This is the peer reviewed final draft of the following article:

Niemistö, J. et al. 2019. Benefits and challenges of streamlined life-cycle assessment for SMEs - findings from case studies on climate change impacts. International Journal of Sustainable Development & World Ecology 26 (7): 625-634.

which has been published in final form at

https://doi.org/10.1080/13504509.2019.1646344

Benefits and challenges of streamlined life cycle-assessment (LCA) for small and medium-sized enterprises (SMEs) – findings from case studies on climate change impacts

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Benefits and challenges of streamlined life-cycle assessment (LCA) for small and medium-sized enterprises (SMEs) – findings from case studies on climate change impacts

Small and medium-sized enterprises (SMEs) have a substantial role in the economy and job creation, but they are a remarkable source of environmental impacts. SMEs often lack skills and resources to compile environmental impact assessments; Streamlined Life Cycle Analysis (LCA) can provide efficient tools for this. An application of streamlined LCA relying heavily on database data, *LCA clinic*, was developed and tested on 23 SMEs in Finland. The climate change impacts were mainly caused by the production of raw materials, electricity and heating, whereas packaging and transportation were not influential. A significant amount of emissions were indirect i.e. caused by production of raw materials. Thus, decreasing emissions from raw material production or selecting raw materials with a smaller environmental load could be a more efficient way to decrease emissions than reducing direct emissions such as those from electricity use. Lack of data in the LCA-databases was considered a challenge. An access to regionally customised datasets is important for the implementation of LCA clinics. Company feedback indicated that LCA clinics were useful in climate friendly product design and increased environmental awareness, but did not lead to immediate actions to reduce emissions because of inadequate investment capabilities. Company managers had limited possibilities to use the results in marketing as comparative assessments would require a full LCA. Many company managers were willing to pay a fee sufficient to cover the costs of an LCA clinic, but some considered that the costs should be covered by external funding sources.

Keywords: Life cycle assessment; life cycle thinking; small and medium-sized enterprises; carbon footprint; eco-design; climate change

1. Introduction

Small and medium-sized enterprises (SMEs) represent 98 % of all enterprises in Finland (Akola and Havupalo 2013). SMEs have a substantial role in the economy and job creation and they also play a major role in cleantech businesses and novel innovations. The combined environmental impact of SMEs is also notable (Revell et al. 2010). The environmental impact of SMEs is not known at either national or regional levels but is widely reported that, as a sector, SMEs could contribute up to 70% of all industrial pollution (Hillary 2004). However, SMEs, especially those which are starting their businesses, need to make significant economic investments and environmental impacts of their products and services may not be priority issues for these entrepreneurs as they usually are battling with limited capital and uncertain market (Judl et al. 2015). This is problematic, as it has been estimated that approximately 80% of a product's environmental performance is fixed during the early phases of the product development process (McAloone and Bey 2011). LCA would be beneficial especially for startup companies as environmental impacts can be more efficiently reduced if an LCA is done early at the product design stage (Hauschild et al. 2004), when it is still possible to fine-tune and adjust production processes to improve their environmental properties.

SMEs often lack skills and resources to compile environmental impact assessments (Testa et al. 2012). Despite these restraining issues, SMEs are being pressurized to adopt more sustainable production systems (Testa et al. 2017). Previous studies by Myllyviita et al. (2017) and Johnson and Schaltegger (2016) demonstrated that companies do acknowledge the importance of sustainable development, but seldom make and publish quantitative assessments. To make sustainability assessments accessible for SMEs, they should be cost-effective and comprehensible, while retaining a sufficient level of reliability. One option would be utilisation of simplified impacts assessment tools (Judl et al. 2015; Myllyviita et al. 2017).

LCA includes an assessment of direct and indirect environmental impacts based on a “cradle to grave” approach. Various decision makers, such as company managers, often use LCA to detect the origin of the environmental impacts of their products (Myllyviita et al. 2014). According to Standard ISO 14040:2006 (International Organization for Standardization 2006), LCA has four phases (Figure 1). The first phase, goal and scope definition, includes a specification of the aims of the study. The second phase, inventory analysis, focuses on collecting suitable data. Inventory data, such as required raw materials and energy use, is attributed to a functional unit, such as one end-product. Then impact assessment takes place. Outputs with similar impacts are characterised into common equivalence units that are then summed to into one parameter as an overall impact category. The final phase constitutes interpretation of the results and includes assessment of sensitivity and reliability. Interpretation makes it possible to use the results in decision making such as product development. For marketing purposes, there are some additional requirements. LCAs used in comparative marketing statements should include assessment of sensitivity and a critical review made by external experts.

SMEs generally lag behind large companies in the implementation of LCA (Johnson and Schaltegger 2016). A full LCA requires a substantial amount of time, resources and expertise. Streamlined LCAs are potential options as a full LCA may be too time-consuming and expensive for SMEs (Curran 2000, Arzoumanidis et al. 2017).

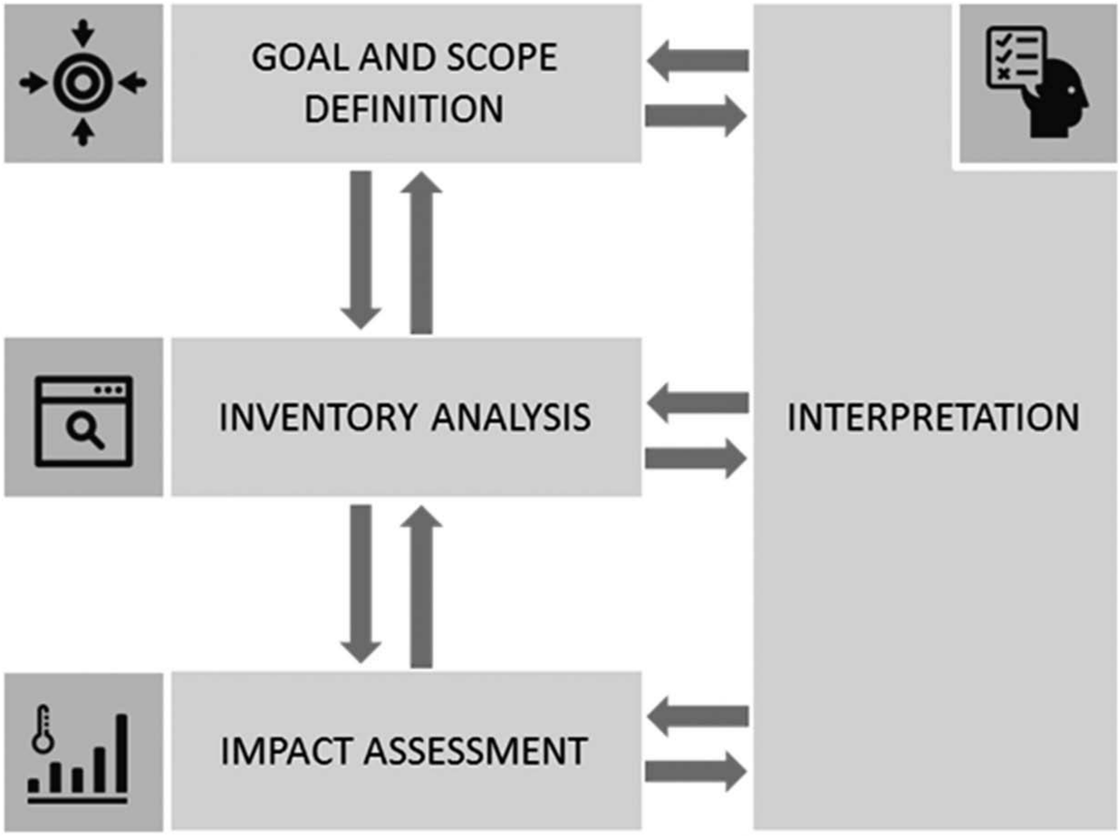

Figure 1. LCA framework with four iterative phases and direct applications of results.

Many large companies have applied LCA to assess environmental impacts of their production systems and have acknowledged the benefits of using LCA as a product design tool (Nygren and Antikainen 2010; Antikainen and Seppälä 2012). Life cycle thinking has been used to assess environmental impacts and in environmentally conscious decision making in Finnish enterprises (Antikainen and Seppälä 2012). From the company managers' viewpoint, the legislative demands, cost-efficiency, customer needs, public image and pressures related to price changes of raw materials were the most prominent factors for applying LCA. Knowledge on environmental impacts can also increase the potential of a company to improve its environmental performance, provide economic profits and improve its public image (Antikainen and Seppälä 2012).

United Nations´ Brundtland Commission defined that ‘Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (World Commission of Environmental and Development 1987). For companies, sustainable development can be seen as the keystone of environmental policy and foremost principle for resource management and decision making.Companies aim to find an equilibrium state between economic return, environmental responsibility and social acceptance (Huesemann 2004). The evaluation of sustainable development is however complex and challenging, although several concepts have been developed. Streamlined LCA considers several environmental impact categories simultaneously across the whole supply chain of assessed product or service. This gives valuable information for decision-making and enables avoiding unintended problem shifting from one part of the life cycle to another when choosing raw materials or other process parameters. (Finnveden et al. 2009)

1.2. The concept and application of streamlined Life cycle assessment

The differences between a full LCA and a streamlined LCA (or simplified LCA) have not been unambiguously defined. Streamlining LCA can be achieved in a number of ways, e.g. by limiting the scope of the research, applying qualitative information, removing some components and including fewer environmental impact categories (Hunt et al.1998; Rebitzer et al. 2004). De Beaufort-Langeveld et al. (1997) argued that simplification should be focused on the life cycle inventory analysis, as it is the most time consuming phase of LCA. Hunt et al. (1998) suggest that data should be collected for all relevant stages and stressors, but in lesser detail. Rebitzer et al. (2004) describe several options to simplify LCA: direct simplifications of process-oriented modelling, LCA based on economic input–output analysis and the so-called hybrid method combining elements of process LCA together with input–output approaches.

The idea of streamlining LCA has been under active development during the past two decades (see e.g. Curran and Young 1996, Graedel 1998). Several studies have indicated that streamlined LCAs can provide important information to support product development. For example, an assessment of climate change impacts of a passenger car with a streamlined LCA approach (excluding manufacture, service life and recycling phases) led to the conclusion that the environmental profile would be improved most by better engine efficiency, using recycled lightweight materials and enhancing longer use of the car (Danilecki et al. 2017). Arena et al. (2013) developed a streamlined LCA approach that can capture the environmental impacts of different technologies over the entire car life cycle. Their model is primarily intended to be applied in the early stages of developing a new vehicle or a technological solution. Arzoumanidis (et al. 2017) implemented three simplified LCA tools in parallel to full LCAs for four different agri-food products. In their study, however, the simplified LCAs gave some results that conflicted with those of the full LCAs. Hochschorner and Finnveden (2003) studied two streamlined LCA methods and concluded that they provide information complementary to a full LCA.

One solution to make a simplified LCA is to apply solely LCA database data as done in a study by Judl et al. (2015). As current LCA databases such as Ecoinvent (Frischknecht and Rebitzer 2005) include a substantial number of datasets on the environmental impacts of various processes, products and raw materials, it is possible to assess environmental impacts of various products using database data. Database data is widely used in full LCAs as well, although it is recommended to use primary data (i.e. data collected first-hand by the LCA practitioner, by e.g. direct measurement, estimation or calculation from the original source) (ISO 14040:2006).

Our aim was to develop an approach to assess environmental impacts of products and services with a streamlined LCA suitable for SMEs. Streamlined LCAs were based on LCA database data. We demonstrated the application of the streamlined LCAs for SMEs with 23 case studies on different kinds of products, mainly from the manufacturing industry and services in the region of North Karelia, Finland. In these case studies, we focused on the assessment of climate change impacts. Based on these experiences, we address the benefits and drawbacks the streamlined LCA. Company managers' motivations as well as their willingness to pay streamlined LCAs were also studied. Finally, suggestions on how to further develop this approach are described.

2. Material and methods

A simplified LCA approach was named as an LCA clinic. An LCA clinic follows the principles of a full LCA (Figure 1). First, a company manager was contacted and a free LCA clinic was offered. Most of the contacted companies were manufacturing industries. If a company manager was willing to participate, a material datasheet was sent together with a short information package about LCA and LCA clinics.

Primary process data was provided by the SMEs and background life cycle inventory (LCI) data from the Ecoinvent database (version 3.1) were used to calculate the climate change impacts of material flows and processes. If there were no suitable data in the databases, reports and scientific research papers were applied. Most of the modelling was done using database data. Energy (electricity and heating and transport originated emissions) were modelled using Finnish data sources. Data on the climate change impacts of electricity and heating were acquired from publicly available sources (Motiva Oy 2010, IPCC 2011, Statistics Finland 2017). In addition, to assess the transport impacts, data from LIPASTO (a calculation system for traffic exhaust emissions and energy consumption in Finland) were used (VTT Technical Research Centre of Finland Ltd. 2017). The product systems were modelled with the openLCA software tool (versions 1.4.1 and 1.5.0) by GreenDelta (Winter et al. 2015).

An LCA clinic session with participation of the LCA specialist(s) and the company manager(s) took place after the inventory phase (Figure 2). If a company manager was able to collect relevant input data, a preliminary LCA was compiled before the contact session. During the contact session, a more detailed discussion was carried out and the life cycle of the product or process was further modelled.

After the manager's contact session, the LCA specialists finalised the streamlined LCA and compiled a report including information on the climate change impacts of the product or a service and a detailed description on the sources of these impacts. For better understanding of the level of the impacts, the results were normalised related to a distance driven by a passenger car, as well as to the annual footprint of an average Finnish consumer. A short report including the results of the assessment together with recommendations on how to decrease the climate change impacts were provided to company managers. Finally, the company managers gave their feedback on the LCA clinic and estimated their willingness to pay for such a service.

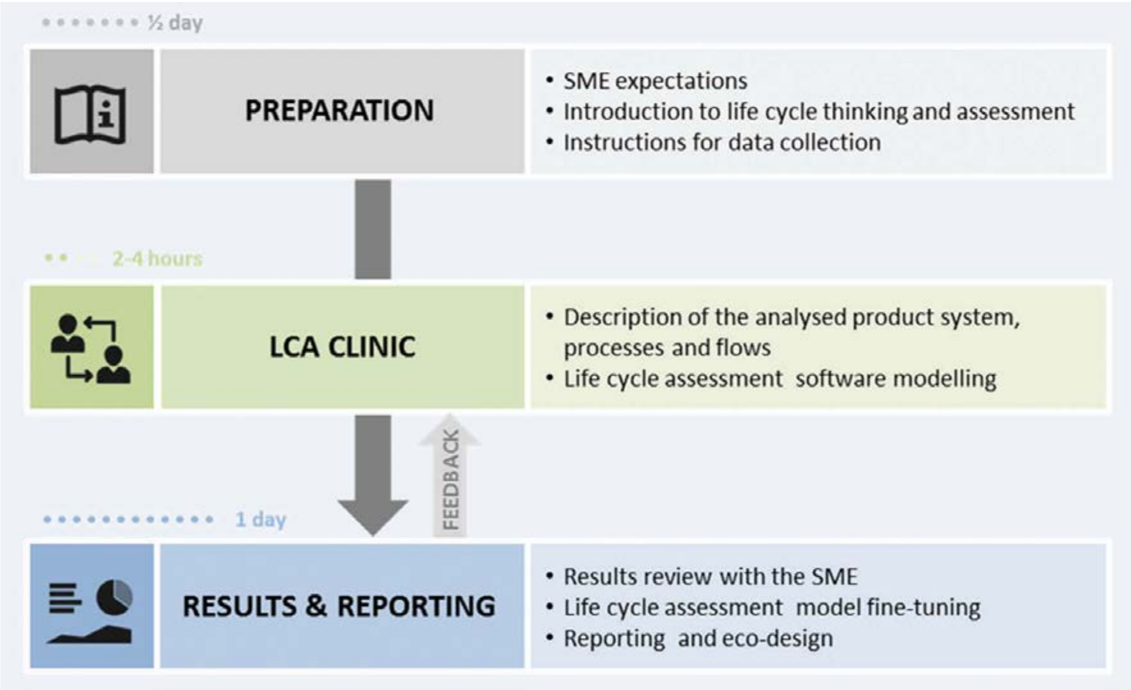

Figure 2. A flow-chart of an LCA clinic.

3. Results

3.1. Climate change impacts of 23 products and services

The experience of the studied 23 LCA clinics suggests that the climate change impacts are mainly caused by certain hotspot areas. In most cases (95% of all LCA clinics), 90% of the impacts were caused by maximum six unit processes (i.e., elements for which data were quantified) and in 57% of the cases up to three unit processes. These were moderately easy to determine, but some cases required substantially more time to model than others. Products with special or rare raw materials were the most demanding ones to model as the database data was insufficient.

The climate change impacts of the 23 products and services mostly from the manufacturing industry assessed with the LCA clinics were mainly caused by the production of raw materials (Table 1). However, there was a wide variation in the results (Figure 3). Packaging and transportation were not the most influential factors in only a few cases. Furthermore, the impacts of electricity and heating varied. In some cases, they had a significant contribution on the total impact of a product. In the assessment of the impacts of energy production, the most relevant factor was the type of energy source considered. Energy intensive products with no renewable electricity sources had high energy-originated impacts. The impacts caused by heat production were also occasionally a prominent factor. However, heating was not often included because its allocation to the functional unit was not possible, since information on heating consumption was available for a certain time not per the assessed product.

There were strong correlations (correlation coefficient almost 1) between total impacts and raw material impacts on climate change (Table 2). The impacts caused by transport were also highly correlated with the total impacts and the impacts caused by raw materials (correlation coefficient nearly 1), although in most cases the impacts of the transport contributed less than 10 % of the total impact (Table 1).

Table 1. Climate change impacts of the products included in the LCA clinics (percentage of total impact) and proportional contributions of raw- materials, packaging, electricity, heat and transport.

Product	**Raw materials %**	**Packaging %**	**Electricity %**	**Heating %**	**Transportation %**
Wooden birdhouse	**93.4**	3.4	2.1	-	1.1
Iceberg lettuce	11.6	8.2	**77.0**	2.8	0.4
Wooden Finnish zither (i.e. kantele, a traditional Finnish music instrument)	13.9	-	3.5*	**78.3**	4.25
Wooden mast	**97.0**	-	-	-	3.0
Hotel overnight	4.9	-	3.9*	**80.8**	-
Sparkling wine made of currant leaves	16.5	**70.8**	1.9	-	10.8
Composite product	**83.3**	-	9.4	1.8	5.5
Connectors	**91.9**	0.3	7.8	-	0.01
Bed (natural fibres)	**90.5**	1.6	0.2	6.9	0.8
Mushrooms	**57.3**	1.2	4.0	37.2	0.3
Apple cider	3.1	32.3	**53.1** (electricity and heat)		11.6
Window	**74.7**	-	5.3	-	20.0
Birch sap drink (1000 l)	10.9	**56.7**	7.1	-	25.3
Bauble jewellery set	18.7	**57.0**	21.9	-	2.4
Karelian pasty	**87.5**	-	9.0	-	2.6
Plastic film for patient transfers	**97.5**	-	-	-	2.5
Dilution culture	**93.7**	-	5.6	-	0.7
Pair of shoes	**74.0**	4.5	17.3	2.0	2.2
Studded bike tyre	41.4	2.5	**46.7**	8.3	1.1
Gift box of plate, spoon and container for drink made of composite material	**77.0**	15.1	1.7	-	6.2
Fireplace made of local soapstone	33.5	8.7	**57.6**	-	0.2
Granulates from recycled bottle caps	9.0	10.1	6.1	**73.5**	1.3
Growth fastener	10.5	5.7	**82.0**	-	8.0

- = missing information

* = renewable energy

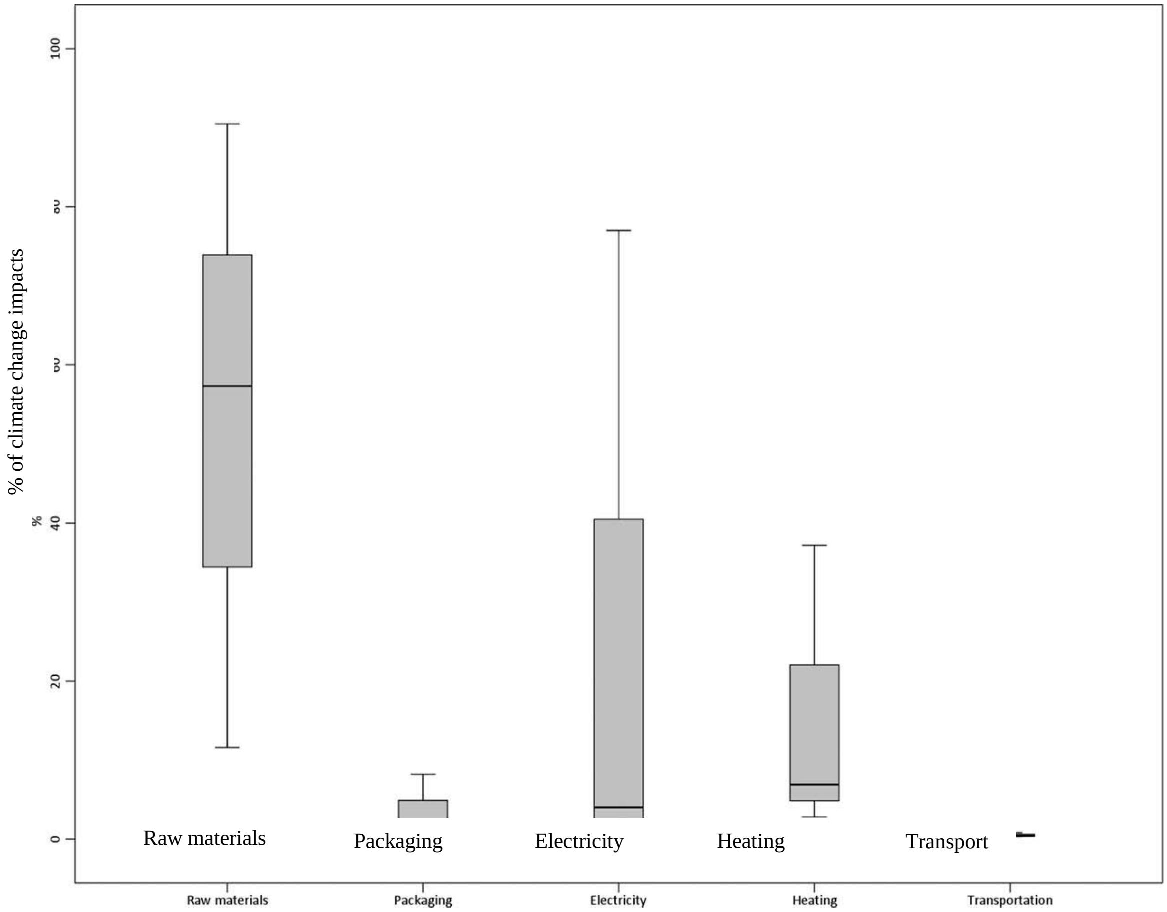

Figure 3. Proportion of the total climate change impacts due to raw materials, packaging, electricity, heat and transportation (23 products or processes included). The central line indicates the median, the bottom and the top edges of the box are the 25th and 75th percentiles and the whisker indicates minimum and maximum values (outliers excluded).

Table 2. Correlation coefficients of the total climate change impacts and other climate change sources of the studied 23 products and services.

	Total impact	**Raw materials**	**Packaging**	**Electricity**	**Heat**	**Transports**
Total impact	1					
Raw materials	**0.9996**	1				
Packaging	0.2246	-0.1046	1			
Electricity	0.6551	-0.0565	0.3334	1		
Heat	0.3110	0.1175	0.3576	-0.1222	1	
Transports	**0.9939**	**0.9940**	0.5184	-0.0537	0.1430	1

3.2. Feedback given by the company managers

After 6-12 months of receiving an LCA clinic report, company managers were requested to give feedback on the LCA clinic, actions made in the company based on an LCA clinic and willingness to pay such a service. Most of the company managers stated that they were pleased with the LCA clinic as it gave them information on the climate change impact of their products and services and improved their understanding of LCA (Table 3). Converting the impacts of their products and services into emissions caused by driving a passenger car (e.g. climate change impact of a product is similar to emissions caused by driving 10 km with a passenger car) was considered especially informative. During the contact meeting, many of the company managers mentioned that they had already discussed the potential environmental impacts of their company's products and processes during their own company meetings, and most of the participating companies were interested in improving their company's environmental performance.

The company managers had different perceptions of the benefits of the LCA clinics. Five company managers did not see any benefits, six found some benefits and four considered the benefits substantial. Two of the company managers that considered the LCA clinic non-beneficial still planned to make some changes in their production systems based on the obtained results. Many of the company managers thought that the results of the streamlined LCA confirmed their prior expectations. Thus, the LCA clinic did not change their perceptions significantly. The given feedback showed that only a few of the company managers had made some environment-based changes in their production system prior to the clinic (e.g. change of raw materials or buying eco-labelled electricity). After the streamlined LCA clinic only three company managers stated that they were not going to make any changes, whereas the rest stated that they would certainly make some changes. Furthermore, many acknowledged that the results may be useful for their product development in the future.

Table 3. Feedback given by company managers.

Company size	**Benefits for company**	**Changes in thinking**	**Changes in behavior**	**Willingness to pay (euros)**
Micro company	No direct benefits	No changes	No changes	1000–2000
Sole trader	-	-	Some changes will be made	0
Micro company	Substantial benefits	Some changes	Some changes will be made	1000
Micro company	No direct benefits	No changes	-	0
Micro company	No direct benefits	Substantial changes	Some changes will be made	800–1300.
Sole trader	Some benefits.	Some changes	Some changes will be made	500–1000
Micro company	Substantial benefits	-	Some changes will be made	1000
Medium sized enterprise	Some benefits.	-	The changes possible in the future	-

Medium sized enterprise	Some benefits.	-	No changes	1000
Micro company	Some benefits.	Substantial changes	Some changes have been made	500
Micro company	Some benefits.	No changes	Some changes will be made	1000
Micro company	Some benefits.	-	Some changes will be made	1000–2000
Micro company	No direct benefits	No changes	Some changes will be made	0
Medium sized enterprise	Some benefits.	Some changes	Some changes will be made	0
Sole trader	-	No changes	No changes	0
Micro company	-	-	-	2000–5000
Micro company	No direct benefits	-	Some changes will be made	500–1000
Micro company	Substantial benefits	Some changes in thinking	Some changes will be made	1000–2000
Micro company	Substantial benefits	Some changes in thinking	Some changes will be made	1000–2000
Micro company	-	-	Some changes will be made	500

- = missing information

Most of the company managers indicated that they were willing to pay for an LCA clinic, the amount ranging from 500 to 5000 euros, while the average was slightly over 1200 euros and the median 1000 euros. Six were not willing to pay at all. Of these six, four considered that the investment should be provided, at least partially, by funding sources other than the company, such as authorities. All company managers who saw substantial benefits were willing to pay for an LCA clinic.

The company managers considered that a major drawback of an LCA clinic was that they could not compare the climate change impacts of their products or services to their competitors' impacts. Many of the managers wanted to use the results of the LCA clinic to support their marketing by publishing the climate change impact figures of their products and comparing them to their competitors' figures. As the LCA clinic is not ISO 14040 compliant, there are limitations related to using them. Comparative LCAs targeted to the general public should, according to LCA standard, include an assessment of sensitivity and a critical review.

4. Discussion

4.1. LCA clinics as a tool to assess climate change impacts of SMEs

The aim of this paper was to develop an approach to assess the climate change impacts of various products and services with a streamlined LCA (i.e. LCA clinic). Most of the datasets were taken from the LCA database. The approach was tested with 23 Finnish SMEs from North Karelia. Based on our study, an LCA clinic is an informative tool for environmental impact assessment of various products and services. The LCA clinic was a feasible tool for providing information on the climate change hot spots of the studied products and services. The factors in the company activities that contribute most to the climate change could then be modified to decrease the total climate change impact of a product or a service. The LCA clinics were convenient to perform and required far less time and effort than a full LCA. The LCA clinics gave support and information for the SMEs on how to reduce the climate change impacts of their products and services. Although the assessment is based on secondary data, LCA clinic will likely detect the most influential factors with a sufficient reliability as typically only 3–6 unit processes contributed to the majority of the company climate change impacts. Thus, identification of these hot spot areas provides relevant information for company managers on where the climate change mitigation actions should be targeted. For instance, transportation and packaging were not prominent factors in most of the cases, whereas changes in the current heating system could in many cases decrease the climate change impacts in a much more efficient and economic manner.

4.2. Applicability of LCA database data

Modelling of the LCA clinics was based on available databases. A full LCA may take up substantial time and resources, and applying databases is a convenient option to save both. However, there are several aspects to be considered when databases are applied in the LCA modelling. The major differences in datasets concern geographical and temporal factors, technological representativeness, system boundaries, allocation methods and different category definitions for the inventories (e.g. Peeredoom et al. 1998; Frischknecht 2006 and Takano et al. 2014). Applying database data for LCA modelling may lead to deviated results. Therefore, an LCA clinic is merely a tool for detecting hot spot areas, and does not replace a full LCA. In addition, a practitioner modelling an LCA clinic should be careful when selecting suitable datasets for modelling. Datasets should be as similar as possible in terms of system boundaries and data originating preferably from the same region. In the 23 streamlined LCAs considered here, one challenge was that most of the datasets were suitable for mid-European conditions, whereas our case-studies were from North Karelia in Finland. For example, Central European forests, forest management and agricultural intensity are very different from those in Finland (Levers et al. 2014, Levers et. al. 2016). The LCA clinics of this study focused on the assessment of climate change impacts, but if assessments were to be focused on eutrophication, the environmental impacts would be highly regionally specific. Another challenge is that LCA databases typically include environmental impacts in the technosystem, and impacts in the ecosystems are less studied. Nevertheless, European datasets can still provide insights into a local LCA and examine a wide spectrum of background processes and environmental flows (Ossés de Eicker et al. 2010). Sensitivity analyses are highly recommended to identify the differences between options offered in databases.

Raw materials with relatively high climate change impacts such as steel and other metals have a notable effect on the climate change impact of a product, thus the reliability of an assessment is strongly influenced by an assessment of these raw materials. For instance, recycling steel usually saves energy and decreases greenhouse gas emissions (Yellishetty et al. 2011). Therefore, although modelling recycled steel and other recycled raw materials can have a considerable influence on their climate change impacts, SMEs are not usually aware of the exact origin of the raw materials used in their production systems. In situations like this, it may not be possible to ensure whether the used raw materials are recycled or not, or to know what the proportion of the recycled material is. Assuming an average ratio of recycling is the most suitable option in uncertain cases. Another important factor in modelling the climate change impact of metal products is to ensure that the manufacturing processes are included in addition to the raw materials as their impacts can be considerable (Olmez et al. 2016).

The products and services with a clear functional unit and system boundaries were the most feasible for an LCA clinic to keep assessments time-efficient. However, often suitable material data was not available. Lack of suitable material and process data in databases has also previously limited the possibilities to use streamlined LCAs (e.g. Arzoumanidis et al. 2017). For example, information on rare chemicals and raw materials was not available in the databases. In these cases, data on the climate change impacts were taken from scientific reports and journal articles. Occasionally, if a suitable dataset was lacking, it was replaced with data on other material that had the most similar chemical structure (e.g. magnesium nitrate was modelled as magnesium oxide). As the number of chemicals is substantial, a single database seldom provides suitable datasets on all of them and proxies are inevitably needed. Selecting a suitable proxy, however, is also one source of uncertainty (Subramanian and Golden 2016). In an LCA clinic, our idea was to model all raw materials and unit processes with the available datasets. If preliminary assessments determined that the raw material did not have a significant effect on the total climate change impact of a product or a service, no further effort was invested in modelling that raw material. When performing a full LCA, there is more time to search for data and to fill the gaps. Tailor-made databases e.g., for regional heat production, transportation or special chemicals would be practical and increase reliability and resource-efficiency of streamlined LCAs.

4.3. Assessment of direct and indirect emissions

Direct emissions (Scope 1) are emissions from sources that are owned or controlled by the organization, such as combustion of fossil fuels. Indirect emissions are defined as emissions from the consumption of purchased electricity, steam, or other sources of energy (Scope 2), whereas other indirect emissions include emissions that are not owned or controlled by the organization, such as production of purchased goods (Scope 3) (The Greenhouse Gas Protocol 2015). Based on data from many companies, Scope 3 climate change impacts are the largest component of most organizations' total impacts (Boles 2018, Downie and Stubbs 2013). This was also the case in the majority of the 23 LCA clinics (Figure 4). Therefore, focusing solely on decreasing direct emissions is usually not the most efficient way to decrease climate change impacts of a product. As raw materials are the major source of climate change impacts of many products, the most efficient way to reduce those impacts is to decrease the emissions caused by the production of raw materials. The LCA clinic provided the companies with more detailed information on the origin of indirect emissions and helped them to find ways to decrease the burden caused by, e.g. production of raw materials. In Finland, SMEs are provided with several tools to identify ways to decrease energy consumption and increase energy efficiency (see e.g. Motiva Oy 2018) but far less attention has been given on minimizing indirect emissions. Thus, the LCA clinic is more comprehensive than tools to assess energy efficiency as it is not restricted to direct emissions

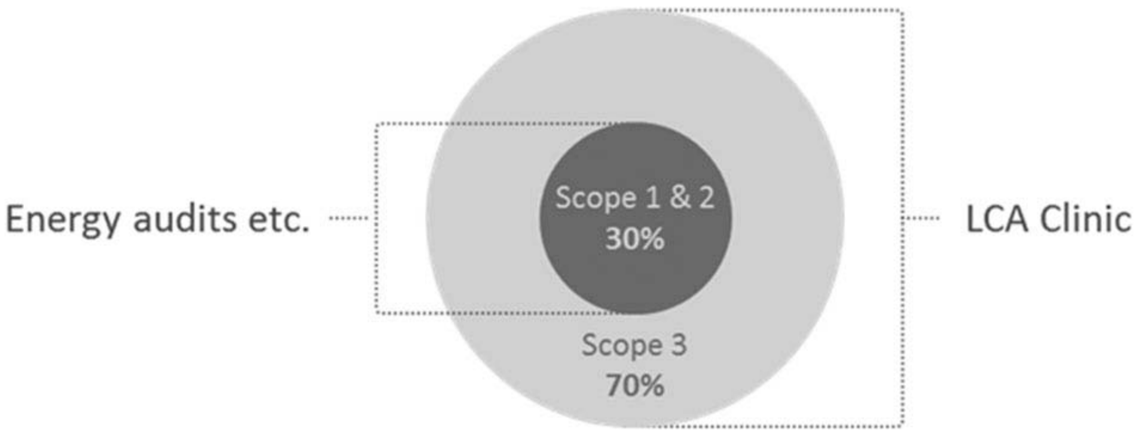

Figure 4. The climate change impacts of the 23 LCA clinics were mostly (70% of the total impacts) caused by scope 3 emissions and rest of impacts were scope 1 and 2 emissions. As an LCA clinic covers scopes 1-3, it is more comprehensive than e.g. energy audits where only scope 1 and 2 emissions are included.

In some cases electricity and heating (i.e. direct emissions) were the major sources of climate change impacts of products and services assessed in this study. Improving energy efficiency could be an effective way to mitigate the climate change emissions of SMEs. As energy expenses are currently quite low in Finland, companies may not be eager to improve energy efficiency (Paramonova and Thollander 2016). Other challenges include insufficient knowledge about energy-efficient opportunities and their costs, high investment costs, lack of time and personnel, other priorities and insufficient economic incentives and policies (see Paramonova and Thollander 2016 and references within). In this study, the company managers were given some advices on how to improve energy efficiency of products and processes but the feedback showed that none of companies had followed this advice. Eco-labelled green electricity was also recommended, but again, none of the company managers made changes to their existing electricity contract. We made no further inquiries on the reasons why these actions were not taken, but as suggested in previous research, it is possible that beneficial climate change impacts alone do not provide a sufficient incentive to change, cost savings are also required (Triguero et al. 2014, Paramonova and Thollander 2016).

4.4. Company managers' perceptions of the LCA clinic

SMEs motivations for participating in an LCA clinic were not assessed in this study. Still, most of them mentioned that they were willing to share information on the climate change impacts of their products with their customers. The company managers were also eager to know how well their products compared to other similar products on the market in terms of climate change impacts. Information on products with the same function was particularly interesting from this point of view. Comparison of LCA results, however, includes several sources of uncertainties, such as different system boundaries, calculation methods and applied datasets (see e.g. Mattila et al. 2012, Goglio et al. 2018). Comparison of two products with a similar functional unit but different assumptions behind e.g. assessment methodology or system boundaries can lead to biased interpretations. Furthermore, the results of an LCA clinic are more likely to include errors than full LCAs as they are not critically reviewed by external experts and a structured sensitivity analysis is not actualised, as described in ISO standard. Because of these limitations, comparisons of LCA clinic results to other LCA results are not recommended.

In an LCA clinic report provided to companies it was noted that the clinic had not been actualised following the ISO 14040 standard, and that results should only be used for internal decision making and product development. Companies can, however, share with their customers and stakeholders the climate change mitigation actions they are planning to make based on LCA clinic results. These actions could be, for instance, changes in electricity consumption or efficiency or exchanging raw material for a less harmful option.

Company managers' willingness to pay for an LCA clinic varied, and many were not willing to pay at all. Judl et al. (2015) have estimated that this type of streamlined LCA for SME would cost, based on the required time (between 10-40 hours of work time), approximately 600-2500 € + VAT (expert's hourly rate 60 €/h). Still, the majority of the company managers were willing to pay required costs. It should be noted that all companies that participated showed at least some interest in environmental issues. In their comments they stated that the costs should not be directed to SMEs but there should be some external funding source. Altogether approximately 60 SMEs were contacted, but some were not willing to participate, although they were offered a streamlined LCA without any cost. Thus, it is likely that only the most environmentally conscious companies would be willing to pay a sufficient amount for the LCA, and the majority are either not willing to pay at all or would participate only if there is a legally binding obligation.

4.5. Further development of streamlined LCAs

The aim of the LCA clinics was to make life cycle thinking accessible for a SMEs.

Therefore, it is important to keep streamlined LCA efficient in terms of time and monetary investments. To do so, some uncertainties have to be tolerated. Most importantly, an LCA clinic should be considered as a hot spot detection tool, not a replacement for a full LCA. The LCA clinics discussed in this study focused on climate change impacts, but other impact categories could be included. It has been demonstrated previously that impact categories are not correlating positively (see e.g. Payen et al. 2015 and Heinonen et al. 2016). Ideally all relevant impact categories (e.g., eutrophication or ecological toxicity) should be included and communicated to improve the reliability of an LCA clinic.

We consider that more development is still needed before LCA clinics can be used to support environmentally conscious decision making. For instance, databases for various materials and processes should be made freely available as they are the basis of a streamlined LCA and there are not comprehensive databases available for free. Development work of Product Environmental Footprint (PEF) methodology by the European Commission´s Joint Research Center may help with this issue if harmonised methodology for calculation together with freely available LCA datasets will be realised (European Commission 2018a; European Commission 2018b; GreenDelta 2019).

Further studies are needed to compare LCA clinics to full LCAs and how the skills of an LCA analyst influence the results. Some differences can be tolerated, but they should not distort the results to such an extent that the actions to decrease greenhouse gas emissions suggested in LCA clinic report are misleading.

Company managers' motivation is a crucial but not well understood aspect. Feedback given by the company managers indicated that they had not followed the recommendations to decrease the greenhouse gas emissions of their productions systems, at least at the time of asking. Why they were not motivated to follow recommendations and how their motivation could be strengthened require further investigation. One solution could be that funders of R&D projects would be compelled to obtain an assessment of environmental impacts of financed products or services with an LCA clinic.

Acknowledgements

The authors are grateful to appreciate all the SMEs which participated in the LCA clinics and were willing to share their data. The study was conducted as part of the Towards sustainable economic systems – key methods and tools, lessons learnt and future outlooks (ToFu) – project funded by the Finnish Environment Institute (SYKE) and the Framework for developing companies' environmental life-cycle impacts -project funded by the European Regional Development Fund and SYKE. The study was supported also by the research project Transition Pathways Towards Circular Economy (TRANSCIRC) (Decision No. 310405).

References

Akola E, Havupalo N. 2013. Restructuring in SMEs: Finland. European Foundation for the Improvement of Living and Working Conditions. [accessed 2019 Feb 5]. https://www.eurofound.europa.eu/sites/default/files/ef_files/pubdocs/2012/476/en/4/EF12476EN.pdf

Antikainen R, Seppälä J. (Eds.), 2012. Elinkaarimenetelmät yrityksen päätöksenteon tukena. FINCLA-hankkeen loppuraportti (The Forum of Life Cycle Methods for Supporting the Decision Making of Companies (FINCLA). The Finnish Environment 10/2012.

Arena M, Azzone G, Conte A. 2013. A streamlined LCA framework to support early decision making in vehicle development. J Clean Prod. 41: 105–113.

Arzoumanidis I, Salomone R, Petti L, Mondello G, Raggi A. 2017. Is there a simplified LCA tool suitable for the agri-food industry? An assessment of selected tools. J Clean Prod. 149: 406–425.

de Beaufort-Langeveld A, van den Berg N, Christiansen K, Haydock R, ten Houten M, Kotaji S, et al.1997. Simplifying LCA: Just a cut? Final report of the SETAC Europe Screening and Streamlining Working Group. Amsterdam, The Netherlands: SETAC.

Boles S. 2018. What are the differences between Scope 1, 2 and 3 Greenhouse Gas emissions? [accessed 23 April 2019]. https://www.bpaww.com/bpaww/#?targeturl=/bpaww/Content/MainContent/Products/icompli_Sustainability.htm&target=2&languageid=1&homepage=/BPAWW/Content/MainContent/Home/index.html&footerpage=/BPAWW/content/maincontent/footer/english.htm

Curran MA. 2000. Life cycle assessment: An international experience. Environ Prog. 19:65–71.

Curran MA, Young S. 1996. Report from the EPA conference on streamlining LCA. Int J LCA. 1:57–60.

Danilecki K, Mrozik M, Smurawski P. 2017. Changes in the environmental profile of a popular passenger car over the last 30 years – Results of a simplified LCA study. J Clean Prod. 141:208–218.

Downie J, Stubbs W. 2013. Evaluation of Australian companies' scope 3 greenhouse gas emissions assessments. J Clean Prod. 56:156–163.

Frischknecht R, Rebitzer G. 2005. The ecoinvent database system: a comprehensive web-based LCA database. J Clean Prod. 13:1337-1343.

Frischknecht R. 2006 Notions on the design and use of an ideal regional or global LCA database. Int J LCA. 11:40–48.

Goglio P, Smith WN, Grant BB, Desjardins RL, Gao X, Hanis K, Tenuta M, Campbell CA, McConkey BG, Nemecek T, Burgess PJ, Williams AG. 2018. A comparison of methods to quantify greenhouse gas emissions of cropping systems in LCA. J Clean Prod. 172:4010–4017.

Graedel TE.1998. Streamlined life-cycle assessment. Prentice Hall, Upper Saddle River, NJ.

The Greenhouse Gas Protocol. 2015. A Corporate Accounting and Reporting Standard. Revised edition. [accessed 01 March 2018]. http://www.ghgprotocol.org/corporate-standard

Hauschild MZ, Jeswiet J, Alting L. 2004. Design for the environment – do we get the focus right. Ann CIRP. 53:1–4.

Heinonen J, Säynäjoki A, Junnonen JM, Pöyry A, Junnila S. 2016. Pre-use phase LCA of a multi-story residential building: Can greenhouse gas emissions be used as a more general environmental performance indicator? Build Environ. 95:116–125.

Hillary H. 2004. Environmental management systems and the smaller enterprise, J Clean Prod. 12:561–569.

Hochschorner E, Finnveden G. 2003. Evaluation of two simplified life cycle assessment methods. Int J LCA. 8:119–128.

Finnveden G, Hauschild MZ, Ekvall T, Guinée J, Heijungs R,Hellweg S, Koehler A, Pennington D, Suh S. 2009. Recent developments in life cycle assessment. J Environ Manage. 91:1–21.

Huesemann MH. 2004. The failure of eco-efficiency to quarantee sustainability: future challenges for industrialecology. Environ Prog. 23:264–270.

Hunt RG, Boguski TK, Weitz K, Sharma A. 1998. Case studies examining LCA streamlining techniques. Int J LCA. 3:36–42.

International Organization for Standardization. 2006. ISO 14040:2006 Environmental management. Life cycle assessment. Principles and framework.

IPCC. 2011: Summary for Policymakers, in: Edenhofer O, Pichs-Madruga R, Sokona Y, Seyboth K, Matschoss P, Kadner S, Zwickel T, Eickemeier P, Hansen G, Schlömer S, von Stechow C. (Eds). IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Judl J, Mattila T, Manninen K, Antikainen R. 2015. Life cycle assessment and ecodesign in a day. Lessons learned from a series of LCA clinics for start-ups and small and medium enterprises (SMEs). Finnish Environment Institute 18/2015.

Johnson MP, Schaltegger S. 2016. Two decades of sustainability management tools for SMEs: How far have we come? JSBM. 54:481–505.

Levers C, Verkerk PJ, Müller D, Verburg PH, Butsic V, Leitão PJ, Lindner M, Kuemmerle T. 2014. Drivers of forest harvesting intensity patterns in Europe. Forest Ecol Manage. 315:160–172.

Levers C, Butsic V, Verburg PH, Müller D, Kuemmerle T. 2016. Drivers of changes in agricultural intensity in Europe. Land Use Policy 58:380–393.

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

McAloone TC, Bey N. 2011. Environmental improvement through product development—a guide, 1st edn. Denmark, Copenhagen.

Motiva Oy. 2010. Polttoaineiden lämpöarvot, hyötysuhteet ja hiilidioksidin ominaispäästökertoimet sekä energian hinnat (in Finnish) . [accessed 8 January, 2018]. http://www.motiva.fi/files/3193/Polttoaineiden_lampoarvot_hyotysuhteet_ja_hiilidioksidin_ominaispaastokertoimet_seka_energianhinnat_19042010.pdf

Motiva Oy. 2018. Private sector. [accessed 25 March, 2019]. https://www.motiva.fi/en/private_sector

Myllyviita T, Hujala T, Kangas A, Eyvindson K, Sironen S, Leskinen P, Kurttila M. 2014. Mixing methods – assessment of potential benefits for natural resources planning. Scand J Forest Res. 29(sup1): 20–29.

Myllyviita T, Antikainen R, Leskinen P. 2017. Sustainability assessment tools - their comprehensiveness and utilisation in company-level sustainability assessments in Finland. Int J Sust Dev World. 24:236–247.

Niemistö J, Myllyviita T, Holma A, Judl J, Sironen S, Antikainen R, Leskinen P. 2017. Elinkaariajattelu pk-ja startup-yritysten ympäristövaikutusten arvioinnissa ja tuotekehityksen tukena. (Life cycle thinking in the environment impact assessment and ecodesign for small and medium-sized enterprises and start-up companies). Finnish Environment Institute 34/2017.

Nygren J, Antikainen R. 2010. Use of life cycle assessment (LCA) in global companies. Finnish Environment Institute 16/2010.

Paramonova S, Thollander P. 2016. Energy-efficiency networks for SMEs: Learning from the Swedish experience. Renew Sust Energ Rev. 65:295–307.

Payen S, Basset-Mens C, Perret S. 2015. LCA of local and imported tomato: an energy and water trade-off. J Clean Prod. 87:139–148.

Peeredoom, EC, Kleijn R, Lemkowitz S, Lundie S. 1998. Influence of inventory data sets on life-cycle assessment results: a case study on PVC. J Ind Ecol. 2:109–147.

Rebitzer G, Ekvall T, Frischknecht R, Hunkeler D, Norris G, Rydberg T, Schmidt W-P, Suh H, Weidema BP, Pennington DW. 2004. Life cycle assessment. Part I: Framework, goal and scope definition, inventory analysis, and applications. Env Int. 30:701-720.

Revell A, Stokes D, Chen H. 2010. Small businesses and the environment: Turning over a new leaf? Bus Strat Env. 19:273–288.

Statistics Finland, 2017. Fuel Classification 2017. [accessed 8 January 2018]. http://tilastokeskus.fi/tup/khkinv/khkaasut_polttoaineluokitus.html

Subramanian V, Golden JS. 2016. Patching life cycle inventory (LCI) data gaps through expert elicitation: case study of laundry detergents. J Clean Prod. 115:354–361.

Takano A, Winter S, Hughes M, Linkosalmi L. 2014. Comparison of life cycle assessment databases: A case study on building assessment. Build Environ. 79:20–30.

Testa F, Battaglia M, Bianchi L. 2012. The diffusion of CSR initiatives among SMES in industrial clusters: some findings from Italian experiences. Int J Technol Manag. 58: 152–170.

Testa T, Nucci B, Iraldo F, Appolloni A, Daddi T. 2017. Removing obstacles to the implementation of LCA among SMEs: A collective strategy for exploiting recycled wool. J Clean Prod. 156:923–931.

Triguero A, Moreno L, Davia MA. 2014. The influence of energy prices on adoption of clean technologies and recycling: Evidence from European SMEs. Ener Econ.46:246–257.

VTT Technical Research Centre of Finland Ltd., 2017. LIPASTO - calculation system for traffic exhaust emissions and energy use in Finland. [accessed 12 December, 2017]. http://lipasto.vtt.fi/en/index.htm

Olmez GM, Dilek FB, Karanfil T, Yetis U. 2016. The environmental impacts of iron and steel industry: a life cycle assessment study. J Clean Prod. 130:195–201.

Ossés de Eicker M, Hischier R, Kulay LA, Lehmann M, Zah R, Hurni H. 2010. The applicability of non-local LCI data for LCA. Environ Impact Assess Rev. 30:192–199.

Yellishetty M, Mudd GM, Ranjith PG, Tharumarajah A. 2011. Environmental life-cycle comparisons of steel production and recycling: sustainability issues, problems and prospects. Environ Sci Pol. 14:650–663.

Winter S, Emara Y, Ciroth A, Su C, Srocka M. 2015. OpenLCA 1.4 Comprehensive User Manual Software Version: 1.4.1, Manual Version: 1.2. GreenDelta GmbH, Berlin.

World Commission on Environment and Development. 1987. United nations general assembly document A/42/ 427. In: our common future. Oxford:Oxford University Press