FLEXIBILITY FOR APPLICATION

Market modelling in LCI databases

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International Workshop on LCI-Quality, Karlsruhe, 2003.10.20-21.

Abstract

Database flexibility is a crucial criterion for database applicability. If stored in a flexible format, the same LCI data may be useful in many different contexts. LCI results often depend on the assumptions made with respect to linking processes through a market. By modelling markets as processes, it is possible to combine the same unit processes in many different ways, depending on the scenario and market conditions appropriate for the individual LCI study. Market modelling is illustrated in two examples: 1) a database linking a comprehensive set of agricultural and food chain processes into product life cycles under actual and prospective market conditions, e.g. with and without production quotas, 2) a national input-output based database with both average and market-based modelling, illustrating the important differences and the possibilities for maintaining flexibility.

Keywords

Application fields and data appropriateness; methodology; database case studies

1. Database flexibility

When designing database structures and data quality requirements, flexibility of application is a crucial criterion. Far too often, databases are designed with a specific application in mind, hampering the use of data in other contexts.

In this presentation, I will focus on one specific aspect of flexibility in relation to LCI-databases, namely the way unit processes are linked when creating aggregated datasets for larger parts of product life cycles or even entire product LCIs.

When linking unit processes, it is unavoidable to determine how the input requirement for one unit process is met by the output of one or more other unit processes, and vice versa. The way this determination is made has an often crucial influence on the LCI results.

Linking inputs and outputs of unit processes, implies a modelling of how processes influence each other though the supply and demand of the goods and services flowing from one process to the other, i.e. it implies a modelling based on understanding of the relevant market conditions.

2. Market modelling

The standard assumption in most life cycle inventory models (as opposed to general equilibrium models) is that the long-term supply is fully elastic: For each process in the life cycle, the demand for 1 unit of product is assumed to lead to the supply of 1 unit of product, and other customers/applications of the product are assumed not to be affected. The current suppliers to the market are assumed to be affected in proportion to their current market shares.

However, there are a number of situations where the standard assumption is too far from reality to be an acceptable approximation [1]: Individual suppliers or technologies may be constrained in the long and/or short term and therefore have an inelastic supply. In this situation, the demand will shift to an alternative supplier/technology that is not constrained. If all suppliers to a specific market segment are constrained, or if one or more production factors are not fully elastic, a change in demand will lead to a change in market price and a consequent adjustment in demand (i.e. a behavioural change). Finally, a special class of constraints are those related to co-production, leading to the need for system expansions [2].

Each of these three situations (shift to alternative suppliers, behavioural changes and system expansion) implies changes with respect to which unit processes are to be linked, compared to the standard assumption.

Since market conditions are not necessarily the same in all scenarios that one wishes to analyse, it is important that the database design allows for flexibility in the linking of unit processes.

3. Designing for database flexibility

3.1 Design prerequisites

There are a number of prerequisites for database flexibility with respect to market modelling.

First, all the necessary unit processes must be present in the database, so that the choice between supplying unit processes and the modelling of behavioural changes and system expansion is not hampered by data availability. In practice, this amounts to a requirement for database completeness (which, however, does not mean that all parts of a database needs to have equal quality). Database completeness is not only a requirement from the point of view of market modelling, but is also a necessity to avoid data gaps that can lead to erroneous conclusions. The necessary database completeness can be obtained e.g. by applying input-output based data as default data [3].

Secondly, the unit processes must not be aggregated, but must be maintained in such a way that their links can be altered as required, ideally by the database user. Specifically, processes with multiple products should be left unallocated, so that the user can adjust the co-producing process to the relevant market situation and add and/or subtract those processes, which are necessary to balance out any dependent co-products [2].

One possibility for facilitating database flexibility with respect to linking of unit processes is to conceive and model markets as processes.

3.2 Markets as processes

A process is defined as a set of interrelated or interacting activities which transforms inputs into outputs (ISO 9000:2000). This implies that a market can also be described as a process. Inputs to the market may come from a number of different suppliers or as "negative outputs" to processes affected by price changes.

The advantage of describing markets as separate processes is that it is possible to combine the same unit processes in many different ways, depending on the scenario and market conditions appropriate for the individual LCI study, without changing the flows in each of the processes supplying and being supplied by the affected market. Furthermore, it is possible to document different market conditions using the same data documentation format as for other processes [4].

3.3 Allowing for market modelling in LCA-databases

Market modelling has been applied more or less consistently in stand-alone LCAs for the last 5 years, but until recently no databases consistently supported such LCAs with market data and options for systematically analysing LCI-results under different market conditions.

Lately, we have had the management of two database projects, where market modelling has been part of the design requirement. These two databases are described below, with a focus on how the options for market modelling was implemented.

4. Example 1: Market modelling in an LCA-database for the food sector

The Danish LCA Food Data Base [5] contains unit process data for 28 representative farm types, together representing the entire Danish agricultural sector, and 7 types of fishery, together representing the entire Danish fishery. The database furthermore contains data on the most important types of aquaculture, processing in the food industry, storage, retail trade and meal preparation.

The unit processes are described on the Internet with meta-data in machine-readable format (ISO 14048-compatible), while the environmental data are available as a SimaPro database with all the individual unit processes. The database user can therefore link the different processes as desired to represent different market conditions, including the standard assumption where all producers are affected proportionally to their current supply to the market.

Data on what farm types are affected by a small (marginal) change in demand are available as part of the database. For crops, these data are based on simulations with the Econometric Sector Model for Evaluating Resource Application and Land use in Danish Agriculture (ESMERALDA) [6], while for fish, sugar and milk, data are provided for both the situations with and without productions constraints (quotas etc.). For milk, the constraints due to the quota system also apply to the dairy where the milk for an increased output will be taken from the least profitable outlets, namely milk powder and butter. Only in the situation without quotas, the output from agriculture is affected and therefore included.

5. Example 2: Market modelling in an input-output-based LCA-database

5.1 The Danish input-output based LCA-database

As part of a project for the Danish EPA, we have recently produced an LCA-database covering the entire Danish production and consumption, based on the national input-output tables expanded with environmental accounts. The database covers all major emissions as determined by the Danish normalisation reference [7]. Imported supplies are modelled on the basis of foreign input-output tables. The database is currently at a fairly large degree of aggregation (160 product groups) but there are several options for further subdivision to any desired level of product detail [3].

5.2 Identifying the production constraints

When input-output tables are used to model the environmental effect of a change in consumption, the standard assumption (that an increase in consumption will lead to a corresponding increase in production, and vice versa for a decrease in consumption, i.e. that the supply is fully elastic) is typically implicit.

To diminish the consequent errors in LCI modelling described in section 2, we have analysed the Danish economy systematically for industries with long-term production constraints. This means that for each sector, we asked:

- Are there any regulatory or political constraints that determine the production output, so that this output cannot change in response to a change in demand?

- Does the sector have any co-products, the output of which cannot change in response to a change in demand, since it is determined by the demand for a determining product?
- Are there any long-term constraints in availability of raw materials, waste treatment capacity, or other necessary production factors?

As a result of our analysis, we identified the following main areas where constraints play a significant role:

- Agriculture, fishery, and the food industry, where some products are limited by quotas or similar regulatory arrangements (as already described in section 4) and where there are a number of dependent by-products, for which the output cannot change in response to a change in demand, notably animal hides, meat from milking cows, and fodder by-products of the food industry, where a change in demand in practice will lead to a change in output of the least-cost unconstrained fodders, typically soy for protein (with oil as a by-product) and grain for carbohydrates.
- The vegetable oil and animal fats industry, where animal fat and soy oil are dependent by-products, for which the output cannot change in response to a change in demand.
- Extraction of crude oil, where a change in demand for the by-product gas does not lead to a change in production volume.
- Electricity generation, where some sources of power are constrained in some regions (wind power, hydropower, nuclear power) and where a change in demand for the by-product heat in most situations does not lead to a change in production volume.
- The recycling industry, which is ultimately constrained by the supply of scrap materials.
- Industries in decline, such as the European ammonia and chlorine industry, where there is a constraint on building of new production plants, so that a change in demand will affect the least-profitable production units, typically with the highest emission factors.

In most other industries, changes in demand will affect the modern plants, typically with low emission factors. This implies that using average emission factors will lead to a systematic overestimation of the impact of a change in demand. To avoid this, it is recommended to supplement the database with specific modern processes in the cases where there is a significant difference in technology and emissions between the average and the modern plants. At the current stage, this last recommendation has not been implemented in the Danish database.

5.3 Technical implementation

The practical implementation of options for market-based modelling in the Danish input-output database has been done by ensuring that each sector with internal constraints are divided into a constrained and a non-constrained part, and then by transferring the constrained supplies to the alternative non-constrained sector.

The constrained outputs are not removed, but they are simply not used by the product life cycles that draw on the constrained markets. In this way, the total production volume and thus the total emissions of all sectors are kept constant, while making the model sensitive to life cycle simulations. This also means that the resulting national LCA-database still contains the data relevant for other environmental policy questions than those narrowly defined by LCA, e.g. questions that focus on non-market-based environmental measures aimed at the constrained sectors.

6. Conclusion

It has been demonstrated how market modelling has been implemented in two large LCA databases in a flexible way that allows many alternative assumptions regarding the actual market conditions, including the traditional standard assumption. This has widened the application field of these databases and increased the options for using the databases to make LCIs with valid and policy relevant conclusions.

References

1. B P Weidema (2003) · Market information in life cycle assessment. Copenhagen: Danish Environmental Protection Agency. (Environmental Project no. 863).
2. Weidema B P. (2001). Avoiding co-product allocation. Journal of Industrial Ecology 4(3):11-33.
3. Matching bottom-up and top-down for verification and integration of LCI databases. Presentation for UNEP International Workshop on Quality of LCI Data, 2003.10.20-21, Karlsruhe. This volume.

4. Weidema B P, Cappellaro F, Carlson R, Notten P, Pålsson A-C, Patyk A, Regalini E, Sacchetto F, Scalbi S. (2003). Procedural guideline for collection, treatment, and quality documentation of LCA data. Available from http://www.pdt.enea.it/doconline/documents/LC-TG-23-001.pdf(Document LC-TG-23-001 of the CASCADE project).
5. Nielsen P H, Nielsen A M, Weidema B P, Dalgaard R, Halberg N. (2003). LCA Food Data Base. http://www.lcafood.dk
6. Jensen J D, Andersen M, Kristensen K. (2001). A Regional Econometric Sector Model for Danish Agriculture - A Documentation of the Regionalized ESMERALDA Model. København: Danish research Institute of Food Economics. (Report 129).
7. Stranddorf H K, Hoffmann L, Schmidt A. (2001). Normalisation and weighting - update of selected impact categories. København: Danish Environmental Protection Agency. Environmental project. Draft manuscript.