A Generalization of the Orthogonal Regression Technique for Life Cycle Inventory

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ABSTRACT

Life cycle assessment (LCA) is a method used to quantify the environmental impacts of a product, process, or service across its whole life cycle. One of the problems occurring when the system at hand involves processes delivering more than one valuable output is the apportionment of resource consumption and environmental burdens in the correct proportion amongst the products. The mathematical formulation of the problem is represented by the solution of an over-determined system of linear equations. The paper describes the application of an iterative algorithm for the implementation of least square regression to solve this over-determined system directly in its rectangular form. The applied algorithm dynamically passes from an Ordinary Least Squares (OLS) problem to the regression problems known as Total Least Squares (TLS) and Data Least Squares (DLS). The obtained results suggest further investigations. In particular, the so called constrained least squares method is identified as an interesting development of the methodology.

Keywords: Allocation, GETLS, Life Cycle Assessment, Multi-Functionality, Orthogonal Regression, Total Least Squares

1. INTRODUCTION

Sustainable development is now a major concern in most of the developed countries, resulting in stricter regulations concerning the impact of the products during their manufacturing, use and end of life. In the European Union, this tendency is confirmed by the Directive 2008/1/

EC (EC, 2008), which obliges the member states to take an integrated approach to the protection of the environment in licensing environmentally relevant installations, taking into account all environmental media (air, water, land).

Life cycle assessment (LCA) is a methodology used to quantify the environmental burdens (i.e., emissions of pollutants into the environment or depletion of natural resources) and impacts (i.e., actual quantitative measure
of the burdens’ harmful effect on the environment) associated with a product, process, or service across its whole life cycle (from raw material extraction, to actual production and/or assembly, to the use and disposal phases). Its main advantage over other site-specific methods for environmental analysis, such as Environmental Impact Assessment (EIA) or Environmental Audit (EA), is that it broadens the system boundaries to include all burdens and impacts in the life cycle of a product or a process, rather than focusing on emissions and wastes generated by the plant or manufacturing site only. In this way LCA, if correctly used, allows to avoid shifts of environmental burdens from a life cycle stage to another.

LCA has developed rapidly since 1990s, at the same time gaining widespread acceptance for various applications ranging from policy development, decision making, strategic planning and design.

Progress in LCA has been marked by some degree of standardization in the form of the ISO 14040 and ISO 14044 standards. As showed in Figure 1, LCA is traditionally divided into four distinct though interdependent phases:

1. **Goal and scope definition.** Attempts to set the extent of the inquiry as well as specify the methods used to conduct it in later phases.

2. **Life cycle inventory analysis (LCI).** Defines and quantifies the flow of material and energy into, through, and from a product system.

3. **Life cycle impact assessment (LCIA).** Converts inventory data into environmental impacts using a two-step process of classification and characterization.

4. **Life cycle interpretation.** Marks the point in an LCA when one draws conclusions and formulates recommendations based upon inventory and impact assessment data.

Even though defining the general framework for LCA, the ISO regulations do not provide detailed methodological guidance. Comprehensive and detailed guidelines are supplied, e.g., by Consoli et al. (1993), Guinée et al. (2002), Hauschild and Wenzel (1998), Heijungs et al. (1992), Lindfors et al. (1995), and Wenzel et al. (1997).

Our focus in this paper is only on the LCI phase. Within the inventory, the processes which play a role in the different phases of the life cycle of the investigated product are assembled. These phases consist of industrial processes (production, assembling, manufacture of raw materials, etc.), consumer processes (use and maintenance of products) and post-consumer processes (waste management and recycling). The collection of processes with their mutual

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**Figure 1. Illustration of LCA phases and representation of their inter-dependencies. At the right hand side of the picture a very short list of possible direct applications of an LCA are showed (International Organization for Standardization, 1997).**
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