufacturing & assembly stages had more than one component or material to be assessed. Hence to concisely present the results of these life cycle stages, the individual scores were averaged using a specific calculation rule. The score obtained by the majority of the raw materials or components within that subcategory was considered as the overall score for that subcategory. Each circle in Fig. 4 represents a level of social performance starting from "committed behavior" the inner circle followed by "compliant behavior" to "risky behavior" the outermost circle. The performance of the desktop in each life cycle stage is represented using a series of colored lines. The closer the lines are to the innermost circle, the better the product's social performance, with a socially responsible company behavior, in that particular life cycle stage.

In the social impact assessment step, different indicators are used to measure different social impacts. There are no scientifically accepted causal chains that establish a link between them. Hence, aggregation of the indicators is carried out based on their importance (Carmo B et al., 2017). In our research, the weight of each indicator was derived based on the score accorded by a group of experts. The experts were invited to judge the relative importance of the selected subcategories within each stakeholder. To obtain the weight of each subcategory, the mean was calculated. Defining weights is important as it helps in aggregating the product's social performance, supports decision making process by reducing the

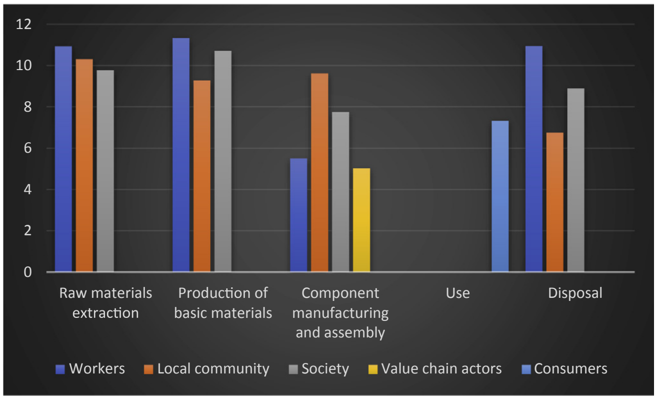

Fig. 6. Comparison of life cycle stages.

large amount of information into concise and easily understandable results (Carmo B et al., 2017). The overall SLCIA results of the desktop after aggregation, by applying weights to the normalized scores is presented in Fig. 5. Each normalized subcategory score is multiplied by the weighting factor derived based on expert consultation.

Comparing Figs. 4 and 5, it can be observed that Fig. 4 has more information, while Fig. 5 has more concise information for the same set of life cycle stages that can reduce the complexity in decision making. The use of different scaling systems to score the indicators in the normalization step affects the social performance of the studied product system and influences the decision made, especially when all risks are treated the same (equal weighting). Hence, aggregation of these social indicators based on expert opinion (ranking the risks) is carried out in this research. This step could possibly provide more concise results. In this study, the aggregation step does not go beyond the individual life cycle stages. It is possible to realize a complete aggregation of all life cycle stages into a single score. However, at this point, scientific methods to count the risks and aggregate results at stakeholder level are quite unclear (Ekener Peterson and Finnveden, 2013 and Souza RG et al., 2015). The reason could probably be the complicated interdependencies of many indicators to a single sub category or lack of data for a few indicators making uniform aggregation difficult. It is also necessary to define the relative importance of different life cycle stages and involved stakeholders for a complicated product like desktop by establishment of weights according to their importance and relevance. MultiCriteria Decision Aid (MCDA) technique could be used for this step.

3. Interpretation of the SLCIA results

Although this SLCA is primarily aimed at testing and evaluating a social impact assessment approach using integrated desktop as a product, the study also looked at the potential social risk involved in the various life cycle stage of the desktop, such as raw material extraction, production of basic materials, component manufacturing, use and disposal. The social performance analysis was conducted over five life cycle stages, by using generic data, in order to assess the possibility of risky behaviors among the company activities, involved at each stage.

This section presents the overall results and discusses their implications on various stakeholders. Fig. 6 presents comparison of different life cycle stages of a desktop based on the aggregated/weighed results. The results have been aggregated for simplification, by averaging the risk, expressed as subcategory scores, for each stakeholder.

This preliminary overview indicates that most life cycle stages and related company activities show risky behavior. With the main supplier located in China, the prevalence of potential social risks is generally high than in counties like US or Canada. Raw material extraction including mining activities are connected to potential social risks. Also, production of basic materials, component manufacturing and disposal phases are more relevant in terms of risky company behavior. Use phase, in general is uncritical. There are some socially impacting practices occurring upstream in the electronic sectors' supply chain (which could not be covered in this study due to lack of data) such as corruption, cultural heritage, non-respect of indigenous rights and unfair competition.

From a stakeholder perspective, workers are the most affected regarding the subcategories assessed despite code of conducts and laws in place for maintaining no child labor, no forced labor and non-discrimination. The stakeholders, local community and society are also subject to potential social risks by specific activities within the life cycle of the desktop. Consumers and value chain actors are not much affected by potential social risks, although a very few problems were detected. The detailed description and evaluation of these risks at each life cycle stage is presented in the following subsections.

3.1. Social risks in the raw material extraction phase

Mining processes happening in the Chinese, Congolese and Indonesian mining sector were analyzed in this study. Generally, it is dangerous to work in mines. There are some potential risks identified in this phase. Workers are the most affected followed by local community and society. Congolese mining companies/sector show higher social risks compared to China and Indonesia.

Minimum wages in the mining sector that do not cover the living costs majorly impact the workers especially in Congo and China. Working hours don't reflect much social risk except in Congolese sector. Occupation discrimination based on gender show risky behavior. Since mining activities are very laborious, this indication can be neglected for this sector. Freedom of association is also severely restricted in the mining sector in all the considered countries except bauxite mining in Indonesia which shows a compliant behavior.

Freedom of expression is restricted in these countries including the mining sectors and not much initiatives are taken for building the community infrastructure. Similarly, companies in this sector extract water for industrial use. Sulphur tailings a major output in the mining activities are not disposed off in a very environmental friendly way. All this increase the social risk related to safe and healthy living conditions of the workers and the local community. The only compliant behavior associated with this phase is the local employment opportunities for the locals and migrants in these countries. However, this comes at the cost of health effects.

Risk of conflicts is very high in the mining sectors especially in Congo. Admittedly, there is no publicly available signed principles/code of conducts by any of these mining companies. Efforts taken by the companies to bring in eco-friendlier technologies in mining operations to improve the working conditions of workers is also very poor. All these indicate only social risks in the related subcategories. Contribution of the company/sector towards country's economic development shows a committed behavior.

3.2. Social risks in the basic materials' production phase

The processes in the production of basic non-ferrous metals and plastics in a desktop are analyzed in this study. All processes are located in China, where the condition is generally worse compared to developed countries. There are some disturbing social risks identified in this phase. Workers are the worst affected followed by society and local community.

The position of trade unions is very weak in China and workers are strictly restricted from posing strikes. Though payment of minimum wages is ordinarily covered by local laws, the wages paid are not sufficient for a decent living in China, which consequently forces workers to work for long hours exceeding the stipulated 48 h a week, resulting in a potential risky behavior. Though the risk factors associated within this industry is supposedly high, inventory data shows compliant behavior related to the health and safety of workers.

This is a very resource intensive sector, hence many resources including water and energy are accessed in production of these materials. Similarly, the effluents in the production processes create a lot of environmental loads and affect the living conditions of the workers and local community. Public commitment to sustainability issues is also weak. This sector generally involves many small-scale companies for production activities, hence research and development are very weak. Consequently, choice of eco-friendly technology for the involved processes is also rather low. More employment opportunities for the locals and improved contribution of these companies/sector to Chinese economy indicate compliant behavior.

3.3. Social risks in the component manufacturing and assembly phase

The main potential social risks related to this phase are associated with issues related to local communities and society. Workers and value chain actors are less critical. The components and manufacturing sites were identified through dismantling. The inventory was primarily collected from audit non-compliance results identified through literature review of various audit reports of HP. The components identified in this study are manufactured in China and Philippines. The companies and their operational sites are in special zones.

Workers are least affected regarding investigated subcategories like fair salary, discrimination, health and safety, social benefits and freedom of association and collective bargaining. The reason could be the supplier code of conduct implemented by HP covering minimum standards related to above social issues and ensuring its practice within the supply chain. However, working hours is still a major hot spot identified within this stakeholder category. The maximum work week is set at 60 h as against the stipulated 48 h and overtime is also quite common.

For the local community, the analysis has documented potential social risks within access to material and immaterial resources, safe and healthy living conditions of the community and local employment opportunities. Local communities are affected by the manufacturing operations, with its activities impacting the health and safety of the population (hazardous emissions into air and water) and limiting their access to basic natural resources (excessive resource consumption, hazardous discharges). Increase in migrant workers especially in China impacts the local population negatively by limiting their employment opportunities, however company's behavior related to delocalization and migration are documented as committed.

Potential social risks are also found from a societal perspective, as major manufacturers in this industry are involved in serious controversies related to corruption, bribery, environmental pollution and poor working conditions, leading to many conflicts. There are some social risks related to public commitment towards sustainability issues, the code of conduct signed by these component manufacturers is still weak and deficient. There are no major social risks identified related to issues like technology development and contribution to the country's economic development for the companies analyzed.

There are no major social risks identified in the value chain actor category in this life cycle phase apart from supplier relationship which also shows a compliant behavior of the involved companies.

3.4. Social risks in the use phase

There are no major social risks identified in this life cycle phase for the studied product. There are no documented cases of any potential danger in the desktop usage impacting the health and safety of consumers; infringement of consumers' private data stored in the device or affecting the psychological well-being of the user. Overall the company shows a compliant behavior due to the presence of management measures to handle consumer complaints, presence of feedback mechanism, transparency in published sustainability reports in reasonably good quality in comparison to other brands and a good company rating among various electronic companies. Addictive usage behavior associated with this product category and its consequent effects on the health and psychological well-being of end users may result in potential social risks but are not within the scope of this study.

3.5. Social risks in the disposal phase

This study considers only the formal recycling in HK in this life cycle phase. The social performance analysis raised a few potential social risks within the formal recycling sector in HK. Most of them are related to the workers category followed by society and local community. The occupational health and safety of workers, working in recycling sector are still characterized by high level of social risks despite the efforts made by the government to improve the situation. Excessive working hours is also common. Among other social risks are some practices with regard to discrimination against ethnic minority and women as well as absence of labor unions and lack of bargaining power for the workers in the e-waste recycling sector. There are no significant social risks specifically related to fair salary and social benefits of the workers, the companies showed a compliant behavior.

The analysis suggested possibilities of encountering risky behavior of the companies, negatively impacting the safe and healthy living conditions of the local population. Among them are the documented cases of dust from these areas that have highest level of lead and copper, PBDEs that are released from PCB (a main component of desktop), while heating, lead levels that are high in dismantled scraps, some of these are likely to be carcinogenic (Cebellos and Dong, 2016). Similarly, the temporary open storage of e waste pending shipment in new territories of HK are also potential sources of hazardous leakage (environmental bureau, 2010). There are no major social risks specifically related to delocalization and migration of workers; employment opportunities for the locals in the sector; and access of the local population to material and immaterial resources.

There are no major potential social risks identified from a societal perspective in this life cycle phase, apart from the issues related to public commitment towards sustainability. The code of conduct implemented between the involved companies and the manufacturer or the government is generally weak as most of the involved companies are small and medium enterprises (SMEs). Relating to technology development, it was possible to document efforts by the government trying to match foreign best practices in this sector to bring in eco and human friendly technologies for recycling activities. There are no significant social risks specifically related to the company's contribution to country's economic development and prevalence of any serious controversies related to

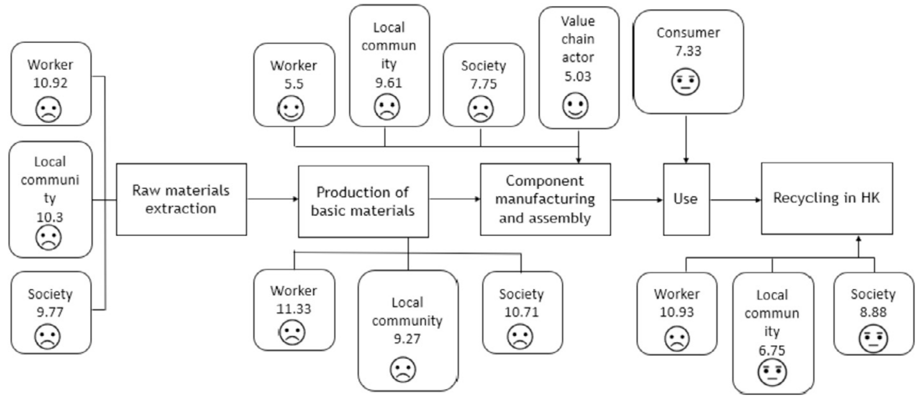

Fig. 7. Summary of SLCA results.

corruption or bribery leading to any conflicts within the sector/region.

4. Discussion

The social impact assessment results indicate that there are many potential social risks related to the desktop, at all life cycle stages. Regarding the workers category, the analysis reflects high possibilities of social risks in production of basic materials (11.33) followed by raw material extraction (10.92) and disposal (10.93) and finally component manufacture (5.5). Local communities are also affected by this product, with its activities in the raw materials extraction phase showing high level of risk (10.3), followed by component manufacture and assembly (9.61), production (9.27) and finally disposal (6.75). Potential social risks are also significant from a societal perspective, indicating high possibilities of social risks in production of basic materials (10.71) followed raw material extraction (9.77), disposal (8.88) and finally component manufacture (7.75). There are no significant social risks identified within the value chain and consumer category along the desktops' life cycle. Unlike previous notebook studies, workers scored better in this work within the component manufacture and assembly stage. This might due the specific brand/company that manufactured the product (HP). The company has a good sustainability rating, increased transparency in sharing sustainability related information to public, empowering and protecting workers with its strict policies and code of conducts. Analogous to previous notebook studies, mining activities and production processes involved are related to high level of social risks for all stakeholder categories. The summary of results is presented in Fig. 7. Overall among the five life cycle stages assessed, raw material extraction and production of basic materials are more critical with high average scores (10.33 and 10.44 respectively) followed by disposal (8.85), use (7.33) and component manufacture and assembly (6.97) in that order.

5. Discussion: comparison, advantages, limitations, challenges faced and future work

There are three case studies of notebooks, and all of them have used type 1 method. Ciroth and Franze, 2011, developed a new valuation method based on color codes; Ekener-Peterson E and Finnveden, 2013 and Benoit et al., 2012 identified countries with severe negative social impacts in the laptop supply chain based on working hours/labor intensity. Comparison of the overall results derived show a similarity. Workers were identified as the most affected stakeholder, followed by local community and society in previous studies. In this work, workers within the component manufacture and assembly phase showed less potential risks compared to other phases, followed by society and then local community. The differences were only marginal. Consumers and value chain actors remained uncritical in this work also. Though they developed their own assessment method, either weighting step was not included (Ekener-Peterson E and Finnveden, 2013 and Benoit et al., 2012) or an equal weighting of all subcategories was assumed regardless of their topical importance in the life cycle of the product. This can lead to problems while aggregating the results finally. This issue is addressed to some extent in this work. This study used a weighting approach according to experts' judgement of relative importance of social issues (Manik et al., 2013; Dong, 2015). The weighting factors obtained from survey results aid in calculating an aggregated end-point indicator in the form of stakeholder scores. This study also has also provided a new insight into the social performance of a latest technology All-in-one PC and the formal recycling sector in HK. The results have also confirmed some of the qualitative findings from previous research (Ekener-Peterson E and Finnveden, 2013; Ciroth and Franze, 2011), that electronics sector has potential risks associated with working hours; health and safety of its workers and local population. This study emphasizes on similar risks associated within the HK recycling industry.

Social impacts are mostly qualitative in nature, hence in previous studies, collected data is converted into a meaningful and interpretable number using a scoring/scaling system. Social impacts are calculated in the normalization and weighting steps, characterization is not used as quantification step. The indicators are assigned values, or scores based on a reference point in the normalization step. Unlike ELCA, the normalization step does not have any scientific basis currently. Analogous to previous studies, the SLCIA method used in this work adopts questionnaire survey, company reports and national statistics as data collection methods and normalizes the indicator values into comparable scores. Hence future researchers should be aware of the possible uncertainties in the normalization step.

Combining different data types still remains a challenge in SLCA (Dong, 2015)). In this study, two types of data are normalized to a range of 1–3, making different data types comparable. Perruzzini M et al., 2017 in their recent study on social impacts of kitchen sink, tries to overcome this huge issue of data conversion using a transformation method. Raw scores obtained in the form of Yes/No and Likert scale answers were all converted into a normal score (%) by calculating the mean, standard deviation and identifying a bench mark value from the samples. Electronic products with complex supply chains and huge data involved, when subjected to these kinds of data transformation techniques in future, could lead to a more detailed analysis. Neugebauer S et al., 2017 in their tomato production study, suggested a charactersation model to calculate fair wage potential. In the model, wages are related to effective working time and accounted for income inequality. Though fair wages are used as quantitative indicators in SLCA, there is no characterization model currently, quantification is done in the normalization step only. This model could be tested on electronic products supply chain, which reflects a lot of social issues related to income inequalities. Such an analysis at midpoint level, could also help conduct accurate assessment of product life cycle.

Though the guidelines recommended over 30 subcategories and many indicators, this study includes only selected subcategories. Also, only one indicator is used to represent a single subcategory. This was primarily due to lack of data. Lack of indicators was also an issue within the use phase. Hence in future studies, there is a need to identify and incorporate relevant indicators and subcategories to improve the accuracy of SLCA results. Similar challenges were faced by Prassara JA and Gheewala SH (2018) while applying SLCA in the Thai sugar industry. Siebert A et al., 2016 developed social indicators to assess wood-based products' social performance from a regional perspective accounting to the organization's behavior. Many scholars in this area have highlighted, SLCA should not only analyze the production and manufacturing phase of a product life cycle, but also focus on the service flow including consumers. Arcese G et al., 2017 in their Italian wine sector study suggested a conceptual framework with related subcategories and indicator definitions that covers all life cycle phases including consumer. Similarly, we also aim to propose a conceptual framework that can assess the use phase of electronic products with relevant set of subcategories and indicators outside the guidelines, in our future work.

A weighting method proposed by scholars in their previous works is integrated into the impact assessment phase for this product category as a first-time application. The weighting factors determined based on expert judgments is easy to understand and can be adapted for other product systems as well. Considering the kind of arbitrary assumptions in the characterization and normalization steps in SLCA, this weighting approach can be considered as starting point towards improving the robustness of results derived. The weighting factors derived in this work are case-specific and can be changed by modifying the subcategory indicators or the number of experts involved. Though this addresses an important gap in SLCA of electronic products, the subjectivity associated with this expert judgment may result in inaccuracy. When the experts don't understand the context of the subcategories, can lead to wrong scale scores. Hence in future work, this limitation can be addressed by conducting a field survey of supply chain stakeholders of all the supplier companies identified and can be used as weighting factors for all the social indicators to calculate an accurate aggregated result that will facilitate the management/company to take a decision. The aggregation process can also be extended beyond the stakeholder dimensions and develop scientific methods to aggregate all life cycle stages for such complicated products.

Data quality has always been an issue within SLCA studies. Unfortunately use of generic data reduces the precision and accuracy of results derived. Dismantling of the desktop allowed understanding of the involved suppliers, but manufacturer information is available at global level and is characterized by high level of uncertainties curtaining the actual behavior of workers and business operations in the supplier location. Also, many of the identified social risks are such that, the electronic sector has very little power to influence or change the trend. For inventory, we had to heavily rely on audit non-compliance results of HP, survey results from sustainability experts and HK recycling companies and previous case studies in this area. The perception of the respondents is subjective, and company owned reports are generally less reliable and considered as green washing (Ciroth and Franze, 2011). In any case, it's important to note that only educated guesses are made; vague and baseless assumptions are avoided. Subjectivity plays a role in the quality of all these data; however, sensitivity and confidentiality of the information involved also needs to be considered. It's definitely not easy to get such sensitive information, the producing company and multinational enterprises are not so cooperative.

This said, it is important to note that the goal of the study was to test an impact assessment approach using a latest electronic screen product and provide a preliminary overview of potential social risks associated with the product in its life cycle. This study does not intend to make a comparison of brands/products nor to draw general conclusions about the electronic screen products. But these can be interesting future research aspects, provided there is more data access from the involved companies, suppliers and stakeholders. An electronic company or manufacturer that intends to incorporate sustainability initiative or more specifically social impact assessment into its products and services throughout its life cycle can easily adopt the proposed impact assessment framework. The results of the weights of the social indictors derived can be used as a reference or can be determined from relevant stakeholders in the company's supply chain using the survey. Further, weights of the social issues can be determined by experts using statistical analysis. Our results imply that major social risks prevail in all life cycle stages assessed. Workers, local community and society are the most impacted. Such information can enable companies to identify areas of improvement in their supply chain activities. Companies could assess the material flow and service flow, engage with suppliers and help them promote sustainable development. This study synthesizes an initial but comprehensive framework for social impact assessment throughout the life cycle of an electronic screen product, which can help the electronic industry understand the social performance of their products from a life cycle perspective.

6. Conclusions

A company specific assessment of social impacts for a HP All-in-one PC was conducted using SLCA approach. The methodology used in this paper sets its basis on the UNEP/SETAC guidelines and extends its application to a latest ICT product. The main contribution to the state of art is related to the impact assessment phase of the SLCA methodology, more specifically when applied to electronic screen products. The proposed framework used Cronbach alpha method to determine the relative weight of each subcategory and indicator in order to overcome the shortcoming of a weighting step in ranking the importance of subcategories. Such procedure is not found in the previous few case studies on SLCA of computers. Hence, the main outcome of the proposed framework is the integration of a robust stakeholder-based approach for the weighting step within IA phase. For the weighting approach, surveys are designed considering the possible social issues that would most likely impact/affect the involved stakeholders. Surveys are submitted to selected stakeholders who are directly or indirectly involved in the computer supply chain, in relation with the goal of the assessment. The survey responses are subject to statistical analysis to calculate the weighting factors. However, survey results are generally subjective. Hence, in future assessments, answers should be taken from the affected/involved stakeholders in each life cycle phase directly, though is extremely difficult and in some cases impossible. Computers have a global supply chain, however, when social implications of a specific electronic product are assessed, use of characterization models from a regional perspective provides better insight. It helps assess how individual companies exert pressure on suppliers in local/regional level. The case study also proposed a scoring methodology based on company behavior to normalize the indicators values, however, more deeper analysis is needed covering more subcategories and indicators to check the robustness of the proposed scoring system. Also, the end points here identified are compliant to a specific social assessment of a HP all-in-one PC, but they are not generic. In relation with the case study, a score is available at stakeholder level for each life cycle stage. Future works need to mainly focus on aggregating the above results and derive a final single score for the electronic product category.

Overall, with the impact assessment methods in SLCA not yet being standardized and a product that consists of complicated supply chains and confidential as well as sensitive data sources, we strove to use a transparent, replicable, secondary and generic data-based assessment method, which will enhance wide usage of SLCA within the electronics sector for various other electronic screen products. From this study, it can be concluded that, HP as a company has shown more compliant and committed behavior (positive social influence) than risky behavior for most of the stakeholder categories. However, HP all-in-one PC as a product was having more potential risks/negative social influences than positive impacts for most of the stakeholders (3/5). Value chain actors and consumers are less critical compared to workers, local community and society. Raw material extraction and production of basic materials were found to have more risks compared to the other life cycle stages of the desktop. Within the production phase, potential risks/negative social influences were found highest for workers, followed by society, and local community. Though there is a strong hypothesis that a good company behavior can influence the social impacts created by the product, it cannot be considered as the end-point indicator. Hence, it is important to develop clear pathways linking company behavior and social impacts, that could aid SLCA to measure positive and negative social impacts of a product, for which data is the key.

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