Re-engineering LCA for simplicity and flexibility

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1. Introduction: Database design strategy

A design strategy for LCI databases was proposed by Weidema (2003), containing three elements: 1) Database completeness 2) Unlinked and unallocated unit processes 3) Markets as separate unit processes.

Database completeness is required to ensure that different kind of models can be applied without being hampered by lacking data availability. Data completeness of course also ensures that comparisons are not biased by differences in completeness of the compared systems.

Having datasets available as unlinked, unallocated unit processes is a requirement for allowing different models to apply different algorithms for linking the datasets. The difference in linking algorithms is what distinguishes attributional and consequential models. Linking algorithms differ in the extent to which they take into account constraints (thus excluding specific unit processes from the supply chain), and in the way they deal with by-products (by substitution or allocation; the latter with many different allocation keys). This also provides a clear distinction between the verifiable, unlinked, unallocated process models that can be checked directly against their real life counterparts, and the linked, mono-product systems that necessarily require the introduction of assumptions, either on how markets react to changes in demand and supply (the economic assumptions of consequential models) or on what constitutes a fair attribution of the exchanges of unit processes to their products (the normative assumptions of attributional models).

Modelling markets as separate unit processes provides a simple way of combining the same (non-market) unit processes in many different ways depending on the system model applied, without changing the flows in each of the processes supplying and being supplied by the market. Furthermore, this makes it possible to document different market conditions using the same data format as for all other unit processes.

While Weidema (2003) reported two examples of databases that had applied this design strategy, the full potential of the strategy was not realised at the time, partly because the market activities were not systematically implemented as separate unit processes, partly because of technical limitations in the LCI data formats and LCA softwares available (e.g. inability to assign more than one property to a flow, inability to handle negative product flows, lack of machine-interpretable technological and geographical identifiers to delimit markets and locations of unit processes).

With the implementation of the ecoSpold 2 data format <www.spold.org> in the context of the ecoinvent database version 3, these identified limitations have been removed.

2. Technical implementation

2.1. The use of flow properties

The ability of the data format to handle several properties of the same flow means that physical and monetary causalities can be modelled within the same integrated framework. This also allows both economic allocation and allocation according to physical allocation keys, for the same flow in different system models, all based on the same unit process data. Alongside the physical and economic product properties, the ecoinvent database also requires production volumes to be specified for each intermediate output, since this information is required to produce market averages and production mixes.

2.2. The use of geographical and technological identifiers

The ecoSpold 2 format specifies geographical information in terms of the geographical coordinates according to the Keyhole Markup Language, used e.g. by Google Maps, and thereby allows machine interpretation of locations and market boundaries and the geographical relationship between datasets, e.g. what activities occur within the boundaries of a specific market.

The ecoSpold 2 format furthermore allows to specify the technological level of an activity in terms of a machine-interpretable classification system (outdated, old, current, modern, new), with current as the default. Thereby, the technological level can be applied as input for consequential model algorithms that place constraints on activities with specific technology levels.

2.3. Completeness and systematic implementation of market datasets

In the ecoinvent database version 3, all human activities are covered, although at different levels of detail, and each product has a corresponding market activity dataset. As a minimum, each activity is represented as a global dataset, when no local datasets are defined. When local datasets are defined, a Rest-of-World dataset is automatically created on the basis of the global dataset, covering the part of the global geography that is not covered by the locally defined dataset.

A market dataset is identified in terms of its output of the marketed product. The inputs of this product to the market dataset is automatically identified as the output from all activities that produce this product within the geographical boundaries of the market, weighted in proportion to their production volumes. Likewise, all other product inputs – to both market and non-market activity datasets – are automatically drawn from the local market, i.e. the market that geographically includes the activity dataset.

The systematic implementation of market datasets implies that all datasets – both market and non-market activity datasets – are completely independent of each other. No linking between datasets is required before upload to the database, which means that the data providers do not have to specify the supplying activity, but only the names of the intermediate inputs required. This also means that each dataset can be supplied and maintained completely separately from the rest of the database, while the correct linking and embedding is ensured by the database linking algorithms for each specific system model.

The completeness of the database implies that any new dataset is in principle a disaggregation of an existing dataset. New datasets are therefore always embedded as an improvement of an existing dataset, and its place, i.e. in the right place, so that all the activities that draw upon the old dataset are improved, without requiring any action from the database administration.

2.4. The use of negative product flows

The ability of the LCA or database software to handle negative product flows means that an output can be modelled as a negative input and an input can be modelled as a negative output. This is particularly useful for the modelling of material outputs (wastes or byproducts) that need treatment, since these materials can only be included in a supply chain calculation if they appear as inputs. By modelling these physical outputs as negative inputs, the mass balance of the producing activity can be maintained, while following the physical and economic causality. The treatment activity can likewise be modelled as having the treated material as a negative reference product rather than as a positive input, thereby reflecting the nature of the activity as producing a treatment service, while maintaining the mass balance of the treatment activity intact.

In consequential models, all by-products are moved to be negative inputs, thereby reflecting the reduction in demand for the by-product caused by the joint production. This modelling algorithm, which was originally proposed by Stone (1960), has become known in LCA as substitution or system expansion, avoiding the need for allocation. The availability of markets for all products provides a consistent and unambiguous modelling of what the by-product substitutes, namely the inputs to the market.

3. Conclusions

The design requirements for database flexibility proposed by Weidema (2003) have been applied to the ecoinvent database, resulting in an LCI database with comprehensive coverage and full flexibility for different applications, for example attributional models with any desired allocation key, and consequential models with any desired level of constraints. At the same time, this design flexibility leads to a reduction in the efforts needed for the maintenance of the database, since allowing many different models to be constructed from the same basic unlinked unit process datasets means that only one dataset needs to be maintained for each unit process, and the maintenance of each dataset can be made independent from the maintenace of all other datasets. Flexibility and simplicity are therefore not contradictions but rather simultaneous results of the new design strategy.

4. References

[1] Weidema BP. (2003). Flexibility for application. Market modelling in LCI databases. Presentation to the International Workshop on LCI-Quality, Karlsruhe, 2003.10.20-21. http://www.lca-net.com/publications/
[2] Stone R. (1960). Input-Output and National Accounts. Paris: OECD.