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An approach for handling geographical information in life cycle assessment using a relational database

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Abstract

A new data model has been developed to handle information relevant to site-specific life cycle assessments (LCA). The model is orientated towards GIS-representations of three generalised subsystems; the technical, the environmental and the social subsystems. The technical and environmental systems are mainly linked through flows of energy and matter, which are the causes of environmental impacts, which subsequently is perceived, evaluated and acted upon by the social subsystem. For all three systems important differences, attributable to geographical locations can be determined. With the new data model a possibility to enhance LCA and reach more relevant results emerge due to a higher site specificity. The high level data model is expressed as relations between different entities using the entity relationship (ER) modelling language. An existing LCA-database, SPINE, which is already used by several companies for decision support in product development, can be utilised since the structure of the database supports geographical information. So far, applications with GIS-data are limited, but examples of area specific LCA impact characterisation factors exist.

Keywords: Life cycle assessments (LCA); Entity relationship (ER); Relational database

1. Introduction

Life cycle assessment (LCA) is a tool for assessing the environmental impact caused by a product or service. The basic principle for LCA is to follow the raw material and the energy used by the manufacturing process for the product or the service-performing process upstream, to the virgin resource extractions and downstream, to the final disposal of the waste produced at each stage during the entire life cycle.

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The environmental impact of a product or process is caused by exchange of energy and matter between the technical (sub)systems, and their surrounding environment. In the case of agriculture, for example, this interaction may be complex, involving several kinds of impacts such as, e.g. land-use (including the occupation of space), leakage of nutrients, emissions from machinery and manure, and compaction of soil.

During the LCA modelling each subsystem of the life cycle is linked together into a chain of processes, in one end extracting resources and in the other giving various types of emissions or waste. This chain of linked processes is referred to as the *technical system*. In reality a technical system is under some sort of human control and designed for a certain purpose, to deliver a certain benefit or good, which in the LCA is expressed through the functional unit of the system. The processes are also located somewhere, which implies that they can be *geographically referenced*.

Environmental impact caused by a technical system, or its LCA equivalent, the functional unit, is estimated in terms of the negative change implied by the technical system upon the *environmental system*, as evaluated by the *social system*. These systems may also be geographically referenced, which is an important starting point for a consideration of the relations between LCA and localised environmental impacts.

The traditional, generic, LCA methodology has been developed out of mass balances studies of production systems covering ‘cradle to grave’, where both cradle and grave belong to the environmental system. Materials and energy flows in the technical system are thus followed from extraction to final deposition. However, as the models of the systems become large and complex, information on locations of different activities are mostly lost when aggregating data on similar material and energy flows. This in turn becomes a problem when trying to assess the impact of different flows to and from the environmental system since the sensitivity of ecosystems are varying.

The aim of the work reported here is to present a data model of the LCA procedure and to include geographical information in such a way that site-specific impacts may be assessed. A geographical expansion of LCA methodology rises demands on data. A such LCA should thus not be considered as part of the standard method of LCA but as a possibility to be used when the study can benefit from this further work, e.g., when the significant environmental impact is a contribution to acidification where differences of ecosystem sensitivity are well established. It seems not likely that geographically referenced information can be used commonly in an LCA today or in the nearest future. However, a data model in itself is not dependent on the amount of data that are arranged according to the model.

2. A data model of LCA

In order to use a relational database as a tool for LCA the method first needs to be expressed, or modelled, into a language that can be used for database design. Fig. 1 depicts a high level model of the relationship between the technical, environmental and social systems, described in the introduction, by using the entity relationship (ER) modelling language [1]. In the ER-language, a box represents an entity, a diamond

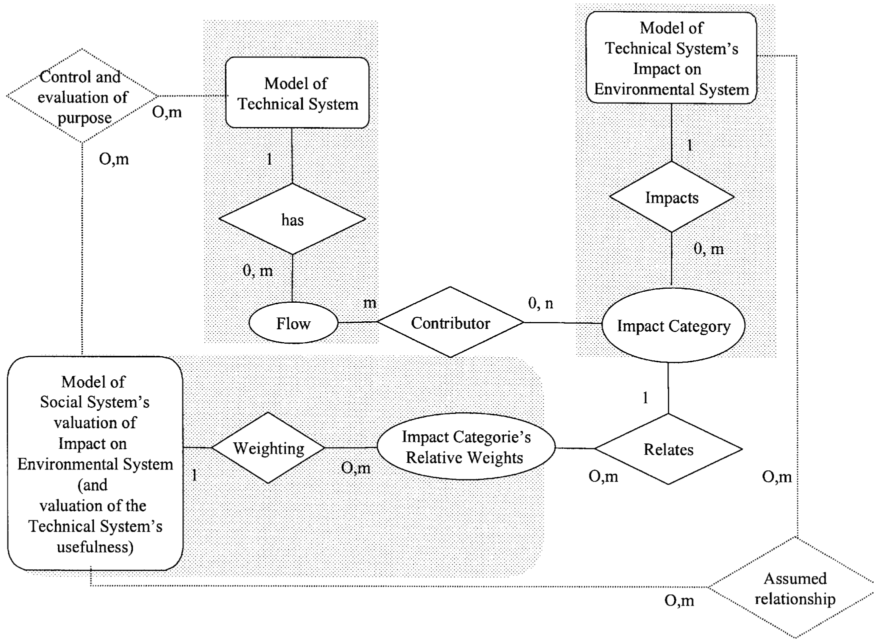

Fig. 1. An ER data model of LCA, that describes the relationship between the three different systems.

represents a relationship, and an oval represents an attribute of an entity like, for example, the flows out from a technical system.

The key to understanding Fig. 1 is given in the following subsections (the relevant attributes of the entities have been lifted out for explication).

2.1. About the systems

2.1.1. The technical system (TS)

A model of a technical system may have zero or many flows (the ‘0,m’ between the ‘has’-relation and the ‘Flow’-attribute).

2.1.2. The environmental system (ES)

A model of the environmental system may have zero or many impact categories (the ‘0,m’ between the ‘has’-relation and the ‘ImpactCategory’-attribute).

2.1.3. The social system (SS)

A model of a social system’s valuation of the impact on an environmental system may concern zero or many impact categories (the ‘0,m’ between the ‘has’-relation and the ‘ImpactCategoriesRelativeWeight’-attribute).

2.2. About the relations between the systems

2.2.1. Relations between the technical system and the environmental system

• Constituted by material and energy flows of TS causing identified changes in ES: The flows of TS may be described in accordance with the model of the impact categories of ES. One specific flow may affect many or none impact categories (the '0,m' between the 'Contributor'-relation and the 'ImpactCategory'-attribute), while one specific impact category may be the consequence of many different flows (the 'm' between the 'Flow'-attribute and the 'Contributor'-relation). Please note that this means that the model does not consider environmental impacts caused by other sources than technical systems.

• Constituted by the change of material and energy flows between the two systems, as implied by changes in ES: Changes in ES force changes on the flows of TS. (Resource depletion enforces substitutions and decrease of certain flows). The model considers no other than material and energy flows between the technical and the environmental systems.

2.2.2. Relations between the technical system and the social system

• Constituted by information flow from TS to SS: SS retrieves information from TS for evaluating the good supplied by TS in relation to the environmental changes it causes. This information generally is carried as the quality or the value (physical or economical) of the good produced by the technical system. In LCA this is an *implicit* part of the evaluation model, in which the good supplied is the purpose of the technical system and the basis for, for example, economical valuation of environmental changes vs. produced products. (The '0,m' between the 'Control and evaluation of purpose'-relation and the entity 'Model of a Social System's Valuation of the Impact on an Environmental System').

• Constituted by information flow from SS to TS: SS controls TS by information input, as a result of an evaluation process. This is the consequence of an LCA, when the result is used to control, manipulate or take any other decision regarding the technical system studied. (The '0,m' between the 'Control and evaluation of purpose'-relation and the entity 'Model of Technical System').

It should be emphasized that the analyst's information retrieval, for the analysis, is not included in the model, i.e. the analyst is not considered part of the social system, which, of course, is a simplification.

2.2.3. Relations between the environmental system and the social system

• Constituted by information flow from ES to SS: Environmental change needs to be identified in order to assess its weight in relation to other identified environmental changes. (The '0,m' between the 'Assumed relationship'-relation and the entity 'Model of a Social System's Valuation of the Impact on an Environmental System').

• Constituted by information flow from SS to ES: SS has no active relation towards ES. (The '0,m' between the 'Assumed relationship'-relation and the entity 'Model of Environmental System'). The meaning of this relation may be discussed, since the idea of 'technical system', implies that any action performed by the social system is realised through the technical system.

3. On ER-modelling

When representing an entity as a box, as in the ER-language, the entities' inner structures are neglected. This allows for a top-down modelling approach, which has two important implications for the modelling of GIS as a tool for LCA. First it allows for focusing on the relations between the entities without having to be concerned about their inner structures. When applying a systems analytical approach it is beneficial to regard these relations as *interfaces*, each relation defines the interface between adjacent systems. This is the interdisciplinary approach of LCA: the relations between the systems can be defined, without having to deal with the complexities within each one of them. Hereby enabling the design of a robust high-level data model of LCA as a tool.

Having designed the high-level model, the competence required while designing the inner structure of any entity need not be interdisciplinary. As long as the high-level model and the relations between the different systems are understood and obeyed by the modelling teams, i.e. as long as the interfaces of adjacent systems are consistent, each team is free to focus on how to model the inner structures of any specific entity.

4. SPINE

SPINE [2] is a relational database structure, designed for storing LCA data. The structure has been used to implement LCA databases at many different locations, both for large databases and as storage device for LCA analysis software. The structure of SPINE follows the model described in Fig. 1.

The inner structure of the entity describing the technical system has been thoroughly modelled in SPINE. This was done in 1994 as a close co-operational project, including chemical and technical engineers and data modelling experts. The result was a structure for the analytical model and data on the technical system and an integrated data dictionary for data describing the data (metadata). SPINE also includes models of the environmental and the social systems, but these are not yet as well modelled as the technical system.

In addition to this, SPINE was prepared also for handling geographical information. In order to realise this enhancement of SPINE, LCA needs to be further analysed from a geographical viewpoint.

5. LCA and geography

Modelling LCA as consisting of three related systems implies that the geographical aspects of LCA is the aggregate of the geographical aspects of each of these systems. The nature of each such geographical aspect is presented in the following three subsections.

5.1. Geography and technical systems

A technical system generally includes processes which might be geographically referenced, and which are connected via different types of transport systems, such as goods (road, sea, air) or energyware (pipelines, electricity grid) distribution systems. The geographic location and extension of such a technical system gives relevant information for the modelling and assessment of its environmental impact [3].

5.2. Geography and environmental systems

Given the geographical location of the different parts of the technical system, it is possible to model the dispersion of various agents, so that the varying sensitivity of ecosystems, regions, etc., can be taken into account where this is relevant [4].

5.3. Geography and social systems

A geographically large technical system (and the environmental impacts of such a system) may cross national, regional and even continental boundaries, and therefore also affects different cultures or groups of people, holding different attitudes towards changes in the environment. Since the environmental impact is a composite measure, based on

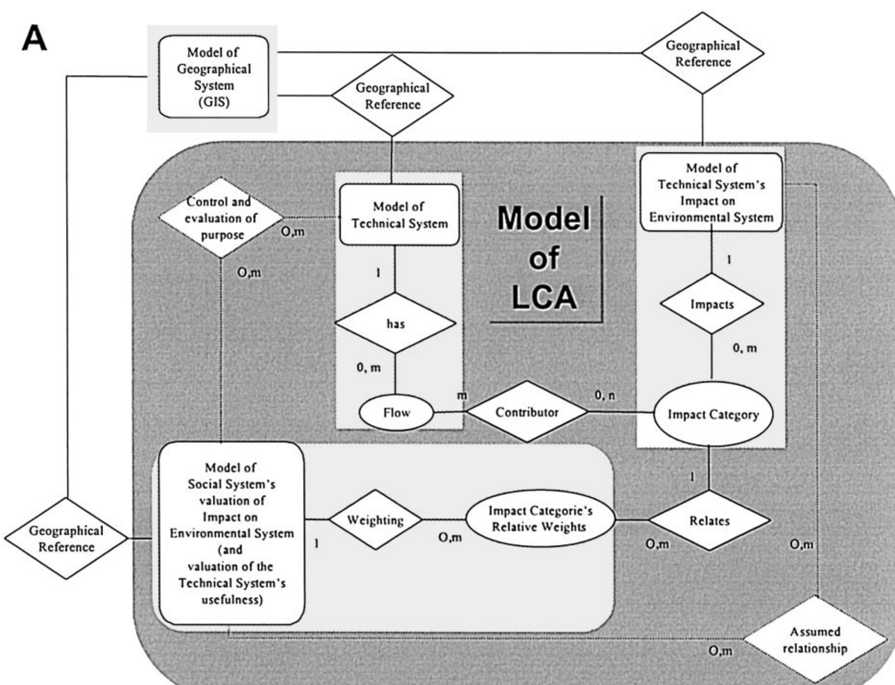

Fig. 2. A data model of LCA complemented with an entity for GIS.

both the changes that take place in the environment and on the social system's attitudes towards such changes, a relevant assessment should have the possibility of taking into regard the attitudes of different social groups [5]. In the LCA study the relevant social system is defined, i.e. what groups of people are relevant in the case in point. Dominant attitudes towards certain environmental changes may be modelled geographically for different social groups.

6. A data model of LCA and geography

We may now add to Fig. 1 a new entity, the model of the geographical system, as depicted in Fig. 2. In accordance to what has been said above, the three other entities, or system models, can be described in relation to this new entity.

This new model gives that the relations between the model of the geographical system and any of the other systems are strictly related to geographical information, i.e., *a geographical reference*. The relational complexity of the three previously described systems is preserved, which indicates that the system model of LCA with the technical, environmental and social systems harmonises well with an expansion covering geographically referenced data.

Fig. 2 may now be simplified, as depicted in Fig. 3. It is assumed that the 'Model of the geographical system' is expressed in terms of a geographical information system

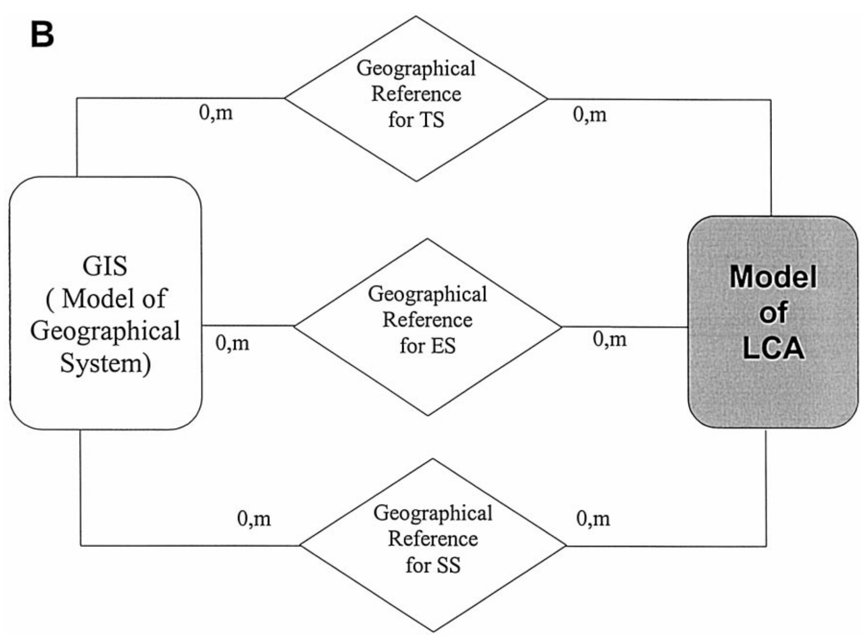

Fig. 3. The relations between a GIS model and a model of LCA. Please note that B is a simplification and a redrawing of A.

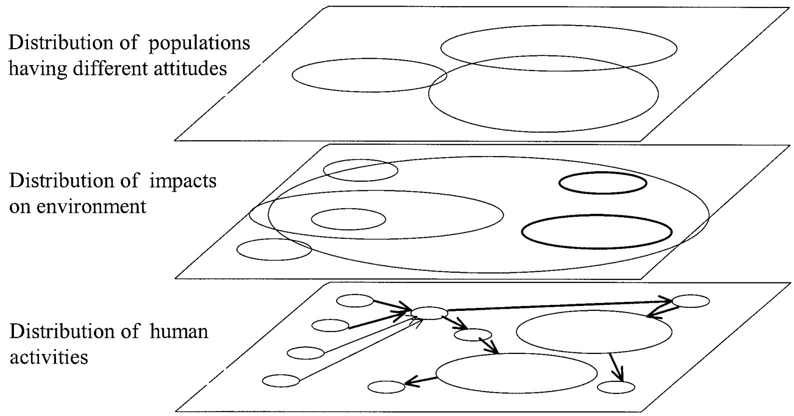

Fig. 4. The three systems in LCA represented as GIS layers.

(GIS), and all LCA specific information has been modelled into an entity called 'Model of LCA'. Due to the geographical independence of the internal relations within the LCA model, there are three parallel and independent relations between the two entities.

7. LCA and GIS

Having organised the information as described in Figs. 2 and 3, an LCA can be performed as follows: the technical system of LCA is aggregated from geographically described subsystems. The environmental changes caused by this system are calculated by use of geographically related data on both the technical and the environmental system. The impact assessment is calculated, or otherwise analysed, by relating each environmental change at each geographical location to the information on each appurtenant local, regional or global attitude to this change (Fig. 4).

8. Discussion and conclusions

LCA methodology is highly dependent on available information from risk assessments and impact assessments. It is not realistic to expect any new such assessments being made within an LCA study. If properly designed with respect to geographical information, LCA methodology may however be a powerful tool to incorporate and communicate knowledge on environmental issues into various types of decision-making such as product development and purchasing.

A stable model of LCA, expressed in terms of related systems, an ER-model and a database structure provides a good foundation for developing GIS supported tools for LCA analyses. Implementation of any such tool is a matter of software development. However, the efforts required to fill these models with workable data should not be underestimated.

Within the nearest future it seems reasonable to assume that information regarding regions and countries will only be used for certain impacts such as acidification and eutrofication and for weighting using comparisons with political goals. Site-specific data may perhaps be used where a sensitivity analysis has shown that local impacts from a certain site is of particular importance for the results. It should however be noted that the data model itself does not require that geographical information is given, it only provides means for storing such data in a structured way.

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