17th European Symposium on Computer Aided Process Engineering – ESCAPE17
V. Plesu and P.S. Agachi (Editors)

Small Scale and Large Scale Plants – Effect on Life Cycle Assessment

Maiya Shibasaki[a], Stefan Albrecht[a], Thilo Kupfer[b]

[a]*Department Life Cycle Engineering, LBP, University of Stuttgart, Hauptstrasse 113, 70771 Leinfelden-Echterdingen, Germany, maiya.shibasaki@LBP.uni-stuttgart.de*
[b]*LCS Life Cycle Simulation GmbH, Ringstraße 73, 71364 Winnenden, Germany*

Abstract

The method of Life Cycle Assessment (LCA) enables the quantification of environmental burdens of products and processes regarding their total life cycle. LCA analyses can be carried out for processes at different development stages, whereas often the main interest is in LCA results for large scale production. Talking about LCA, it is mostly not considered at which stage of development the considered process or product actually stands. There can be significant differences in LCA results, depending on whether the considered process is a mini plant, pilot plant, small scale plant or finally in large scale plant.
The LCA analysis for processes at early stage of development do not necessarily reflect the environmental burdens of large scale processes – technical changes due to scale up can affect the LCA analysis. Especially in comparative studies, in which the environmental burdens of processes under development are compared to processes already running in large scale , there is the necessity to make assumptions for a large scale plant. This paper reports on the importance of such scale up prognosis and the first approach of a systematic method, which enables a scale up of LCA result based on small scale plants respectively pilot plants.

Keywords

LCA, Scale Up, Process Synergy, Pilot Plant, Large Scale Plant

1. Introduction

In recent years, society as well as politic emphasize more and more the “sustainability” of products and technologies. Accordingly, industry and society give more than ever priority to environmental issues, which establish together with economic and societal aspects the fundament of sustainability.
Life Cycle Assessment (LCA) is a method which is widely implemented in industry, research and development in order to analyze the environmental performance of systems i.e. of products, materials and technologies [1]. With this method the entire life cycle of a system can be taken into consideration for an environmental evaluation – production, utilization and end of life. Using direct data from industries for processes under scope, a LCA analysis shows the actual environmental impacts of regarded systems.

Present LCA analyses are carried out for processes and product systems at different development stages: for already commercially existing systems as well as for processes and products at early design stage.
A process development passes through several theoretical and experimental development phases. Experiments can be carried out at laboratory level, at mini plants or pilot plants [2]. During a process development, LCA experts can either deal with a so called “mini plant”, “pilot plant” or sometimes also with a process at laboratory stage – although in most cases the main interest is in LCA studies for an industrial scale process.

2. LCA and Processes at different stage of development

Taking a process, for instance a coating process, under development into consideration, the LCA results do not necessarily represent the environmental burdens which would be caused after scaling up to a typical mass production - although the quality of the LCA analysis is assured due to direct and accurate processes data. The reasons are summed up in the following:

Firstly there might be changes due to scale up in process yield as well as in energy efficiency of the process. These can influence the environmental burdens, as these affects the material and energy use as well as the amount of emissions and waste. The consideration of this aspect is integrated in the system “Process”.

Secondary, change in technology and for the material or energy provision affects the LCA results as well. The below mentioned system “Process Line” covers this aspect.

At last, in LCA analysis of pilot plants, processes are often seen as isolated or independent of each other. “Synergy effects” (see an example in Chapter 3.3) among processes are disregarded as well. Additionally effects due to changes in plant utilization are not considered sufficiently. The system "Plant Complex" considers these aspects in Chapter 3.

There are LCA analyses which take into considering the fact of scale up. However these integrate only selected aspects in the LCA analysis in order to make prognosis for large scale plant. Up to now, no systematic procedure has been established yet, which serves as a guideline to make a systematic "scale up" assumption of LCA possible considering the above mentioned aspects – therefore, by making assumptions, only some arbitrarily chosen single technical scale up aspects are considered. Thus, the considered aspects are not consistently among those studies. Therefore, there is a demand for a systematic method, which gives the LCA experts a guide how to deal with processes under development. The dept. LCE at LBP (former IKP) of University of Stuttgart is working on this topic. The importance of such method is reflected in questions about the actual relevance of LCA analysis, which had been carried out for processes under development. In the following, the first approach is presented how to establish a guideline for making assumptions in LCA scale up.

3. Scale Up in Life Cycle Assessment

In order to make LCA prognosis for a large scale plant based on a pilot plant, a systematic procedure must be compiled.
Assuming the availability of a detailed LCA analysis of pilot plant and design of the large scale plant, this approach covers the above mentioned aspects systematically. The "design" for the industrial plant includes those information which are determined respectively pre-calculated by plant producers – e.g. energy and material efficiency for 1 kg product.

A scale up prognosis should be carried out considering both technical and LCA aspects. As a result, a gradual consideration of the processes and the plant should be followed. Summing up, there are three categories each to be looked at, which are described in the following subchapters.
Consideration of

1. Process as system
2. Process line as system and
3. Plant complex as system.

3.1. Process as System

In the category "Process as System", which is to be considered at the beginning of the prognosis procedure, each process in a life cycle phase will be considered itself. A scale up can lead to changes in material and energy efficiency of a process – these affect the LCA results of the process / product.

It is not meaningful to track each small change in an apparatus or plant complex, which contribution in total life cycle is negligible at the stage of the first LCA analysis. A prognosis is basically bound with uncertainties. In addition, the LCA has an error margin, which depends on the details of the analyses and made assumptions, but is not absolutely avoidable [3]. A prognosis should therefore concentrate on relevant aspects. Hence, the first step of a prognosis is the relevance analysis of the considered process (to be scaled up) on basis of the LCA analysis of the pilot plant.

A relevance analysis should identify the relevance of considered apparatus and of their in- and outputs in the LCA results (material and energy). Fig. 1 shows an example for such analysis for a recycling strategy of a used product, taken a particular environmental impact category into consideration.

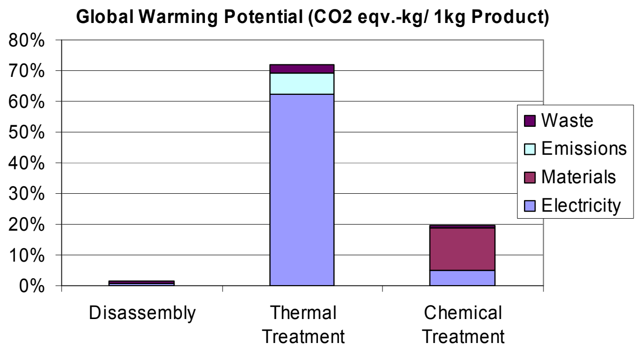

Fig. 1Exemplary result of a relevance analysis

The relevance analysis comprehends a life cycle phase – production, utilization or end of life. Whereas the scale up of processes under consideration is assumed to be part of production/end of life phase and not of utilization. Assuming the "product" or so called "functional unit" remains the same, the environmental impacts of a life cycle phase is usually not affected by a process in another life cycle phase.Therefore only the relevant life cycle should be taken into consideration in a relevance analysis. For instance the production has no influence on the use phase, as long as the quality of the product is the same. Only for relevant processes, a scale up prognosis should be carried out. In case of Fig. 1 the process 4 is not relevant, if the threshold of the relevance analysis is set as 10 %.

Only for processes with relevant contribution and which are to be scaled up, recalculation of environmental burdens must be carried out using the planned material and energy efficiency. Concerning energy efficiency an assumption must be carried out by the plant producer. The dependency of energy requirement on technical parameters such as dimension of the plant, temperature and pressure as well as material property is highly complex, so that a over-all statement for each process type cannot be carried out. In case this number cannot be given by the producer, best-case and worst-case numbers can

be determined in order to estimate a range of the environmental burdens due to the change of energy efficiency.
The material efficiency can as well be given by the producer. However, contrary to the energy efficiency, in case of materials also information must be determined which are usually not point of focus within the conventional plant development.
Depending on the type of the process the prognosis for the change of their inputs and outputs differ. Diffuse emission, solid emission (dust) and waste are those outputs, which occurrence depends on the process type. For the purpose of establishing a systematic method, these process depending aspects will be transferred into LCA depending categories.

3.2. Process line as System

In the system "Process Line" the upstream and downstream processes must be taken into account. With "Process Line", the technical and LCA aspects are brought together. The so called "up-stream" and "down-stream" processes stand for material and energy provisions respectively waste, waste water treatment or co-product processing, which are within the boundary of LCA analysis (see Fig. 2). Hence, changes in these up-stream and down-stream processes have influence on the LCA analysis. For instance electricity for a heating system can be substituted by thermal energy provided by natural gas.

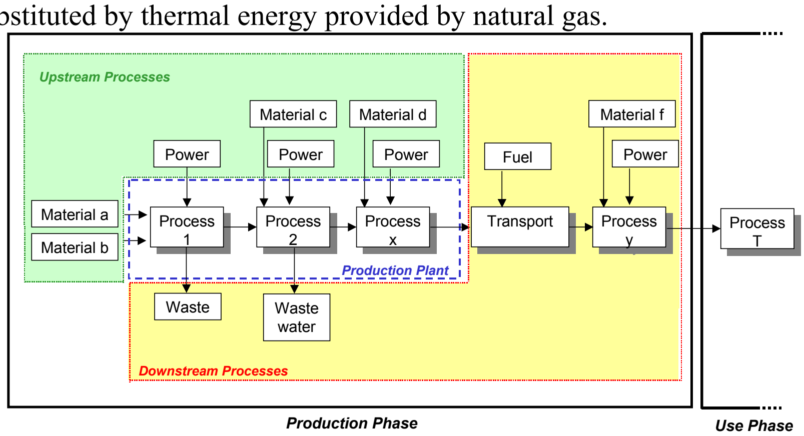

Fig. 2 Example schema of LCA boundary

3.3. Plant Complex as System

In the context of this paper, the system "plant complex" includes the plant (processes / apparatus and equipment) and, as it is in the above described system "Process Line", also the raw material production and energy supply as well as waste treatment of each apparatus. Not only the changes in inputs and outputs of the certain process can have influence on the LCA results as described above, also changes within a plant configuration (e.g. apparatus arrangement) can have effect on the result which can be classified in:

- Change in plant configuration
- Energy optimization

These two issues are usually considered at the stage of plant design in order to achieve more efficient and more economical plant systems. Optimization potentials can be found in the use of synergy effects among the process parts. An example for such synergy effect is the use of waste heat from one process part in another process part within the same production plant.
In the past, conducted projects aiming at energy optimization have shown significant reduction potential in primary energy use. Either by consequently use of synergy effects or by other strategies (e.g. better thermal isolation).

4. Conclusions & future work

Due to scale up, in most cases the LCA analysis of a pilot plant does not correspond to the LCA of a large scale plant. Therefore there are demands and necessities for a systematic prognosis for a scale up of processes and plants using the actual LCA analysis based on pilot plants. A prognosis method must take into account and integrate both technical scale up and LCA related aspects. For this purpose, relevant aspects must be determined for establishing such a method.
5.The relevant aspects are identified and with respect to their sources (technical or LCA aspect) categorized in a meaningful way. For a prognosis these categorized aspects must be passed thoroughly. Using these identified scale up aspects, LBP University of Stuttgart is working on development of this method, which enables a prognosis for a larges scale plant LCA based on LCA of pilot plant.

References

1. ISO 14040, "Environmental Management-Life Cycle Assessment: Principals and Framework", 1997
2. Shibasaki, M., Upscaling effect and Life Cycle Assessment, 13th CIRP International Conference on Life Cycle Engineering, Leuven, 2006
3. Ciroth, A., Fehlerrechnung in Ök obilanzen, Prozesswissenschaften der Technischen Universität Berlin, 2001