Lca implementation in firms environmental management system trough modular product life cycle descriptions

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Abstract The quantitative environmental performance based on comparative life cycle assessment (LCA) constitutes an increasing area of interest for the suppliers competitiveness in the product chain. However the sources of uncertainties still constitute a relevant barrier for the full LCA utilization. Such reduced precision may invalidate the whole reliability in the comparison of environmental impacts for different products. Using standard modules of information for single life cycle stages this paper presents a systematic methodology for the application of an independent information modules approach (IIMs) in order to deal with the complexity in manufacturing chains. Such approach requires a dedicated modular description both for the enterprise activity and for the supply framework conditions. The resulting description is "firm specific" and based on shared assumptions in order to be rapidly reusable. A case study was carried out in the footwear chain for different products. Findings of this preliminary study show that the clear definition of relevant parameters can limit the redundancies in LCAs and firm efforts in the inventory of consumption and emission patterns. Further deepening of such methodology can introduce an integration of attributional and consequential LCA approaches by emphasizing the dependencies between product life cycle scenarios and the resulting impacts.

1 Introduction

Life Cycle Assessment of consumer product can present nowadays several barriers in his pervasive application at firm level. Despite his scientific completeness such evaluation approach still find limitations in product certification [1]. In particular effectiveness of the LCI phase is influenced by the lack of reliable and uniform information to be gathered along the whole supply chain [1]. From a small

medium enterprise (SME) point of view a detailed LCA can represents a prohibitive investment in terms of time spent and cultural growth. Lack of shared methodology in comparisons and in aggregating data can reduce significantly the adoption of LCA based quantitative standards in industries. A severe simplification and standardization of LCA for each production stage, as proposed by industries and designers, could then significantly improve legitimacy and credibility of environmental considerations within the general manufacturing context [2] .
Simplified quantitative evaluation methods applied to Life Cycle Assessment such as gate-to-gate or cradle-to-gate assessment can be seen as promising approaches in order to support rapid and reliable application [3]. New tools are nowadays oriented to support product designer since conceptual phase by integrating such simplified assessment within CAD methodologies in order to provide preventive environmental profile calculation on the basis of inventoried data [4]. Flexible context of use for similar materials and components (i.e. technological processes, auxiliary materials, transport, etc.) can however introduce an high variance in final quantitative assessment. Such variance can invalidate comparison between similar products or materials particularly when produced by different firms integrating different eco design strategies.
In such work will be firstly presented relevant general barrier in implementation of LCA procedures within the small medium enterprise context, secondly a modular approach to deal with product complexity will be presented with specific reference to firm routines and to reliability requirement, finally an application of such criteria will be dealt with reference to footwear components.

2 Open issues in methodological application of LCA at SME level

At industrial level LCA holistic approach can weigh value of different manufacturing solutions by assessing the produced environmental and social impact in a wider context than those limited to the field of application [5]. This approach can be particularly relevant in enforcing green engineering area trough the comparison of specific environmental profiles referred to different products or different eco-design firm strategies (i.e. energy efficiency, green supply management, clean production etc.) [5].
A number of barriers can however affect the application of LCA methodology at level of small-medium enterprise (SME). Most relevant of them can be reported hereafter.

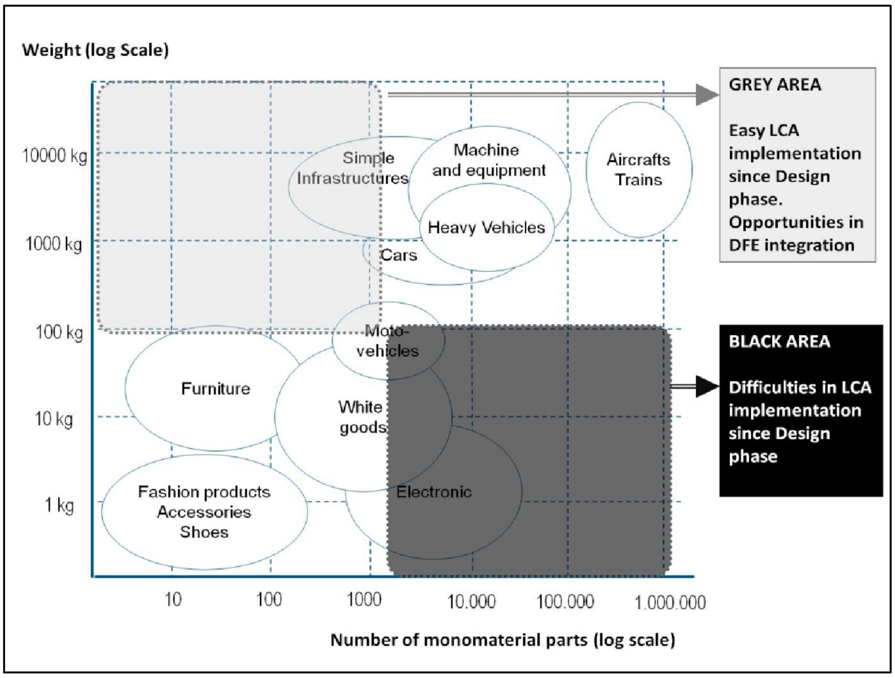

Fig.1: Classification of products according to their weight and number of elementary components.

- *Product portfolio complexity*

Cradle-to-gate assessment studies can suffer from inadequacy when reused in wider manufacturing contexts than the analysed one. Such problem is particularly evident when product is composed by an high number of parts or when the same product suffer from an high degree of variability in his bill of materials (i.e. fashion products). Number of different elements in each product can be considered an indirect measurement of LCA complexity (figure 1). Simple products composed by limited number of parts (>100) can be considered more easy to be analyzed. However rapid changes in supply conditions at product data management (PDM) level can imply further extension in LCA studies. However the shorter delivery time of new products makes the use of LCA since early design phases quite critical also for this product category. Cradle-to-gate LCA approaches dealing with entire products rather than single parts appear to be then less reusable than modular approaches referred to common parts.

- *Sampling of internal flows in LCI*

Cradle-to-gate assessment for common SME manufactured product are carried out on the basis of direct sampling of energy and material flow for production facilities. According to Jasch flow accounting are registered at macro level, this approach requires a further flows attribution to the different products provided by the same facility [6]. Such assignment requires specific allocation methodologies that can be based on statistical methodologies. A dedicate physical sampling of such flows could reduce variance coming from statistical allocation criteria.

- *Sampling of external flows in LCI*

A relevant contribution to cradle-to-consumer impact for SME product can be correlate to supply conditions [5]. Environmental burden from external suppliers is related to purchase of energy, of auxiliary materials, of outsourced services and of items to be processed. Making mention to material supply industry every year only in Europe can be purchased hundreds of new materials. At the same time information related to environmental flows can be related to confidential information and then not available. In absence of accurate data external flows can be modelled with attributional methodologies by introducing a certain degree of uncertainty [7]. The same LCA study can then present different degree of traceability in used data. A major traceability is related to direct energy and material flow sampling within production line while a minor traceability comes from aggregation of data based on LCI international databases especially for external process analysis. The average nature of such aggregated data can significantly alter the final accuracy of simulation and assessment.

- *Environmental information management at SME level*

In order to be properly used for design purpose final LCA information should require an alignment within decisional context between different information manager such as suppliers, life cycle analyst, product designer, production and product managers. LCA can influence positively product managers when assessments are provided in operative routines such as the bill of material (BOM) description or product data management level. Subsequent analysis are instead realized when environmental impact is "de facto" fixed.

3 Modular assessment integration in ubiquitous and enterprise environment

The approach followed by the current study tends to lower the complexity of the LCI input and output requirements, on a side reducing the relevant information to a small set of parameters easy to manage, to share and to understand, on the other side developing an effective and easily adoptable data exchange infrastructure.
Two main class of elective end-users have been targeted: product designer and final consumer, whose need are complementary but homogeneous.

Designers needs tools, able to help them in foreseeing the overall view of the product they are realizing, both in term of structural/functional and eco/sustainable aspects. Such tools should possibly be integrated as add-on of their habitual PDM/CAD instruments and should allow easy and efficient search and comparison functionalities, to support a selection of product components also based on eco/sustainability criteria.

Final consumers, on their side, needs a clear and reliable information about the environmental impact of the products they choose and purchase. Such an information should be evident and explicit, in order to raise the users' consciousness and commitment about their choices. Moreover, it should be easily included in public documentation of the product, compliant with search and comparison functionalities available on the web.

In both these mentioned use cases, common needs are the ubiquity of the LCA information and its usability by both software tools and human consumption, therefore the conformance to a standard representation formats and semantics.

To address such requirements in an homogeneous and scalable way, the approach followed by this study was to adopt the innovative ICT technologies which are the building blocks of the incoming Semantic Web [8], namely the RDF data model and the whole set of supporting technologies including HTTP protocol extensions and RDF/OWL based existent ontologies.

The RDF based approach offers simple mechanism to define and integrate reusable data in different already existent data models. In the examined application case this allows the effective integration of LCA information with technical data supporting the design of final products, their components / materials and their production phases.

On the basis of a proper theoretical and operating methodology presented in this paper, a small OWL ontology was therefore defined, to represent relevant parameters for the environmental assessment of a product. Such a set of properties could be associated to any product or component at any level of its BOM and published on the web Specific products and their attribute are identified by means of URIs , so they are uniquely addressable. Such a data is published conforming to the set of syntaxes and protocols supported by the Semantic Web community, so they are understandable by any existent RDF compliant tools.

A web based network allows to value chain suppliers to publish explicit and commonly understandable data about the sustainability of each product or component they produce, supporting in this way the design decision process of aggregate products. Such a process is recursive: on a side, component producers could access technical and LCA information from their suppliers, about raw materials; on the other side final consumers can obtain aggregated information about the environmental impact of the product they choose to buy.

Finally, RDF encoded LCA data could be understood by existent PDM/CAD tools, to complement technical and functional information about components and raw materials. Having this goal in mind, a proof of concept implementation of a PDM add-on is being developed in the context of Corenet project [9], to support a design for sustainability process in the shoemaking context.

4 Modular assessment model

Modular LCA based information requires specific LCI framework to aggregate information which are both simplified, verifiable and comprehensible by different stakeholders. Such framework is based both on products and processes incremental description and on "firm specific " data in order to be reusable and comparable for quantitative evaluation purpose.

Modelling of product cradle-to-gate environmental impact

An additive approach was applied [3] in order to reduce complexity and to increase reliability for cradle-to-gate product life cycle assessment. As reported in equation 1 preproduction impact is modelled by simple addiction of environmental modular profiles based on independent evaluations and referred to purchased items at BOM stage. The unitary impact is defined on correspondence of a set of physical commercial parameters (single piece, unitary mass, unitary area etc.). The use of standard assessment criteria (Ecopoints, EMS, CML etc.) enable the parallel monitoring of environmental impact along the product chain in correspondence of items aggregations or partial operations.

$$E_{CG}P = \sum_{i=1}^{p} n_i \cdot m_i \cdot \vec{e}_{CGmi}(e_1, e_2 ... e_q) = \sum_{i=1}^{p} n_i \, \vec{e}_{CGn}(e_1, e_2 ... e_q) \qquad (1)$$

$E_{CG}P$	Cradle-to-gate environmental profile for unitary product p for preproduction phase
m_i	Weight of item i composing final product p
n_i	Number of item i composing final product p
$\vec{e}_{CTGim}$	Unitary impact referred to unit of mass of item i
$\vec{e}_{CTGin}$	Unitary impact referred to single unit of item i

Tab.1: Variables and parameters related to the cradle-to-gate LCA

Cradle-to-gate LCA for each item is then provided by the aggregation SMEs contribution within "extended enterprise" providing the item (from material supply to customer delivery). Independent information modules can be built as an integral part of SME performance indicator for the purchased item.

Modelling of unitary impact relatively to manufacturing operation assessments
Information modules for single items unitary impact has been related to single manufacturing operations. The whole manufacturing process has been split in sequences of internal and external operations. Each operation can correspond to single transformation processes or to production stage as reported in equation 2.

$$\vec{e}_{CGi}(e_1, e_2 .. e_q) = \sum_{j=1}^{S} \vec{e}_{iSME}(e_1, e_2 .. e_q) + \sum_{k=1}^{T} \vec{\bar{e}}_{j\,SUP}(e_1, e_2 .. e_q) \qquad (2)$$

e_{CTGi}	Unitary environmental impact referred to item i purchased to industry
$\vec{e}_{iSME}$	Incremental impact for additional operation performed by a SME
$\vec{\bar{e}}_{jSUP}$	Incremental impact for additional operation performed externally to SME

Tab.2: Variables and parameters for unitary impact calculation

Such subdivision can make explicit the additional contribution of each industrial operation by emphasizing relevance of possible sources of uncertainties assessment along the product chain.

5 Experimental application

In the preliminary stage of the project Corenet independent information modules model has been applied to a real SME providing materials for the footwear sectors. Manufacturing of five different materials for shoe upper has been tracked since early stage in order to provide modular impact to be used at BOM level from shoe manufacturer. Relevant flows referred to processing and auxiliary materials has been tracked within production facility on the basis of sampled consumption, emission and waste for each item purchased. On the other hand information provided by different suppliers has been integrated to model the environmental impact of external supply systems. Unitary impacts has been modelled by using CML at the characterization stage in order to enable maximal reuse of general information. Outcoming result for BOM of materials are showed in figure 2.

$\vec{e}_{CGn}$	Material 01	Material 02	Material 03	Material 04	Material 05	Reference unit
e_1	1,04E-02	5,78E-03	1,06E-02	1,06E-02	1,20E-02	2 Shoe Uppers
e_2	1,30E+00	6,93E-01	1,32E+00	1,33E+00	1,47E+00	2 Shoe Uppers
e_3	7,88E-03	3,95E-03	8,05E-03	8,06E-03	8,97E-03	2 Shoe Uppers
e_4	1,34E-03	6,26E-04	1,37E-03	1,37E-03	1,54E-03	2 Shoe Uppers
e_5	4,20E-02	2,12E-02	4,27E-02	4,28E-02	4,95E-02	2 Shoe Uppers
e_6	1,29E-01	6,43E-02	1,22E-01	1,27E-01	1,41E-01	2 Shoe Uppers
e_7	1,98E+02	1,05E+02	1,99E+02	2,00E+02	2,20E+02	2 Shoe Uppers
e_8	2,29E-08	1,63E-08	2,02E-08	2,10E-08	2,30E-08	2 Shoe Uppers
e_9	6,92E-04	3,88E-04	6,97E-04	7,01E-04	8,02E-04	2 Shoe Uppers
e_{10}	2,88E-09	1,43E-09	2,84E-09	2,86E-09	3,11E-09	2 Shoe Uppers
e_{11}	3,60E-03	2,29E-03	3,62E-03	3,65E-03	4,21E-03	2 Shoe Uppers

Fig. 2: Modular environmental impact for five different shoe materials performed by a SME

$\vec{e}_{CGn}$	Standard impact categories (CML categories)
e_1	Abiotic Depletion (ADP) [kg Sb-Equiv.]
e_2	Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]
e_3	Acidification Potential (AP) [kg SO2-Equiv.]
e_4	Eutrophication Potential (EP) [kg Phosphate-Equiv.]
e_5	Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB-Equiv.]
e_6	Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]
e_7	Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB-Equiv.]
e_8	Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]
e_9	Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]
e_{10}	Radioactive Radiation (RAD) [DALY]
e_{11}	Terrestric Ecotoxicity Potential (TETP inf.) [kg DCB-Equiv.]

Basic structure for LCI aggregation is showed in the figure 3.

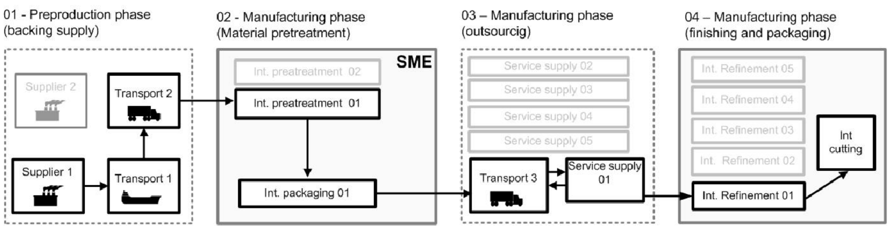

Fig. 3: Information modules structure in the examined product chain segment (production of the material 1)

The whole manufacturing process has been subdivided in four stages for all the five materials: an external pre-production stage for material supply, a first internal manufacturing, an external manufacturing activity and a final internal manufacturing of the upper (fig 4). Auxiliary process like energy supply, waste dismissal or operational material supply (oils, packaging materials etc.) has been considered included within such modules. Each deepening in modular LCA makes explicit contribution of different suppliers to final performance by extending supply network.

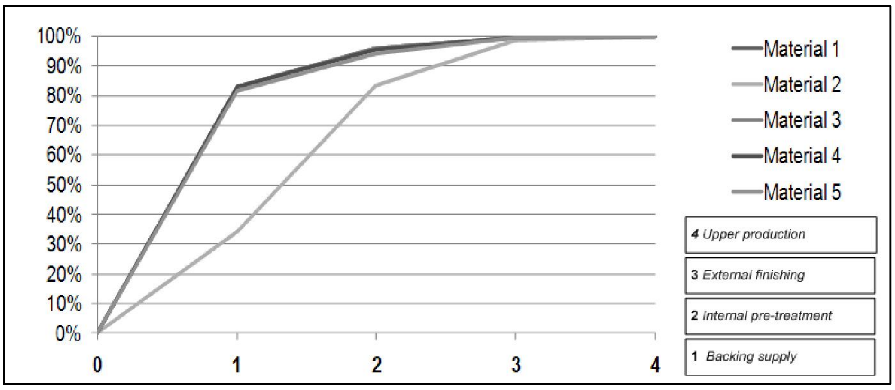

Fig.4 : Global warming potential percentage contribution within manufacturing chain.

Analysis of incremental burden of single processes show a deep prevalence of contribution of external processes to final environmental impact for all performance criteria (up to 80% of the final contribution) while the SME incremental contribution due to internal operations appears limited. Such prevalence calls for an improvement in flows description for the preproduction phase.

6 General conclusions

In such work a modular approach is presented in order to measure SME environmental performance in an extended supply chain trough a cradle-to-gate LCA approach. Within the Corenet project was developed an inventory method to provide quantitative information by evaluating additional environmental impact for different components. The application within SME context was explored and his extension to an ICT infrastructure is under study.

Preliminary application seems to demonstrate that a standard quantitative information, in terms of direct product pre-certification, can enforce competitiveness in the green engineering area. SME product manager can select

best component on the basis best environmental profile since BOM stage in absence of specific LCA studies for new products. On the other side application of new modular approach was explored at process level to support identification of possible area of close examination for LCA study within product chain.
The reduction the complexity related to LCA information can reveal under this light further advantages. Firstly, the ontology defined to support it appears requires a limited number of information, so it could be easily adopted by both the Semantic Web and the LCA communities with no excessive effort. Secondly the set of required data can easily be embedded in existent publishing vehicles, like web pages (through RDFa extension) or web services. This also can ensure that LCA data can be tracked also trough common web search engines, which are nowadays evolving towards the understanding of embedded RDF information, in order to support semantically significant searches.

7 References

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