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Proceedings

of the International Workshop on Quality of Life Cycle Inventory (LCI) Data

Forschungszentrum Karlsruhe
October, 20th to 21st , 2003

C. Bauer, L. Schebek, J. Warsen,
S. Wursthorn
Institut für Technische Chemie

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Preface

At present, a number of Life Cycle Inventory (LCI) databases are available and widely used by LCA practitioners, and several new database development projects are being carried out or planned in an increasing number of countries. For all these databases it is highly important to develop harmonized indicators and measurement procedures for data quality in order to give an orientation to LCA practitioners. Therefore, an international process for addressing quality issues of LCI data sets and databases and a 3rd party peer review has been proposed in the LCI Definition Study of the UNEP/SETAC Life Cycle Initiative.

The different nature (qualitative, quantitative) and level (elementary flow, unit process, product system) of LCI uncertainty information results in a challenging task to provide adequate information on data quality and representativeness in order to supply high quality information and aggregate it towards higher levels within LCA studies. The rising demand for high-quality LCI data in various application fields led to numerous approaches addressing data quality, representativeness, and appropriateness - extending from qualitative descriptions to stochastic methodologies. Decision-makers and decision supporters therefore face a multitude of - in parts controversial - quality criteria and measures, which complicates the selection of LCI data and interpretation of the reliability of LCA results based upon them. Communication and transfer of data to and amongst practitioners is even more difficult due to different ways of quality reporting.

Under the auspices of the UNEP/SETAC Life Cycle Initiative LCA practitioners in industry, academies, and consulting, LCI data providers and government agencies have been invited to convene in this workshop and discuss contentious issues. The aim of the workshop is to contribute to a guideline document for a structured quality measurement, documentation and application.

This volume contains the papers presented at the International Workshop on Quality of LCI Data at Forschungszentrum Karlsruhe October 20-21 in Karlsruhe, Germany. As the papers in this proceedings show, the field of Quality of LCI Data is an important issue in various scientific contexts. Not only detailed theoretical contributions but also practical examples reveal the need of an international discussion track towards a common understanding of data quality in terms of data appropriateness.

Thanks are due to the contributing authors and participants, the members of the steering committee and the local organisers without which the conference would not have been possible.

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Chair of the steering committee
Karlsruhe, October 1st, 2003

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USE OF GENERIC DATA IN LCA-STUDIES

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ABSTRACT: When performing an LCA it is rather common to use generic data for life cycle sections. This holds true in reference to the goal of the study, e.g. when the object of investigation is a complex product or the investigation focuses on the manufacturing processes whereas the generic data are used in adjacent sections. Sections following the use phase of a good are particularly modelled with generic data obtained from LCA-Databases or literature.
However, the influence of subsequent sections on the overall result is considerable, so the consideration of quality issues that arise when using generic data is a prerequisite. Unlike manufacturing processes, end-of-life processes are designed for a wide range of input materials, resulting in a wide range of possible emissions whereas causal connexions remain unexplained. So the use of generic process data that are not appropriate may cause distortion in the overall results, also does the omission of sections where the sufficiency of the available data is questionable. A third approach, data collection on site for end-of-life processes if feasible still leaves unresolved tasks: using generic data among other data, e.g. measurements on site, in an accurate manner must be ensured by the way the complete system or parts of the system are modelled.
We will outline in our presentation possible shortcomings and preferable attributes of generic data considering aspects that influence the data quality like modularity and time horizon. Alternative approaches for dealing with subsystems will be described, regarding their possible influence on the overall result. The possible unfavourable effect resulting from the integration of generic data of different origin will be described. The use of specified data among generic data in a complete system will be analysed in order to derive general requirements for the modelling. These approaches will be illustrated by examples from two case studies, covering different fields of application. The preferable attributes for generic data which are needed to avoid methodological errors are based on a practitioner's point of view.

Keywords: Generic Data, Preferable Attributes, Reliability of Decision Support

1 MOTIVATION AND INTRODUCTION

The use of generic data is rather common while performing an LCA, founded by a variety of reasons. Among them is the fact that using generic data is a successful strategy to reduce effort, to simplify the collection process and to accelerate the modeling of a Life Cycle Inventory (LCI). Another field of application for generic data is using them for processes that are specified only on a limited scale and vary in details, e.g. basic supply processes. Moreover, generic data are used to bridge data gaps and thus to generally establish a complete system.

Basically every LCI contains generic data, but extent and approach differ. Two different examples may illustrate the demand for generic data in practice:

Example 1: Modeling the LCI for a complex product like a washing machine requires a great many of processes that has to be considered. Performing the LCI without generic data in an appropriate time is not feasible. Depending on the goal of the study there are some unspecific processes like basic processes for material extraction. In addition there are life cycle sections that represent average scenarios for a specific area.

Example 2: When optimizing processes in industrial production, changes in technology are established that influence foremost a single plant (core system), but also trigger changes in supply and disposal processes (casing system). A survey to evaluate the changed technology focuses on the core system; still generic data are needed for processes in the background system. As the technology change may be marginal, the effect can be easily overlapped by systematic deviation in the casing system, so the requirements for generic data are high.

Regardless of the reason to use generic data, their use has a particular disadvantage compared to specific data. The precision of the data does not necessarily change with the transfer of generic data to a specific application so the distribution and spread of the generic data may be used as an estimate. The accuracy however can be downgraded and an additional systematic error can be caused. This effect will be illustrated in the following figure. The correct answer for the generic data is not met by the average actual value (indicated by the maximum of the distribution). As the correct answer for a specific case differs from the correct answer for generic data, a deviation is added.

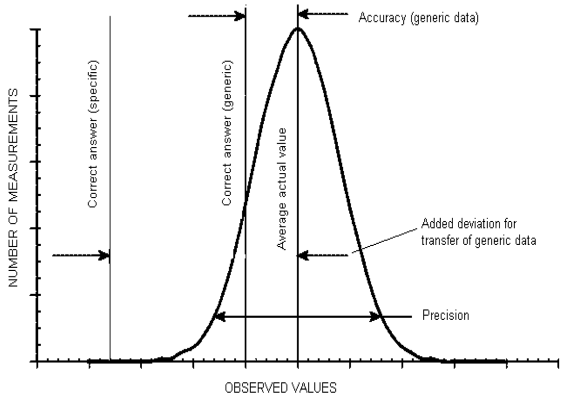

Figure 1: Accuracy and precision of data

Special approaches which strive to incorporate actual instead of potential environmental impacts and therefore add site-specific information will generally be more biased as the chance to find the accurate site-specific data in a database will be generally low. However, though the lack of spatial and temporal dimensions is acknowledged as a source of uncertainty, this task is currently not an issue for LCA studies [1].

In order to deliver reliable decision support it is necessary to ensure that the generic data-sets meet basic requirements that can be derived from the methodological background.

2 METHODOLOGICAL BACKGROUND

2.1 Generic Data in General

Generic data are used in the case of lack of data to fill data gaps, whereas lack of data can be specified in a complete lack of data and a lack of representative data.

Generic data are based on average values, which can be found in literature or LCA-Databases. In contrary to generic data there are specific data which fit to or come up from a specific process. Both kinds of data can be limited to a specified basic population, thus being more or less representative-depending on the goal of the study. Their representativeness refers to:

- the age of data (time-specific data),
- geography (site-specific data)
- and the used technology (technology-specific data).

The item age of data considers the temporal dependency of data. In regard to geography is taken into account that production conditions in the area relevant for the study and in the geographical area covered by the study may differ. Representativeness in relation to the used technology considers the aspects of e.g. different available techniques in different enterprises.

The use of generic data is common for the following life cycle stages: energy production, transportation processes, production of raw materials and fuels and disposal processes, which is based on practical and historical reasons. The first efforts to make a collection of generic data available have been done for this range of processes, e.g. [2]. As this kind of processes occurs almost in every LCA-Study, it was from outmost interest to provide generic data for them. Moreover these auxiliary processes are usually acquired from external suppliers and therefore vary due to markets (e.g. availability, prices). So even in product systems containing highly particular processes, these auxiliary processes are well covered by average data.

2.2 Data Quality

With data quality being an attribute that affects the certainty of results, this issue has been extensively discussed in the LCA-community. The following paragraphs summarize findings that should be considered with regard to generic data.

Data quality is defined as characteristic of data that bears on their ability to satisfy stated requirements [3], it denotes the fitness for the objective of data. Data quality requirements shall be defined in the first step of an LCA, to enable to meet the goals and scope of the LCA study [4]. The description of data quality is important to understand the reliability of the study results and to interpret the outcome of the study. The appropriateness of the used data and reasonability in relation to the goal of the study is one step of the critical review. Quantitative indicators like accuracy, completeness or uncertainty and qualitative indicators like comparability, consistency or representativeness are used to review the quality of data. The choice of indicators for the quality of data depends on the goal of the study. Common weak point of these quality criteria is that there is no direct correlation between the results of quality indicators and the results of the LCA-study. Prerequisite for the application of quality indicators is therefore a non-aggregated form of data-sets.

Another way to measure and to deal with data quality is to use uncertainty analyses, which is an area of great complexity in LCA [5]. The Society of Environmental Toxicology and Chemistry (SETAC) European working group on ‘Data Availability and Data quality’ provide a framework for uncertainty and possible methods to calculate data uncertainty [6] with stochastic modeling, which can be performed by Monte Carlo Simulation, recommended to be a promising technique for dealing with lack of precision of data in LCIs [5, 6].

Using non representative data in reference to the goal of the study belongs to the field of systematic error. [7] introduced five quality indicators in a pedigree matrix to consider temporal, geographical and further technological correlation between data used and data needed, the reliability of the source of data and their completeness. The three indicators mentioned first consider the correlation between the used and needed data with regard to their representativeness for the available technique. Uncertainty factors should be introduced for the three data quality indicator to assess the correlation between the used and needed data in a quantitative way.

The extent to which generic data fit for a specific application is often included as an aspect of data quality thus designated as data validity [8]. As the use of generic data implies the possibility to especially affect this aspect of data quality should be addressed separately within this context.

2.2.1 Excursus: Site-specific data

[9] investigated the extent to which it is practical and valuable to collect site-specific data instead of generic data for analyzing actual environmental impacts. In their case study they compared a number of plastic-based packaging systems in Australia. They stipulate that for all non-global environmental processes, site-specific information is necessary to determine whether an emission will make a significant contribution. Otherwise the used data will introduce uncertainties which vary depending on the environmental impact category. Site specific data for non-global impact categories enhance the reliability of the results of an LCA. This information about the dependence between site-specific data and impact categories manages to draw conclusion at least in a qualitative way, which part of the impact categories is more reliable (condition: ceteris paribus), even if the set of data is aggregated. This conclusion becomes only true, if the used technology is nearly representative and only the area, where emissions are spread is different. Nevertheless if the goal of the study focuses on actual local or regional environmental impacts, it is necessary to apply different impact assessment methods that consider regional differences besides the using of site-specific data. As we mentioned in the introduction this source of uncertainty is currently not an issue for LCA-studies.

2.3 Modeling requirements

Whereas the term data quality refers especially to the attributes of values used in the LCI, it has also to be ensured that the system as a whole is modelled correctly

[10]. Modelling requirements include symmetry of data; [11] also deduces the same structuring of modules, the same detail of depth of the modules and defined interfaces for the delivery of information.

In order to prevent methodological errors, there must be symmetry of used data within an LCI. These criteria must be met in every case. A comparison between a well documented process and its less completely analyzed counterpart may e.g. end up in results which will favor the less documented process [6]. This effect might occur, if data of different databases or sources are integrated in an LCI, because different details of depth might have been integrated.

3 APPROACHES TO USE GENERIC DATA FROM A PRACTITIONER´S POINT OF VIEW

3.1 Data appropriateness in the context of the respective goal and scope of the study

Example 1: Analyzing complex Products

In order to analyze the influence of different end-of-life scenarios within the product life cycle we performed an LCI for a washing machine. As these EOL-scenarios represent average scenarios for Germany, the modelling required average data for that specific region. We used generic data for material extraction processes in the production phase. These processes are - in reference to the goal of the study - unspecific processes, i.e. it is not known where a specific raw material has its origin, because they vary due to market. Thus, we used data from the same database, which are based on average values for material extraction.

For all transportation processes, generic data were used whereas the transportation distance was applied as one parameter among others to make them more specific: e.g. in the production phase the average transportation distance for the delivery of parts.

Example 2: Establishing a background system for an industrial production process

In several Small and Medium Enterprises (SMEs) a variety of strategies was proposed to optimize industrial process chains. To evaluate the optimization effect and to choose the best strategy the potential states were compared to the present state. To detect the overall optimum it was not sufficient to compare just the changed process chain within the SME, though the changes took place only in this core system. As the changed core system also triggers changes in the casing system containing supply and disposal processes, this had to be considered as well. As the setting of the casing system is primarily determined by market conditions and therefore varies. The use of average values is altogether an appropriate approach to fill data gaps. As the changes in the core system tend to be of moderate extent, a systematic error deriving from the transfer of misfitting data can still determine the result altogether.

3.2 Shortcomings

General shortcomings, which became apparent by using generic data, are described. When a data set for a process or several processes is provided in a database, there are often auxiliary processes included calculated for average conditions. Though the user may find this more convenient, the level of documentation is in most cases too low. The poor documentation combined with the high level of aggregation leads to errors, as it becomes impossible for the user to recognize double counting. However, from a practitioner's point of view the data sets are mostly stored in an unfavorable way. Foremost, for reviewing data quality in order to assure data representativeness expertise is necessary. In most cases the level of aggregation in data sets is too high which makes the review more difficult. One reason for a level of aggregation in data-sets is that enterprises need to code specific data.

Shortcomings resulting from multifunctional processes are exemplarily shown for waste processes. It is necessary to have a good understanding of waste management to enable the proper use of LCA data for waste treatment, because they are strongly related to specific products and materials [12]. The structure of the chain of processes depends among others on the source and properties of waste. Furthermore there is on the one hand need of data for waste processes, which refer to specific products, because the emission resulting from waste processes are based on the chemical composition of the product under study. On the other hand there is a need of generic data for waste processes, which refer to the emission of the process.

4 CONCLUSIONS

4.1 Preferable Attributes of Generic Data

Generic data are supposed to be used in decision-processes with a high demand for information both quantitative and regarding the reliability. Thus there can be formulated several attributes that are referred to as useful.

Transparency is a prerequisite. Even if the data have to be presented in an aggregated manner by reason of confidentiality, it must be ensured that the user can identify sources of (systematic) error that is caused e.g. by inappropriate basic conditions, double accounting of auxiliary processes.

The requirements for documentation are remarkably high. Preferably documentation should enable the user to estimate the usability for their task. Therefore it should include the stochastic error inherent in the data module, quality indicators and a detailed description of basic conditions, thus allowing for an estimation of transferability.

Different data sets representative for a variety of temporal, geographical and further technological conditions will be needed and should be provided. This approach (a in figure 2) can be realized only to a certain extent as it may lead to rather extensive data bases where data sets in particular cases have to be stored for a one-time application.

Another approach to provide a wide range of data sets is to enhance the modularity of the database by maintaining a high degree of segmentation (b in figure 2). Auxiliary processes like energy supply and transport should not be included in the process data as the user may want to incorporate specific information like the transport distance or other parameters.

As this approach is limited because it would disclose industry data and information that has to remain confidential, the provision of customizable data sets seems to be favorable. The user then has to formulate a query where specific information is defined. With these parameters, a customized data set is calculated that bridges the data gap (c in figure 2). This approach makes high demands on the functionality of the database, e.g. the backtracking of confidential sub-modules has to be excluded; on the other hand, it broadens the applicability of the generic data. The three different approaches a illustrated in the following figure 2.

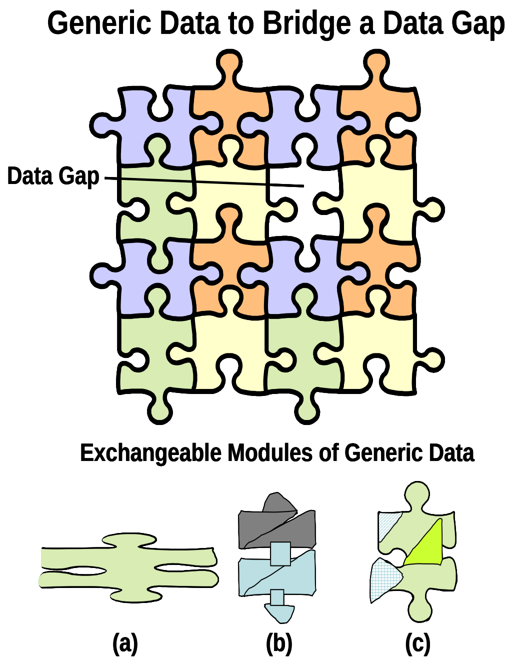

Figure 2: Integrating an existing module into a data-gap

4.2 Alternative approaches:

If the available generic data do not meet basic requirements, there remains the possibility to leave data gaps "as they are". This approach also causes an error to the overall result as the zero values introduced in inventories certainly differ from the actual values. However, it is not feasible to estimate whether the deviation caused by zero values exceeds the deviation caused by invalid generic values as the correct values remain unknown. A feasible approach in this context should be the sensitivity analyses. If the results of the analyses indicate an interaction of these unknown values in reference to the results of the LCA-Study measurements for gathering actual values is absolutely required.

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ALLOCATION APPLIED ON CO-PRODUCTION PROCESSES IN LARGE LCI PROCESS NETWORK DATABASES

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ABSTRACT: Multi-output processes are ubiquitous in LCA product systems. They are present in the energy industry (e.g., combined oil and gas production, oil refineries, combined heat and power production), in the mining industry (e.g., platinum group metals), in the chemical industry (e.g., phosphoric acid production) or in the electronics industry (silicon purification). In most classical LCA case studies, only one of the co-products and the inputs and outputs allocated to it are of interest. The remaining inputs and outputs, that consequently should be allocated to the other co-products, are often disregarded. Such isolated considerations may lead to the situation that (substantially) less or more than 100% of the inputs and outputs of a multi-output process are allocated to its co-products when adding up LCI results of different studies. To avoid such undesired situations and to model multi-output processes consistently in large LCA databases, multi-output processes should be modelled in their unallocated state. This allows for considering all co-products with one consistent set of allocation factors at the same time. The paper gives reasons why this approach makes sense and shows how multi-output processes can consistently be modelled in large LCA databases.

Keywords: multi-output process, allocation, life cycle inventory, ecoinvent database

1 INTRODUCTION

Multi-output processes are ubiquitous in LCA product systems. They are present in the energy industry (e.g., combined oil and gas production, oil refineries, combined heat and power production), in the mining industry (e.g., platinum group metals), in the chemical industry (e.g., phosphoric acid production) or in the electronics industry (silicon purification). In most classical LCA case studies, only one of the co-products and the inputs and outputs allocated to it are of interest.

However, in large background LCI databases one needs to consider all co-products at the same time because in general the LCI results of all of them are of interest. Furthermore, Heijungs claimed that LCI databases should include information about multifunction or multi-output processes *before* allocation [1].

The ecoinvent database respected this suggestion and established a database software system which can accommodate unallocated multi-output processes and their derived single (co-)product output processes [2]. Allocation factors are separately recorded and may be adjusted according to personal choices or new market situations. The ecoinvent software system tests whether 100% of all input and output flows of the unallocated process are attributed to its co-products. This guarantees that no emissions are lost or counted twice. This approach allows for some basic insights into the mechanisms of LCI allocation and its effects on the environmental competitiveness of co-products.

2 CASE STUDY DESCRIPTION AND PROBLEM SETTING

Within the product system of photovoltaic power plants the production of silicon wafers is one of the most important processes [3]. The purification of metallurgical grade (MG) silicon is especially energy intensive. The purification process leads to three products: electronical grade (EG) silicon, off-grade silicon and silicon tetrachloride (see Figure 1).

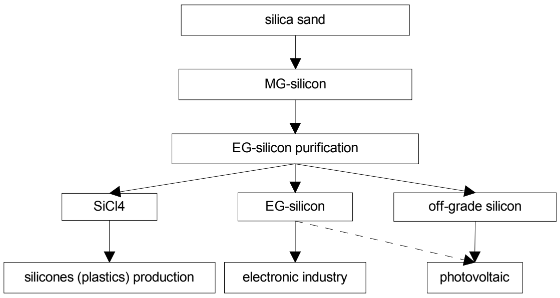

Figure 1. Flow chart EG-silicon purification and the use of its co-products.

In several photovoltaic LCA case studies all inputs and outputs for the purification process of MG-silicon have been allocated to the EG-silicon (required for wafer production) and none to the silicon tetrachloride ($SiCl_4$, raw material for silicic acid production). However, in an LCA study of vacuum insolation (based on silicic acid) inputs and outputs of the purification process have been allocated on the basis of the revenues of EG silicon and $SiCl_4$. Hence, more than 100% of total inputs and outputs of the MG-Si purification process have been allocated to the two co-products, when adding up the LCI results of EG-silicon and $SiCl_4$ of the photovoltaic and the vacuum insolation study, respectively.

According to ISO 14041 (subclause 6.5.2 allocation principles), "the sum of the allocated inputs and outputs of a unit process shall equal the unallocated inputs and outputs of the unit process" [4]. This is also known as the 100% rule.

To comply with this rule in an isolated case study is quite straightforward and one might argue that an analysis that does not respect this rule is not worth being called an LCA. However, in most cases an LCA case study focuses on one particular product or product group (in our case photovoltaics, and silicones, respectively). That is why the environmental burdens attributed to some co-products are often disregarded when it comes to conclusions and recommendations.

Large background LCA databases require a consistent modelling of processes. Hence, the input and output flows attributed to the co-products from one multi-output process need to be interdependent, and hence need to be modelled in a way that correctly reflects this interdependence.

3 ALLOCATION IN JOINT PRODUCTION

3.1 Context-specific allocation criteria

J.S. Mill is often mentioned as one of the first economists who raised the question of an adequate procedure to allocate (private) costs to two jointly produced goods [5]. Criteria used today for the allocation of costs are for instance given in [6]. They differentiate between the following criteria:

a) cause and effect,
b) benefits received,
c) fairness or equity, and
d) ability to bear.

Ad a) The criterion "cause and effect" relies on physical, chemical or biological causation. It may be applied for the analysis of combined production (see footnote 1) where the output of co-products can be varied independently such as an oil refinery producing oil products (light fuel oil, gasoline, bitumen, et cetera). This criterion corresponds to the second step of the ISO 14041 procedure and is not applicable to joint production processes.

Ad b) The criterion of "benefits received" is used to allocate common costs according to the individual profits achieved by spending these common costs. The costs of common marketing activities, for example, may be allocated to the respective goods according to their individual increase in turnover due to these common activities. The criterion may be applied in cases where no market determines the price (value) of goods (products and services).

Ad c) A fair allocation of common costs is required when several decision-makers are involved in a joint production process. It implies that there is a problem of decision-making which includes negotiations in view of a commonly accepted and supported solution. This may be necessary for investments in a dam, for instance, that is used for electricity production, flood protection, drinking water supply and irrigation, and where several decision-makers and profiteers are concerned. In Life Cycle Assessment such a situation may occur in voluntary coalitions, e.g., in the waste treatment sector. Waste "producers" may look for companies that are interested in using the waste as a secondary raw material. The criterion "fairness or equity" is not provided by the ISO procedure.

Ad d) The criterion "ability to bear" allocates costs according to the co-product's capacity to bear production costs. The gross sales value and the estimated net realisable value method are representatives of an operationalised concept relying on this criterion. They consider the competitiveness of jointly produced products and result in a price structure that is optimal for the company's profit maximisation.

This short overview shows that different positions and situations may lead to the application of completely different allocation principles and approaches. Background databases should therefore be flexible in terms of allocation principles and factors applied.

3.2 Interdepence of co-product LCIs

Figure 1 shows the interdependence of environmental burdens attributed to two co-products α and ρ[7]. When about 60% of all input and output flows are allocated to commodity 2 (point A in Figure 2), our co-product ρ shows lower impacts compared to competing products σ, τ, and υ of commodity 2. However, the environmental impacts of co-product α are still higher as compared to product δ of commodity 1. The graph shows that no allocation factors exist where both co-products α and ρ show lower environmental impacts as compared to their competing products. The combination of single output products δ / υ is environmentally preferable in this situation.

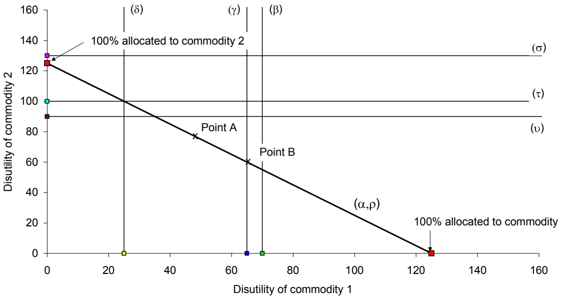

Figure 2. Graphical solution for a comparison of the life-cycle based disutility (=environmental burden) of alternative combinations of products of commodities 1 and 2. The thick line shows the disutility of the joint products α and ρ. The points on the abscissa and the ordinate show the disutility of products from single output processes β, γ, δ, and σ, τ, υ, respectively. Intersections of the vertical and horizontal auxiliary lines above the thick line show combinations of single-output processes with a higher disutility than that of the joint products α und ρ. The scales show arbitrary units [7].

4 IMPLEMENTATION OF MULTI-OUTPUT PROCESSES IN THE ECOINVENT DATABASE

4.1 Multi-output process reporting

The ecoinvent database allows for a documentation of multi-output processes. These processes deliver more than one "useful" output (product and/or service). There reference flow is not one of these outputs but either an input (such as 1 kg of MG-silicon to purification) or one year of production (such as one year of combined oil and gas production in the North Sea).

Table 1 shows an excerpt of the inputs and outputs of the MG silicon purification process and the allocation factors as modelled in the ecoinvent database[1]. The first three lines show the co-products EG-silicon (0.68 kg), off-grade electronic grade silicon (0.084 kg) and silicon tetrachloride (1.2 kg). The next six lines show some of the inputs required for the purification of 1 kg of MG-silicon. The three columns to the right show the allocation factors: For instance, 71.1 % of the MG-silicon, at plant are allocated to the 0.68 kg of EG silicon, 8.9 % to 0.084 kg off-grade silicon and 20 % to 1.2 kg $SiCl_4$.

Each multi-output dataset includes information about the allocation factors. This information is available per

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[1] The ecoinvent database is accessible via www.ecoinvent.ch

individual input and output respectively. Each pollutant, each working material or raw material input may therefore have his individual allocation factor, if adequate or necessary. Additonally, the allocation method applied may be specified (descriptive purpose only). Hereby one may choose between (taken from SPOLD 99):

- undefined
- physical causality
- economic causality, and
- other method.

Allocation factors need not to be between 0 and 100%. They may well be negative and above 100%. However, the sum of the set of allocation factors of one particular input or output needs to add up to exactly 100%. This 100%-rule is automatically controled and a warning is issued if the sum does not match 100%, while editing the dataset.

Datasets with multi-output processes are imported into the ecoinvent database in XML-format (just like unit processes). However, when importing a multi-output process, unit processes describing the allocated inputs and outputs for the co-products are additionally generated. Table 2 shows an excerpt of the derived unit process raw data for the three co-products of MG-silicon purification.

For instance, when the dataset "MG silicon, to purification" is imported into the database, three additional datasets are generated, namely the unit process datasets for "silicon, electronic grade, at plant", "silicon, electronic grade, off-grade, at plant", and "silicon tetrachloride, at plant".

Thereby, the amount of the inputs and outputs is multiplied by the respective allocation factor and divided by the respective amount of the co-product.

For instance, the input of 1.0 kg MG-silicon, at plant is multiplied with the allocation factor 71.1% and divided by 0.68 (the amount of EG silicon). Hence, 1.1 kg MG-silicon input are attributed to the production of 1 kg of EG silicon. Only 0.2 kg are attributed to the production of 1 kg of silicon tetrachloride. The raw material inputs (0.8 kg hydrochloric acid and 0.2 kg MG-silicon) for $SiCl_4$ production add up to 1 kg, the amount of $SiCl_4$ output.

	Name	Location	Unit	MG-silicon, to purification	silicon, electronic grade, at plant	silicon, electronic grade, off-grade, at plant	silicon tetrachloride, at plant	Allocation criteria
	Location			DE	DE	DE	DE	
	Unit			kg	kg	kg	kg	
allocated products	silicon, electronic grade, at plant	DE	kg	6.76E-1	100	0	0	
	silicon, electronic grade, off-grade, at plant	DE	kg	8.44E-2	0	100	0	
	silicon tetrachloride, at plant	DE	kg	1.20E+0	0	0	100	
technosphere	MG-silicon, at plant	NO	kg	1.00E+0	71.1	8.9	20.0	Material balance
	polyethylene, HDPE, granulate, at plant	RER	kg	6.37E-4	72.0	2.4	25.6	Revenue all products
	hydrochloric acid, 30% in H2O, at plant	RER	kg	2.00E+0	48.4	1.6	50.0	Stoechometric calculation
	natural gas, burned in boiler condensing modulating >100kW	RER	MJ	1.22E+2	96.8	3.2	-	Revenue purified silicon
	electricity, natural gas, at combined cycle plant, best	RER	kWh	8.66E+1	96.8	3.2	-	Revenue purified silicon
	electricity, hydropower, at run-of-river power plant	RER	kWh	2.74E+1	96.8	3.2	-	Revenue purified silicon
	price	GLO	€	70.36	75.00	20.00	15.00	
	revenue	GLO	€	70.36	50.67	1.69	18.00	

Table 1. Excerpt of the multi-output process raw data of the purification of 1 kg of MG silicon and allocation factors used for the three co-products [3].

	Name	Location	Unit	MG-silicon, to purification	silicon, electronic grade, at plant	silicon, electronic grade, off-grade, at plant	silicon tetrachloride, at plant	
	Unit	0	0	kg	kg	kg	kg	
allocated products	silicon, electronic grade, at plant	DE	kg		1	0	0	
	silicon, electronic grade, off-grade, at plant	DE	kg		0	1	0	
	silicon tetrachloride, at plant	DE	kg		0	0	1	
technosphere	MG-silicon, at plant	NO	kg		1.1	1.1	0.2	Material balance
	polyethylene, HDPE, granulate, at plant	RER	kg		6.79E-4	1.81E-4	1.36E-4	Revenue all products
	hydrochloric acid, 30% in H2O, at plant	RER	kg		1.4	0.4	0.8	Stoechometric calculation
	natural gas, burned in boiler condensing modulating >100kW	RER	MJ		174.2	46.5	-	Revenue purified silicon
	electricity, natural gas, at combined cycle plant, best	RER	kWh		124.1	33.1	-	Revenue purified silicon
	electricity, hydropower, at run-of-river power plant	RER	kWh		39.2	10.5	-	Revenue purified silicon

Table 2. Derived unit process raw data for the three co-products. Input and output flow of the multi-output process times allocation factor divided by co-product output equals input and output flows of the derived unit processes [3].

4.2 Computing of LCI results

The ecoinvent database system uses matrix inversion to calculate LCI results. If the matrix contains multi-output processes, the matrix is no longer square and it gets impossible to compute meaningful results (see also [8]). The reference flow of the multi-output process (1 kg MG silicon to purification) is not available as input for other processes. Only their (co-)products may be used as inputs.

The calculation of the cumulative LCI results uses only the allocated unit process dataset derived from the multi-output process as described above. A disadvantage of this concept is, that the cumulative LCI results of the multi-output process cannot be calculated at the same time.

5. ECOINVENT AND THE AVOIDED BURDEN APPROACH

The ISO allocation procedure advises to firstly avoid allocation by either subdivision of processes or by system expansion. The ecoinvent software system is not only able to accommodate flow specific allocation factors as described above. It is also suited for modelling system expansion. For that purpose, a multi-output process delivers only one (positive) product output. All other co-product outputs are noted with a negative sign. This notation represents a model in which the co-products cause a reduction in output of other, (in most cases) single output processes (avoided burden approach).

Let us apply this concept to the silicon example introduced in section 4. Firstly, we need to determine the reference flow. We choose 1 kg of "silicon, electronic grade, at plant". Secondly, the co-product output flows of "silicon, electronic grade, off-grade, at plant" and "silicon tetrachloride, at plant" get a negative sign, namely –0.084 kg of off-grade EG silicon and –1.2 kg of $SiCl_4$. In this case we do not use any allocation factors[2].

The inventory table is calculated by subtracting the environmental burdens of alternative off-grade EG silicon and $SiCl_4$ production from the overall burdens caused by the multi-output process. How the alternative production processes may be identified has been described for instance by [9] and [10]. The computation of results is again easily done by matrix inversion. The LCI and / or LCIA results may be negative or positive. If negative, the currently analysed multi-output process shows a better environmental performance as compared to producing the three co-products with alternative (single output) processes. If the scores are positive, the multi-output process is still environmentally preferable, if the scores are lower as compared to a single output production of EG silicon.

Because the avoided burden approach always attributes 100% of the avoided burdens to the product of interest, this approach can be seen as an extreme case of the classical allocation approach described above. As long as all avoided burdens are attributed to the multi-output process at issue, the avoided burden approach leads to possibly poorly balanced LCIs.

The avoided burden approach has additionally some drawbacks if applied on large background databases. Because a main reference product output is required, the multi-output process gets asymmetric. If one aims at a generic database, LCI data for all co-products are required. However, the avoided burden approach highlights only one output (at least per avoided burden approach). Hence, in our MG silicon purification process we would require three process datasets, namely one each for "EG-silicon", "off-grade EG-silicon", and "silicon tetrachloride". In each of these processes the respective remaining two outputs are avoiding production somewhere else. The environmental impacts of the three processes will most probably not add up to 100 % of the original multi-output process.

6 CONCLUSIONS

The way how multi-output processes are implemented in the ecoinvent database can be characterised as follows:

- Input and output flows of multi-output processes are available before any allocation.
- Allocation factors can be determined per each individual input and output flow.
- The sum of all allocation factors for one particular flow always sum up to 100%.
- Unit processes of the co-products are derived when importing multi-output processes into the database.
- For calculation, the derived unit processes are used.

This approach has the following advantages:

- Allocation is done in a fully transparent way because all allocation factors are reported.
- The 100% rule is always obeyed (if not, datasets may not be imported into the database).
- LCIs of all co-products are fully consistent.
- If necessary, allocation factors may be changed (under the conditions just mentioned) and LCI results recalculated.

One major disadvantage is that the cumulative LCI results of the multi-output process (before allocation) are not available. However, they can be calculated with the help of the LCI results of the derived unit processes and the amounts of co-product outputs of the multi-output process.

The ecoinvent database also principally supports the system expansion (avoided burden) approach. However, the ecoinvent team refrained from using this approach because on one hand benefits (avoided burdens) are attributed unequally among the co-products and because it seemed not practical to implement it in large background databases where modelling and data consistency is one important precondition.

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[2] Although one could argue whether all avoided inputs and outputs related to 1.2kg $SiCl_4$ production may be credited to the manufacturing of EG silicon. One could as well argue that the buyer of $SiCl_4$ co-produced with EG silicon should profit from this joint production synergy.

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AN INTEGRATED APPROACH TO UNCERTAINTY ASSESSMENT IN LCA

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ABSTRACT: The use of stochastic models and the presentation of ranges and confidence intervals enhances the decision support capabilities of an LCA study. However, an uncertainty analysis should not merely quantify the uncertainty in the output, but provide a mechanism to direct effort back into the LCA models to manage those uncertainties. This paper demonstrates the valuable assistance an uncertainty assessment can provide to an LCA study, including the selection of meaningful criteria against which to evaluate systems, directing further data collection and modeling effort, and systematically generating scenarios for comparison. The uncertainty assessment takes place according to a 3-layered framework, which is based on the recognition that different sources of uncertainty require different methods for their analysis and reduction.

Keywords: quantitative uncertainty analysis, framework, uncertainty importance

1 INTRODUCTION

A number of studies have demonstrated that the use of stochastic models and the presentation of results in ranges or as confidence intervals enhances the decision support capabilities of an LCA study (e.g. [1; 2; 3]). Quantitative uncertainty analysis is therefore an increasingly accepted component of an LCA study. However, the relative ease with which probabilistic uncertainty simulations (Monte Carlo and others) can be carried out raises the danger of over simplifying the problem and creating a false sense of credibility in the results. It is not well recognized that randomly varying dependent parameters (as happens in a probabilistic simulation of a "black box" LCA model) can lead to meaningless results, nor that a probabilistic treatment of uncertainty is not meaningful for all parameters input into an LCA model. In addition, the ranges or uncertainty intervals (e.g. ±50%) applied to completed inventory items are usually considerable underestimates [4].

This paper argues that for an uncertainty assessment to be meaningful it needs to be an integral part of the LCA process, and begun at the lowest level of the analysis. Furthermore, it contends that the end goal of an uncertainty assessment should not merely be to quantify the uncertainty in the results, but to provide a mechanism to direct effort back into the model to manage those uncertainties.

2 ASSESSMENT OF UNCERTAINTY

The need for a framework to guide uncertainty assessments is evident from the diversity of tools used to address the uncertainty of LCA results [5]. The framework presented here is based on the recognition that different sources of uncertainty require different methods for their assessment. The discussion thus starts with an overview of the sources of uncertainty encountered in LCA models. The brief description of the framework given here is intended only to provide a basis for the following section on the management of uncertainty. A thorough exposition, including a case study applying the framework, can be found in [6].

2.1 Sources of uncertainty

A listing of the general sources of uncertainty relevant to LCA models is given in Table 1. The classification in Table 1 is similar to that of Huijbregts, and incorporates the emphasis he and Weidema place on variability [7; 8]. However, a notable difference is that the classification in Table 1 is according to the appropriate method for analyzing the particular uncertainty. In Table 1, quantities input into LCA models are broken down into two broad classes: empirical parameters and model parameters.

Empirical parameters comprise the majority of data inputs into LCA models. These represent properties of the world, and as they are the only quantities that are, at least, in principle, measurable either now or sometime in the past or future, they are the only type of quantity that may appropriately be represented in probabilistic terms [9]. Decision variables and model domain parameters, on the other hand, define the operating state of the system, and do not have true values, as it is up to the decision maker to select their value. Although there is likely to be uncertainty about the "best" value to choose, it is not meaningful to represent this uncertainty probabilistically, as these parameters have appropriate or good rather than true values. Value parameters are grouped under model parameters, as these quantities are also best suited to assessment via a parametric sensitivity analysis. This is because value parameters tend to be among those quantities decision-makers are most unsure about, and representing them probabilistically may hide the full impact of their uncertainty [9].

The third class of uncertainty in Table 1 is uncertainty about the form or structure of the model itself. Any model is a simplification of reality, so even if a model provides a good approximation of a particular system, it can never be exact. A competing model may be said to give better predictions, but it cannot be called a more probable model. A sensitivity analysis is thus the most appropriate tool to examine the effect of model uncertainty [9]. Although likely to have the most substantial effect on the uncertainty of the results, few opportunities exist through which uncertainty in model form can be investigated. As they are currently conceived LCA models incorporate a fair degree of irreducible model uncertainty, particularly due to the spatial and temporal limitations intrinsic to the LCA method [10; 11; 12].

Table 1. Summary and description of sources of uncertainty relevant to LCA models (based on [9]).

Sources of uncertainty	**Breakdown according to parameter type / source**		**Description / Examples**
Empirical Parameters	Parameter uncertainty	Measurement errors	Random errors, e.g. in monitoring data
		Inherent randomness	Unpredictability, e.g. ore quality
(Probabilistic assessment)		Subjective judgement	Systematic errors, e.g. measuring proxy quantity, biases in measurement etc.
		Approximation	“Best guess” values
	Variability	Geographic variability	Variation across regions, countries etc.
		Temporal variability	Variations with age, season etc.
		Technological variability	Variations not accounted for by regional or temporal variability.
Model Parameters *(Parametric sensitivity analysis / multivariate analysis)*	Uncertainty arising from choice of variables to specify system	Decision variables	Quantities over which decision maker exerts direct control, e.g. plant capacity
		Model domain parameters	Quantities specifying spatial and temporal domain of system model.
	Disagreement	Value parameters	Preferences of decision makers, e.g. panel weights in valuation.
Model structure / form	Limitations on form of model	Choice of LCA method	Degree of sophistication of model, e.g. allocation method.
(Sensitivity analysis)	Limitations of LCA model structure.	Spatial limitations	Aggregation over plants, regions etc.
		Temporal limitations	Aggregation over time.
		Inherent model uncertainties	Epistemological and paradigmatic uncertainty (particular “world view” forced by LCA model).

However, for certain aspects of the LCA model, various degrees of model sophistication have been developed (e.g. characterization models), which provide some scope to investigate model uncertainty using sensitivity analyses.

2.2 A framework for the assessment of uncertainty

The framework presented here builds on those presented in the literature [2; 13], but places a particular emphasis on providing a structure to evaluate the way in which the three major sources of uncertainty interact. The analysis takes place according to a three tier process, in which the three major sources of uncertainty are analyzed in a series of nested loops.

Empirical parameter uncertainty is analyzed in an iterative probabilistic assessment. The LCA model is initially defined with a single model form, and the most likely model parameter values. Probability distributions are assigned to each empirical parameter, and a simulation using Latin Hypercube sampling is used to propagate the input uncertainty through the inventory models to the output sample. The analysis is iterative in that each empirical parameter is initially assigned a “quick and dirty” probability distribution (an over-estimate of uncertainty incorporating the range encountered in data collection and subjective estimates to cover any suspected sources of uncertainty not covered by the data sample). The rough estimates for those parameters found to contribute significantly to the output uncertainty in an uncertainty importance analysis, are then refined in subsequent iterations. The iterations are continued until the variance is reduced to a level compatible with the goal and scope of the study (see section 3.1).

The second tier of the analysis is an assessment of model parameter uncertainty, in which the effect the choice of each model parameter value has on the output is analyzed in a parametric sensitivity analysis (i.e. a sensitivity analysis in which the variables are systematically “stepped” through their operating ranges in combination with the other model parameters). In a study with a manageable number of decision variables the analysis is formalized in a multivariate analysis (or factorial design), whilst in those studies with a large number of decision variables, a pre-screening sensitivity analysis is applied. The significance of the range in output the choice of model parameter introduces is assessed with respect to the empirical uncertainty, and operating “states” (appropriate combinations of model parameters) are chosen to reflect the range in results (see section 3.3).

The top tier of the analysis is a assessment of uncertainty in model form, where possible model forms are analyzed in a sensitivity analysis (e.g. allocation method). To fully span all possible outcomes of the study, the alternative model forms should be calculated for each scenario selected in the previous layer of the analysis.

2.3 Characterizing input parameter uncertainty

By far the most challenging aspect of a quantitative uncertainty analysis lies in determining relevant ranges and probability distributions for the input parameters. The framework presented here is developed specifically for process LCA (i.e. where the basic building blocks of the LCA model are process models). Specifying the model domain parameters (with the exclusion of value parameters) poses less of a problem than the empirical parameters as their range is most often restricted by operability requirements (i.e. a decision maker generally only considers technically operating, profitable processes). The probabilistic analysis, on the other hand, presents some considerable difficulties.

The first of these is the requirement that the input parameters be specified at the lowest level of aggregation possible. This is important for two reasons. In a probabilistic simulation, the independent random sampling of the input distributions of correlated variables leads to infeasible combinations of parameters. The best way to avoid hidden dependencies between the variables is to model the process at a sufficiently detailed level that correlated variables are broken down into the individual variables and the relationships between them. Although a balance obviously has to be reached between increasing the accuracy of the model on the one hand and its complexity on the other, “black box” models should be avoided if at all possible (or at least, restricted to "background" processes only). The second reason requiring the model to be specified at a low level of aggregation is to improve the realism of the uncertainty estimates. This allows a more meaningful and far simpler definition of uncertainty, as the probability distribution is applied to the actual measured quantity (for which statistical data is frequently available), rather than to an aggregated quantity for which uncertainty information can only be estimated. Furthermore, ranges of values are incorporated into the models as they arise in data collection, removing the need to isolate an often unrealistically defined average or "most likely" value.

Another considerable constraint to specifying quantitative probability estimates is that, if these are to be comprehensive, they inherently include a degree of subjectivity. Even when based on large, representative data samples (which is all to often not the case in LCA models), the statistically measurable component of uncertainty only accounts for a small portion of the overall uncertainty [14]. It is therefore necessary to estimate the portion of uncertainty not accounted for in the data sample. This estimation can be most conveniently structured against an independent set of data quality indicators (DQIs) (such as found in the "pedigree matrix" [15]). For quantitative estimates of uncertainty, it is important that the DQIs be independent, or the estimates of uncertainty are not additive, whilst the DQI set chosen also needs to cover all potential sources of uncertainty. A considerable constraint to making quantitative uncertainty estimates is that these rely on knowing something about the quality of the data (e.g. its geographical coverage, the time period over which it was collected etc.).

3 MANAGING UNCERTAINTY

An uncertainty analysis forms an integral role in the LCA process, where the aim of the LCA is to support the decision making process. This is shown in Figure 1, where the uncertainty analysis is placed in the context of the overall decision making process. The key decision making steps to which the uncertainty analysis contributes are choosing the criteria against which options will be compared, generating the options to be put forward for possible implementation in the decision, and aiding with the selection of the best option.

3.1 Uncertainty importance analysis

The iterative procedure for the probabilistic assessment of empirical uncertainty outlined above rests on the ability of the uncertainty importance analysis to direct attention to those parameters contributing the most to the variance in the output. As the procedure starts by defining "quick and dirty" definitions of the probability distributions (simple distribution shapes with overestimates of variance), the first solution to addressing a parameter returned with high uncertainty importance is to make a more considered estimate of its probability distribution (i.e. to use whatever statistical and qualitative information is available on the parameter, or similar parameters, to determine as accurately as possible its distribution shape and variance). If the parameter is still returned with high uncertainty importance in subsequent iterations, it is an indication that the variance in the output cannot be reduced further without reducing the uncertainty of this parameter. For most empirical parameters this requires increased data collection and/or modeling effort, hence the importance of having a mechanism to direct where effort can best be invested.

The uncertainty importance analysis uses a rank-order correlation analysis to obtain a relative ranking of each parameter's contribution to the overall uncertainty. This simple method, compatible with the simulation approach to probabilistic uncertainty analysis, estimates the effect of the uncertainty of a particular input on the uncertainty of the output, averaged over all possible combinations of values of the other inputs weighted by their probabilities. In many instances, the overall uncertainty in a particular impact category or environmental intervention is found to be dominated by only a few key input parameters. It may not always be possible to reduce the uncertainty in these parameters (see following section), but identifying the limiting parameters is important, as it prevents unnecessary effort addressing the uncertainty of those input parameters with lower uncertainty importance (where this yields no significant reduction in the overall uncertainty).

3.2 Managing empirical uncertainty

The management of uncertainty in models tends to focus on empirical uncertainty, partly because empirical parameters constitute the majority of quantities input into models, but also because the uncertainty of these parameters can be reduced within the current model form. Generally speaking, uncertainty in empirical parameters arise because of shortcuts and simplifications made during data collection and the modeling process. The necessity of better data collection or additional modeling effort is therefore common to reducing the uncertainty of all empirical parameters. The way in which the uncertainty can best be reduced is dependent on the source of uncertainty.

Measurement errors and inherent randomness are usually the easiest of the sources of parameter uncertainty to reduce, as often all that is required is that more measurements be taken. This allows the error due to the measuring process to be better defined, or for a more accurate characterization of the random quantity. For measurement errors, if taking additional measurements still does not allow a sufficiently precise determination of the parameter, a more accurate measuring procedure would have to be developed. Whilst for truly random quantities, this is the most than can be done to reduce the uncertainty. However, for many apparently random quantities, closer examination yields some underlying cause of the variability. For such pseudo-random quantities, the uncertainty can be reduced by modeling the processes responsible for the variability. A similar strategy can be employed to reduce the uncertainty due to approximations. However, the fact that these quantities are initially characterized as random or by approximations generally means that modeling their causal mechanisms is too complex, introduces too many additional variables into the analysis, or that data is not available. Uncertainty associated with subjective judgement is probably the least straightforward to reduce. It may be possible to refine the measurement to better relate the measured quantity to the quantity of interest, or to find a more appropriate quantity on which to base the measurement. However, the uncertainty associated with subjective judgement is generally vastly underestimated, so a better understanding of the mechanisms involved is probably more likely to increase rather than reduce the estimate of uncertainty [9].

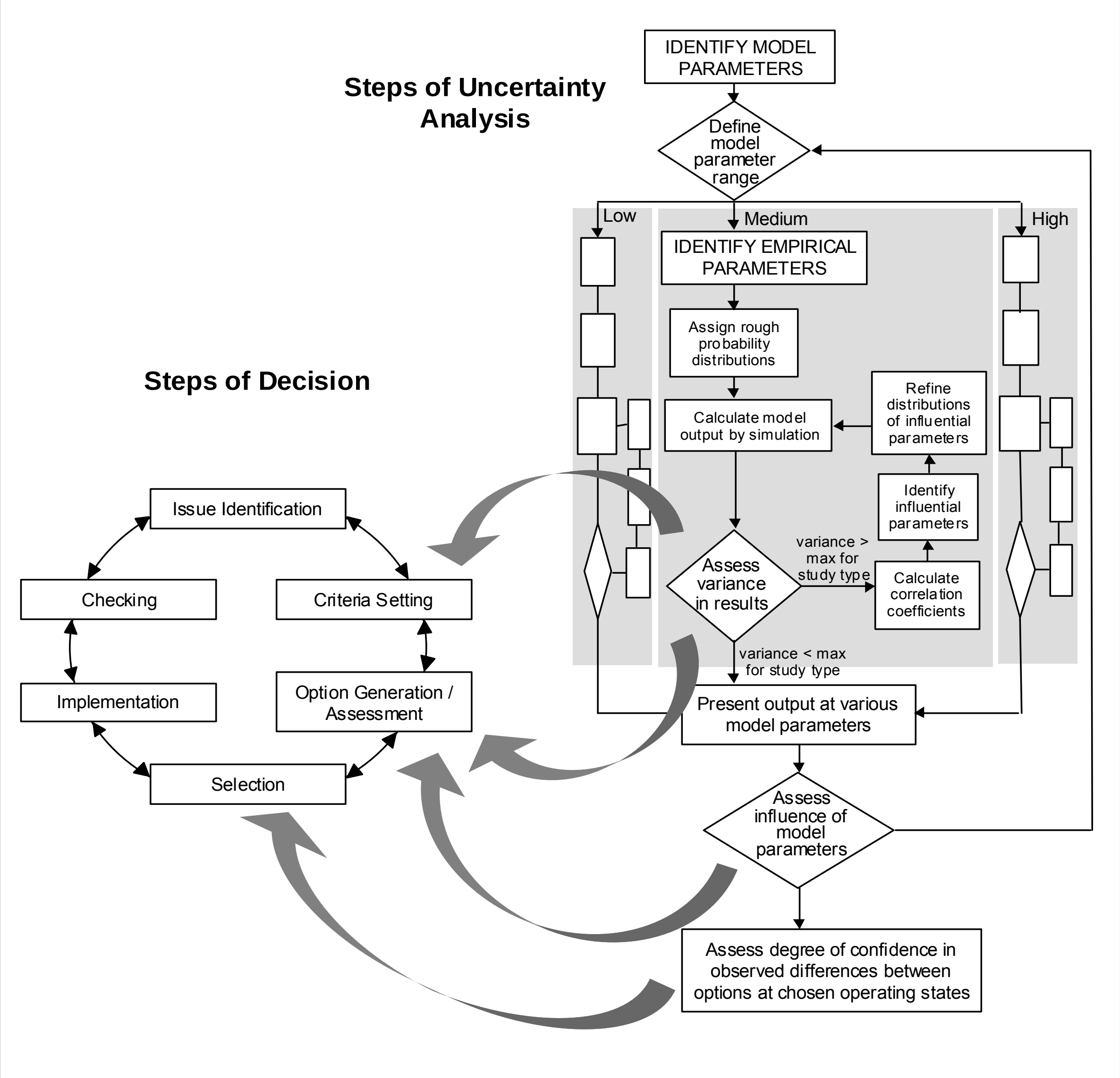

Figure 1. Schematic of the bottom two tiers of the uncertainty framework described in section 2.2, placed in the context of the overall decision making process.

Variable quantities have two distinct components to their uncertainty. The uncertainty associated with selecting a value for the parameter from the range of possible values the quantity may have (i.e. sampling its frequency distribution), as well as uncertainty associated with measuring or estimating this value. The latter is a result of the measurement errors and/or subjective judgement discussed above, so it is the first component of uncertainty that is of note here. A distinction between uncertainty due to variability and parameter uncertainty is made in Table 1 because the uncertainty in variable parameters can uniquely be reduced by a better definition of the temporal, spatial and technological placing of the quantity of interest. Focussing on the particular region, time-span or technology of interest (essentially disaggregating the data set) results a narrow span of variation over the actual zone of interest, and consequently less uncertainty associated with sampling the frequency distribution.

Breaking down highly variable parameters into narrower and more manageable bands of variability offers an important opportunity for managing empirical uncertainty in LCA models. This is especially significant in processes where highly variable parameters dominate the empirical uncertainty (e.g. resource-based industries [16]). For example, in a case study evaluating the fluidized bed combustion (FBC) of discard coal the sulfur content of the waste coals identified as possible fuel sources for the FBC boiler is highly variable. Good data, available from a number of collieries over a number of years, is available, allowing for a good characterization of the probability distribution of sulfur in discard coal. However, because of the high variability of this parameter, it is not possible to discern any clear differences between the options under consideration in those impact categories for which this variable has high uncertainty importance. A solution is found by breaking up the parameter into a number of scenarios to be incorporated into the model parameter analysis (see Figure 2). As the new parameter has a narrower range of variability, this essentially shifts a portion of the empirical uncertainty to the model parameter uncertainty. The potential range in results is therefore not lost, but it is now possible to discern differences between the options with greater clarity.

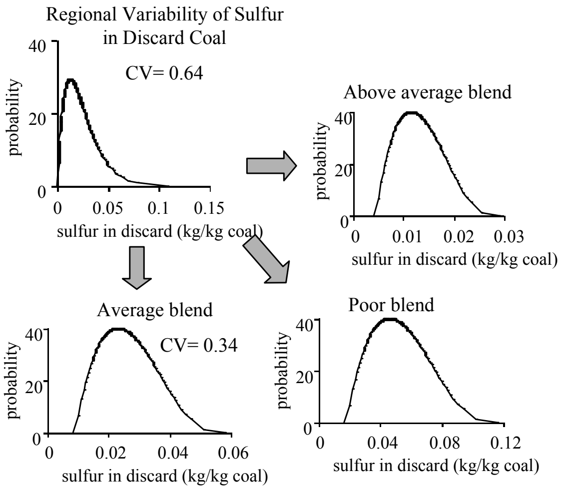

Figure 2. High variability of sulfur in waste coal is broken down into three discard scenarios, each with a more manageable variable range (CV = coefficient of variation, the ratio of the standard deviation to the mean)

Where little is known about a parameter value, an analyst has no recourse but to estimate high uncertainty. This is particularly problematic in LCA studies, where good data quality information is often lacking. In particular, aggregated LCI data (as found in LCA databases) is associated with high uncertainty. This is partly because sufficient information is rarely included in LCI databases for a user to make meaningful estimates of uncertainty, and partly because the nature of LCI data is that it is highly variable (averaging over regions, technologies etc). Better documentation would allow for a more informed estimate of uncertainty, but reducing the uncertainty further would require disaggregating the inventory (e.g. to obtain an LCI for the actual technology affected in the particular region of interest).

3.3 Criteria Selection in Comparative systems

Criteria setting is an iterative process, where an initially comprehensive range of impacts is subsequently refined by removing those criteria not helpful to the analysis. The uncertainty analysis is helpful in this process as it identifies those criteria for which the systems are too uncertain or the differences between them too slight to say with a high degree of confidence that one system always performs better than another.

An analysis of the variance present in the systems and of the magnitude of the differences between them can identify those criteria for which it is not possible to achieve high confidence levels within the constraints of the study. For example, in a case study looking at technology options for coal-fired power generation, it was determined that for comparative systems with coefficients of variance (CVs) of around 20% and less than 20% difference in their mean values, it could not be predicted with more than 80% probability that the one system would always perform better than the other system. Such “rules of thumb” can provide useful guidelines for setting realistic certainty criteria (e.g. in this case study, since data restrictions limited the variance in the output of most impact category results to CVs in excess of 20%, those categories exhibiting differences of less than 20% could not be considered meaningful selection criteria). In fact, the very high uncertainty in certain impact categories in this case study meant that for these impact categories comparisons were not meaningful even where significant differences in the mean values were observed, e.g. an 80% difference in carcinogenic effects was found between certain options, but there was only a 50% probability that this would occur.

3.4 Uncertainty in model parameters and model form

Uncertainty in model parameters and model form can better be said to be managed rather than reduced. The central idea in the management of these sources of uncertainty is ensuring that the potential range covered by the results is made explicit when they are presented. The following discussion centers on decision variables, since these offer greater opportunities for exploring model parameter uncertainty within the restrictions of the LCA model. An assessment of model form is typically restricted to the common choices encountered in LCA studies, whilst guidelines and “common practice” create the apparent sense that the effect of the choice of model domain parameters does not need to be investigated. Those that are able to be identified (e.g. time horizon considered, time interval modeled, degree of spatial breakdown etc.) can be considered in the parametric sensitivity analysis along with the decision variables.

The value of the systematic model parameter analysis outlined in section 2.2 is that it forces a consideration of all decision variables, thereby allowing an exploration of the full solution space of the system. A multivariate analysis of all model parameters found to be significant results in the output for a potentially very large number of scenarios being computed. However, the judicious choice of a few key scenarios covering the full range of results can usually keep the number of scenarios that need to be presented to a manageable number (e.g. best performance, worst performance, mid-range performance etc.). High uncertainty arising from the choice of decision variables can sometimes be reduced by revisiting the goal and scope definition phase of the study, and more tightly defining the problem to be addressed. However, in some studies, especially those of a more strategic nature, the very nature of the problem is a loosely defined option set. In such cases, the model parameter uncertainty analysis is invaluable, as it provides a structure for generating scenarios, and allows an informed selection of the best operating states (appropriate combination of operating parameters) to be taken further in the decision.

The significance of the model parameter uncertainty needs to assessed with respect to empirical uncertainty. If the empirical uncertainty causes a high degree of overlap between the options, it is an indication that model parameter uncertainty might be of lesser importance. However, if the opposite is true, it is an indication that additional effort would best be focussed on a better definition of the system, rather than exhaustively refining empirical parameter uncertainty. For example, Figure 4 shows the range in operating performance found for an FBC power generating plant relative to a conventional PF plant. NO_x emissions are seen to have low model parameter uncertainty (as seen by the range covered by the extreme scenarios in Figure 4), and the empirical uncertainty dominates the analysis (large overlap between the options). SO_2 emissions, on the other hand, show very significant model parameter uncertainty, with the choice of operating scenario determining whether the system performs better or worse than the comparative “base case”.

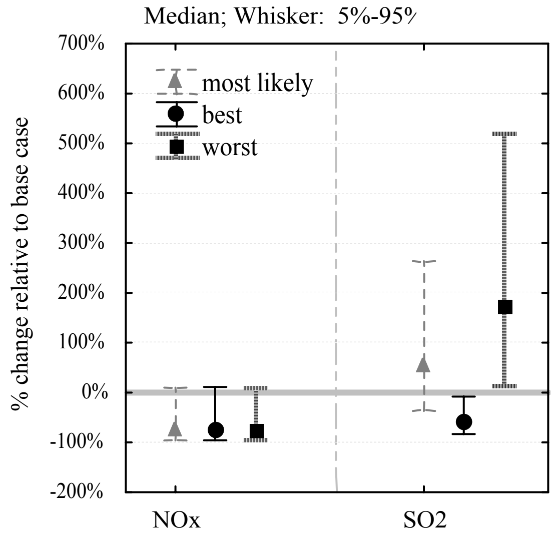

Figure 3. Range in performance of a small FBC power plant relative to a base case PF option. The median value and the interval in which 90% of the data falls is shown for best and worst operating performance, and for the most likely combination of operating parameters..

4 CONCLUSIONS

A quantitative uncertainty analysis adds considerable value to the decision making process, and goes beyond merely providing an indication of the confidence decision makers can have in the results. Where the purpose of the LCA is to support environmental decision making, the uncertainty analysis assists in the selection of meaningful criteria against which to evaluate system performance, directs further data collection and modeling effort, and assists in generating scenarios for comparison. In fact, given the inherent subjectivity in estimating the uncertainty of the input parameters (where these include all sources of potential uncertainty and not merely that reflected in the data sample), rather than expecting the uncertainty analysis to provide objective, realistic estimates of output uncertainty, the value of the analysis in structuring and guiding the decision analysis process should rather be emphasized.

A framework capable of delivering valuable assistance to the decision making process is presented. Although particularly developed for process and decision-oriented LCA applications, the uncertainty analysis framework is compatible with the general framework for LCA set out by ISO [17]. The ISO standards stress the importance of including sensitivity analyses and uncertainty estimates, yet provide no clear procedure for doing so [18]. The ISO standards also provide little guidance on scenario selection, although the choice of scenario to model has the potential to completely change the outcome of an analysis. The framework presented here aims to address these shortfalls, and also to place the uncertainty analysis in the overall context of the decision making process.

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UNCERTAINTY CALCULATION FOR LCI DATA: REASONS FOR, AGAINST, AND AN EFFICIENT AND FLEXIBLE APPROACH FOR DOING IT

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ABSTRACT: The issue of uncertainty in LCA data has been treated since the beginning of LCA; many practical examples and theoretical thoughts have stressed its importance. However, the use of quantitative uncertainty assessment is by far not common for LCA studies today. This text explores reasons for this reserve and wariness, spanning from technical to practical to psychological aspects. It gives a brief overview of an approach for calculating uncertainties in LCI data quantitatively, and with optimised effort and accuracy. It further shows and discusses its application for the calculation of aggregated processes, and full product system inventories, for a web server and a stand alone application, respectively. This comparison reveals that existing trade-offs between accuracy and performance ask for an algorithm tailored to, or adaptable to, the needs of the specific application environment. Finally, we confront this finding with possible reasons for and against an uncertainty assessment identified in the beginning, and question how far it contributes to a framework for performing a sound uncertainty assessment for LCI data.

Keywords: Quality Criteria and Measurement, methodology and uncertainty

1 THE ISSUE OF UNCERTAINTIES IN LCAS

Uncertainty may be defined as random deviations, or fluctuations, between a measured, ‘given’ value, and the unknown true value [1, p 5]. Since an error is, in terms of measurement theory, the difference between true value and measured value [2, p 105], uncertainties reflect random errors in data. Systematic errors, on the other hand, are constant, deterministic deviations of true value and measured value. Hence, systematic errors affect the accuracy of a result, while random errors affect its precision [1, p 2].

Transferred to the case of Life Cycle Assessments, given values are the amount of exchanges and elementary flows, of characterization factors, of normalization factors if used, and so forth. Within an LCA case study, these values usually stem from sources like public databases, in house databases and sources, inquiries, and questionnaires. Systematic errors in these values may have reason in modeling choices and systematically missing data (e.g. the omission of chlorofluorocarbons in the inventory, [3, p B13]). Random errors may result from a vast variety of reasons, the distinction to systematic errors solely lies in that the random error itself is neither constant nor reproducible. Random measurement errors inherent in data taken from databases, human failures in occasionally selecting non-appropriate data sources, and a full bundle of other effects (see e.g. [1, pp 3; 4]) have the consequence that every value used in an LCA case study may contain random errors. Which is, of course, not specific for LCAs, but common for any measurement.

Uncertainties, introduced in an LCA, propagate in the calculation process and finally find, to some extent, their way in the result produced, which may either be a ranking of different products, a ranking of hot spots in a single product system, or also the aggregated inventory of a product system.

2 REASONS FOR AND AGAINST A QUANTITATIVE UNCERTAINTY ASSESSMENT

2.1 Reasons for…

The following reasons argue for performing an uncertainty assessment:

1) **Better decision support**: LCA commonly is understood as a decision support tool. Backing the reported figures and results with uncertainty information allows assessing the stability of the result, and in some cases, a ranking order may be changed by considering the underlying uncertainty (see also fig. 1). Evidently, in a decision, information that changes a ranking of alternatives is of high importance, but also information on the stability of the result provided is immensely helpful.
2) **Transparency**: Uncertainty certainly is an unwanted property, the less uncertain data are, the better. The need to provide uncertainty information on data, and on LCA studies, bears the chance to clearly see the quality of data with that respect, and to identify, in a case study, ‘hot spots’ in data quality.
3) **Quality competition:** Transparency of data quality information entails a competition towards higher quality, less uncertain data. The transparently displayed uncertainty is, especially if it is estimated to be too high, or if high uncertainty in the result does not allow giving a clear recommendation in the valuation, an incentive for reducing it and thus to improve the data quality. This ‘competition’ aspect holds both within a case study and for independent data sources.

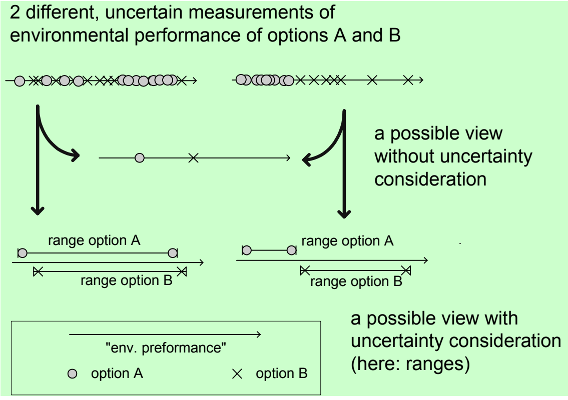

Figure 1. Representing uncertainty in the result may be essential for finding significant differences

2.2 … and reasons against

On the drawback side, there is, against a quantitative uncertainty assessment:

1) **Additional effort**, for collecting uncertainty information, for estimating the uncertainty in the outcome, and for dealing with the uncertainty in the outcome.
2) **Human nature**: What you don't know won't hurt you: People seldom behave rationally, facing uncertainty. A common behavior is to give more credit to a single value than to one that explicitly states its underlying uncertainty, especially if the uncertainty is high [11].
3) **Lack of methods**: Many authors state, in recent publications, the infancy, or complete lack, of methods for assessing and calculating uncertainties for LCAs, including also an inability to cope with the uncertainty in the result [8-9] – How should the uncertainty be calculated, and what is needed to be able to state a significant difference between two, uncertain, options? Obviously this question has strong relations to statistical test theory. But are the answers equal for all types of applications, and decision makers?
4) **Additional errors**: Adding the uncertainty aspect to an LCA model is some sort of sophistication. In doping so, the original model becomes more complex and error-prone, and especially the representation of uncertainty might be erroneous. Better none than a bad consideration of uncertainty.

2.3 Conclusions: requirements for the calculation of uncertainties

Uncertainty is additional information to figures provided in an LCA result. Basic rule for a decision is to consider all relevant aspects *provided* they may be represented adequately in the decision model [10]. Unless proved otherwise, uncertainty is relevant for decisions that are supported by LCA studies. To be able to 'adequately represent' the uncertainty in the result and study, the lack of methods should be allayed, and methods developed shall minimize possible errors caused by explicitly introducing uncertainty. A quantitative uncertainty assessment should be based on a method that is able to provide the uncertainty figures as accurately, and precisely, as possible, and that further reduces the effort for additional data collection, and for the calculation itself.

3 AN APPROACH FOR QUANTITATIVELY CALCULATING UNCERTAINTIES IN LCAS

3.1 Aim

Aim is to have a method that calculates the uncertainty in an LCA system as accurately as possible, and with optimum time and resources demands. The method may combine different best available techniques; the fact that the uncertainty is calculated accurately shall be validated.

3.2 Basics

The approach is based on a model that implements the calculation of an LCA in an abstract manner (without any measured data), but as realistic as possible. The model allows dividing the calculation's input values into true values and random errors. Both true values and random errors can be followed in the course of the calculations, and it is hence possible to investigate the propagation of random errors in LCAs. Within the model, approximation formulas (Gaussian error propagation formula, Taylor series formulas, an extension of the Gaussian formula given by Bader and Baccini [6, p 108]) and a Monte Carlo Simulation are implemented. Since true values and 'true values for errors' are known in the model (in contrast to any real measurement), the performance of the approximation formulas can be analyzed. The model was initially developed and investigated in a dissertation [5]. The thesis determined threshold values for each formula analyzed. These values are relative errors as calculated by the approximation formulas. They indicate whether an approximation formula is able to provide a correct estimate for the uncertainty. If the relative error exceeds the threshold, the approximation generally underestimates the uncertainty. Based on these findings, the thesis further recommends a combined use of approximation formulas and Monte Carlo Simulation.

3.3 Extensions

The initial model used in the thesis consists of a single, linear chain of processes, evidently an ideal abstraction and simplification. To determine the effect of loops in the product system, a follow-up research was performed. The original linear chain was extended by adding a closed loop (fig. 2; 'p' denotes processes, the lines are exchanges between processes, 'p l' are the processes in the loop). Values were set so that for the true values, a convergence in the loops was achieved.

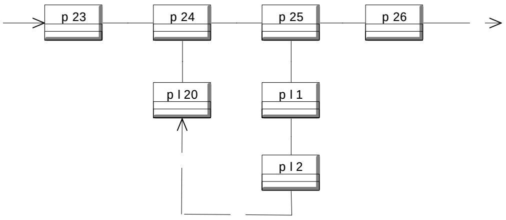

Figure 2. Principle structure of a loop, as investigated

Our research found that:

- High input uncertainties may yield, in the case of the Monte Carlo Simulation, non-converging loops. In those cases, the simulation calculates extreme values for the uncertainty. Fig. 3 shows an example (parameter settings for the example are: Initial scaling factor — ratio of input to output exchange —

of each process in the loop 0.99, uncertainty in exchanges of 0.05. The simulation was performed using 10,000 runs, assuming normal distribution of random errors). Results for the approximation formula are not visible in the figure.

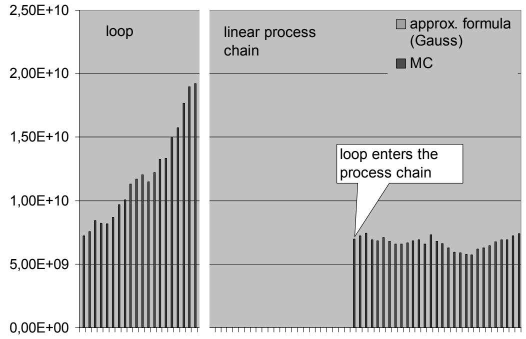

Figure 3. Results for the calculated uncertainty for loop and linear process chain, calculation of process scaling factors. Abscissa: processes in loop / in linear chain

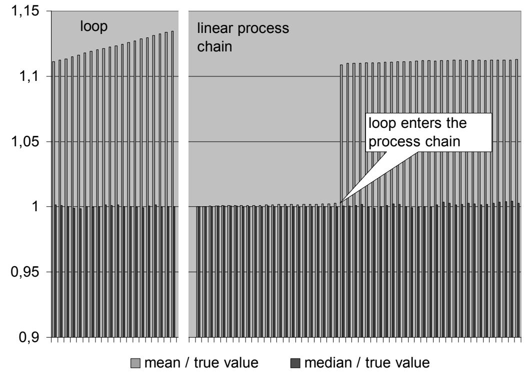

Figure 4. Ratios of mean and true value and median and true value, in the calculation of process factors

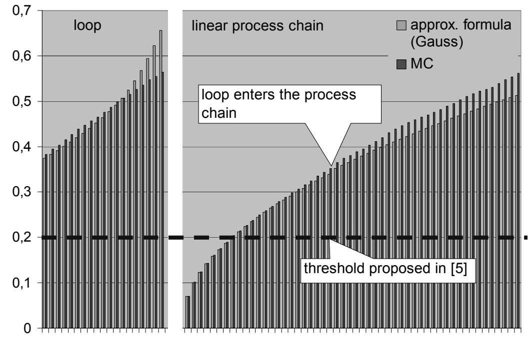

Figure 5. Comparison of the relative uncertainty calculated by Gaussian approximation formula and Monte Carlo Simulation, calculation of process scaling factors.

- In the loops, the simulation yields to a biased probability distribution, and in consequence, the mean does not well reflect the true value any more. As a conclusion, the relative error should, in the case of loops, be no longer calculated based on the arithmetical mean, but on the median which is more stable to extreme values (fig. 4, parameter settings: Initial scaling factor of each process in the loop 0.99, uncertainty in exchanges of 0.01).
- Threshold values for the approximation formulas, as given in [5], could be confirmed, also for a product system with loops, but with the recommendation to use the median instead of the mean. Fig. 5 shows the calculated relative uncertainty, parameter settings: Initial scaling factor of each process in the loop 0.9, uncertainty in exchanges of 0.05.

3.4 Conclusion

A combination of approximation formulas and Monte Carlo Simulation to estimate the uncertainty in the result of an LCA makes sense and is feasible also in the common case of loops in the product system. In the combination, approximation formulas are preferred, since they produce instantly a result, and with minimum calculation resources, and are not affected by loops that do not converge due to high uncertainties. A simulation is performed where the relative error of approximation formulas exceeds threshold values. The simulation may and should be performed locally (only at those distinct places where the threshold is exceeded), for sake of computation time. The approach is efficient for that reason, and it is validated, helping to provide uncertainty figures as accurately as possible, see also 2.3.

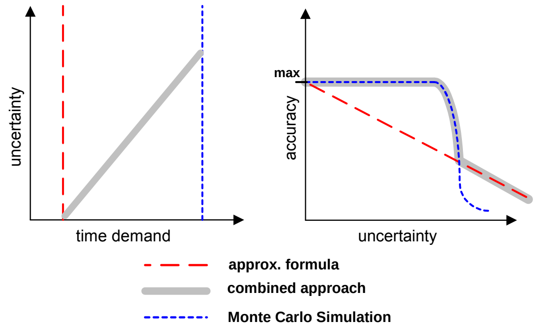

Figure 6. How uncertainty influences time demands (left), and how accurately simulation, combined approach and approximation formulas alone manage to provide estimates for uncertainty, depending on the uncertainty (right)

Finally, fig. 6 shows, in abstract fashion, relations between ‘the uncertainty’ (of the overall system considered, for sake of simplicity here), time demands in the calculation, and accuracy of the calculation result, for simulation, approximation formula, and the combined approach as described in this chapter: Time demand for simulation and formulas does not depend on the uncertainty, the application of formula is obviously faster. Since, with increasing uncertainty, the combined approach makes increasing use of simulation, its time demands rise from formulas to simulation (fig. 6, left). With higher uncertainty, approximation formulas have increasing difficulties to estimate the uncertainty; hence the accuracy of the estimate decreases. On the other hand, since the simulation, in the case of loops with high uncertainty, may not be able to provide good uncertainty estimates, the accuracy for the simulation may decrease suddenly, and even discontinuously. In these cases, approximation formulas may provide more accurate results. The combined approach is able to re-select the approximation formulas in these cases, and thus to provide a higher accuracy than the simulation alone.

4 APPLICATIONS

4.1 Hoarded calculation results vs. calculation at runtime in a database

For a database with the aim to provide unit process balances, aggregated process balances, and inventories, *together* with the uncertainty, there are two basic approaches:

1) Calculating every data set possibly demanded by user queries in advance, storing it in the database, and delivering it to the user when on request.
2) Calculating the data set actually demanded during runtime, e.g. in a tier located between database and user interface, triggered by user requests.

In the first case, storage demand is critical, calculation time is not. A lot of identical, redundant data (e.g. identical process data) must be stored as calculation results in the database. Since the database is not able to react in a flexible manner on user data demands, different data demands have to be foreseen and calculated in advance in a "data supply pool". Time demands for uncertainty calculation are not that critical. Unless there are loops that do not converge due to high uncertainties (see 3.3), a Monte Carlo Simulation is the easiest choice. Note that any changes in (uncertainty, and other) data require a recalculation of all affected data.

For the second case, the opposite holds: Time is critical, and, since ideally the database does not contain redundant data (except where required for database administration reasons), storage demands clearly are lower. The use of time consuming simulation seems questionable, but uncertainty approximation formula are applicable, of course, unless formula and calculation specific thresholds in relative uncertainty are exceeded, see 3.3.

Compromising between both, extreme, concepts seems the most promising, time and resource efficient way for uncertainty calculation. Formulated as a **recipe for uncertainty calculation**: Calculate commonly needed, or difficult to calculate, data in advance, store them in the database[3], and use in the calculation procedure the combined approach as described in chapter 3 and [5] for estimating the uncertainty. Provide, additionally, the possibility for users to further specify and individualize calculated data, by enabling them to add single, stored unit processes to the calculation, or by enabling them to change parameters in parameterized processes, typically transport, waste and waste water treatment processes.

4.2 Application environment ─ a thought on stand alone and web server applications

The decision on to what extent an application follows the database of the "hoarding" or the "runtime calculation" type largely depends on the application's environment. In case the database is used in a stand alone, single user environment, calculation time generally is not that critical, but the user certainly will demand to be able to calculate an individual system. In case the application is, on the other hand, a web server accessed by hundreds of users simultaneously, each of them starting simulations of 10,000 runs will not be tolerable. Hence a web server application will rather tend to the "data hoarding" type, while a stand alone application will rather follow the "runtime" option. The ecoinvent web server, which went online in September 03, strictly follows the first type, using solely Monte Carlo Simulation for estimating the uncertainty [7].

5 CONCLUSIONS

A quantitative uncertainty calculation for LCI and LCA is of high importance for a sound decision support, if performed by a method that is able to provide the uncertainty figures as accurately, and precisely, as possible, and that further reduces the effort for additional data collection, and for the calculation itself. This paper presents a method that tries to satisfy these requirements, and may help to mitigate the often stated lack of appropriate methods in the field of uncertainty calculation.

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[3] One would rather use two or several databases for doing so, we speak here of "the database" without caring for actual implementation, for sake of simplicity.

AN EXPERT SYSTEM APPROACH TO LCI DATABASE MANAGEMENT

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ABSTRACT: Tools to check for errors and inconsistencies in LCI databases are currently lacking, as are systems to aid in the selection of LCI data. This is because the large and aggregated nature of LCI databases make them difficult to evaluate. However, if viewed as a multivariate problem, where the product and processes are interpreted as the independent variables and the environmental exchanges as the dependent variables, it is possible to take advantage of the many statistical and mathematical techniques developed to gain insight into multivariate systems. In this paper, an expert system combining data retrieval and multivariate data analysis techniques is proposed to enhance database management. Through the use of exploratory pattern recognition techniques, such as correlation analysis and principal component analysis (PCA), the expert system will be able to alert a user to unexpected differences between inventories of the same or similar processes, to identify redundant entries, and to warn of possible errors in the data or mistakes in the data entry process. The expert system can be applied both to a single database and to a network of databases, thus providing a means for integration of diverse data sources.

Keywords: data, database management, expert system

1 INTRODUCTION

LCI databases are difficult to evaluate. Whilst significant steps have been made towards developing a consistent format in which to report and document LCI data (e.g. ISO 14041 technical standard [1]), tools to check for errors and inconsistencies in LCI data are generally not available. The fact that there is a considerable need for such tools is attested by the startlingly high degree of variability found across inventories of seemingly identical products [2; 3; 4]. For a particular product, a factor 10-100 (or higher) variation can be expected for process-specific emissions [4], whilst considerable inconsistencies are likely as to which life cycle stages and emission parameters are included [2]. The way in which the data are typically presented in LCI databases (large tables with very many entries) means that these large variations and inconsistencies are unlikely to readily identified by a user.

The lack of stringent requirements on the amount of meta-data that should be reported with LCI data means that many LCI databases are still published without adequate supporting documentation. In such cases it is very difficult, if not impossible, to make judgements on the quality of the data and its adequacy for use in a specific study. Even when LCI databases are well documented (which is all too often not the case) it is difficult to get a “feel” for data presented in vast tables with possibly hundreds of data entries. This disconnect between user and data is compounded by the fact that LCI data is most often reported summed and normalised, or otherwise aggregated to some high degree. This obscures the underlying information used to construct the inventory, leaving a user no option than to rely completely on the often scanty documentation included with the inventory to interpret its quality.

The volume of LCI data in circulation is steadily increasing, with a number of private and national database initiatives being undertaken around the world [5]. These are of varying degrees of quality and completeness, and often built upon existing data sources. The need for guidance in selecting the best data for a particular application is therefore becoming increasingly necessary. Furthermore, with the movement towards uniformity in format, and the existence of large data sets, it is increasingly feasible that an expert system could be developed to fulfill these needs. In particular, a system is envisaged that is able to contrast and compare inventories, thereby highlighting inconsistencies and possible errors in the data.

2 PROPOSED APPROACH

Vast tables of numbers may appear very difficult to interpret from an LCA practitioner viewpoint, but if viewed as a multivariate problem, where the products and processes are interpreted as the independent variables and the environmental exchanges as the dependent variables, it is possible to take advantage of the many statistical and mathematical techniques developed to gain insight into multivariate systems. These techniques have been developed precisely for such systems, where the high dimensionality of the data matrix (e.g. many variables measured over many processes) means that the data can no longer simply be interpreted “by eye” (e.g. in 2-D or 3-D graphical plots of the data). Instead, exploratory statistical methods aim to use the information content of the data to understand something of interest about the systems from which the data has been collected. In essence, the methods attempt to recognise patterns in the data which can provide useful information about the sample from which the data is collected [6].

The potential of using statistical methods to analyse LCI databases has been demonstrated by Huele and van den Berg (1998), who successfully apply simple correlation analyses to find identical and redundant entries in a large LCI database [7]. The use of the multivariate data analysis technique, Principal Component Analysis (PCA), has also been demonstrated in LCA studies, where it is shown to be a valuable aid in interpreting LCA results, capable of providing a unique visualisation of the structure of the results [8; 9].

These studies hint at the powerful insights that may be possible with more sophisticated multivariate data analysis techniques. In particular, the factor-based or cluster analysis techniques, with their ability to recognise patterns within the data, have considerable potential to provide insights into LCI data that are at present not easily achievable, e.g. exposing actual from apparent differences between inventories by identifying inventories dominated by processes for which identical data sets have been used. The pattern recognition techniques are also able to alert users to possible errors and inconsistencies in the data sets by highlighting large or unexplained differences between inventories of the same or similar products (see following example). Given a sufficiently large number of varied and independent life cycle inventories, it is proposed that by using "supervised learning" tools, such as SIMCA (Soft Independent Modelling of Class Analogies), the insights gained through the analysis of those inventories for which sufficient meta-information is available, can be used to provide information on those inventories for which detailed documentation is lacking.

2.2 PCA example

Figure 1 presents an example of the sort of insights into large data sets able to be gained through the use of multivariate statistical methods. The example is only intended to provide a feel for the sort of results possible, and it is not within the scope of this paper to fully describe the method illustrated (principal component analysis). The theory of PCA can be found in most multivariate statistical analysis and chemometrics textbooks, e.g. [10; 6].

The goal of PCA is to represent the variation present in many variables in a small number of factors (or principal components), which are found via a mathematical manipulation of the data matrix. A new space in which to view the data is constructed by redefining the axes using the factors found, rather than with the original variables. The new axes allow the analyst to view the true multivariate nature of the data in a relatively small number of dimensions, allowing him/her to identify structures in the data that were previously obscured.

It is these structures or patterns in the data that are of interest in Figure 1. The distances between the points representing the various LCIs are what concern us, as these are used to define similarities and differences between the inventories. The axes do not have any physical meaning, they are merely measures of proximity that are interpreted as similarity. It is thus the relative distance between the points that is of note.

Figure 1 shows the results of an analysis of the LCIs of four different chemicals (ammonia, sodium hydroxide, ethylene and benzene) from four different data sources: ETH (Okoinventare fur Energiesysteme), APME (Ecoprofiles of the European Plastics and Polymer Industries, Reports 4, 6 and 14), Tenside (Petrochemical Intermediates, TS1, and Sulphur and Caustic Soda, TS3) and IDEA (An International Database for Ecoprofile Analysis) (data referenced as in the source, the LCA software model PEMS [11]).

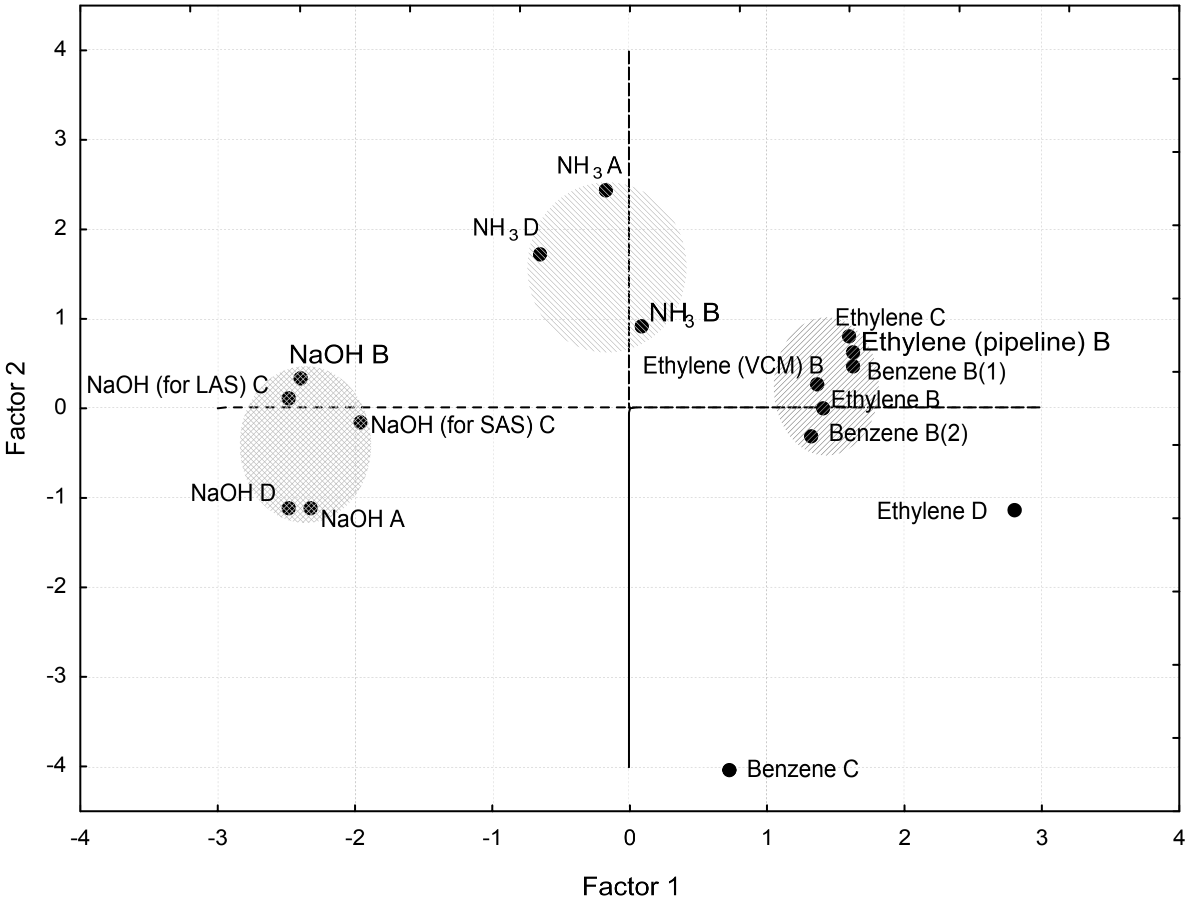

Figure 1. Principal component "scores" (data points projected on to the 1st and 2nd principal component axes) from an analysis of the inventories of four different chemicals using four different data sources. A: ETH, B: APME, C: Tenside and D: IDEA.

The four data sources have very different levels of completeness and little uniformity in format, so for this simple example, the analysis is based on only ten inventory items (see Figure 2). Even with this very reduced data set, three distinct clusters can be discerned in Figure 1, corresponding to the inventories for ammonia, sodium hydroxide and the organic chemicals (benzene and ethylene) (see hatched areas in Figure 1).

Immediately evident in Figure 1 is that Benzene from data source C shows characteristics significantly different to the inventories of the other organic compounds (it falls well outside the cluster of like inventories). To determine what is causing this significant deviation from the other inventories it is necessary to look at the principal component "loadings". These are a measure of each variable's contribution to the principal components, and indicate which variables are best at discriminating between the cases under investigation. In Figure 2, the length of the lines and their orientation indicate which variables have had the greatest influence in "pulling" the data apart to create the patterns in Figure 1. Interpreting Figure 1 and Figure 2 simultaneously (imagine the two overlain), indicates BOD to have been influential in pulling Benzene C away from the other inventories. A check with the data confirms this, and finds that the BOD measurements for this inventory are more than two orders of magnitude greater than the others. This is considerably larger than the variation shown by any of the other inventory items (which show at most a factor 5 variation), indicating that the BOD value may be an error. The PCA analysis finds where the greatest variations are occuring, not where the largest absolute changes in emissions occur. This is because it is based on correlations between the data points. The analysis is thus not influenced by the relative magnitude of the various inventory items, and can also include inventory items in different units (e.g. MJ and kg).

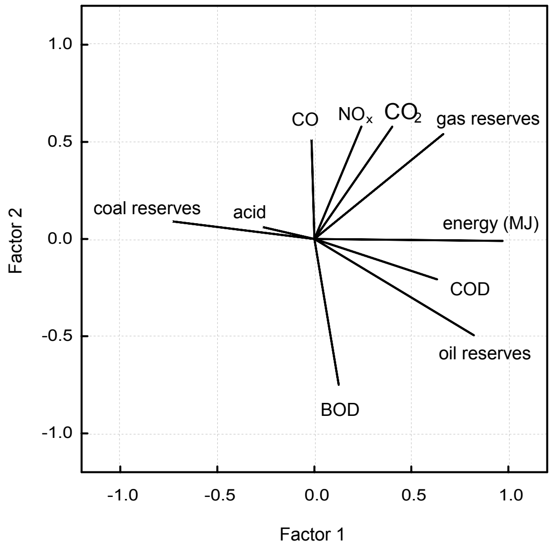

Figure 2. Principal component "loadings" (the contribution of each variable to the 1^{st} and 2^{nd} principal component axes) in the analysis of the inventories of four different chemicals using four different data sources (see Figure 1).

Clearly there is a need for an expert system to translate the results of the analysis to information useful to the user (i.e. a user is given a warning regards the anomalous BOD values without needing to understand PCA or to be able to interpret Figures 1 and 2). An expert system is necessary so that a user does not need to understand the intricacies of the statistical methods used to benefit from the insights they give into the data.

3 PRACTICE AND LIMITATIONS

The expert system will enhance traditional database search features by providing information regards the quality and completeness of the data. For example, a search for an inventory of a specific product/technology from a specific region would return the inventory for that region, but inform the user of gaps or significant differences between the inventory and others it contains for that or similar products. As the expert system is only making apparent what is hidden in the data, it is up to the user to determine whether to accept or reject the advice. For example, if a specific product inventory is seen to have significant differences between it and others in the database, this does not necessarily mean these differences are errors. A very large difference in a single inventory item might indicate a data entry error, however a pattern of differences would require closer examination. If indications are that all other inventories for this product have been built upon the same data (e.g. their dominant emissions are all from electricity production where identical data has been used), the inventory showing a different pattern of emissions may in fact be of higher quality. The expert system will present the differences with the possible underlying causes, but ultimately the course of action (e.g. to use another inventory, adjust the suspect inventory item, etc.) is up to the user.

It is important to note that the information the expert system provides can only be as good as the database upon which it rests. For example, where a user is interested in an inventory from a particular region, and the system shows large differences between this inventory and those from other regions, instead of merely alerting a user to these differences, the expert system would ideally be able to evaluate them in light of what it knows of regional variability. However this would only be possible if the database provided a number of inventories from different regions to allow for such an analysis. The success of the expert system therefore hinges on it being provided sufficiently large and well documented data sets in a common format. Whilst the expert system is able to inform a user about an inventory for which detailed documentation is lacking, this is only possible after the system has been "trained" and validated using well documented data.

The expert system is intended not to be limited to any one particular database, and ideally will be able to be used across a network of databases. However, a consistent format across the databases is a key requirement, since the expert system is only able to evaluate data in the same format as that it in which it has been "trained". Similarly, the criteria able to be used by the expert system to search a database are limited by the format of the database, and how complete and detailed the documentation is for the database. In other words, for the expert system to return and evaluate inventories closest to meeting a set of particular criteria, at a minimum, the inventories must have completed fields for those criteria (e.g. technology, region etc.). The more well specified the database, the better the expert system will be able to function.

4 CONCLUSIONS

Given a sufficiently large and well documented LCI database, it is proposed that exploratory mathematical and statistical techniques can be used to “unlock” some of the information in LCI databases obscured by layers of aggregation and normalisation. By using advanced statistical methods to explain unexpected variations, gaps and clustering of inventories, powerful insights into the data can be passed on to a user to assist with data selection. The expert system is not intended to choose the data for the user, but to help the user make a more informed decision about the best data to use in his/her particular study.

The expert system will combine conventional database search features with information on the quality and completeness of the data. In a specific search, the expert system will thus not only return the data that is closest to meeting a user’s specific search criteria, but also evaluate the returned data in light of the other data in the database. The expert system thus allows a user to get an overview of the data not presently possible in LCI databases, and to get a feel for variations in emission values, levels of completeness, etc.

A prerequisite for the success of the expert system is a consistent data format and well specified data entries. The degree to which the expert system can interpret the variations it observes in the data rests on the availability of sufficiently large and well documented data sets with which to “train” and validate the system.

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A METHOD TO AGGREGATE LCA-RESULTS WITH PRESERVED TRANSPARENCY

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ABSTRACT: This paper presents a method to maintain data quality while aggregating and communicating LCA-results. It also includes a practical example of an application of the method, i.e. how a prototype of a simple and operative LCA tool is built, including a description of the practical design procedure and preparation for a specific context. The method is based on the assumptions that a rational decision-maker requires access to all information and that a LCA model is a statement about the real world. Further, the introduction of the dynamic “recursive” and “parametric” LCA model is crucial for the data quality maintenance. The LCA tool shows that the method is easy and practical to work with, since it enables quick results that are easy to understand, but still allows for updates and transparent reviews. However, since the principle of this type of LCA tools requires a special design depending on each specific context, the information management has an initial cost that is higher than for a traditional LCA tool. This initial cost will be met by a matching cost reduction over time, if there is a need to produce many similar LCA results. Thus, it is crucial that the context for a specific design of this tool is carefully chosen.

1 A METHOD TO MAINTAIN DATA QUALITY

This paper presents a method to maintain data quality, in terms of transparency, when aggregating and communicating Life Cycle Assessment (LCA)-results.

It is demonstrated that this method is valid for very simple and quick LCA’s. This is made with a practical example, the development of a simple and operative LCA software tool. The software tool has a high system perspective, like screening LCA tools, but allows for transparency at the detailed level of more complete and sophisticated LCA studies.

2 BASIS FOR THE METHOD

The method presented in this paper is developed for an ideal context, in which the end-user of information is a theoretically rational decision-maker. In this ideal context it is important that an LCA is designed to produce correct results, i.e. results that would closely reflect real measurements, if such were performed to verify or reject the result of the LCA.

The rational decision-maker and the correct LCA study are described further below, as they establish principles for the method. By establishing a method on ideal principles we argue that the result may have ideally high qualities with regard to any real application.

2.1 A rational decision-maker

The method described in this paper is designed for an ideal context where the end-user of information is a rational decision maker who has access to all information about the decision, i.e. knowledge of all alternatives and its consequences. [1] For example, in this case a rational decision maker in theory does not settle with qualitative judgments from experts or any lack of documentation in the LCA, but requires real measurements and a transparent and complete data foundation.

However, a rational decision maker in practice has to make compromises and make decisions based on somewhat insufficient information or lack of knowledge, due to e.g. deadlines and budget.

The purpose of having an ideal context with a rational decision maker as a basis for the method is to set the limitations for the quality requirements on the database of the tool.

2.2 LCA as a statement about the real world

An LCA may be regarded as a statement about the real world. In this sense, a LCA model is a reference model, which describes certain properties, relations, and variations in the real world. Thus, an LCA model may be used, and reused, to run measurements that verifies or rejects the statements of the model. Such verification measurements may be carried out in the future, after the first LCA result has been produced. Regardless of the fact that this future sometimes is very far ahead, this viewpoint can nevertheless be held about the LCA methodology and LCA as such. In this paper we consider LCA in this way, and we make use of this viewpoint by stating that in principle, LCA’s can produce results that can be verified by measurements in the real world. [2]

The purpose of having LCA results based on real measurements as a basis for the method is to aim at an LCA model that correspond with reality as well as possible, i.e. that has a high precision.

3 DATA QUALITY AND TRANSPARENCY

The applicability of a data set in e.g. decision making or market communication is very much dependent on the reliability of the data. A data set will be reliable if it can be transparently reviewed. Thus, if the data is described in a relevant, structured, and understandable way, e.g. including references to original sources and specification of system boundaries under the headline where expected to find it and in a language that can be read, the data may be transparently reviewed.

Other aspects of reliability, are the competence of the people handling the data and the precision, i.e. the numerical accuracy of data, see Figure 1. For example, if data from a plant is used, the data will be more credible if it is acquired by someone at the plant, than if it is acquired by an LCA-practitioner.

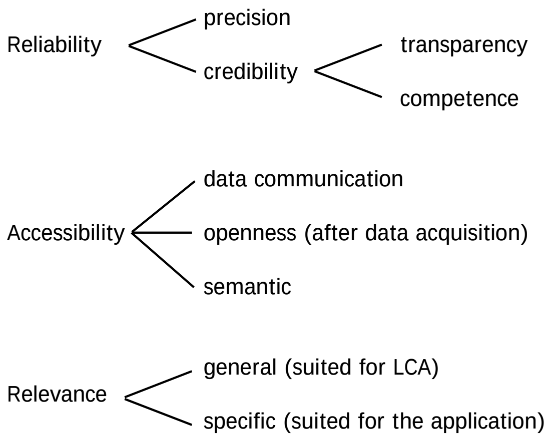

Figure 1 The data quality dimensions as defined at the Swedish competence Centre for environmental assessment of Product and Material systems (CPM). [3]

Other dimensions of data quality are accessibility, i.e. the data communication, and relevance, i.e. the applicability of the data. The technical and linguistic communication issues are not addressed further in this paper; neither are the aspects of data suitable for a specific assessment tool, which is LCA in this case, or study. [3]

4 THE DYNAMICS OF AN LCA MODEL

In this paper the dynamics of an LCA model is described in two dimensions. The two dimensions are chosen because they correspond to the decision maker's area of responsibility and his or her possibility to have an influence on certain parameters. For example, the area of responsibility for environmental coordinators will differ very much from product developers. Further, the parameters they want to vary, study the consequences of, or that they may have an influence on will be very different.

The model dynamics described in this paper enhance the usability of the model remarkably, by facilitating inventory up-dates, transparent reviews, and quick and easy assessments, e.g. to be used as screening LCA's without lowering the data quality requirements.

4.1 The recursive LCA model

The dynamics of an LCA model can be described in terms of a recursive model, see Figure 2. A recursive LCA model includes a choice of resolution for parts of the model. For example, a large system with low resolution has the possibility to become a system with increased resolution by adding new inventories. In this way, the model may get higher precision by increasing the resolution, i.e. get closer to the measurements in the real world. The recursive model is advantageous to apply in a LCA model as it facilitates updates and transparent reviews.

For example, the data documentation format ISO/TS 14048 [4] has the capability of a recursive LCA model, which allows selection of an arbitrary level of process aggregation, without losing transparency, by organizing internal references to unit processes and included product system.

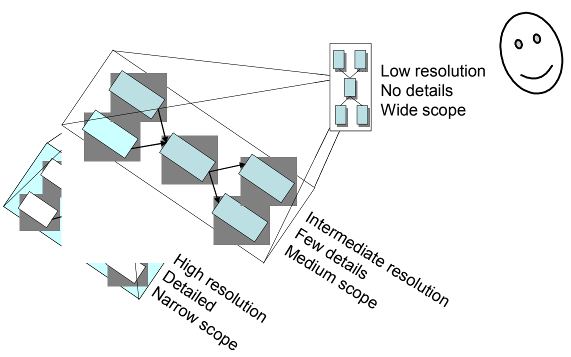

Figure 2 Recursively analysed production system. The analyst can navigate between high and low resolution, with narrowing and widening of the scope, and level of detail arbitrarily and correspondingly changing.

4.2 The parametric LCA model

Another perspective of a dynamic LCA model is described in terms of a parametric model, see Figure 2. A parametric model includes an arbitrary choice of parameters that connects to the goal and scope of the study. In order to answer the questions posed or study the relations described, physical properties of the studied system can be varied, such as the amount of raw material input, distance of transportation, octane content in fuel, incineration efficiency, geographical area of emission etc. The parametric model is advantageous to apply in a LCA model as it facilitates quick and easy LCA's for a specific context.

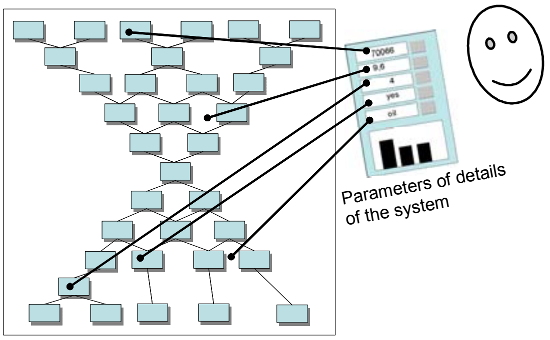

Figure 3 Parametrised analysis of a production system. The analyst has a fixed resolution and scope of the system, but can manipulate detailed parameters at any level of detail of the entire system.

4.3 The combination of a recursive and parametric model

If the recursive and parametric properties of an LCA model is combined, it will facilitate transparent reviews, easy up-dates, and quick LCA's, specially prepared for a certain context. Due to the dynamics in the model, the data quality will be maintained.

5 THE TOOL LCA-E

The LCA tool LCA-E (Life Cycle Assessment – Electronics) is a tool thoroughly prepared for the specific context of screening LCA in the Design for Environment (DfE) phase for printed circuit boards. [5] It is developed by CPM in the project "Strategy of life cycle assessment in the electronics industry", managed by the Swedish industrial research and development corporation IVF and tested against a reference group including ABB Corporate

Research, Autoliv Electronics AB, Ericsson Radio Systems AB, Skanova AB, Volvo Car Corporation, and Quest AB. The project ran between 2000 and 2003. [6]

The aim when developing the tool was to facilitate transparent reviews and updates of the database. Further, the users were product developers, who had little time to spend on assessments of environmental aspects and therefore needed a simple tool that could provide exactly the modularity and result they needed to make the right decisions.

5.1 The scope and quality of the database

The LCA tool is based on the framework of ISO 14040, enabling the perspectives of target audiences, commissioners, practitioners, and people involved in data collection and design of impact assessment approaches. The tool makes use of ISO/TS 14048 and a compatible data format for impact assessment. The compatible impact assessment model allows for assessment at any level of aggregation of the product systems.

The context "product development for printed circuit boards" and the data access set the scope of the Life Cycle Inventory (LCI)-database, i.e. the choice to include prefabrication, manufacturing, and use processes for printed circuit boards in the inventory. Data for those processes were acquired and documented in line with ISO/TS 14048 [4], using practical data quality requirements [3] based on the data quality dimensions defined at CPM, see Figure 1.

In a similar way, the Impact Assessment (IA)-database was created on the basis of a policy chosen specifically for this context. The impact categories in the Environmental Product Declaration (EPD)-system [7] provided the base for this policy. Further, the policy was used as a guideline to identify which indicators, characterization models, and weighting methods to choose or create. The impact assessment methods Eco-indicator '99, EDIP, and the EPS system were included because they were already accessible on a for the tool usable format.

The connection between the LCI- and the IA-databases was performed by a strict mapping of the data categories from the LCI-database to the data categories in the IA-database. This strict mapping e.g. involved the processing of different flow interface's and nomenclatures.

5.2 The dynamics of the LCA model

The LCA model in LCA-E is both recursive and parametric, to meet the users requirements.

The parameters that the product developers wanted to play about with in the tool was the amount of components (cables, capacitors, connectors etc.) in the product phase and the electricity needed for the use phase.

The recursive choice of resolution was based on inventories of electronic components accessible at that time. The inventories are easy to study and review directly in the tool and can be updated at any time.

5.3 The final qualities of the tool

The result is a tool with a simple interface that is very easy to use, but at the same time has a complex database structure and design behind the interface. This makes the tool suitable for e.g. screening LCA's, where the assessments need to be quick and the results easy to interpret for the decision-makers. In addition, the data quality is maintained, as the data documentation and structure makes it possible to up-date and transparently review the data.

6 CONCLUSIONS

A method for maintaining data quality, in terms of transparency, when aggregating and communicating LCA results, is generated and demonstrated in practice by the LCA tool LCA-E.

The assumptions for the theoretical base, i.e. that a rational decision-maker requires access to all information and that a LCA model is a statement about the real world, are necessary for the development and usability of the method. Further, the introduction of the dynamic "recursive" and "parametric" LCA model is crucial for the data quality maintenance, hence, usability of the tool.

The LCA tool shows that the method is easy and practical to work with, since it enables quick results that are easy to understand, but still allows for updates and transparent reviews.

7 DISCUSSIONS

Since the principle of this type of LCA tools requires a special design depending on each specific context, the information management has an initial cost that is higher than for a general LCA tool. This initial cost will be met by a matching cost reduction over time, if there is a need to produce many similar LCA results. For example, within the Environmental Product Declaration (EPD)-system [7] there could be a need for a LCA tool specifically designed for a Product Specific Requirement (PSR)-group or when establishing a database for a line of business in general e.g. within the aluminium, plastic or pulp and paper industry.

Thus, it is crucial that the context for a specific design of this tool is carefully chosen, if the tool shall be commercially practicable.

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A NEW INVENTORY DATA MODEL AND METHOD FOR UNCERTAINTY EVALUATION IN LIFE CYCLE ASSESSMENT

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ABSTRACT: When reviewing an environmentally conscious product or process, life cycle assessment (LCA) has been proven a good tool in evaluating alternative options. It is important to know to what extent the outcome of an LCA is affected by uncertainties, as it may be helpful for decision makers in better judging the significance of differences between options. However, conventional inventory data model uses averages among identified factories in the scope of LCA. This data model cannot incorporate the effects of uncertainty into the LCA result because the information of variance is lost. In this paper, a new model for inventory data and method of inventory analysis is presented. This data model reflects the differences of input/output per unit production between comparable factories which produce the same product into the LCA results, without publishing individual data from industry. This paper uses a case study which illustrates the selection of chemical recycling system for PET bottles and shows how the model enables decision makers to consider the alternatives with uncertainty.

Keywords: Uncertainty Evaluation, Inventory Data Model, Decision Making

1 INTRODUCTION

When reviewing an environmentally conscious product or process, life cycle assessment (LCA) has been proven a good tool in evaluating alternative options. It is important to know to what extent the outcome of an LCA is affected by uncertainties, as it may be helpful for decision makers in better judging the significance of differences between options.

Hanssen & Asbjørnsen discussed that differences of input/output per unit production between comparable factories producing the same product result in the variable lifecycle inventories [1]. Huijbregts further analyzed these differences as variability between objects/sources in the inventory phase of LCA, and classified such into various types of uncertainty which should be made operational. He argued that it would be informative to know the actual range of environmental impacts, when the goal of study is to improve the environmental profile of a product system [2]. However, conventional inventory data model, which uses weighted average of scattering input/output based on market share, cannot fully incorporate the effects of uncertainty into the LCA results.

There are several factors which cause differences of input/output between factories. Production emissions may widely vary according to the plant's scale and to the process technology. For example, difference in technology and management applied to pollutant treatment system causes scattering input/output [1]. In addition to these inherent differences, data obtained from a factory may also vary by errors in the data treatment. Causes such as error in measurement, allocation of emission from a process which supplies utility to several processes, and seasonal variation of production are cited as factors.

To treat these uncertainties within the data obtained from industries, we propose a new inventory data model and method of inventory analysis. The use of this data model can reflect the scattering of individual data in the results without publishing individual data. Stochastic modeling which can be performed by using Monte Carlo simulation yields the outcome of an LCA as probability distribution.

2 INVENTORY DATA MODEL AND INVENTORY ANALYSIS METHOD

2.1 Conventional data model

Figure 1 illustrates a factory which uses raw material X_i, utility Y_i and waste Z_i per unit production within production process. The input/output of production process which includes identified factories in the scope of LCA are conventionally given by weighted average based on the market share such as,

$$X = \mu_X = \sum_{i=1}^{n} w_i X_i \tag{1}$$

where w_i is the market share of factory$_i$ inside the scope of LCA study. This inventory data model cannot incorporate the scattering of X_i into X which is used in the LCA calculation.

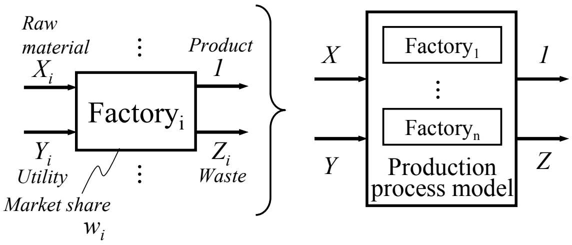

Figure 1.Modeling production process including several comparable factories.

2.2 Proposed data model

Proposed data model describes the LCA data as probability distributions and correlation coefficients between uncertain components to preserve the scattering of input/output. In Figure 2, X_i and Y_i are described in the scattering plot. After specifying the type of distribution, the parameters to determine the distribution are then estimated by using Maximum Likelihood Estimation (MLE). In example above, X, Y are then obtained as probability distributions. Z can be modeled by $1- X$ to keep the mass balance.

The type of distribution to be fitted depends on the property of the data sets. Several works analyzed proper distributions to be fitted [1], [3]. Goodness-of-fit (GOF) statistics assist us in finding the best-fit distribution among a set of candidates [4]. When normal distribution or lognormal distribution is fitted to X, Y as is in Figure 2, MLE gives the mean and standard deviation which then define the distribution. X can be expressed as,

$$X = Lognormal(\mu_X, \sigma_X) \tag{2}$$

where the mean value μ_X is equivalent to the value in Eq. (1).

Inter-dependencies between uncertain components have to be recognized [4]. For example, factories which have better production efficiency are likely to have better thermal efficiency. Such correlations between input/output are modeled as a rank order correlation coefficient which quantifies the correlation of two variables ranging from –1 to 1. In the example in Figure 2, a positive value may be obtained for a rank order correlation coefficient between X and Y.

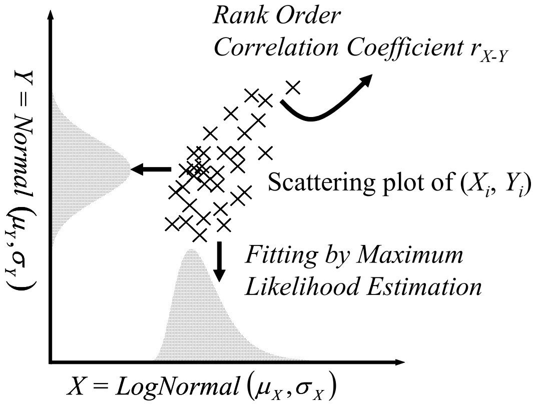

Figure 2. Fitting probability distribution with preservation of correlations.

In Figure 3, conventional/proposed inventory data models are compared. Conventional data model calculates mean value using data from factories *(X_i, Y_i, w_i)*. This model has the ability to mask the individual data by averaging them, but loses the information of variance. In the proposed model, LCA data is described as probability distributions and correlation coefficients between uncertain components. Scattering input/output can be incorporated into LCA data without publishing the individual data.

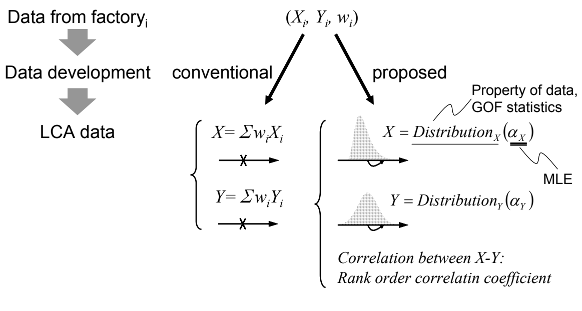

Figure 3. Comparison of conventional/ proposed data model and its development process.

2.3 Maximum Likelihood Estimation

MLE is most common technique used to fit distributions to available data sets [4]. The maximum likelihood estimators of a distribution are the values of its parameters that produce the maximum joint probability density for the observed data. Consider a probability distribution type defined by a single parameter, *α*. The likelihood function *L(α)* is proportional to the probability that a set of n data points X_i could be generated from the distribution with probability density *f(X)* and given by

$$L(\alpha) = \prod_{i=1}^{n} f(X_i, \alpha) \tag{3}$$

In case above, market share w_i is assigned to data point X_i as a probability. Then the likelihood function can be given by,

$$L(\alpha) = \prod_{i=1}^{n} \left(f(X_i, \alpha)\right)^{Nw_i} \tag{4}$$

where N is arbitrary number such as 1000 which is large enough to make Nw_i an integer. The maximum likelihood estimator is then that value of α that maximizes *L(α)*. It is determined by taking the partial differential of *L(α)* with respect to *α* and setting it to zero.

$$\frac{\delta L(\alpha)}{\delta \alpha} = 0 \tag{5}$$

In case of normal or lognormal distribution, both mean and standard deviation determine the property of the distribution and become maximum likelihood estimators. The Mean and standard deviation of fitted normal distributions are thus equivalent to those of data before fitting.

2.4 Rank Order Correlation Coefficient

Correlations between input/output are preserved as correlation coefficients. Spearman's rank order correlation coefficient is used, which is defined by

$$r_{X-Y} = \frac{\sum_{i=1}^{n}\left(rank(X_i) - \frac{n+1}{2}\right)\left(rank(Y_i) - \frac{n+1}{2}\right)}{\frac{n(n+1)(n-1)}{2}} \tag{6}$$

Using rank order correlation coefficient makes it possible to generate correlated variables from two probability distributions in the Monte Carlo simulation; numbers which were once generated independently are transformed to desired distributions preserving rank order correlation coefficient [5].

2.5 Inventory analysis method by stochastic modeling

In Figure 4, the connection of two processes whose input/output parameters have probability distributions are shown. The system of product life cycle can be modeled by connecting relevant activities, and parameters for life cycle inventory are thus yielded as probability distributions. With this stochastic model, cumulative LCA result can be calculated using Monte Carlo simulation.

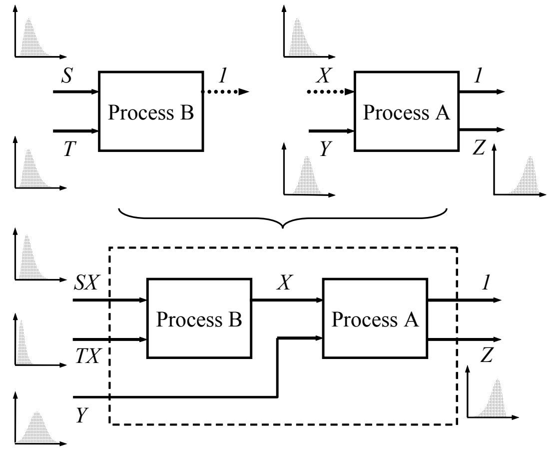

Figure 4.Creation of stochastic model for inventory analysis

3 CASE STUDY

The actual monitoring of resource usage and emissions is not a common industry practice; many producers do not provide the data necessary for useful LCAs [6]. Toward the future development of general LCA database, it is preferable to show the merits to deal with uncertainty during the data development phase.

For this purpose, case study has been performed with assumption that data have been developed according to the proposed method; we assumed probability distributions for the absolute values which have been already available in LCA databases [7], [8].

3.1 Chemical recycling system of used PET bottles

A case study has been performed on the design of chemical recycling system for used PET bottles, which depolymerize PET to monomers such as ethylene glycol (EG), terephthalic acid (TA) and its derivatives shown in Figure 6. The monomer materials have the same quality as virgin materials and can be used to reproduce PET resin. In this depolymerization system, neither the stain nor the color of the bottles have any influences on reaction and purification processes in contrast to the conventional recycling system in which fibers are reproduced by mechanically flaking and washing of used bottles [9], [10].

There exist several options to recover monomers, mainly depending on the reaction. In this work, three options are designed on the chemical process simulator, and evaluated to find out the promising option which can reduce CO_2 emission in the life cycle most.

- *Option 1* PET → PTA → New bottle

Flaked PET bottles are decomposed to purified TA (PTA) and EG by hydrolysis in the super critical water [11]. Yielded monomers are purified are used to produce new beverage bottles.

- *Option 2* PET → DMT → PTA → New bottle

PET flakes are decomposed by glycolysis reaction to obtain bis(hydroxyethyl) terephthalate (BHET) . Succeeding methanolysis and hydrolysis reaction produces PTA and EG that are used to produce new bottles.

- *Option 3* PET → DMT → New fiber

Dimethyl Terephthalate (DMT) and EG are obtained from glycolysis and hydrolysis reaction. Polymeriyation of these monomers produces new polyester fibers instead of bottles which cannot be produced by the resin from DMT.

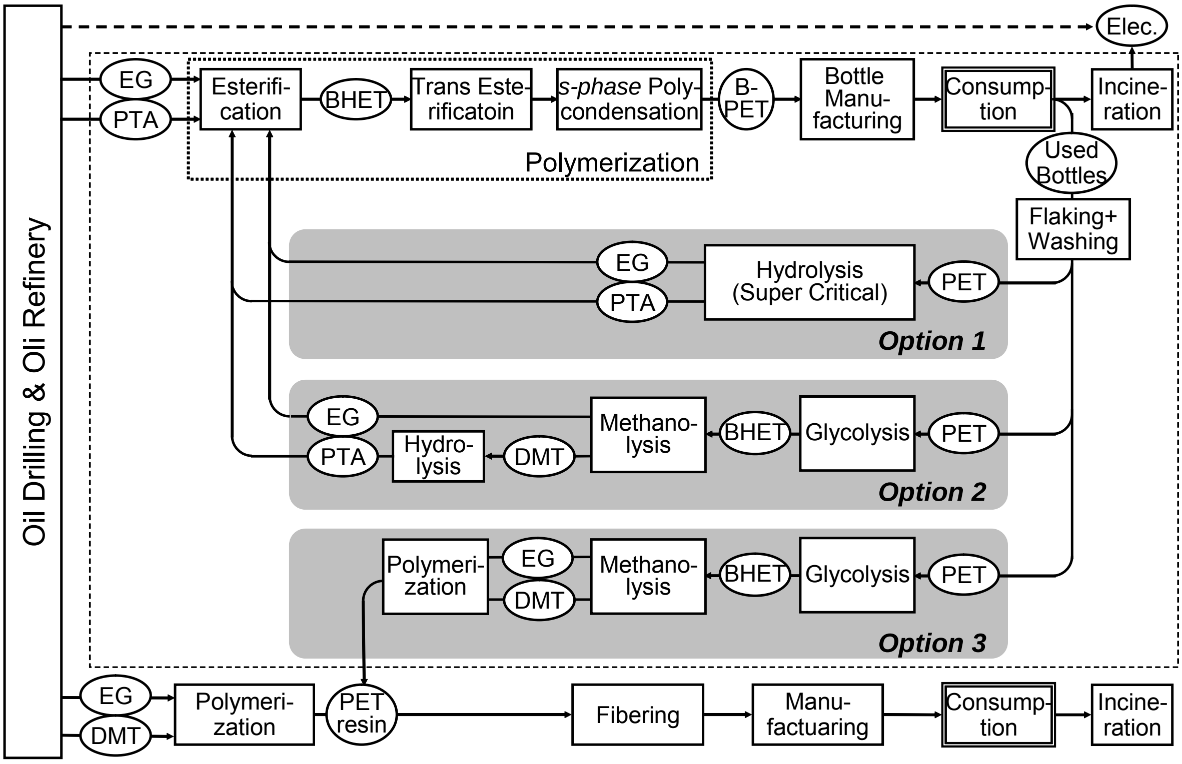

Figure 5. Life cycle of PET products considering different options for chemical recycling processes. Light grey boxes indicate recycling processes.

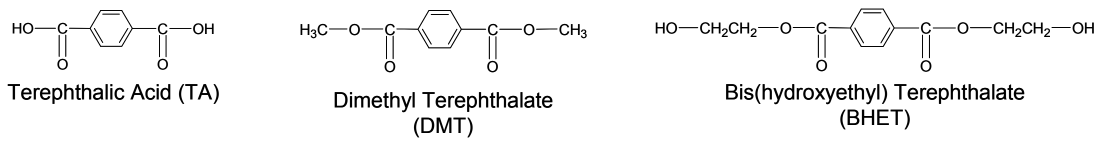

Figure 6. Terephthalic acid and its derivatives obtained from chemical recycling processes.

3.2 Model and data to perform LCA calculation

A system shown in Figure 6 includes the life cycle of PET bottles, PET fibers, and chemical recycle process. In each option, used bottles are supplied to recycling processes at 1000 t/yr. Base case is set as a life cycle system without recycling process: used PET is incinerated at 1000 t/yr with generation of electricity.

For the inventory analysis, each existing unit process (shown as a box in Figure 6) is modeled using public database for PET products [7] while recycling processes are modeled using chemical process simulator. CO_2 emission in the base case and option *i* (*i*=1~3) are calculated using Eq. (7), and Changes of CO_2 emission from base case are calculated by Eq. (8),

$$\Omega_i(CO_2,\boldsymbol{p}_i) = Out(CO_2,\boldsymbol{p}_i) + \sum_s In(s,\boldsymbol{p}_i)\cdot\varphi(CO_2,s) - \sum_s Out(s,\boldsymbol{p}_i)\cdot\varphi(CO_2,s) \quad (7)$$

$$\Delta\Omega_{i,BaseCase}(CO_2) = \Omega_i(CO_2,\boldsymbol{p}_i) - \Omega_{BaseCase}(CO_2,\boldsymbol{p}_{BaseCase}) \quad (8)$$

where *Ω(CO₂)* is CO_2 emission from life cycle, ***p*** is set of probabilistic parameters for input/output of each unit, *Out(CO₂)* is CO_2 emission occurring directory from the boundary, *In(s)* and *Out(s)* is input/output of substance *s* to/from the boundary, and *φ(CO₂, s)* is the CO_2 emission factor for material *s* which is cumulative CO_2 emission of the needed material (i.e. kg CO_2 per unit amount of material).

Proposed data model is applied in the inventory of existing processes existing unit processes. However, almost no information on the variance in inventory of existing processes is available up to date. Therefore, assumption is made that the inventory data has been created by following the proposed data model. Under this assumption, parameters related to utilities such as electricity, steam, and gas emission are set as log normal distributions, with setting the available value [7] as mean, and coefficient of variance as 0.1~0.5. Coefficient of variance represents the ratio of standard deviation to mean. Parameters in each unit process are assumed to be positively correlated; 0.8 as a coefficient.

Besides, transportation distances between activities in life cycle are also different. They are assumed to be triangle distributions, ranging ±50% around the mean value [7]. CO_2 emission factor for electricity is also different depending on the energy source [8]. Discrete distribution is created based on the share of energy recourse. No probability distribution is assumed on other CO_2 emission factors.

3.3 LCA result

Figure 7 shows the evaluation of $\Delta\Omega_{i,BaseCase}(CO_2)$ by mean value. While the CO_2 emission increases within the recycling processes, it decreases in the production processes making virgin materials for bottles and fibers due to the substitution by reproduced products. It also decreases in the incineration process of PET bottles which has electricity generator, because of the law heat of combustion of PET. The summation indicates that all three recycling options reduce CO_2 emissions within life cycle, and Option 1 is the most promising design.

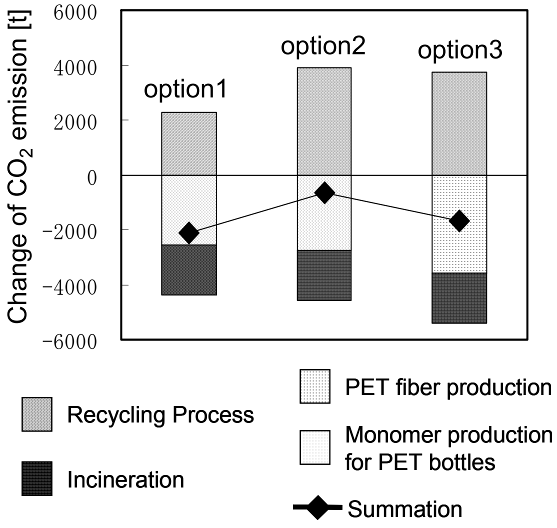

Figure 7.Changes of CO_2 emission after installing process plants at 10 kt/yr with mean value.

3.4 LCA result with uncertainty evaluation

Figure 9 shows $\Delta\Omega_{i,BaseCase}(CO_2)$ with a 99%, 95% interval and mean value. Distributions for Option 1 and 3 are below the CO_2 emission within base case (99% C.I.), while the upper tail for option 2 exceeds the level of base case. This means that Option 2 does not necessarily lead to an overall reduction in CO_2.

In order to compare the options which overlap, relative measurements help us judge the significance of such difference [13]. This can be calculated as follows;

$$\Delta\Omega_{i,j}(CO_2) = \Omega_i(CO_2,\boldsymbol{p}_i) - \Omega_j(CO_2,\boldsymbol{p}_j) \quad (9)$$

This is equivalent to taking option j as the base case. In Figure 10, the result of $\Delta\Omega_{i,1}(CO_2)$ (*i*=2,3) is graphically shown. The probability that option 1 becomes superior to option 3 can be determined by integrating the distribution of $\Delta\Omega_{3,1}(CO_2)$ over 0; 62%. Option 2 can be regarded as inferior to Option 1 by 99%. If the process designer sets the significance level as 90%, Option 2 can be rejected as a promising design to implement. Option 3 may remain in the scope of comparison to be analyzed more.

3.5 Sensitivity analysis

Parameters which cause the largest spread in the model outcome should be given priority to be corrected. The contribution of the parameters to the total uncertainty may be estimated using multiple regression method [2], [6]. Figure 11 shows the top 5 of standardized partial regression coefficients of the parameters for $\Delta\Omega_{3,1}(CO_2)$, which ranges –1 to 1. The result shows that discrete distribution of CO_2 emission factor contributes most to $\Delta\Omega_{3,1}(CO_2)$ and this distribution should be given priority toward further analysis.

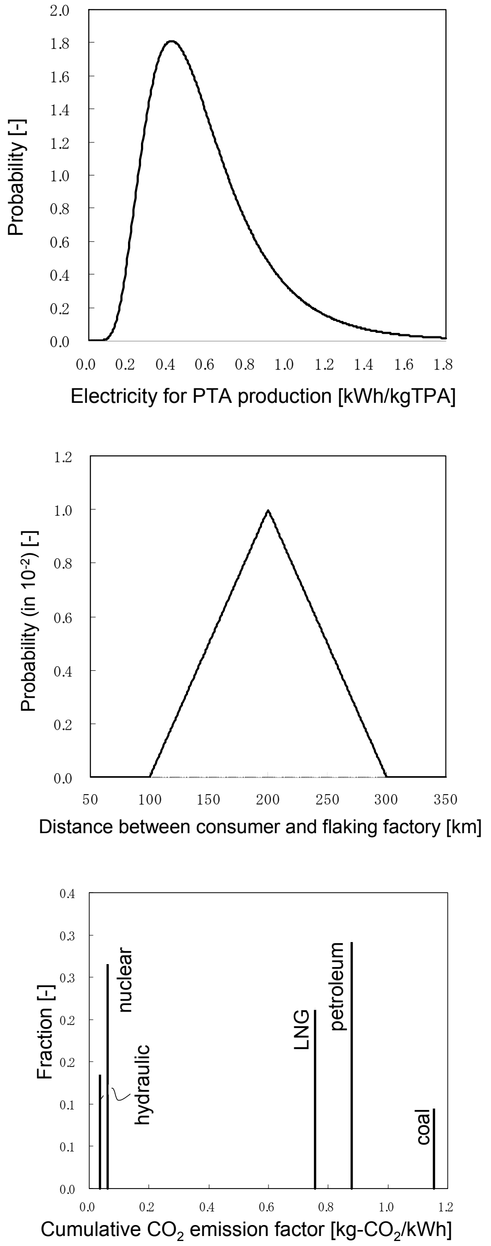

Figure 8.Different types of probability distributions for Monte Carlo simulation.

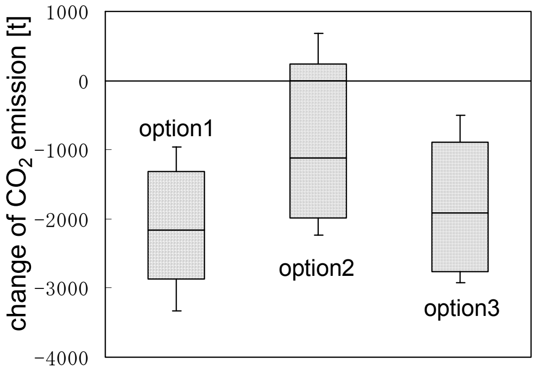

Figure 9.Changes of CO_2 emission with uncertainty evaluation at 1%, 5%, mean, 95% and 99%. The mean value is the same as the summation value in Figure 7.

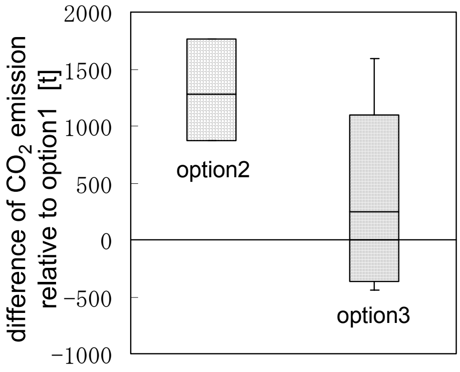

Figure 10.Relative measurement to Option 1. Option 1 can be regarded as superior to option 3 at 62% possibility.

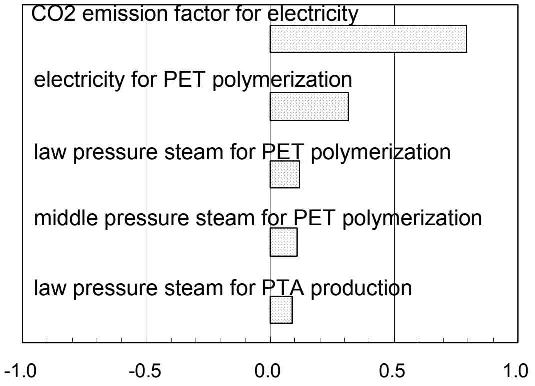

Figure 11.Sensitivity analysis for $\Delta\Omega_{3,1}(CO_2)$ Regression coefficients between input distribution of inventory data and output distribution of $\Delta\Omega_{3,1}(CO_2)$ is shown.

4 DISCUSSION

Current inventory databases are paying most of the efforts to collect mean or representative value of each industrial sector consisting of several companies, and little information on their scattering is available. For this reason, the demonstration of the proposed data model using actual industrial data is difficult, and the assumption can not be avoided in the case study. However, the data development process or data model for uncertainty analysis should be prepared for the future publication of inventory data from each industrial. Therefore, case studies should be performed to demonstrate the effectiveness of uncertainty evaluation in the decision-makings even if they are based on assumptions.

5 CONCLUSION

A new inventory data model and method of inventory analysis have been developed. Proposed model incorporates the differences of input/output between comparable factories into LCA data as probability distributions and correlation coefficients. With this stochastic model, cumulative LCA result can be calculated using Monte Carlo simulation. The case study has shown how the model enables decision makers to consider the alternatives with uncertainty. This new approach hopes to better empower decision makers within the industry throughout product/process design toward making more informed, and environmentally conscious decisions.

6 ACKNOWLEGDEMENTS

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ENVIRONMENTAL INFORMATION MANAGEMENT IN PRACTICE, USING PRINCIPLES OF TOTAL QUALITY MANAGEMENT

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ABSTRACT: It has been found to be a fruitful apply the concept of industrial total quality management (TQM) systems for environmental information quality management. Important aspects of TQM systems are focus on end user needs and requirements, understanding and commitment from people involved in production, integration of quality assurance in business processes, and continuous improvement. Experience from industrial application show the success of defining LCI data sets as well defined items, as natural and intuitive as a physical product. PHASETS (PHASEs in the design of a model of a Technical System) is a model that describes the separate and consecutive tasks needed to produce an LCI data set with ideal precision and transparency. PHASETS has been successfully used as template for design, test and implementation of quality assured environmental information management systems in industry, and has also proved valuable due to ease of assimilation and use. In this paper we will describe how TQM, PHASETS and ISO/TS 14048 are used to form an environmental information quality management system, and how they have been tested and received in industry.

Keywords: TQM, total quality management, PHASETS, phases in the design of a model of a technical system, ISO/TS 14048, LCA, data documentation format

1 INTRODUCTION

One of the major obstacles that disqualify LCA as a strategic and operative decision-making tool is a justified lack of faith in the information quality of LCA studies. System level quality approaches has failed to persuade decision-makers and the public. This paper address LCI data quality from the perspective of its origin, i.e. the management of the tasks and procedures that are needed to generate an LCI data set.

There are problematic and important issues of information quality related to industrial environmental information management, such as credibility, consistency, transparency and independence from individual bias.

Lack of credibility for environmental information may lead to that companies lose ethical credibility, that improvement decisions are avoided due to lack of faith in data, or that clear environmental policies cannot be formulated. Lack of consistency may lead to incompatibility and incomparability between different facts concerning e.g. the same product or production plant. Lack of transparency may lead to low credibility due to difficulties to verify that e.g. an information system consistently generates facts with a high precision. Information systems that are sensitive to individual bias are not credibly verifiable.

Due to the lack of feedback concerning impact from errors in environmental information, the environmental information quality management within companies has evolved quite slowly. There has been no cost associated with errors. However, due to that some environmental mistakes has attracted the attention of NGOs, media and the public, with consequently negative publicity, the interest for environmental information quality management has increased.

Many approaches to improving quality have been attempted. For singular measurements the problem is strictly scientific, i.e. the measured entity must be properly measured and reported. For sets of information describing e.g. production plants and processes, the problems are related mainly to normalization to common parameters, such as time, production capacity or energy consumption. This area is addressed on the issue of corporate and governmental environmental reporting. Regarding data for life cycle assessment (LCA) many system level approaches has been made, with attempts to estimate information quality statements without necessarily being forced to trace all aggregated data back to its origin, i.e. the solutions has been attempted at the system level. But due to an almost complete lack of verifiable reference data at system level, all these attempts have failed to establish faith in LCA results.

This paper describes an approach for environmental information quality management that is based on the same scientific principles as individual measurements, and that is applicable for industrial organizations, and which will provide quality assurance to LCA:s, if applied in full.

In order to establish such environmental information quality management system within an industrial organization, a policy decision is required. The environmental information management purpose needs to be taken seriously, and organizational resources needs to be allocated accordingly. This decisiveness will require strongly persuasive approaches to information quality management, such as strong integration into business organization and successful industrial tests.

From the perspective of an environmental information system, environmental reporting are the products. The quality of these products is defined in terms of data formats, report designs, and minimum statistical uncertainty. In this paper we focus on management of statistical uncertainty and data format requirements in terms of ISO/TS 14048.

2 FRAMEWORK AND PURPOSE

The approach described in this paper is developed for, and tested in industry. It takes into regard the practical requirements from organizational routine, limited time for decision-making, and realistic economical limitations. It has also been tested with regard to its compatibility with the standards in the ISO 14000 series, and especially ISO 14001 [1] and ISO 14041 [2].

3 PRINCIPLE AND COMPONENTS

The fundamental principle of the approach described, is that it proposes a solution to complex problems within the area of environmental management by introducing simple concepts that are relatively easy to understand, intuitive to apply, and that are similar to concepts applied in other areas.

The approach for environmental information quality management described in this paper is based on three components; total quality management (TQM), a procedural approach for the design of a model of a technical system (PHASETS), and a data documentation format for documentation of the environmental performance of a technical system (ISO/TS 14048 [3]).

3.1 Total quality management (TQM),

The methodological framework of total quality management (TQM) is that the product should be well-defined, that the limitations of the design and the production should be well understood and dealt with, and that the product quality should be expressed in terms of customer satisfaction (accepted quality). TQM was developed and implemented in industry because the concept of statistical product quality no longer satisfied the market requirements. Industries faced a frustrating situation when quality deficiencies were revealed when the product was already delivered to the customers, and were there producing uncontrollably bad image, bad public relations, bad publicity and decreased market competitiveness.

Since environmental behavior and ethics is expected from all commercial actors, environmental deficiencies are not accepted by the general public, and violation may lead to uncontrollably bad image, bad public relations, bad publicity and decreased market competitiveness. Examples of such environmental deficiencies are impact on human health, irresponsible contribution to global warming, unnecessary contribution to waste generation, etc.

Our approach to apply TQM for environmental information quality management is based on the analogy between commercial risks and management to reduce product quality deficiencies, with commercial risks and management to reduce environmental deficiencies.

3.2 A procedural approach for the design of a model of a technical system (PHASETS)

The PHASETS model identifies the following general procedures needed to compile a transparent and reviewable report, that describes a model of a technical system, based on scientifically acquired measurement data [4]:

0. *Defining an entity for a selected parameter;* The choice of entity to measure and the setting up of the measurement system defines the simplest concept; i.e. the meaning of a measured value.
1. *Sampling an individual value;* The sampling results in a value for the simplest concept, i.e. a measured value
2. *Forming a frequency function from a set of sample values;* The frequency function aggregates sets of measured values into statistically expressed concepts.
3. *Synthesizing a model of a technical system;* The systems synthesis further aggregates the frequency functions from phase 2 into structured models of technical systems.
4. *Aggregating models of technical systems;* The models of technical systems synthesised in phase 3 may be aggregated into complex concepts describing e.g. averages or cradle to gate systems
5. *Communicating information between different contexts;* between any two phases 0-4 the resulting data and information, is communicated from the generator to the consecutive phase.

3.3 Data documentation format for documentation of the environmental performance of a technical system (ISO/TS 14048)

The data documentation format for documentation of the environmental performance of a technical system ISO/TS 14048 provides a framework and requirements for the unambiguous documentation of Life Cycle Inventory analysis (LCI) data. It follows the general framework for LCA and is intended to support transparent reporting, interpretation and review of data collection, data calculation, data quality and data reporting [3].

Although ISO/TS 14048 is primarily intended for documentation of life cycle data, the data documentation format is also applicable for the management of environmental data, e.g. for reporting, performance assessment and benchmarking.

In the context of this paper it is important to stress that ISO/TS 14048 contains a list of requirements for the documentation, but does not include a procedural specification. Due to the lack of such a procedural specification, there is a need for the PHASETS model.

4 TOTAL QUALITY MANAGEMENT FOR ENVIRONMENTAL INFORMATION

4.1 TQM, PHASETS, and ISO/TS 14048 in system

By following the methodology framework of TQM [5] one must start with a clear customer focus. The product must be identified and defined in terms of the requirements of the customer. By applying ISO/TS 14048 as data format for reports, the information-product can be well identified and defined for both the ‘customers’ and ‘producers’ of the environmental information. But the data format in itself is not enough, since the format is flexible to allow a wide range of specifications, both with regards to the technical systems described and with regards to the quality of the description. To ensure quality according to TQM the customer requirements needs to be understood in any given situation, so that it is understood whether e.g. the customer requires data about a given production plant, and that the expected precision of any quantitative data is within the range of 10%. With ISO/TS 14048 a general product specification, the quality requirements can be expressed in at least as many dimensions as there are fields in the format.

TQM stresses the need for management support, and experience shows that this is equally important when introducing an environmental information quality management system. It will affect many people within the organization, from the users of information to the technical staff responsible for monitoring different performance facts about the business. TQM also stresses the need to involve all these people.

TQM requires that an organizational sequence or routine should be structured into well-defined and identifiable processes that are organized into a system. PHASETS is a process approach to environmental information quality management. Each distinguishable and separate stage in the procedure of producing a model of a technical system is identified and defined. The product out from each stage, and the input required is also well defined, as well as the quality dimensions of the input and output.

TQM also stresses the need for continual improvement, and this is made possible only if the quality dimensions of the functions of the organization are well understood. Above we described that both the qualitative and quantitative quality dimensions of ISO/TS 14048 are well understood.

4.2 TQM, PHASETS, and ISO/TS 14048 in practice

In practical tests with PHASETS in industry the TQM organizational routine has been established in the following way:

- Starting with assessing the reporting needs (phase 5)
- Identifying the tools needed to generate the needed reporting (phase 4)
- Considering a model of a technical system i.e. the production plant (phase 3)
- Assessing the available measurement systems to ensure that the needed data can be acquired (phase 0)
- Acquire sample data from the measurement system (phase 1)
- Statistically treat sampled data (phase 2)
- Synthesise a model of the production plant, including statistical data from all relevant measured entities and indicators (phase 3)
- Perform necessary aggregation, e.g. yearly average (phase 4)
- Produce reporting in accordance with needs (phase 5)

5 EXPERIENCES FROM TESTS IN INDUSTRY AND ELSEWHERE

The approach described in this paper was initially developed and tested in industrial case-studies among CPM-companies in 1997, in an early attempt to acquire well-documented and reliable data for the Swedish LCA database SPINE@CPM [6]. The tests were considered so successful, that the Swedish pulp and paper industry decided to perform a large-scale implementation of the methodology into many production-plants in parallel between 1999 and 2001 [7]. The results from this implementation are encouraging but are not public.

In addition to the early industrial tests, the PHASETS model and suggestions to its implications was also presented to the international CODATA Working Group on Environmental Life Cycle Inventories, who adopted the methodology with great interest [8].

PHASETS has been successfully used for educational purposes within the framework of CPM to aid people in industry to practically apply ISO/TS 14048 and its forerunners. Due to this, it was also introduced into the work in the European project CASCADE as layout for a cooperatively written procedural guideline for collection, treatment and quality documentation of LCA data [9].

6 CONCLUSIONS

The approach for environmental information quality management described in this paper does not quickly solve problems for screening LCAs and does not improve data quality in existing databases or software. This approach is strategic and optimistic into the future. It relies on a faith for LCA as a tool for sustainable development, and is based on the certainty that the industrial society will transform into the organizational forms are needed for sustainability. TQM for environmental information is one dimension of that organizational form.

The simplicity of this approach, gives that it is easy to integrate with real organizations. A TQM for environmental information can be introduced in any organization with arbitrary environmental information quality, and with arbitrary quality ambitions. By having established the structure and identified the routines and responsibilities, it is without effort to introduce the concept of continual improvement for the different stages of the PHASETS model, and for the different report generated. The continual improvement is facilitated by a data format that allows for sufficient flexibility, such as ISO/TS 14048.

The approach described in this paper has proved successful in tests. Corporate environmental reporting can immediately make use of the approach to reduce costs and improve information quality. With regard to LCA, as a tool and as a scientific area, the approach is especially valuable in the long run, since it indicates a future when quality assured data may be acquired from full product life cycles.

There is a need for further case-studies within different industrial sectors to fully understand the scientific, technical and economical consequences from applying TQM on environmental information management. For example, we are still not in the position of forecasting how much more weight environmental information will get in real life decisions if the information is actually reliable, i.e. if the environmental information is actually of substantial value to the decision-maker. The authors assume that decision-makers will put much more emphasis on environmental aspects if the information is reliable.

There is of course much testing and development still needed before the real role and position of TQM for environmental information is fully understood and correctly merged into the ordinary business environment, but the successful results achieved by the authors and the positive responses from industry carries a promise that this practical approach for fact-based environmental management are here to stay.

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USE OF LCI DATA IN THE CONSTRUCTION OF ECOLOGICAL INDICATORS FOR REGIONS

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ABSTRACT: This Life-Environment project, called ECOREG, aims to produce indicators for monitoring changes in the eco-efficiency of a region. The ecological indicators of the project will be based on an environmental analysis of the major economic sectors. The basic techniques in the inventory phase correspond to the techniques used in LCI, although in our work we do not use product-specific functional units. The interventions of each sector are calculated per the total annual production volume of the sector. The basic regional data are mainly collected and processed from public statistics and databases maintained by environmental authorities. The data pertaining to upstream processes outside the region are acquired from diverse available LCI databases. The aim is that the LCI data related to the material and energy flows of the sectors should be product chain -specific to the extent possible. In the approach described, the data quality of the conventional emissions from point sources is good. On the other hand, the estimation of the emissions from diffuse sources, toxic pollutants and land use interventions includes large uncertainties.

Keywords: Quantitative vs. qualitative measures, interaction of LCI and LCIA uncertainty, application fields and data appropriateness.

1 INTRODUCTION

Recently, a growing interest has focused on regional eco-efficiency, which is based on improving the eco-efficiency potential of individual regions. In Finland, an ongoing (2002–2004) Life-Environment project "The eco-efficiency of regions – case Kymenlaakso (ECOREG)" [1] aims to demonstrate the concept and practical implementation of eco-efficiency at the regional level using the Finnish province Kymenlaakso as a case study. The aim of the ECOREG project is to produce indicators for monitoring the changes in the eco-efficiency of the Kymenlaakso region.

In a broad sense, eco-efficiency is considered to encompass all the three dimensions (ecological, economic, social and cultural) of sustainable development. The aim of the ECOREG project is to produce indicators for each dimension and use them for monitoring eco-efficiency. For this reason, seven interrelated work packages will be carried out in the ECOREG project (Figure 1).

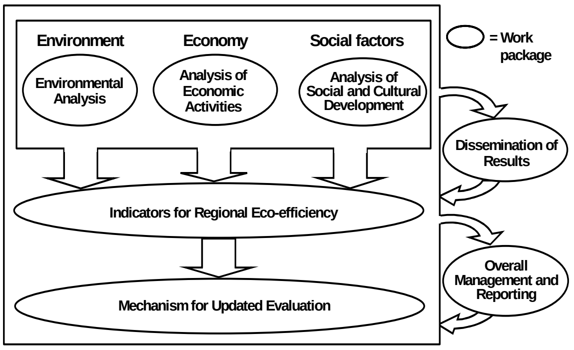

Figure 1. The work packages of the ECOREG project.

In the first three packages, ecological, economic and social and cultural indicators for regional development will be designed. Here, the term indicator means the factors that measure directly or indirectly the degree to which each of the dimensions of eco-efficiency is met. Indicators can be aggregated (e.g., the Gross Domestic Product) or non-aggregated (e.g., CO_2 emission) variables pertaining to ecological, economic and social and cultural themes.

In the context of the ecological theme, there are two types of indicators: interventions (emissions, resource extractions and land use) and impact category indicators (e.g., CO_2 equivalents) calculated using the life cycle impact assessment (LCIA) methodology. In the environmental analysis, interventions caused by human activities in the Kymenlaakso region are assessed and impact category indicator results are calculated on the basis of inventory data taking into account the life cycle perspective.

After the environmental, economic and socio-cultural analyses, there will be a bulk of indicators within each theme. For decision makers, their number may easily be too large. In order to obtain a focused view of the changes of eco-efficiency of the Kymenlaakso region, there is a need to identify the most important indicators in each theme. The aim is to monitor these key indicators annually for obtaining a rough view of the progress made in eco-efficiency.

This paper addresses the use of LCI data from the perspective of regional environmental analysis. In our presentation, we discuss the role and use of site-specific and generic LCI data in the construction of ecological indicators for regional eco-efficiency. Particularly, we deal with the specific points and problems encountered when integrating datasets of different origin. In addition, we discuss the data quality in the regional assessment.

2 THE ROLE OF LCI DATA IN REGIONAL ENVIRONMENTAL ANALYSIS

The regional environmental analysis consists of the inventory and impact assessment phases. The inventory is conducted in two stages. First, interventions that occurred in the Kymenlaakso region in 2000 are assessed in the regional inventory (RI). The data cover the interventions caused by both point and diffuse load sources. The objective of the RI is to produce a site-specific view of the interventions in the Kymenlaakso area. In order to aid the assessment work, the data are arranged according to economic sectors, such as agriculture, forestry, fishery, peat production, extraction of soil resources, industry, communities and transportation. The interventions of each sector are gathered per the total annual production volume of the sector.

Secondly, interventions occurring outside the region, related to the various sectors, are assessed in the so-called upstream inventory (UI). Data on the use of raw materials and energy for each sector are gathered. In the UI, the interventions are assessed on the basis of these flow data. In practice, the assessment is carried out by connecting data acquired from LCI databases and other sources to the corresponding material and energy flows. Thus, import – described here as upstream processes – and its environmental interventions are taken into account as extensively as possible (Figure 2). It would be very difficult or at least time-consuming to define the interventions of export (downstream processes), which are spread worldwide, so the downstream processes are excluded from the environmental analysis.

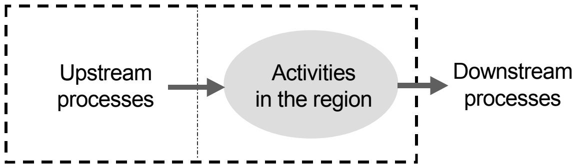

Figure 2. The boundaries of the environmental analysis.

In order to identify the most harmful interventions causing impacts on the environment, an impact assessment is carried out. The method used [2] covers all phases of life cycle impact assessment (LCIA): selection of impact categories, classification, characterisation, normalisation, and weighting. However, the objective of the assessment is that the results can aid in prioritisation, taking into account the actual impacts as far as possible.

The impact assessment includes site-specific characterisation factors for regional and local impact categories (e.g., aquatic eutrophication, tropospheric ozone formation). In addition, another specific feature of the assessment model is that all important interventions are taken into account within the relevant impact categories – despite the fact that they may not have scientifically-based characterisation factors, or that there may be no measured data for them. This means that the quantitative inventory data will be supplemented by information on non-measurable or qualitative interventions, which are considered significant especially in the Kymenlaakso region or in the material flows used by the sectors.

3 REGIONAL INVENTORY (RI)

In practice, the RI of the environmental analysis for the Kymenlaakso region is carried out by collecting all intervention data from the economic sectors and processing them further. Hence, the data are based on measurements, calculations and expert judgments. The inventory of the emissions has been concluded in spring 2003 [1].

Earlier LCIAs have revealed that site-specific interventions related to resource extractions and land use are important from the point of view of ecological effects. For example, the major factor reducing biodiversity in Finland consists of the forestry practices (harvesting, draining etc.) [3]. The inventory will thus include data about activities that indirectly or directly describe the environmental effects of unconventional impact categories, such as smell, noise, and impacts on biodiversity (caused by land use). The collection of these data will be conducted during the autumn 2003.

The time-related coverage of the RI in our study is the year 2000. A year is an appropriate period for this kind of regional review, because in the Finnish northern conditions the seasonal variations may greatly influence the LCI results.

The geographical area in our RI is a province (less than 2% of the total area of Finland), and the site-specific data cover all regional activities. We need not consider the technical coverage in the RI, because the emissions are connected to the annual production of the defined year.

In the regional approach, as usually in LCAs, the collection and processing of the primary data are the most time-consuming steps. The local activities have their own characteristics and therefore different procedures must be used for assessing their emissions to the environment. In the RI, the human activities were divided into seven economic sectors. The collection of data for the most relevant sectors is discussed here.

a) Agriculture and forestry. Nutrient loading to watercourses from agriculture (including field cultivation, domestic animal production, milk- and greenhouses) were mainly assessed with the help of Finnish experts and their models.

The atmospheric greenhouse gas emissions from agriculture were assessed by applying the results of the national greenhouse gas emission inventory, related to the UN Framework Convention on Climate Change [4].

The area-based leaching coefficients for nutrients from forestry were based on Finnish national studies. In the context of forestry, future scenarios and knowledge about the contributions of the various forestry practices to leaching were also utilized [5].

Actual regional statistical data (e.g., arable land, production volumes, the amount of timber felling) were received either from Statistics Finland [6], the Information Centre of the Ministry of Agriculture and Forestry [7] or the Finnish Forest Research Institute [8]. A problem with these data was that all the necessary figures did not pertain precisely to the Kymenlaakso region but to a larger area, South-East Finland, which consists of two provinces, Kymenlaakso itself and South Karelia – these provinces together compose an administrative unit in the Finnish environmental administration. In these cases we had to divide the data between the two provinces using different allocation principles. Similar difficulties were encountered while using the model developed for the national reporting of the greenhouse gas emissions caused by agriculture. The emissions of the working machines used in agriculture and forestry for the whole Finland are reported in a calculation system of working machine emissions [9]. We allocated the total emissions to the regional forestry sector in ratio to felling amounts, and to the agriculture sector in ratio to working machines.

b) Industry. The large-scale industry and part of the medium-sized industry are obliged to report their emissions to environmental authorities. These data are easily available from the Finnish environmental data system VAHTI [10]. Thus, the challenge was how to assess the emissions caused by small-scale industry. Our solution was to calculate the emissions using fuel consumption data for the regional industry and theoretical emission coefficients for the fuels.

The industrial landfills, with their water emissions through leaching, are well documented in the VAHTI database, and the methane emissions can be assessed by using the calculation methods of the IPCC [4].

c) Communities. This sector consists of energy supply for buildings, municipal wastes and municipal waste waters. The local energy production data were collected from the VAHTI database. The amounts of wastes disposed of to landfills are recorded in the same database. The methane emissions from landfills were assessed as in the industry sector.

In the inventory, data on leaching from municipal landfills to watercourses were lacking. Although the measurement results are available from all landfills, they are not yet in a useable form. The old landfills have no collection systems for leaching water. For this reason, it is quite impossible to estimate the effect of municipal waste on water emissions.

d) Transportation. In Kymenlaakso, the role of transportation is significant. There are two important seaports in the region, and a large part of the trade traffic between Russia and Finland – including "transito", the freight traffic that passes from one country to another through a third country – passes through Kymenlaakso.

It was natural to divide the transportation sector firstly into road, rail and sea traffic. The assessment of the emissions of local road traffic caused us more work than the other traffic modes due to the need to allocate the entire traffic also to local, trans-regional and "transito" traffic. The purpose was to calculate those emissions which are really caused by the local activities. The problem was not the emissions but the mileages. All unit emissions for traffic were taken from the calculation system of exhaust emissions and energy consumption of the various traffic modes in Finland, LIPASTO [11].

We received all the mileages from the Finnish Road Administration [12]. The allocation of the mileages between passenger and freight traffic caused us some difficulties, because the documentation was different in the various statistics. For instance, in one set of statistics the mileages were divided into heavy and light traffic so that heavy traffic included both trucks and busses (which belong to passenger traffic) and light traffic passenger cars and vans (which belong to freight traffic). We had to separate the bus traffic and van traffic from the data with the help of other statistics and our own calculations.

The mileages of trans-regional road traffic were estimated at our request by experts at the Finnish Road Administration.

In the traffic sector, we also considered the purpose of travels in the passenger traffic using the national averages.

e) Energy. The activities of Kymenlaakso consume more energy than is generated in the region itself. The emissions and wastes of the energy power plants of the Kymenlaakso region were directly obtained from the VAHTI database. Purchased energy will be handled in the upstream inventory.

Considering the RI as a whole, the accuracy and reliability of the regional conventional emission data are good. We had an opportunity to use the best available Finnish data from the Finnish studies, models and expert judgments. Some estimations, however, had to be made by ourselves. The conventional emissions lacking in the RI, such as the atmospheric emissions from air traffic, peat production and inland water transportation, have a minor relevance in the region.

The estimation of the emissions from diffuse sources, toxic pollutants and land use interventions includes large uncertainties. In particular, there is a need to improve the monitoring of land use interventions. Furthermore, the emissions caused by the pesticides of agriculture and the toxic pollutants of contaminated soils are not well known.

All our regional LCI results, to be published in the end of the ECOREG project (late 2004), will be verifiable and reproducible. In the documentation, the rules and practices recommended in LCI guides will be used. The documentation will be transparent, so that updating the RI will be possible. Methods or indicators for assessing data quality will also be considered.

4 UPSTREAM INVENTORY (UI)

In the autumn 2003, we will deal with the upstream processes. The first task is to define the major material and energy flows of each sector and to assess which part of these flows occur inside and outside the region. The use of public databases, official statistics and – possibly – questionnaires to companies are ways to gather the energy and material data. In the VAHTI database, only the use of energy and raw materials of the largest companies is included. In addition, some inputs are lacking because of data confidentiality requirements.

A critical point in the UI is the availability and collection of product chain -based data. In order to monitor the changes of eco-efficiency in the Kymenlaakso region, it would be preferable that the interventions assessed outside the region represent actual product chains. In this way, it would also be possible to take the real abatement measures of environmental protection, located outside the region, into account in the eco-efficiency assessment. However, this approach requires a huge amount of work and in practice, we will try to trace only the main energy and material flows regarding the real product chains. Thus, in the UI, the basic intervention data related to the flows will be acquired from LCI databases in which data do not precisely represent the product chains related to the sectors of Kymenlaakso.

To illustrate the use of LCI data in the UI, the pulp and paper industry and the electricity sector are presented here as examples.

The material and energy flows of the pulp and paper industry can be divided into three parts: upstream, regional and downstream processes (Figure 3). The upstream processes include activities outside the region, such as timber harvesting, manufacturing of chemicals, production of fuels and energy generation. In the region, the manufacture of end products (e.g., newsprint and magazine paper) represents site processes. In addition, part of the used raw materials and energy originate in the region.

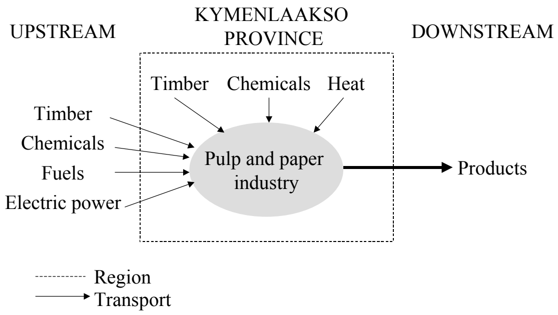

Figure 3. The flow chart of pulp and paper industry.

In the RI, site-specific emission data from the Finnish pulp and paper mills (seven of them situated in the Kymenlaakso region) are easily available due to the annual documentation in the public environmental database, VAHTI, maintained by the environmental authorities. VAHTI also offers data for raw materials and heat produced in the region.

A Finnish pulp and paper research company, KCL, has a KCL-EcoDatabase [13], especially developed for LCAs of pulp and paper products. LCI data for the raw wood and the most relevant chemicals (e.g., sodium hydroxide, sodium chlorate, sulfuric acid) are available in this database. There are also chemicals (e.g., kaolin, talc), for which LCI data have been collected directly by the producers in previous LCA studies and stored in our own database.

Thanks to the KCL database, the data collection of the raw materials for pulp and paper industry is relatively straightforward. The situation is different with the upstream processes of the other industrial branches.

The pulp and paper industry uses a large part of their wastes, such as black liquor, for producing energy for their own processes. In addition to these, the mills need other fuels, e.g., natural gas, coal and fuel oils. There are several international databases in which one can get information about fuel manufacturing. The pulp and paper mills also consume a lot of electricity. It is necessary to use the country-specific electricity production model in the regional part, and of course as much as possible in the raw material data, too.

Electricity. Approximately one half of the electric power consumed in Kymenlaakso in the year 2000 was generated outside the region. The Finnish average electricity production model was used to assess the emissions from energy production. The model is based on the Finnish electricity breakdown in 2000, and the emissions arising from electricity production in Finland and the production of imported energy from neighboring countries. The proportion of different energy sources used for grid electricity production, and their emissions, were obtained from an expert of a Finnish energy company. Using these data, we assessed the average specific emission coefficients for the electricity consumed in Finland.

At this stage of our project, we are not able to present any special requirements for the generic data. Certainly, the generic data for the upstream processes are going to be less representative, and generalizations must be made because of the abundance of processes.

5 CONCLUDING REMARKS

Regional environmental analysis can be carried out according to similar principles as product-specific LCA. However, there are also differences. Instead of product-specific functional units, interventions are assessed per the annual production volumes of the economic sectors (agriculture, forestry, etc.) of the region. Basic regional data are mainly collected and processed from public statistics and databases maintained by authorities. In general, the data quality of the conventional emissions from point sources is good in the regional inventory. The estimation of the emissions from diffuse sources, toxic pollutants and land use interventions includes, however, large uncertainties.

The determination of the material and energy flows of the economic sectors offers a basis for the assessment of interventions occurring outside the region. In order to describe real changes in the eco-efficiency of the sectors in Kymenlaakso, it would be important that the interventions represent the actual product chains related to the sectors. Currently, however, product chain -specific data are not commonly available for the various sectors. Thus, in order to depict even a rough overview of the life cycle impacts, the only possibility is to use general LCI databases. To offer a more advanced approach, the LCI databases should in the future include data describing interventions of different life cycle stages, and the sources of the data should be documented clearly.

6 ACKNOWLEDGEMENTS

The support given by the LIFE financial instrument of the European Community and the Finnish Ministry of the Environment for the ECOREG project is gratefully acknowledged.

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ON THE CHARACTERIZATION OF DATA QUALITY IN THE 1ST BRAZILIAN GHG INVENTORY

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ABSTRACT: There is a real lack of material available in Brazilian statistics about LCI, mainly based on the lack of awareness of Brazil's commitments under Life Cycle Thinking approach, on the lack of sufficient resources for wide-ranging studies and on the existence of deep-seated questions (conscious or subconscious) about the benefits accruing to institutions involved in this process. In this paper 1st Brazilian Inventory of Anthropogenic Greenhouse Gases is assessed taking into account three issues, data availability, results and data quality. Although it is a very valuable collection of information, acquired after a meaningful data gathering process, the reports of the 1st Brazilian Inventory of GHG accomplished requirements made by IPCC. In the context of LCA, IPCC's inventories are less detailed than LCI's. The reported work required the estimation of indicators and collection of data that were not available in the national scientific literature. The statistics available in the country do not always allow an adequate evaluation of emissions. In the absence of these data, this work relied on either the values recommended by the IPCC. Otherwise, it should be recognized that the development of a national life cycle inventory is a resource-intensive undertaking.

Keywords: Documentation and Communication of Quality Information; Developing Countries

1 INTRODUCTION

This paper assesses the 1st Brazilian Inventory of Anthropogenic Greenhouse Gases (GHG) [1], focusing in three specific aspects:

- Data availability within Brazilian data bases;
- Results presented, either by direct measurements and/or their mathematical treatments, or by customizing indirect measurements already obtained elsewhere; and
- Data quality, regarding their technological, temporal and geographical scales.

The information analysed in this study is compiled throughout 14 reports (the whole set consists of more than 2000 pages, and is available at http://www.mct.gov.br/clima/) prepared by Brazilian Minister of Science and Technology, under Brazilian commitment with the Intergovernmental Panel on Climate Change (IPCC). Namely, there were performed 13 studies on anthropogenic sources of GHG:

1. Carbon dioxide and methane emissions from brazilian hydroelectric reservoirs
2. Emissions and removals of carbon dioxide by soils from land use change and liming
3. Carbon dioxide emissions and removals from changes in the stocks of planted forests
4. Emissions of greenhouse gases from burning of agricultural residues
5. Methane emissions from livestock
6. Methane emissions from rice cultivation
7. Nitrous oxide (N2O) emissions from agricultural soils
8. Greenhouse gas emissions from fuel combustion: bottom-up approach
9. Carbon dioxide emissions from fuel burning: top-down approach
10. Fugitive emissions from coal mining and handling
11. Greenhouse gas emissions from movable sources in the energy sector
12. Greenhouse gas emissions from industrial processes and use of solvents
13. Methane emissions from waste treatment and disposal

Besides, due to Brazilian territorial characteristics, a fourteenth report on "Greenhouse gases emissions from biomass burning in the nonanthropogenic Cerrado using orbital data" was also performed.

All the reports used the methodology suggested by the IPCC, specifically applied to each one of the eight cases, using either direct or indirect data, Brazil-related or reported to characterize others countries.

Due to the high amount of information, the analysis accomplished in this work depicts very specific topics that can be used to demonstrate the three issues targeted by this work. These reports are based on a huge number of bibliographic references, which will not be listed hereinafter. I strongly suggest the reader to go through the original reports as they encompass the most up-to-date collection of information regarding GHG emissions within Brazilian scenarios.

2 BRAZILIAN REGIONAL CHARACTERISTICS

The Federal Republic of Brazil is the fifth largest country in the world, with an area of about 8,500,000 km2, composed of 26 states and one Federal District (Brasília, the capital). The country is divided into 5 geographical regions, with different characteristics:

- North: Amazonas, Pará, Acre, Rondônia, Amapá and Roraima - 7,350,000 inhabitants or 4.9%;
- Northeast: Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe and Bahia - 43,950,000 inhabitants or 29.3%;
- Center West: Goiás, Mato Grosso, Mato Grosso do Sul, Tocantins and Distrito Federal - 9,450,000 inhabitants or 6.3%;
- Southeast: Minas Gerais, Espírito Santo, Rio de Janeiro and São Paulo - 65,250,000 inhabitants or 43.5%; and
- South: Paraná, Santa Catarina and Rio Grande do Sul - 24,000,000 inhabitants or 16%.

Along with the existing regional diversities, the entire country is undergoing a large-scale urbanization process, which is increasing social, cultural and economic contrasts.

It is the eighth largest economy, very complex and dynamic, a large agricultural producer and one of the greatest producers in the world of several products, including pig iron and steel, cement, aluminum, chemical products, petrochemical feedstock and petroleum.

Weather also varies considerably from region to region:

- North: hot climate, with temperatures between 25 and 40ºC, and an humidity between 64 and 91%. The region is primarily forested and has about 20% of all fresh water on the planet.
- Northeast: semi-arid, temperature from 20 to 35ºC.
- Center West: tropical climate, hot and damp, characterized by heavy rain in summer and very dry climate in winter. Temperature from 15 to 35ºC.
- Southeast: the annual weather variation is bigger, with temperatures varying from 15 to 40ºC.
- South: average temperatures are lower, varying between 13 to 40ºC, and there is no drought.

2.1 The Brazilian Energy System

The Brazilian energy matrix is characterized by a significant share of renewable sources, including Firewood, Charcoal, Hydro Energy, Bagasse and Ethyl Alcohol from sugar cane.

Gross domestic supply of energy since the 1940s is presented in Figure 1.

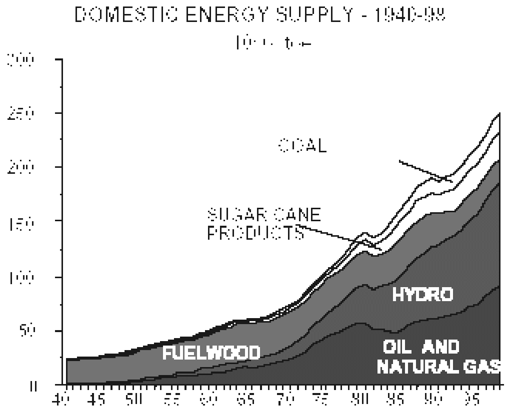

Figure 4 Domestic energy supply, 1940 to 1998

3 REPORTS ON BRAZILIAN ANTHROPOGENIC SOURCES OF GHG

In order to fulfill its commitments under the IPCC Convention, Brazilian Ministry of Science and Technology coordinated an institutional Program targeting the preparation of the sectorial reports. This was accomplished by independent specialists and institutions with recognized capacity in each specific area, involving around 100 institutions and 500 specialists from the energy, industrial, forestry, agriculture, and waste treatment sectors.

The methodology adopted under the Convention was developed by the Intergovernmental Panel on Climate Change - IPCC together with the Organization for Economic Cooperation and Development - OECD and the International Energy Agency – IEA, allowing the calculation and presentation of the net anthropogenic national emissions of greenhouse gases.

The next thirteen chapters highlights main issues on those reports.

4 EMISSIONS AND REMOVALS BY SOILS FROM LAND USE CHANGE AND LIMING

The methodology covers estimates of annual net CO2 emissions from three processes: changes in carbon stocks of mineral soils resulting by changes in land use and i) management practices; ii) CO2 emissions from use of organic soils for agriculture or forestry plantations; iii) CO2 Emissions from reaction of neutralization of lime used in agriculture.

4.1 Data Availabitity

Because of the lack of data on cultivated organic soils, this report considered only emissions from land use changes and liming.

For the calculation of net CO2 emissions from soils, the following sources of data were used: a) statistical data from the Agricultural census for 1970, 1975, 1980, 1985 and 1995-1996; b) map of Brazilian soils; c) map of vegetation; and d) data on agricultural lime sales in Brazil.

The information used were the amounts of agricultural lime sold annually in Brazil, provided by ABRACAL (Brazilian Association of Agricultural Lime Producers).

4.2 Results

To calculate CO2 emissions associated with the use of lime to correct acidity of agricultural soils, the amount applied annually in Brazil was considered.

Emissions from application of lime (CaCO3) in agriculture were estimated at 9.0 Tg CO2 in 1994.

Total CO2 emissions from soils (from changes in carbon stocks in mineral soils and from liming) were estimated at 64.8 Tg CO2 in 1994.

4.3 Data Quality

In Brazil, estimates of carbon stored in soils are still scarce. The quality and quantity of organic material added and the rate of decomposition of organic carbon in the soil are determined by the interaction between climate, soil type and type of land use/management.

In native ecosystems, climate and soil conditions are the primary determinants of the carbon balance, because they control the rates of production and decomposition.

In agricultural systems, the type of land use and management alter both the entrance of organic material and the rate of decomposition through production of residues, selection of cultivars, fertilization, harvest techniques, soil tillage practices and waste management.

Values for Soil Carbon – SCn, used in calculating CO2 flows, showed a standard deviation of around 10%.

There is little data which can be used for estimating Impact Factors (base factor, cultivation intensity factor and entrance level factor) for the tropics. In the absence of specific data for Brazil, the different factors used were obtained from the coefficients suggested by IPCC (1997) for tropical regions.

5 EMISSIONS AND REMOVALS FROM CHANGES IN THE STOCKS OF PLANTED FORESTS

This report presents the estimates of CO2 uptaken by forests that were planted for industrial uses in Brazil.

5.1 Data Availabitity

Data on the area of planted forests per tree genus were obtained from two major Brazilian agencies in the forest sector, the National Pulp and Paper Manufacturers Association - ANFPC, based in São Paulo, and the Brazilian Association of Renewable Forests - ABRACAVE, based in Belo Horizonte.

5.2 Results

The total planted area reported by these sources for the period from 1969 to 1994 was 6.9 million hectares, with 93% of the total area planted with *Eucalyptus* and 7% with *Pinus*.

Net CO2 removals were estimated to be 11 TgC/year for the 1990–1994 period, with the *Eucalyptus* areas being responsible for 93% of the total amount.

The forests planted for industrial use showed a positive total change in stock of 43.74 million tonnes of fixed carbon between 1990 and 1994, with the estimated contribution of the *Pinus* genus of 3.04 million tonnes, while *Eucalyptus* contributed with 40.70 million tonnes of fixed carbon.

5.3 Data Quality

The most important variables were the planted area and the amount of dry material in the trunk, crown and roots. In the production of dry material of the trunk the basic density was used as a factor for changing the volume units into mass. The carbon content in the wood is also fundamental.

Thus, accuracy estimates of each of these variables are given below.

Planted areas: accuracy of the estimate of planted areas is very hard to quantify, because of the variance in figures available.

Trunk production: estimating methods and processes are well developed and understood. Accuracy was estimated at around 85% for the *Pinus* and 80% for *Eucalyptus* genus, due to the difficulty in estimating an annual average production figure on a national scale.

Basic density: basic density of the timber is a well-studied variable. An accuracy of 85% was estimated as an average value at the national level.

Carbon content: Also an extensively researched variable. An accuracy of 90% was estimated for carbon content.

Crown of trees: ratio between dry material production of the crown and trunk varies between species, age of forest and sites. Estimated accuracy for this variable was 70%.

Roots: Few publications have been found, and the figures provided were quite heterogeneous, so the accuracy for this variable is unknown.

6 EMISSIONS FROM RICE CULTIVATION

This report presents the estimates of methane emissions from flooded rice fields in Brazil.

6.1 Results

In 1994 there were approximately 1,468 thousand hectares of flooded rice fields in Brazil (including rice grown under a continuously flooded regime, an intermittently flooded regime and on floodplains), accounting for 33% of all rice growing area in the country (4,452 thousand hectares).

Methane emissions from paddy rice in Brazil were estimated to be 240 Gg in 1990 and 283 Gg in 1994.

In 1994, methane emissions from continuosly flooded rice amount to 261 Gg (92.2%), intermittently flooded rice 0.6 Gg (0.2%) and rainfed rice fields 21.4 Gg (7.6%) of the total estimated flooded rice crop.

6.2 Data Quality

Studies have shown that methane emissions are strongly influenced by daily changes of temperature, reaching peak values in the hours of highest solar radiation.

The effect of the temperature on the production and emission of methane seems to be masked by other factors, such as the fotosynthetic activity, the stage of growth, soil organic matter content, etc.

Basic field research is necessary to allow a more accurate estimation of methane emissions in the country, since it will enable the collection of enough data for the determination of methane emission factors and seasonal variability in the rice growth.

Regional climatic and physiographic variations should be considered in the estimates, given the size of the country and its different kinds of ecosystems and climatic conditions.

7 EMISSIONS FROM BURNING OF AGRICULTURAL RESIDUES

This report presents estimates of emissions of CH4, CO2, N2O and NOx resulting from burning of agricultural residues in Brazil.

7.1 Data Availabitity

In Brazil, the principal crops whose residues are burned are sugar cane (prior to harvest) and herbaceous cotton (after harvest).

Data were obtained through consultations with research institutes and specialists in sugar cane and cotton growing.

7.2 Results

In 1990, Brazil produced 262,674,150 tonnes of sugar cane on a harvested area of 4,287,630 ha, as well as 1,783,175 tonnes of cotton on a harvested area of 1,391,880 ha.

In 1994, estimated emissions from burning of sugar cane and cotton in Brazil were 0.13 Tg of methane, 2.79 Tg of carbon monoxide, 0.0066 Tg of nitrous oxide and 0.26 Tg of nitrogen oxides.

Figure 2 presents the emissions of methane, carbon monoxide, nitrous oxide from burning of agricultural residues in 1990 and 1994.

8 NITROUS OXIDE (N2O) EMISSIONS FROM AGRICULTURAL SOILS

This report presents the annual estimates of N2O emissions from agricultural soils in Brazil, including N2O emissions from manure management and emissions from human sewage treatment.

According to the IPCC methodology, the following sources of N2O were considered: (1) direct emissions from agricultural soils; (2) direct soil emissions from manure from grazing animals; and (3) emissions indirectly induced by agricultural activities.

It also includes N2O emissions from animal waste management systems and from treatment of human sewage.

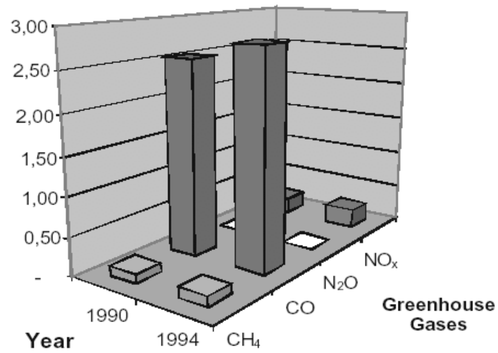

Figure 5 Emissions of CH4, CO, N2O and NOx from burning of agricultural residues

8.1 Data Availabitity

Basic data about systems of agricultural and animal production were obtained from IBGE (Brazilian Institute for Geography and Statistics) official statistics.

Specific data about manure management, use of manure as agricultural fertilizer, and human protein consumption were obtained from the existing literature and from consultations with experts.

8.2 Results

For the year 1994, emissions of N2O from agricultural soils were estimated at 476 Gg N2O, with 218 Gg of emissions from manure from grazing animals (46%), 132 Gg N2O

In 1994, total direct emissions of N2O from agricultural soils were estimated at 125.72 Gg N2O, with an average of 123.06 ± 6.11 Gg N2O for the 1993–1995 period.

Crop residues (34% or 43.09 Gg N2O emitted) and biological nitrogen fixation (21% or 26.39 Gg N2O emitted) were the main contributions in 1994.

8.3 Data Quality

Much of the data required by the IPCC methodology is not available in an organized form in Brazil, such as the area of cultivated organic soils (histosols), the amount of protein consumed by the Brazilian population, and the fraction represented by each different animal waste management system, as a result of the immense physiographical, climatic and cultural differences within the country.

There are still few assessments of N2O emissions in the country, which prevents the use of more appropriate factors for the different Brazilian regions. It is thus necessary to foster studies focusing on measurements of N2O fluxes under different soil management systems, climatic and pedological conditions.

Factors used for N2O estimates in this inventory were primarily based on emission factors obtained in other countries, so a certain level of uncertainty is expected.

Quantities of dry biomass from crop residues, with and without biological fixation, and resulting nitrogen introduction into soils, should be better investigated in the future in order to obtain more precise estimates.

Also, nitrogen incorporation into pastures through legumes should be studied, as well as the mechanisms of gas flux in these systems.

9 EMISSIONS FROM BIOMASS BURNING IN THE NONANTHROPOGENIC CERRADO USING ORBITAL DATA

This report presents the estimates of directly human-induced greenhouse gases emissions from biomass burning in the non-anthropogenic Brazilian Cerrado for the year 1999, which geographical distribution is displayed by Figure 3.

Figure 6 Geographical distribution of the Cerrado

In Brazil, biomass burning in the Cerrado (the Brazilian savannah) is followed by a rapid recovery to the pre-fire condition.

The fire is normally used to control pests, to remove dead biomass, to stimulate the recovery of the vegetation, to facilitate hunting, and to clean areas for agriculture usage.

9.1 Data Availabitity

As the Brazilian Cerrado covers an area of approximately 2,0 x 106 km2, a statistical sampling strategy was necessary for estimating the area burnt in the non-anthropogenic cerrado. TM-Landsat scenes from the June/July period were selected as samples. These samples were selected according to a stratification design, by area and degree of human intervention.

Brazil was the first country in the world to implement an operational system for fire detection, based on images of the sensor Advanced High Resolution Radiometer (AVHRR) onboard the polar orbit satellite National Oceanographic and Atmospheric Administration (NOAA).

However, it has been conceived for meteorological applications and present several limitations to applications related to biomass burning (inadequate spectral bands, easily saturated mean infra-red band etc.).

9.2 Results

Using the estimates of area and biomass density, the total GHG emissions from biomass burning in the non-anthropogenic Brazilian Cerrado for the year 1999 were estimated as being: 306 Gg CH4, 8,036 Gg CO, 3. 8 Gg N2O and 137. 3 Gg NOx.

9.3 Data Quality

The method is based on some assumptions, the most constraining between that the images from July capture the burns that have occurred during the month of June; i.e., it is assumed that the scars from the burns that occurred in June are still visible in the images from July. There is very little information in the literature regarding burning scars and their mean permanence in a Landsat image.

The Vegetation Maps updated for the purposes of this report also presented limitations that need to be corrected: the files were not consistent (the vegetation classes varied from state to state), and do not cover all the areas where the cerrado vegetation can be found.

There are not, for each orbit/point, completed sets of images to cover the entire burning season, characterizing a serious handcap to produce better estimates of the area burnt in a given year.

Obviously, it is also important to know the efficiency of the gasification, which indicates how complete is the process of combustion, representing the amount of carbon that reacts to CO2.

10 EMISSIONS FROM LIVESTOCK

This report presents the estimates of methane emissions from enteric fermentation and animal wastes from livestock production in Brazil.

Methane production is part of the normal digestive process of the ruminant herbivores, occuring within the rumen (or cud). During this transformation CO2 and CH4 are produced, partially eliminated with the breathing gases. Methane emissions intensity depends on the animal type, the amount/degree of digestibility of the digested mass, and the physical activity of the animal.

10.1 Data Availabitity

Official data for livestock from IBGE were used and specific data about Brazilian animal production systems were obtained from specialists and existing literature.

10.2 Results

In 1994, 67% of the livestock in Brazil, not including poultry, consisted of cattle, 87% of which were beef cattle and 13% dairy cattle. The next largest category is swine, which constitutes 15% of the total livestock, then sheep (9%) and goats (5%).

In 1994, the methane emissions were estimated at 9.8 Tg, being 9.4 Tg caused by enteric fermentation and 0.4 Tg by animal wastes management systems.

In 1994, the category of beef cattle was responsible for 81% of methane emissions from livestock in Brazil.

10.3 Data Quality

The lack of basic data necessary for an adequate characterization of cattle populations (distribution by categories, live weight, food consumption, food digestibility rate, and other parameters), constituted the main problem in estimating methane emissions from livestock in Brazil. In the tropics and sub-tropics, ruminants experience seasonal fluctuations in food supply and quality of grazing land, due to season and climatic conditions

Because statistical data about production, disposition and treatment of animal wastes are not available in the country, this report was based on information obtained in consultation with specialists in the area.

CH4 emissions from livestock should be estimated by separating the categories and sub-populations of animals in terms of the production systems practiced in the different regions of the country, in order to relate the zootechnical information to socioeconomic components.

11 EMISSIONS FROM BRAZILIAN HYDROELECTRIC RESERVOIRS

The present study is aimed at developing a methodology for measuring carbon dioxide and methane emissions in reservoirs, and consequently the assessment of contributions of hydroelectric facilities to greenhouse gas emissions in Brazil.

The methodology currently provided by IPCC does not consider anthropogenic emissions of greenhouse gases from hydroelectric reservoirs.

11.1 Data Availabitity

In Brazil, except for the studies by COPPE/UFRJ for Eletrobrás in 1992-1993, for FURNAS in 1997-1998 and for Itaipu Binacional in 1998-1999, there are no reports of *in loco* scientific studies to determine the total emissions of GHG, through a program of systematic sampling. Even internationally there are few such studies.

In this project, measurements were carried out in the Miranda, Barra Bonita, Segredo, Três Marias, Xingó, Samuel and Tucuruí reservoirs, located in two different climatological regimes.

Emissions of carbon dioxide and methane in each of the reservoirs selected, whether through bubbles or diffusive exchange between water and atmosphere, were assessed by sampling, with subsequent extrapolation of results to obtain a value for the reservoir.

11.2 Results

Figure 4 and 5 present the emissions of CO2 and CH4 from hydroelectric reservoirs studied.

11.3 Data Quality

A great variability was found in the intensity of emissions, linked to the influence of various factors, including temperature, depth at the point of measurement, wind regime, sunlight, physical and chemical parameters of water, the composition of the biosphere and the operational regime of the reservoir. For CO2, emissions could be a function of latitude, such that in higher latitudes the reservoirs would tend to have lower emissions.

The fact that emissions from areas with different vegetation, such as the Amazon forest, *caatinga* or *cerrado* are not very different from each other, as will as the relatively low correlation between emissions and the age of the reservoir, could be related to the fact that emissions result not only from the decomposition of the preexisting stock of terrestrial biomass, but also from the organic material from the upstream drainage basin and from the organic material produced internally in the reservoir.

Consideration should be given to variations in emissions of gases within and between reservoirs, given that reservoirs have different regimes of water circulation, which provides differing conditions of water quality and generation of organic material.

The principal scientific controversy was in the extrapolation of the emissions measured in selected parts of the reservoir to the total area of the reservoir. The emissions also vary over time, probably with a rapid peak occurring soon after flooding, and thereafter following an unknown trend. Long term monitoring studies should be undertaken to characterize the curve of emission behavior.

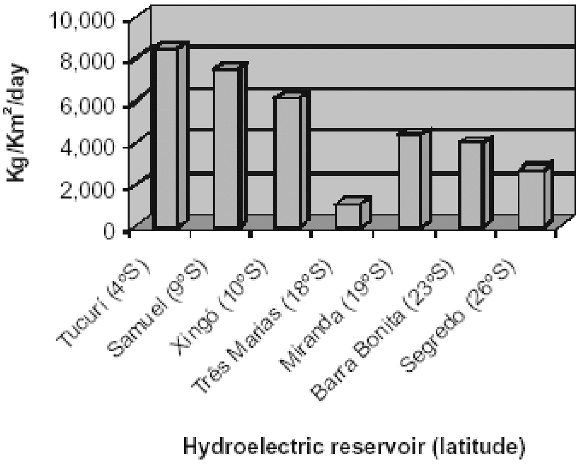

Figure 7 *Emissions of CO2 from hydroelectric reservoirs studied, in kg/km2/day*

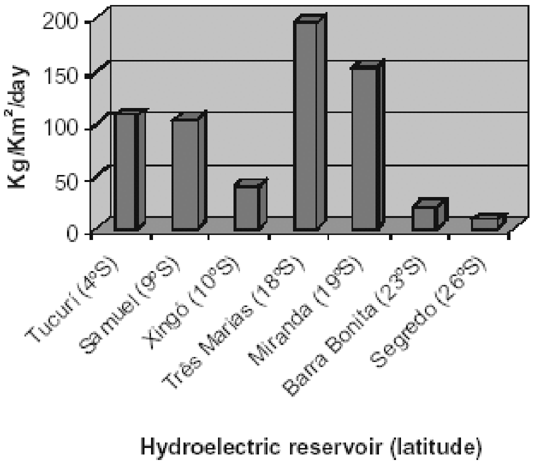

Figure 8 *Emissions of CH4 from hydroelectric reservoirs studied, in kg/km2/day*

12 EMISSIONS FROM FUEL COMBUSTION

This report presents estimates of emissions of carbon dioxide (CO2), methane (CH4), carbon monoxide (CO), nitrogen oxides (NOX), nitrous oxide (N2O) and non-methane volatile organic compounds (NMVOC), from fuel combustion in Brazil.

The emissions are analyzed based on the peculiarities of the Brazilian energy matrix, in which the use of renewable energy sources such as firewood, water energy, charcoal, and bagasse and alcohol from sugar cane are the predominant sources of the country's energy supply.

12.1 Results

For a total end use energy consumption of 190,858,000 Toe in 1994, emissions were 231,408 Gg of CO2, 12,266 Gg of CO, 293 Gg of CH4, 1,601 Gg of NOX, 8.7 Gg of N2O and 1,169 Gg of NMVOC.

In terms of CO2, in 1994 the fuel responsible for the greatest amount of emissions was Diesel Oil (75,067 Gg of CO2) and the sector with the highest emissions was Road transportation (83,302 Gg of CO2).

CO2 emissions from fossil fuel combustion were estimated to be 55.2 TgC in 1990 and 64.4 TgC in 1994. Emissions due to liquid fossil fuels consumption amounted to 77% of the total in 1994, while solid fossil fuels and gaseous fossil fuels were responsible for 19% and 4% respectively.

The fact that CO2 emissions from fossil fuels increased at a faster rate than total gross domestic energy supply, indicates a greater use of carbon-intensive fuels in the Brazilian energy system, at the expense of renewable biomass sources. CO2 emissions from biomass use in the Brazilian energy system are of 52.5 Mt C in 1994.

12.2 Data Quality

In compiling the CO2 emissions from the Brazilian energy system, it became obvious that there is a need for the collection and validation of various physical coefficients required by the methodology used, among which are: Lower heating value (LHV) of fuels; Carbon emission factors of fuels; Carbon storage factor of fuels; Oxidized fraction in fuel combustion. Much of this data exist dispersed in the technical literature. However, its use requires a verification of its validity in terms of the physical and chemical characteristics of the fuels examined in this research, which is based on the Brazilian Energy Balance - BEB.

In the absence of these data, this work relied on either the values recommended by the IPCC, which perhaps do not accurately reflect the conditions of production and use of energy in Brazil, or on estimates or hypotheses that should be further investigated.

13 EMISSIONS FROM COAL MINING AND HANDLING

This report presents the estimates of greenhouse gas emissions from the coal industry in Brazil, including fugitive emissions of methane from open pit and underground mines as well as CO2 emissions from coal deposits and waste piles.

13.1 Data Availabitity

Two types of coal are produced in Brazil: steam coal used industrially in the generation of steam and energy, and coking coal that is used in the steel industry.

The production of coal in Brazil occurs in the three southern states of Brazil, *Rio Grande do Sul*, *Santa Catarina* and *Paraná*.

The supply of coking coal in Brazil was increasingly dependent on imports from 1990 to 1994. In 1994, imported coking coal share in Brazil was close to 99%.

13.2 Results

Total methane emissions in 1994 were estimated to be 53 Gg, with underground mining accounting for 89%

of this total, while surface mines were responsible for 2% of the emissions and post-mining activities for 9%.

14 EMISSIONS FROM MOVABLE SOURCES IN THE ENERGY SECTOR

This report presents the estimates for GHG emissions from mobile sources in the energy sector, including road transport in the light and heavy vehicle categories and air transport. It shows Brazilian emissions of CO2, CO, CH4, NOx, N2O and non-methane volatile organic compounds (NMVOC) resulting from the burning of fuels and evaporative emissions in light vehicles, from diesel combustion in heavy vehicles and from combustion of aviation kerosene in Brazilian domestic routes.

The detailed Tier 2 methodology uses statistics on landings and takeoffs by type of aircraft. Information for the year 1995 was used, as a methodological assessment, because information for previous years was not available.

14.1 Data Availabitity

The data related with light and heavy vehicles was supplied by the Planning Service of Petróleo Brasileiro S.A. (PETROBRAS), the Environmental Management Directorate of the Environmental Sanitation Technology Company (CETESB), the Association of Sugar and Alcohol producers of the State of São Paulo (ÚNICA), the Institute of Electro-technology and Energy (IEE) of the University of São Paulo (USP), the Engineering Graduate Programs Coordination Office (COPPE) of the Federal University of Rio de Janeiro (UFRJ), the Ministry of Transport (GEIPOT), the Ministry of Mines and Energy (MME) and the National Association of Automotive Vehicle Manufacturers (ANFAVEA).

The aircraft fuel information necessary for preparing this report was provided by Brazil's Civil Aviation Institute (IAC).

14.2 Results

The Brazilian fleet of light vehicles in 1994 was estimated to be 11.745 million vehicles, of which 35% were fueled by ethyl alcohol. This fleet was responsible for emissions of 21,940 Gg of CO2, 4,610 Gg of CO, 5.7 Gg of CH4, 237 Gg of NOX, 1.04 Gg N2O, and 861 Gg of NMVOC.

The Brazilian heavy vehicle fleet for the year 1994 was estimated at 1.497 million vehicles, of which 60% were trucks, 28% light vehicles and 13% buses. In 1994 the fleet was responsible for emissions of 58,207 Gg of CO2, 1,276 Gg of CO, 3.8 Gg of CH4, 1,640 Gg of NOX, 0.454 Gg N2O and 316 Gg of NMVOC.

In 1995, Brazil consumed 1.443 million m3 of aviation kerosene in domestic routes, of which 43% were consumed in 547,000 operations of landing and takeoff and the remainder consumed while cruising. The corresponding estimated emissions were 3,563 Gg of CO2, 13.18 Gg of CO, 0.32Gg of CH4, 10.75 Gg of NOX, 0.12 Gg N2O and 3.28 Gg of NMVOC.

15 EMISSIONS FROM INDUSTRIAL PROCESSES AND USE OF SOLVENTS

This report presents the estimates of emissions of greenhouse gases from production process in the Brazilian industrial sector and from the use of solvents.

Emissions are estimated for CO2, CH4, N2O, hydrofluorocarbons (HFCs), perfluorcarbons (PFCs), CO, NOx, and other NMVOC.

Emissions were estimated for the mineral products industry, the chemical industry, the metallurgical industry, the production and consumption of HFCs, the food and beverage industry, and the paper industry.

In the mineral sector, emissions were estimated for the cement, lime and barilla (neutral carbonate of soda) industries.

The electrolysis of aluminum oxide (bauxite) produces molten aluminum, generating emissions of CO2 from the reaction of oxygen with the carbon of the anode, and emission of tetrafluoromethane (CF4) and hexafluoroethane (C2F6) (undesired occurrence of the "anodic effect"), as well as emssions of NOx and CO in the production process.

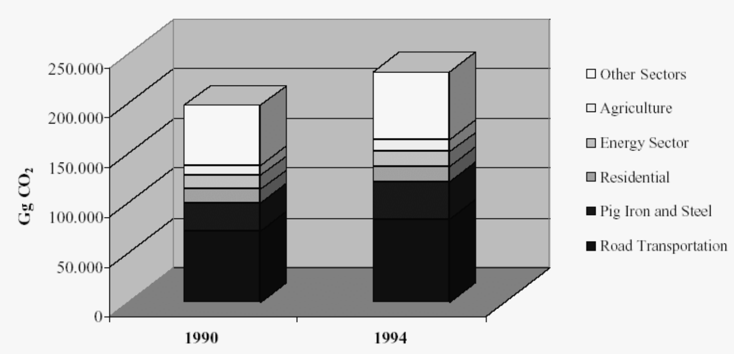

Figure 9 *CO2 emissions from fossil fuel combustion, by sector*

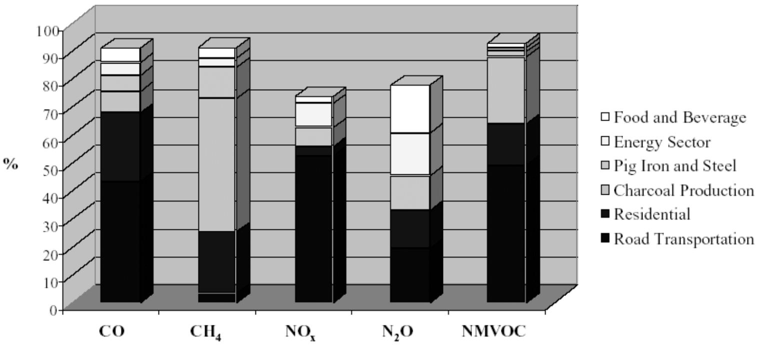

Figure 10 *Greenhouse gas emissions, except CO2, from fuel combustion in 1994, by sector*

15.1 Data Availabitity

In this study, only cement, lime and barilla figures are presented.

Cement-related emissions were estimated based on data on annual clinker production, provided by the National Cement Industries Association (SNIC). Lime-related emissions were estimated based on the annual values for lime production provided by the Brazilian Association of Lime Producers (ABPC), which represents most large and medium-sized industries in the sector, complemented by information from the Mineral Summary of the Ministry of Mines and Energy. Barilla-related emissions were estimated based on production, import and export data for barilla provided by the Brazilian Chemical Industry Association (ABIQUIM).

15.2 Results

In the cement production, calcination process emitted 9,337Gg of CO2.

In the lime production process, lime is calcined, generating 4,152Gg of CO2.

In production of barilla (neutral carbonate of soda), there were emitted 187Gg of CO2.

16 EMISSIONS FROM WASTE TREATMENT AND DISPOSAL

This report presents the estimates of methane emissions from solid waste disposal and wastewater treatment in Brazil.

In Brazil, municipal solid waste generation is estimated to be around 54 thousand metric tons per day, with its composition varying according to each region. The generation per inhabitant of a Brazilian city varies from 0.4 to 0.7 kg/inhab.day.

16.1 Data Availabitity

According to sanitation data from the National Survey on Basic Sanitation, from the 4,425 municipal districts of the country, 2,091 had sewage collection and from these, only 345 had some kind of collective treatment.

Solid waste disposal and treatment is distributed in the following way: 76% are deposited in open dumps, 22% in controlled and sanitary landfills and 2% have other destinations, such as composting plants and incineration.

16.2 Results

Methane emissions from solid waste in Brazil for the year 1994 have been estimated to be 677 Gg.

16.3 Data Quality

The IPCC methodology is based on a statistical data survey in order to define characteristics of the population and the country's industrial sector. It is necessary to know the total urban population, along with the conditions of effluent treatment and waste disposal, implying determining the volume of waste generated, its organic matter content and the nature of sanitation facilities, such as landfills or open dumps and anaerobic sewage treatment, in a given year.

IPCC also suggests that to the greatest extent possible, local technical information should be taken from the national literature regarding, namely the generation of organic loading of industrial effluents as a function of a unit of production, the efficiency of organic matter removal in each system employed, the characteristics of decomposition in landfills and industrial effluent treatment systems and the potential biogas generation and amount recovered.

17 CONCLUSIONS

In the context of the Life Cycle Thinking approach, and more specifically, data gathering processes and data quality assessment for life cycle inventories, this paper assesses the 1st Brazilian Inventory of Anthropogenic Greenhouse Gases, taking into account three main issues, data availability, results and data quality.

The analysis of the reports of the 1st Brazilian Inventory of GHG showed that, although it is a very valuable collection of information, IPCC's inventories requirements are less detailed than LCI's.

In that sense, the data gathered and put together in these reports describe aggregated mass flux crossing Brazilian economy, without the detail required by LCI.

The reported work required, in many cases, the estimation of indicators and collection of data that were not available in the national scientific literature, as well as information from national private companies.

The best possible estimate was sought, taking into account the current stage of scientific knowledge and availability of human and financial resources. The statistics available in the country do not always allow an adequate evaluation of emissions. Generally, where no information existed for particular sectors, specific methods were developed to assess the level of activities.

In the absence of these data, this work relied on either the values recommended by the IPCC, which perhaps do not accurately reflect the conditions of production and use of energy in Brazil, or on estimates or hypotheses that should be further investigated.

These questions emphasize the importance of region-specific conditions in the evaluation of our contribution to global environment, such as greenhouse effects. For this reason, LCA must take into account local characteristics and regional specificity, particularly to build the Life Cycle Inventories (LCI). In addition, socials, economic, geographical, technological and industrial specific conditions must also be included, when the Life Cycle Impact Assessment (LCIA) is made.

It should be recognized that the development of a national life cycle inventory is a resource-intensive undertaking. Priorities should be established for carrying out research and studies of impacts for the principal social and economic sectors.

18 COPYRIGHT

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GUIDELINE FOR COLLECTION, TREATMENT AND QUALITY DOCUMENTATION OF LCA DATA

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ABSTRACT: A guideline for collection, treatment and quality documentation of LCA data has been produced in the context of the EU-project CASCADE. The guideline is based on a general model for collection and treatment of data for describing technical systems, PHASETS (PHASEs in the design of a model of a Technical System). The target group for the guideline is managers of LCA databases and data collection systems, as well as the experienced LCA data collector. Technical guidance and recommendations are given for the procedures to be used for data collection and data treatment, as well as minimum requirements for data quality documentation. A procedure for certification of data according to the guideline is also suggested. The guideline follows the terminology of ISO-standards 14041, 14042, 14043, and 14048, and should be seen as a technical supplement to these standards. This guideline covers establishment of data collection systems, the collection of individual data values, formation of probability distributions, description of processes, and data aggregation. For each individual topic, the guideline covers definitions, a description of the actions to be taken, procedures for documentation of these actions, validation procedures and communication issues.

Keywords: Guideline, data collection, process description, data aggregation

1 INTRODUCTION

In this paper we present a guideline that has been produced within the European thematic network CASCADE (Co-operation and Standards for life Cycle Assessment Data in Europe) (contract no. G7RTCT-2001-05045) [1][2].

The guideline is intended as a quality support in the production of LCA data [2].

2 BACKGROUND AND PURPOSE

The guideline for collection, treatment and quality documentation of LCA data has been compiled in a collaborative work in the European thematic network CASCADE (Co-operation and Standards for life Cycle Assessment Data in Europe). The report has the purpose to support the development, implementation and maintenance of data collection systems within environmental product life cycle assessments (LCAs) and hence improve the quality and comparability of LCA data.

The aims of the CASCADE network is to further standardise LCA data documentation formats, so that they can be more readily integrated with industrial information systems, such as CAD (Computer Aided Design) and PDM (Product Data Management) systems and to compile state-of-the-art knowledge into practically useful training material, guidelines and tools. Being a thematic network, CASCADE excludes all new development, but is focused on reworking, integration and merging of knowledge. This is performed by information and knowledge transfer between and within the different competence groups in the network; LCA, information modeling, and training.

The guideline presented in this paper is a new merging of knowledge that were available in the CASCADE team, but which had not previously been compiled into the form of a general and publicly available guideline for practical purposes.

The target group for this guideline is managers of LCA databases and data collection systems, as well as the experienced LCA data collector. The guideline provides technical guidance and recommendations for the procedures to be used for data collection and data treatment, and includes minimum requirements for data quality documentation. A procedure for certification of data according to the guideline is also suggested.

The guideline does not cover the more practical aspects of data collection, such as how to design data collection protocols, how to train data collection personnel, or the psychological aspects of how to address data suppliers most efficiently.

3 PRINCIPLES

The key components applied in the CASCADE network that are included with in the guideline described in this paper are first of all the ISO-standards 14040 [3], 14041[4], 14042 [5] and 14043[6], and the technical specification ISO/TS 14048 [7]. Since these ISO documents does not provide support for how to produce data documentation, CASCADE also included PHASETS [8], which gives a structure for producing the data and documentation. Also, since the ISO documents do not provide a format for documentation of environmental impact assessment, CASCADE included the data model IA 98 [9], that describes such a format.

The role of the different components is that the overall LCA standard ISO 14040 provides the framework for the guideline, and the standard for interpretation of LCA results ISO 14043 provides the overall roles and requirements for transparency, interpretability and review. ISO 14041 is at focus, since the core of the report describes how data regarding industrial processes should be acquired, aggregated, documented and reported, based on the data documentation format ISO/TS 14048 and the PHASETS model. The guideline also includes data acquisition, aggregation, documentation and reporting of life cycle impact assessment data, according to ISO

14042, based on the data documentation format IA 98 and the PHASETS model.

4 OUTLINE FOR THE GUIDELINE

In the CASCADE network it was decided that the layout of the procedural guideline should follow the PHASETS model, and that all practical guidance should be described in terms of the separate phases of this model. The reason for this choice is that PHASETS provides a simple and generally applicable sequence of types of activities (phases) that are general when describing any industrial process, regardless of whether it is a single machine or a global life cycle product system. Within each phase of the PHASETS model, there is a wide flexibility for how to perform a data acquisition, aggregation, documentation and reporting task. This flexibility has been narrowed for the specific scope and intended application of CASCADE, and results in a informative textbook that can be used to establish the fundamentals of a procedural approach to the collection, treatment and quality documentation of LCA data.

To facilitate the use of the guideline, each section is divided into:

- Definitions
- Actions
- Documentation requirements
- Validation
- Communication

The guideline includes the following steps of collection, treatment and quality documentation of LCA data:

- 4.1 Establishing data collection systems
- 4.2 Collecting individual data values
- 4.3 Forming a probability distribution
- 4.4 Describing a process
- 4.5 Aggregating models of processes
- 4.6 Describing environmental mechanisms
- 4.7 Describing a value system

In the following activities of each step of the guideline is briefly introduced to present the content of the guideline.

4.1 Establishing data collection systems

The data collection system is established by considering the following issues:

- Objectives of the data collection system.
- Data requirements, in terms of included items (processes, environmental mechanisms, groups of people) and the properties for which data are to be collected, and the quality requirements for these data.
- Procedure for identification and treatment of data gaps.
- Required frequency of data collection, location of data collection points, data collection methods and units, and how this matches the nature of the properties for which data are to be collected (type of data to be collected, natural variation versus requirements on precision, accessibility to measurement points, etc.).
- Required documentation, validation and communication of the data to fulfil the objective.
- Personnel involved, both at management and operational level.

4.2 Collecting individual data values

The actual data collection follows the prescriptions documented when establishing the data collection system (see 4.1) such as locations, frequency, methods and units.

For interpretation of the resulting quantitative fact it is important that deviations to the rules established for the data collection system are documented.

4.3 Forming a probability distribution

To facilitate interpretation and manageability of the collected data, they need to be aggregated into frequency and probability distributions. The guideline investigates these statistical issues in good detail.

Determining a frequency distribution is a relatively straightforward procedure. The many well established statistical methods are simple to apply, and give robust results provided a sufficiently large data sample is available (a minimum of 30 data points is recommended for homogeneous populations). However, these methods are only able to represent the variability encountered in the data sample, and the frequency distribution formed does not account for such aspects as the reliability of the data collection.

Where only a single estimate or small data sample is available, basing the analysis on subjective probability estimates may be unavoidable. Large representative data samples are not typical for LCA data, where often only a few sample values are available, frequently from a different time frame from the one under consideration (e.g. historical data used to predict future conditions), or data are taken from a system similar to the one directly of interest (e.g. data from a different geographical location or technology). In addition, often only a proxy quantity is measurable (e.g. laboratory or pilot-scale data used to model a future process not yet operated at full scale). The data sample is therefore often inadequate, in which case it is necessary to use additional information to infer the parameters of the probability distribution if the full uncertainty associated with the quantity is to be represented.

Classical statistical methods are concerned with estimating the frequency rather than the probability of a variable's occurrence (where probability is defined according to the subjectivist or Bayesian view). To obtain an estimate of a variable's full empirical uncertainty, it is necessary to augment the above methods with subjective estimates of uncertainty. Although inherently a subjective procedure, this subjectivity can be minimised by following a structured framework.

The variability captured in data samples is strongly dependent on the time intervals over which the data are collected. Typically, the longer the time interval, the more the variability will have been "dampened" out (e.g. annual variability is typically less than monthly or daily variability). Thus it is important to decide over which time interval data variability should be represented in a probability distribution.

Bias gives rise to systematic errors in the data set, where a systematic error is the difference between the true value of the variable and the value to which the mean of the measurements converges as increasing numbers of measurements are taken. Systematic errors may be due to e.g. imprecise calibration, faulty reading of scales or inaccurate assumptions used to infer the actual quantity from the observable measurements. Bias cannot be reduced by collecting more data. Whilst large data samples may be able to accurately represent data frequency or variability, they tell us nothing of the systematic errors that may be present in the data set.

When faced with a particular data sample, it may be possible that its elements come from two different parent populations (i.e. that it is not homogenous). It is therefore always recommended to first draw up a frequency table of the data, which can then be plotted in a histogram. This allows a good “first look” at the data, and allows a qualitative examination of its various features.

4.4 Describing a process

The level of detail in process modelling (e.g. whether a production process is described at the level of individual machines or production lines, at plant level or at sector level) depends on one hand on the needs of the user and on the other hand on the data availability.

In the context of LCA, process data are required with the aim of suggesting improvements to the investigated processes and systems. Thus, the degree of detail required in process data depends on the level at which the investigated processes can be influenced. If controls can only be made at plant level, detailed information on machine level is unnecessary. However, when the end user or final application of the data is unknown, the largest possible degree of detail should be strived for. This applies both to the choice of detail in process modelling and to the issue of transparency in aggregated data (see 4.5).

The individual data to describe a process (e.g. data on specific inputs and outputs) may be available at different levels (e.g. data on energy use may be available at production line detail, VOC emissions only available at plant level, while other emissions are only calculated at sector level).

Following the principle of “the lowest denominator,” the least detailed data determine the level of detail possible for the entire process. However, data with a low degree of detail may be regarded as representative for the more specific situation. This assumption will be least problematic in a homogeneous population.

The guideline also provides support for the description of defining system boundaries in time, system boundaries towards the environmental system, and Geographical system boundaries, system boundaries towards other processes.

4.5 Aggregating models of processes

Description of unaggregated processes was treated in 4.4. An unaggregated process can be both a unit process and a complex composite system, such as a production system for a specific product from cradle to gate. Unaggregated processes are simply described by providing information on each unit process as well as information on how these unit processes are linked.

Aggregation of processes can be done for different purposes, for example, when compiling the product system for a life cycle inventory (LCI) or when compiling different types of averages of processes. These compiled aggregates are new models of processes, with specific purpose, properties, functions and scopes. As examples, two important types of aggregates are discussed in the guideline; averages and aggregation of linked processes.

4.6 Describing environmental mechanisms

Based on the ISO definition an environmental mechanism of a certain impact category is described by :

- the category indicator representing the impact,
- the LCI results causing the impact, and
- the description in formulas of all physical, chemical and/or biological processes linking the LCI results to the category indicator, which form the characterisation model.

The indicator can be selected to be more or less close to the category endpoint - the real damage of human beings, animals etc. Indicators close to the endpoint should be preferred. However, up to now for many categories there are methodological problems to achieve this goal. The fate of emissions is sometimes, the exposure often not included. Without exposure information for most of impacts no real damages can be assessed; exceptions are global effects as greenhouse warming for which the term exposure is not meaningful. Therefore, the derivation of characterisation factors for the aggregation of substances to equivalents with respect to a certain physical property is the common procedure (e.g. GWP: IR absorption). Such indicators are called mid-point indicators. From the broad variety of environmental mechanisms of different complexity it is clear that characterisation factors for end- as well as for mid-point indicators can cover variable number of specific mechanisms and factors for individual substances and individual environmental processes.

Derivation of characterisation factors can thus be seen as an aggregation of environmental processes in parallel to the aggregation described in 4.5 for technical processes.

The different steps of environmental mechanisms are usually researched by different sciences (for example, the environmental mechanisms involved in human toxicology are studied in meteorology, soil science, plant physiology, and human toxicology). Further research, specifically for LCA purposes and with participation of LCA experts, is not common. Therefore, in some cases characterisation factors are taken directly from the environmental scientists studying the mechanism in question (e.g. IPCC for global warming), in other cases they are proposed by LCA experts (e.g. for acidification). Consequently, the compatibility of information related to different steps must be considered when calculating and using the factors.

4.7 Describing a value system

Values are not objective. For each person they are the subjective result of social and cultural imprint, personal experiences, information on the world out of the individual life, and reflections on all of this.

Definition and description of value systems are especially relevant for ranking of impact categories and weighting of indicator data, although other phases of LCA may also contain choices that based on opinions, interests and values, e.g. the goal and scope definition. Therefore, value-choices play an important role deriving recommendations and decisions from LCI and LCIA results.

For ranking, the following issues may be considered:
- Ecological threat potentials,
- Reversibility of the effect,
- Scale of the effect (global, regional, local),
- Environmental preference of the population,
- Relationship of present and/or previous pollution to quality goals.

For weighting of LCIA results the value-choices can be based on or expressed in e.g.:
- Monetary values
- Authorised standards or targets
- Weights established in an authoritative panel procedure.

Because of the subjectivity of values it is a must to mark all steps containing value-choices. But subjective does not mean arbitrary. A reasonable value-choice can be reasoned and communicated to other people of a similar information level. It can be made plausible and also differences can be made plausible. Therefore, full information of all stakeholders is the precondition for setting up values for sound decisions.

5 CONCLUDING REMARKS

The procedural guideline compiled in the CASCADE project is a substantial contribution in the dissemination of LCA data quality knowledge that has been generated within the narrow expertise in the community of sciencies for environmental management.

Even though some errors and misunderstandings of the original layout can be found in the organisation of the text, such as the aggregation of systems of processes in the context of designing not-aggregated systems, and the definition of data collection systems during data collection, the guideline provides a good description and map of the problems and possibilities during collection, treatment and quality documentation of LCA data.

The guideline demonstrates the value that general frameworks and models can provide to the area of LCA. It can be assumed that the reason for this is that since LCA is very complex in many different dimensions, each issue addressed and improved must first be related to a meaningful model and a guiding structure that relates that dimension of LCA to the reality.

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COMPARISON OF TWO APPROACHES HOW TO DEAL WITH CUMULATIVE LCI DATA IN A UNIT PROCESS DATABASE

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ABSTRACT: In the last years many companies and industrial organisations have published life cycle inventory data for their products. On the one hand side this development is welcomed by LCA practitioners on the other side major problems for data quality can arise if cumulative data from different origin are combined in one study or if the data do not cover all aspects of an inventory. Quite often only cumulative data are published, e.g. the total amount of CO_2 emitted in the life cycle, but no information on the specific energy consumption in different stages. Many companies and associations do not support specific LCA studies with more detailed information. This presentation focuses as an example on the use of LCI data provided by the European plastics industry (APME) and its integration in the database ecoinvent. The cumulative data do not cover important aspects like land occupation or radioactive waste, they handle certain aspects like waste in a way not compatible with the database and the background data are different from the ones in the database. Thus it is necessary to find a good way how to harmonize data sets from different origin. Two approaches how to integrate these data (1:1 integration or disaggregation) are compared. Major advantages and disadvantages are summarized. The example shows that it will never be possible to achieve the same level of accuracy as it is possible with information provided on a unit process level.

Keywords: cumulative data, life cycle inventory, data quality, harmonization

1 INTRODUCTION

In the last years many companies and industrial organisations have published life cycle inventory data of their products (e.g. [1, 2]). These data are published and they are helpful while performing LCA studies. But, these companies or associations do often not support specific LCA studies with more detailed information by indicating that these data have already been published or that further information is confidential.

On one hand side this development of more LCI data becoming publicly available is welcomed by LCA practitioners. On the other side major problems for data quality can arise if cumulative data from different origin are combined in one LCA study or if the published data do not cover all aspects of an inventory.

When building up a high quality, standardized database with datasets from different origin it is necessary to follow certain guidelines [3, 4]. This paper is based on the experiences made during the investigation of data for the ecoinvent database (www.ecoinvent.ch) [5, 6].

The following paragraphs focus on possible solutions for this principal problem and the communication and documentation of quality for this issue.

2 CHALLENGES

Quite often only cumulative data of complete product systems are published, e.g. the total amount of CO_2 emitted in the life cycle of a product or service, but no information, e.g. on the specific energy consumption or on process specific emissions in different stages is provided. Moreover, such cumulative data do seldom cover all important aspects like land occupation and they handle certain aspects like the treatment of waste in a way that is not compatible with the new database. The background data, e.g. for electricity supply or for transport services are different from the ones in the database and they might be outdated. However, they cannot be corrected if only cumulative data are available. Uncertainties of the respective figures are mostly unknown.

3 POSSIBLE SOLUTIONS

There are two principal approaches how to integrate such cumulative data in a database like ecoinvent that collects data on a unit process basis. The first one is a direct implementation of the reported cumulative flows without any linkage to other datasets in the database. The second possibility is a disaggregation of cumulative data based on the available information. For instance, the amount of crude oil extracted is used to assess the demand for fuel oil in combustion processes, or the reported amount of water resource use is assumed to be a demand for tap water, etc.

The first approach leaves the whole responsibility for the data quality to the original data generator, as data are not changed. New developments like for instance a more efficient electricity supply cannot be considered. Aspects which are not considered in the original data are completely neglected (e.g. land use). Models applied for transport distances or waste management options differ from the standards set for the database.

The second approach makes the data more comparable to the other unit processes in the database. E.g. all emissions of combustion processes are taken into account with the same assumptions. But there are large uncertainties due to the assumptions required while disaggregating the data.

4 CASE STUDY

Let us have a look at the implementation of LCI data of “epoxy resin, liquid, at plant”. These data have been published in [1]. ***Table 2*** shows the inventory table for the cumulative data, converted from the original source according to the first approach. ***Table 3*** shows the disaggregated data converted from the same source according to the second approach [5] . In ***Table 2*** only the amount of waste (and thus its treatment) is linked to background data from the ecoinvent database because emissions from waste disposal are not modelled in the original source [1, 6].

Table 2 Life cycle inventory for the production of liquid epoxy resin based on cumulative data for the life cycle [1].

	Name Location InfrastructureProcess Unit	Location	Infrastructu	Unit	*epoxy resin, liquid, at plant* *RER* *0* *kg*
product	epoxy resin, liquid, at plant	RER	0	kg	1.00E+0
solid waste	disposal, hard coal mining waste tailings, in surface backfill	GLO	0	kg	3.00E-1
	disposal, municipal solid waste, 22.9% water, to sanitary landfill	CH	0	kg	4.51E-2
	disposal, average incineration residue, 0% water, to residual material landfill	CH	0	kg	6.10E-2
	disposal, hazardous waste, 0% water, to underground deposit	DE	0	kg	1.90E-2
	disposal, facilities, chemical production	RER	0	kg	3.20E-5
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	5.80E-3
	disposal, plastics, mixture, 15.3% water, to sanitary landfill	CH	0	kg	4.30E-4
	disposal, wood untreated, 20% water, to municipal incineration	CH	0	kg	2.00E-5
energy resources	Oil, crude, in ground	-	-	kg	6.70E-1
	Gas, natural, in ground	-	-	Nm3	2.13E+0
	Coal, hard, unspecified, in ground	-	-	kg	3.60E-1
	Coal, brown, in ground	-	-	kg	2.10E-1
	Peat, in ground	-	-	kg	8.30E-4
	Wood, unspecified, standing	-	-	m3	3.04E-6
	Energy, gross calorific value, in biomass	-	-	MJ	2.06E-1
	Energy, potential, stock, in barrage water	-	-	MJ	1.30E+0
	Uranium, in ground	-	-	kg	2.22E-5
material resources	Barite, 15% in crude ore, in ground	-	-	kg	4.10E-4
	Aluminium, 24% in bauxite, 11% in crude ore, in ground	-	-	kg	1.27E-3
	Clay, bentonite, in ground	-	-	kg	1.30E-4
	Anhydrite, in ground	-	-	kg	1.30E-5
	Chromium, 25.5 in chromite, 11.6% in crude ore, in ground	-	-	kg	5.00E-7
	Clay, unspecified, in ground	-	-	kg	1.40E-5
	Dolomite, in ground	-	-	kg	2.90E-4
	Feldspar, in ground	-	-	kg	5.00E-7
	Manganese, 35.7% in sedimentary deposit, 14.2% in crude ore, in ground	-	-	kg	2.84E-6
	Fluorspar, 92%, in ground	-	-	kg	3.90E-5
	Granite, in ground	-	-	kg	5.00E-7
	Gravel, in ground	-	-	kg	8.00E-6
	Iron, 46% in ore, 25% in crude ore, in ground	-	-	kg	2.40E-3
	Calcite, in ground	-	-	kg	7.10E-1
	Nickel, 1.13% in sulfides, 0.76% in crude ore, in ground	-	-	kg	5.00E-7
	Olivine, in ground	-	-	kg	2.10E-5
	Phosphorus, 18% in apatite, 12% in crude ore, in ground	-	-	kg	2.20E-4
	sylvite, 25 % in sylvinite, in ground	-	-	kg	2.90E-2
	Rutile, in ground	-	-	kg	5.00E-7
	Sand, unspecified, in ground	-	-	kg	1.20E-3
	Shale, in ground	-	-	kg	3.70E-5
	Sodium chloride, in ground	-	-	kg	1.80E+0
	Sulfur, in ground	-	-	kg	7.30E-3
	Zinc 9%, Lead 5%, in sulfide, in ground	-	-	kg	4.50E-6
water	Water, unspecified natural origin	-	-	m3	1.91E-2
	Water, river	-	-	m3	9.20E-5
	Water, salt, ocean	-	-	m3	9.50E-5
	Water, well, in ground	-	-	m3	1.40E-5
	Water, cooling, unspecified natural origin	-	-	m3	3.84E-1
emissions to air	Particulates, > 10 um	-	-	kg	4.80E-3
	Particulates, > 2.5 um, and < 10um	-	-	kg	6.45E-3
	Particulates, < 2.5 um	-	-	kg	3.75E-3
	Carbon monoxide, fossil	-	-	kg	2.20E-3
	Carbon dioxide, fossil	-	-	kg	5.90E+0
	Sulfur dioxide	-	-	kg	1.90E-2
	Nitrogen oxides	-	-	kg	3.50E-2
	Dinitrogen monoxide	-	-	kg	5.00E-7
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	5.60E-3
	Methane, fossil	-	-	kg	3.10E-2
	Hydrogen sulfide	-	-	kg	3.00E-6
	Hydrogen chloride	-	-	kg	4.60E-4
	Chlorine	-	-	kg	6.00E-6
	Hydrogen fluoride	-	-	kg	1.20E-5
	Lead	-	-	kg	5.00E-7
	Fluorine	-	-	kg	5.00E-7
	Halogenated hydrocarbons, chlorinated	-	-	kg	1.10E-5
	Hydrocarbons, aromatic	-	-	kg	2.80E-5
	Hydrocarbons, aliphatic, alkanes, cyclic	-	-	kg	5.00E-7
	Aldehydes, unspecified	-	-	kg	4.70E-5
	Cyanide	-	-	kg	4.80E-7
	Sulfate	-	-	kg	4.90E-7
	Hydrogen	-	-	kg	3.20E-3
	Mercury	-	-	kg	1.00E-6
	Ammonia	-	-	kg	4.00E-6
	Carbon disulfide	-	-	kg	5.00E-7
	Ethane, 1,2-dichloro-	-	-	kg	5.00E-7
	Ethene, chloro-	-	-	kg	5.00E-7
	Heat, waste	-	-	MJ	9.81E+1
water emissions	COD, Chemical Oxygen Demand	-	-	kg	5.10E-2
	BOD5, Biological Oxygen Demand	-	-	kg	1.20E-3
	Carboxylic acids, unspecified	-	-	kg	6.10E-5
	Solved solids	-	-	kg	1.70E-2
	Hydrocarbons, unspecified	-	-	kg	5.70E-3
	Ammonium, ion	-	-	kg	5.00E-6
	Suspended solids, unspecified	-	-	kg	8.30E-2
	Phenol	-	-	kg	1.20E-5
	Aluminum	-	-	kg	5.00E-7
	Calcium, ion	-	-	kg	5.40E-2
	Copper, ion	-	-	kg	5.00E-7
	Iron, ion	-	-	kg	1.00E-6
	Mercury	-	-	kg	5.00E-7
	Lead	-	-	kg	5.00E-7
	Magnesium	-	-	kg	1.70E-5
	Sodium, ion	-	-	kg	3.80E-1
	Potassium, ion	-	-	kg	8.20E-4
	Nickel, ion	-	-	kg	5.00E-7
	Zinc, ion	-	-	kg	5.00E-7
	Nitrate	-	-	kg	1.00E-6
	Nitrogen	-	-	kg	1.00E-5
	Chromium VI	-	-	kg	2.60E-7
	Chloride	-	-	kg	9.80E-1
	Cyanide	-	-	kg	5.00E-7
	Fluoride	-	-	kg	1.00E-6
	Sulfate	-	-	kg	8.10E-3
	Carbonate	-	-	kg	1.50E-2
	Phosphate	-	-	kg	9.68E-5
	Arsenic, ion	-	-	kg	5.00E-7
	Ethane, 1,2-dichloro-	-	-	kg	5.00E-7
	Ethene, chloro-	-	-	kg	5.00E-7
	Oils, unspecified	-	-	kg	6.90E-5
	Chlorine	-	-	kg	2.40E-5
	Chlorinated solvents, unspecified	-	-	kg	7.20E-5
	Sulfide	-	-	kg	1.00E-6

In the second case, the data for energy uses, transports and waste management are disaggregated as far as possible. Emissions from these processes are subtracted from the original data, and the remaining amounts are reported as process emissions.

In some cases it was necessary to rely on information from a previous version of the same dataset [7]. All data have been disaggregated and linked to datasets from the database ecoinvent. For that purpose, the following tables from the section Ecoprofile Data in [1] have been used: fuel use (Table 1, energy content of delivered fuel), the feedstock energy (Table 1), the consumption of water resources for processing (Table 5), process specific emissions into water (Table 9) and air (Table 6) and data for wastes associated with the process operations (Table 8).

Important materials like sodium chloride were also considered with their resource use, but not with the requirements for the production, because these environmental impacts are included in the aggregated figures. All inputs with a figure <1mg/kg are assumed to be 0.5mg/kg. Own assumptions have been used for transports, the type of supply chain for the fuels used and the waste management.

Table 3 Disaggregated life cycle inventory for the production of liquid epoxy resin [1]

	Name Location InfrastructureProcess Unit	Location	Infrastructu	Unit	epoxy resin, liquid, disaggregated data, at plant RER 0 kg
output	epoxy resin, liquid, disaggregated data, at plant	RER	0	kg	1.00E+0
resource, in ground	Calcite, in ground	-	-	kg	7.10E-1
	Gas, natural, in ground	-	-	Nm3	6.78E-1
	Oil, crude, in ground	-	-	kg	3.55E-1
	Sand, unspecified, in ground	-	-	kg	1.20E+3
	Sodium chloride, in ground	-	-	kg	1.80E+0
	sylvite, 25 % in sylvinite, in ground	-	-	kg	2.90E-2
resource, in water	Water, well, in ground	-	-	m3	1.40E-5
	Water, river	-	-	m3	9.20E-5
	Water, salt, ocean	-	-	m3	9.50E-4
	Water, cooling, unspecified natural origin	-	-	m3	3.84E-1
	Water, unspecified natural origin	-	-	m3	6.10E-3
technosphere	electricity, medium voltage, production UCTE, at grid	UCTE	0	kWh	2.19E+0
	heavy fuel oil, burned in power plant	RER	0	MJ	1.10E+1
	natural gas, burned in industrial furnace >100kW	RER	0	MJ	5.77E+1
	tap water, at user	RER	0	kg	1.30E+1
	disposal, municipal solid waste, 22.9% water, to sanitary landfill	CH	0	kg	2.98E-1
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	5.80E-3
	chemical plant, organics	RER	1	unit	4.00E-10
	transport, freight, rail	RER	0	tkm	1.74E+0
	transport, lorry 32t	RER	0	tkm	6.06E+1
emission air, unspecified	Acetaldehyde	-	-	kg	4.70E-5
	Ammonia	-	-	kg	4.00E-6
	Carbon dioxide, fossil	-	-	kg	6.50E-1
	Carbon monoxide, fossil	-	-	kg	2.60E-4
	Halogenated hydrocarbons, chlorinated	-	-	kg	1.10E-5
	Heat, waste	-	-	MJ	7.87E+0
	Hydrocarbons, aromatic	-	-	kg	2.80E-5
	Hydrogen chloride	-	-	kg	2.30E-4
	Hydrogen fluoride	-	-	kg	5.00E-7
	Hydrogen sulfide	-	-	kg	3.00E-6
	Lead	-	-	kg	5.00E-7
	Mercury	-	-	kg	5.00E-7
	Methane, fossil	-	-	kg	2.00E-4
	Methane, chlorotrifluoro-, CFC-13	-	-	kg	8.00E-6
	Nitrogen oxides	-	-	kg	2.70E-3
	Particulates, > 2.5 um, and < 10um	-	-	kg	7.10E-3
	Sulfur dioxide	-	-	kg	1.70E-3
	NMVOC, non-methane volatile organic compounds, unspecified origir	-	-	kg	4.94E-4
emission water, river	Ammonium, ion	-	-	kg	3.00E-6
	Arsenic, ion	-	-	kg	5.00E-7
	BOD5, Biological Oxygen Demand	-	-	kg	1.10E-3
	Calcium, ion	-	-	kg	5.40E-2
	Carboxylic acids, unspecified	-	-	kg	5.90E-5
	Chloride	-	-	kg	9.80E-1
	Chlorinated solvents, unspecified	-	-	kg	1.13E-4
	Chromium VI	-	-	kg	5.00E-7
	COD, Chemical Oxygen Demand	-	-	kg	5.10E-2
	Copper, ion	-	-	kg	5.00E-7
	Cyanide	-	-	kg	5.00E-7
	DOC, Dissolved Organic Carbon	-	-	kg	1.70E-2
	Fluoride	-	-	kg	1.00E-6
	Oils, unspecified	-	-	kg	6.90E-5
	Hydrocarbons, unspecified	-	-	kg	6.40E-5
	Iron, ion	-	-	kg	1.00E-6
	Magnesium	-	-	kg	1.70E-5
	Mercury	-	-	kg	1.00E-6
	Nickel, ion	-	-	kg	5.00E-7
	Nitrate	-	-	kg	1.00E-6
	Nitrogen	-	-	kg	1.00E-5
	Phenol	-	-	kg	6.00E-6
	Phosphate	-	-	kg	2.20E-4
	Potassium, ion	-	-	kg	8.20E-4
	Sodium, ion	-	-	kg	3.80E-1
	Sulfate	-	-	kg	8.10E-3
	Sulfide	-	-	kg	1.00E-6
	Suspended solids, unspecified	-	-	kg	8.30E-2
	VOC, volatile organic compounds, unspecified origin	-	-	kg	5.20E-3
	Zinc, ion	-	-	kg	5.00E-7

5 DATA QUALITY

Data quality of the cumulative data has not been reported in the original publications. Thus, not much is known about standard deviation of the data or quality indicators like age and representativity of the data.

For all other processes in the ecoinvent database data quality is assessed with information about the standard deviation, a probability function (always lognormal) and a clarifying comment. Due to the lack of respective information in the original source [1], no uncertainty assessment was possible.

6 INVENTORY RESULTS

The cumulative LCI results for the two cases have been calculated with the help of the ecoinvent database. ***Table 4*** shows selected LCI results and the cumulative energy demand of the two datasets.

In some cases the elementary flows calculated for the disaggregated data are higher than for the original data. The difference is especially high for flows which are not modelled in the original data like land occupation.

On the other side there are flows like NMVOC or NO_x which are higher for the cumulative data. This might be due to older or different background data for energy supply and transport services.

Table 4 Selected LCI results and the cumulative energy demand for the production of 1kg of liquid epoxy resin

		Name		epoxy resin, liquid, disaggregated data, at plant	epoxy resin, liquid, at plant
		Location		RER	RER
		Unit	Unit	kg	kg
		Infrastructure		0	0
LCIA results					
	cumulative energy demand	non-renewable energy resources, fossil	MJ-Eq	141.0	125.0
	cumulative energy demand	non-renewable energy resources, nuclear	MJ-Eq	11.30	12.50
	cumulative energy demand	renewable energy resources, water	MJ-Eq	1.8E+0	1.3E+0
	cumulative energy demand	renewable energy resources, wind, solar, geothermal	MJ-Eq	2.9E-1	2.6E-4
	cumulative energy demand	renewable energy resources, biomass	MJ-Eq	1.8E-1	2.2E-1
further LCIA results					
total	ecological scarcity 1997	total	UBP	6'230	7'550
climate change	IPCC 2001	GWP 100a	kg CO2-Eq	6.8E+0	6.7E+0
total	eco-indicator 99, (E,E)	total	points	5.2E-1	5.8E-1
total	eco-indicator 99, (I,I)	total	points	3.2E-1	4.4E-1
total	eco-indicator 99, (H,A)	total	points	6.1E-1	6.8E-1
LCI results					
resource	Land occupation	total	m2a	3.0E-2	3.2E-3
air	Carbon dioxide, fossil	total	kg	6.3E+0	5.9E+0
air	NMVOC	total	kg	3.0E-3	5.7E-3
air	Nitrogen oxides	total	kg	9.7E-3	3.5E-2
air	Sulphur dioxide	total	kg	1.4E-2	1.9E-2
air	Particulates, < 2.5 um	total	kg	4.9E-4	3.8E-3
water	BOD	total	kg	1.1E-2	4.9E-3
soil	Cadmium	total	kg	5.2E-10	1.4E-11

7 IMPACT ASSESSMENT

Figure 11 shows a comparison of the two datasets based on an impact assessment with the method Eco-indicator 99 (H,A) [8, 9]. The results for the original data are higher. This is mainly due to the higher value for respiratory effects. Respiratory effects of the cumulative data are dominated by the higher NO_x emissions. On the other side the fossil fuel use is higher for the disaggregated data. The results for other pollutants, although not important for the overall assessment, might be quite different between the two datasets.

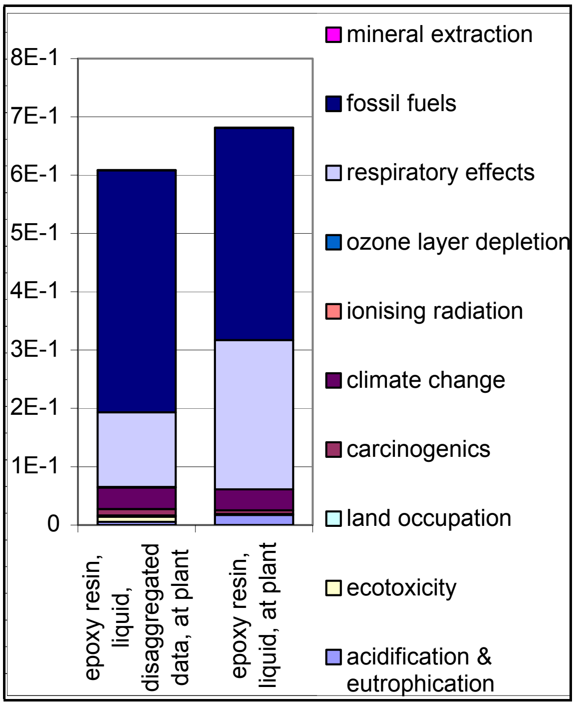

Figure 11 Comparison of the two datasets in Eco-indicator 99 (H,A) points per kg liquid epoxy resin

Figure2 shows the same type of comparison based on impact assessment with the method ecological scarcity 1997 [10]. Again the disaggregated data show a lower score. This is due to the lower emissions of the important air pollutants. Again the difference for NO_x emissions is quite important. On the other side the figure shows that radioactive wastes are not considered at all in the cumulative inventory.

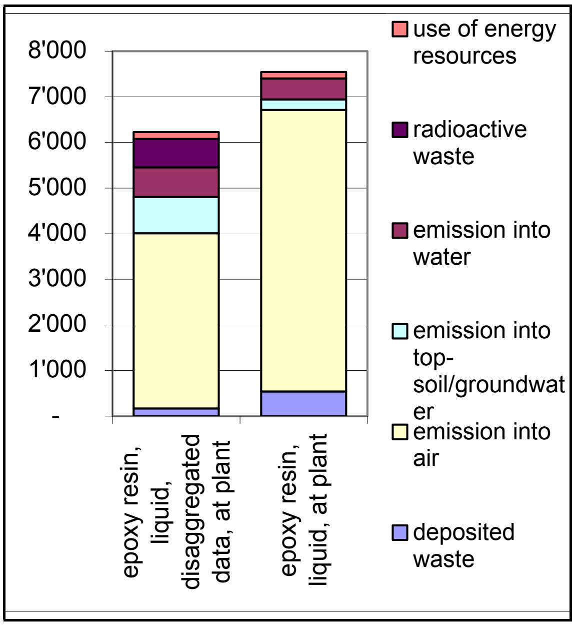

Figure 2 Comparison of Ecological Scarcity points for the two case studies

8 SUMMARY

Disaggregating published cumulative life cycle inventory data is a difficult task. The data quality of a study based partly on such cumulative data remains always poor. Using the original cumulative data might lead to neglecting important interventions. Different background data e.g. for transports or energy supply might dominate the outcome of the comparison. Disaggregating data is neither a good solution as it will never be possible to use the same assumptions for direct interventions as in the original study.

Important aspects might be neglected and products and processes are not investigated in the same depth. Thus it is always recommended to use unit process data as far as possible and available, instead of relying on cumulative data.

Within the ecoinvent database generally original data have been used if no unit process data were available. Only the emissions from waste management have been modelled with actual information [6]. Thus these datasets are not fully consistent with other data sets in this database.

It is recommended that producers that plan to publish life cycle inventory data for their products publish them in a unit process format. This makes it possible to establish the same assumptions for environmental interventions and background data throughout the whole database. The compatibility of such unit process datasets, although established by different organisations at different places, is much better and a combination of such processes is much easier.

A helpful example for such policy is the inventory for aluminium [11]. Data from this report could be used to a large extend for the ecoinvent database. Nevertheless confidentiality could be maintained for such figures which are really crucial for the companies.

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MATCHING BOTTOM-UP AND TOP-DOWN FOR VERIFICATION AND INTEGRATION OF LCI DATABASES

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ABSTRACT: A combination of traditional bottom-up process-based LCI databases with top-down databases based on industry input-output statistics provides fruitful opportunities for mutual verification. The sum of all processes is verified against the global totals, thus identifying missing data and filling data gaps. The global totals also provide continuously updated normalisation references for the process-based data. At the same time, the process-based data provide much more detail, allowing a breakdown of the industry totals. By integrating the two data sources in one database approach, it becomes possible to avoid data gaps while still providing the necessary detail in process modelling. The integration of bottom-up and top-down is illustrated by two examples: 1) a database linking national agricultural statistics to detailed farm models, providing a comprehensive set of data for Danish agricultural products 2) the use of national material flow analyses and national input-output databases to provide an updated background dataset to which individual process-based data and product life cycles are linked for continuous database improvement.

Keywords: integration of data of different origin; input-output databases; normalisation

1 INTEGRATING BOTTOM-UP AND TOP-DOWN

Traditionally, LCI databases have been produced “from the bottom up”, i.e. based on data for specific unit processes, often aggregated or linked into larger processes finally modelling larger parts of product life cycles or entire product LCIs.

An alternative “top-down” source for LCI-data is the national input-output statistics in combination with national environmental accounts and national material flow analyses.

Integrating these two sources of data into the same database provides a number of opportunities, which are further explored in this presentation:

- Combining the advantages of detail and completeness.
- Mutual verification of the two sources of data.
- Continuously updated normalisation references.

2 COMBINING DETAIL AND COMPLETENESS

2.1 Advantages of the two complementary data sources

Since the bottom-up and the top-down data both model the same reality, they should in principle arrive at the same result.

However, the more specific bottom-up data often have a problem of data gaps, since the detailed and systematic tracing of all inputs and outputs requires a large effort. Besides the more conscious decisions to apply cut-off rules to leave out flows that are considered insignificant, there is always a danger of missing important flows by simple ignorance. From experience, bottom-up LCIs can have data gaps that add up to 50% of the total environmental exchanges [1].

Top-down data, on the other hand, have a problem of lacking resolution, and can therefore not stand alone as a data source for LCIs of specific products. In practice, most top-down data are also indirectly derived from bottom-up data, and therefore rely on the quality of more specific data. Nevertheless, top-down data have a higher degree of completeness, due to the many options for verification of national totals. For example, the national totals for emissions of CO_2, SO_2 and NO_X are typically calculated from the detailed statistics of trade in energy carriers, combined with industry-specific emission factors, resulting in highly reliable totals. For heavy metals and several other chemicals, it is also the total trade figures from material flow analyses that allow a verification and reliability of the total emissions. In a few lucky cases, total emissions may also be verified by matching actual levels of pollution, e.g. for N-tot and particle emissions.

When adding up - bottom-up - all known processes within one industrial sector, they should in principle come close to the result arrived at from top-down for the same sector. However, in practice the bottom-up processes often have to be adjusted for omitted or forgotten emissions before the two totals match.

The top-down data thus becomes an important tool for completing the bottom-up data, which on the other hand have the advantage of larger resolution.

Thus, rather than seeing the two sources of data as incompatible, they should be seen as complementary.

2.2 Combining the two data sources in one database

There are few practical problems in combining top-down and bottom-up data in the same database. The traditional LCI-process model as described by ISO 14048 can represent both types of data.

In the context of LCI-databases, the top-down data can best be seen as default processes, which are then broken down into more specific processes by the aid of the bottom-up data. When the bottom-up data represent the entire top-down process, it is possible to make consistent corrections to all the bottom-up processes, which afterwards entirely replaces the top-down process. In the less ideal (but probably more often real) situation, the bottom-up data represent only a part of the top-down process, and the remaining part will have to remain in the database as a residual process.

For example, in modelling the dairy industry, we obtained high quality process specific data for production of the main products milk, yellow cheese, powder milk, butter and spreads. However, this left us with a residual of caseinates, fermented milk, processed cheese, ice cream, whey, lactose and ready-made foods, all dairy products for which we have currently only an average emission factor (calculated from the residual emissions when the emissions from milk, yellow cheese, powder milk, butter and spreads had been subtracted from the original total). As our data collection continues, this residual will be further broken down and will eventually disappear.

3 EXAMPLES OF VERIFICATION

3.1 Verifying agricultural emissions

The Danish LCA Food Data Base [2] contains unit process data for 28 representative farm types, together representing the entire Danish agricultural sector. Each farm type is represented by a technical model covering the external and internal (from arable land to stable and from stable to land) turnover of fodder, fertiliser and energy. The technical models are based on standard recommended requirements and technical coefficients, which have a very large empirical basis.

The farm models have been validated at two levels: Internal coherence within each farm type and overall coherence between the sum of farm types and national level input use and production. On the farm level, the validation has primarily been done by checking the coherence between land use, crop yields and livestock production (e.g. the feed needed for the herd matches the home-produced feed plus imported feeds less sold cash crops and the sum of homegrown feeds and sold crops fits the land use).

At a higher hierarchical level the land use has been validated by comparing the sum of area for each crop over all farm types with the national statistics for the same year, e.g. checking that the total wheat area and total wheat yield does not differ more than a few percent from the national statistics. Likewise, the total estimated use of inputs like diesel, fertilizer and concentrated feeds across all farm types have been checked against national statistics. In case of differences that could not be ascribed to an error in a specific type, a general correction factor was multiplied into all types for the relevant input item. This was the case for the nitrogen input, where the sum of the farm models could only account for 95% of the nitrogen purchased.

For energy use, the first run of farm models has only accounted for approximately 50% of the energy purchased according to the national energy statistics. Part of the difference could be explained by combustion of crop residues for heating and a larger fuel use in private cars than initially estimated. However, a significant part of the energy use still remains to be accounted for, which implies that until further information has been obtained, the residual energy purchased has to be allocated over the farm products on a less satisfactory basis (the typical default allocation being the economic value of the output). However, this is still preferable than leaving out this energy use (and its emissions), which would have been the result if the results of the farm models had not been verified against the national totals.

3.2 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 Accounting (input-output) Matrices expanded with Environmental Accounts, known as the Danish NAMEA. Imported supplies are modelled on the basis of similar foreign NAMEAs. The basic NAMEA from Statistics Denmark only cover the main air pollutants, based on the annual national CORINAIR reporting. However, based on further national emissions monitoring, material flow analyses and similar national data, typically based on trade statistics and industrial information, it has been possible to expand the coverage to all major emissions as determined by the Danish normalisation reference [3].

Comparing the resulting data to more traditional bottom-up data has so far revealed that transport processes may be more significant than hitherto believed. Since the transports are often spread out over many different products, each with their cut-off, a large part of the total transport ends up being ignored. Similarly, large parts of the emissions from retail trade, repair and maintenance tend to have been left out in raw bottom-up process data.

4 UPDATING NORMALISATION REFERENCES

The verification examples in section 3 deal mainly with verification of bottom-up data by top-down data. However, high quality bottom-up data may also in some cases lead to revision of top-down datasets. This may be the case when detailed process data reveal sources of an emission, not hitherto included in the national totals.

In our work with the two databases mentioned above, we found the quality of the detailed models superior in the cases of CH_4 and N_2O emissions from agriculture, which lead us to revise the national totals for these two substances, compared to the national emissions statistics. Similarly, we have found evidence that application of standard emission factors for NM-VOC on available process data result in higher emissions than in the national emissions statistics. While investigating possible gaps in the national statistics, we have for the time being lowered the technical emission coefficients so that the sum of our processes matches the total national value.

These examples illustrate that the integration of detailed bottom-up data into the framework of the NAMEAs allow a continuous updating of national normalisation references for use in LCA. Normalisation references are mainly used when comparing different emissions as part of the impact assessment, but the national normalisation references are fundamentally just an LCI (i.e. a sum of all environmental exchanges) for a national economy.

In 1997, the Danish EPA asked for the Danish LCA-normalisation reference to be updated to the year 1994. This normalisation reference was ready for publication in year 2001 [3] (but due to unfortunate circumstances still not officially published) i.e. giving a delay of 7 years. As a by-product of producing the national LCA-database described above, we updated the national normalisation reference this year (2003) to year 1999 (i.e. a delay of 4 years which is close to the minimum achievable due to the delay in publishing of national statistics). We found that in the 5 years between 1994 and 1999, the normalisation references for some impact categories had been doubled (increases in emissions of nitrogen compounds) for others halved (SO_2-emissions) and for some even reduced with 80% (mainly due to reductions in heavy metals emissions). As long as normalisation references play a significant role in impact assessment, any unnecessary delay in revision of normalisation references should be avoided.

Due to the completeness of the input-output based databases, national normalisation references can be kept as updated as the corresponding national LCA databases.

5 CONCLUSIONS

The advantages of combining traditional bottom-up LCI databases with top-down databases based on national input-output statistics have been illustrated. By integrating the two data sources in one database approach, it is possible to ensure completeness while still providing the necessary detail in process modelling.

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HOW COMPATIBLE ARE THE SWISS ECOSPOLD AND THE SWEDISH SIRII-SPINE FORMATS FOR DATA DOCUMENTATION AND EXCHANGE

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ABSTRACT: This paper presents a comparison of two formats for data documentation and exchange – EcoSpold and Sirii SPINE. In the beginning of September 2003 ecoinvent, the Swiss national Life-Cycle Inventory database, was published on the internet. Besides about 2'700 unit processes included in this database, EcoSpold – the data(exchange)format – based on the former SPOLD format, is one of the cornerstones of the whole project. In Sweden, the Sirii SPINE Environmental Data Network is online since the summer 2002. The cornerstones of the Sirii ED Network are the commonly accessible application for data documentation and exchange, the internet-based data base network and the concept of On the Way to EPD. The main characteristics of each respective format where considered in the comparison. The aim was to assess the possibility of a future exchange of datasets between the two formats. The results show similarities as well as differences. Some differences may fairly easily be over won to make future data exchange possible. It is our hope that the findings of this comparison may form the basis for the needed, further work in the direction of compatible data documentation and exchange formats between European LCI data bases.

Keywords: Communication of quality information, Data exchange format, Ecospold, Sirii SPINE

1 INTRODUCTION

One of the most discussed topics within the framework of Life Cycle Assessment (LCA) is the harmonization of formats for data documentation and exchange, as well as of the therefore used nomenclature. Several initiatives – from global efforts like the UNEP/SETAC LCA initiative, through e.g. European efforts within the framework of COST Action 530, to national initiatives like e.g. ecoinvent and Sirii SPINE – try to go one step ahead within this field.

Within the framework of a short term scientific mission (STSM) of COST Action 530, a first comparison of two different data base systems for LCA data – the Swiss database ecoinvent and its EcoSpold format and the Swedish Sirii Environmental Data Network and its Sirii SPINE format – was established.

2 COMPARED SYSTEMS

2.1 The Swiss database ecoinvent

The Swiss national life cycle inventory (LCI) database ecoinvent – accessible online (www.ecoinvent.ch) since the beginning of September 2003 – provides Swiss and European LCI data allowing administration, industry and consultants to calculate complete value-added chains.

Since the beginning of the 90s several institutes within Switzerland started to establish their own inventory databases for life cycle studies. As support and regular actualization of such a type of database are time consuming activities – often much too large for one single institute – in 1998, under the leadership of EMPA, the "Swiss Centre for Life Cycle Inventories" (short: ecoinvent centre) was created as a joint initiative of the ETH domain and Swiss Federal Offices to bring together the different efforts in the area of LCA. In parallel the project ecoinvent 2000 was initiated aiming at a unified, harmonized, transparent and actualized high quality life-cycle inventory database. Each participating institute is thereby responsible for the data of exactly defined areas – based on LCI knowledge already build up within the last decade. For the communication of the central database with the other components and with commercial LCA software, "EcoSpold" – an open, future-oriented data exchange format based on XML-technology has been developed following international standardization efforts in the area of LCA data exchange (e.g. SPOLD, ISO 14'048) [1], [2].

All in all, in this online accessible database about 2'700 consistent and coherent LCI unit process data are found allowing an easier performance of LCA studies and thus increasing the credibility and the acceptance of life cycle results.

2.2 The Swedish Sirii Environmental Data Network

The Sirii Environmental Data (ED) Network is made up of several institutes that perform research and consultation within different branches of the industrial world in Sweden and abroad. The Sirii ED Network group holds a broad competence on the product-, material- and process-related issues of the entire Swedish industry. It also holds long experience on product-related environmental information within the field of life cycle management.

To help spread the knowledge and facilitate the use of analytical tools, such as LCA, within the industry, the Sirii ED Network has created a commonly accessible, user-friendly application (available free of charge at www.sirii.org) for environmental (LCI) data. The application is based on a specified documentation format – Sirii SPINE (which is compatible with SPINE – Sustainable Product Information Network for the Environment) – and independent of commercial software. It has been created to facilitate a complete, structured and consistent documentation and communication of environmental (LCI) data. In addition to this, the Sirii ED Network has created a common platform – a data base network – where well-documented LCI data generated at the Sirii Institutes are publicly available. It is the intent that the Sirii ED Application and the Sirii ED Platform shall help facilitate a time- and cost-efficient product-oriented environmental work within companies.

The Sirii ED Network has agreed on common quality guidelines and created a routine for quality review, with respect to the correctness of documentation as well as the reasonableness of the numerical values of flow data, for a dataset documented in the Sirii SPINE format [3], [4]. The Sirii SPINE format will be compatible with the ISO 14'048 in the future.

A further application of data documented in the Sirii SPINE format that has been developed by the Sirii Institutes in cooperation with the Swedish Environmental Management Council is the concept of "On the Way to EPD (Environmental Product Declaration)" (see further www.sirii.org).

3 PROCEDURE & EXAMINED PARAMETERS

3.1 Procedure

The basis of the work has been done within the framework of an STSM of COST Action 530.

The aim of an STSM is to contribute to the realization of the scientific objectives of a COST Action. Such missions shall strengthen the existing networks and thus makes possible the exchange of a scientist for a specific mission between two institutions from different countries contributing both to the respective COST Action. Such an exchange can be from three days up to one month. In the specific case here, the STSM took four working days in St. Gallen at the end of July 2003.

The structure of the STSM is shown in Figure 1. A short report on the results of the mission was written for the Management Committee of COST Action 530 and its working group "data base" [5].

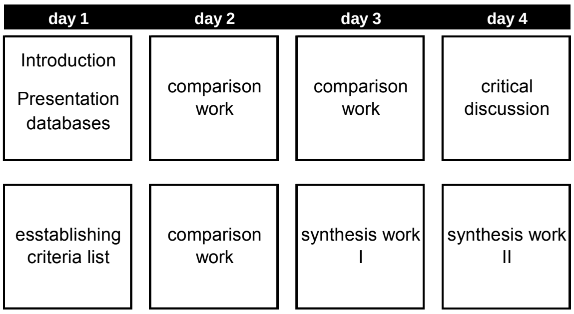

Figure 1. Structure of the STSM "Sirii@ecoinvent"

After the first synthesis work, a critical discussion of the results was performed together with the central project manager of ecoinvent – Rolf Frischknecht.

3.2 Compared parameters

The first step of the comparison work was to create a list of the included documentation fields of each format (see figure A.1 and A.2 in the annex of this publication), and match the equivalents. Each of the authors then separately compared the two formats by attempting to exchange data from one format to another in both directions – i.e. from ecoinvent to Sirii SPINE and from Sirii SPINE to ecoinvent. The degree of success in exporting information from a field in one format to the equivalent in the other format was evaluated. Both the content of the respective fields as well as the feasibility for electronic exchange without loosing significant information were considered. The degree of success in export was graded a (1) for "successful exchange, a (2) for exchange after some modifications and a (3) for "exchange difficult without major modifications".

4 RESULTS

An LCI dataset consists of two parts – (i) a descriptive part (meta information) and (ii) the numerical flow data (in- and outputs of the system which is described by the dataset). The following chapters first handle the documentation fields for meta information and then the fields for flow data. As the allocation question can be handled in both of these parts, it is shown here as a separate point between the two mentioned chapters. For a more detailed presentation of the results of the comparison see [5].

4.1 Comparison of meta information

The two formats include long lists of documentation fields for meta information. Therefore, to illustrate the results of the comparison, the most important aspects of a dataset where singled out and focused on in the presentation (the full list of aspects and compared documentation fields may be found in the annex tables A.1 and A.2). The resulting list of important aspects is shown in Table 1 along with the evaluation of data exchange between the formats, in both directions.

Table 1. Important aspects of meta information of an LCI dataset and its exchange compatibility

Aspect of data set	**Data exchange**	
	Sirii to ecoinvent	**ecoinvent to Sirii**
Name of technical system/unit process	1	1
Description of system content including significant system data gaps	1	1
Original practitioner/ Data generator	2	2
LCI/LCA reviewer/ Validation	2	2
Functional unit (short description, amount and unit)	2	1
Geographical coverage	1	2
Time coverage	1	2
Data representativeness and technology coverage / extrapolations and process information on technology	1	1
Data completeness and precision/ uncertainty adjustments	1	1
Original publication	3	1

Table 1 shows inconsistent results in the evaluation of data exchange for the significant aspects. For some aspects documented information may easily be exchanged without the loss of significant information, for other aspects some underlying documentation fields need to be modified in order to make data exchange possible.

For the specific aspects the differences in the documentation formats are mainly characterized by one of the following:

- One format holds an extra documentation field for which there is no homologue in the other format. This may imply difficulties to exchange data without loosing significant information and calls for a minor modification, e.g. in the form of adding a extra field to the other format, in one of the formats to reach compatibility.

- One format holds two or several documentation fields for specific information, whereas the other format holds one field that is intended to contain the same information. Again, this obstacle is fairly easily over won either by adding one or several extra documentation fields to the appropriate format or by adding specific instructions on how information should be documented in the single documentation field in order to allow for a split of the information when exchanging it to the structure with two or several fields.

In summary, the aspects of meta information that are considered important are the same for both formats. This is a good start! In the way of a successful meta data exchange stands a few obstacles that may be over won by modifying one of the two formats. The two following paragraphs show examples for each of the two differences; (i) “practitioner/generator information” as a case of the first point, (ii) “publication” as a case of the latter point mentioned above.

Practitioner/Generator information

The problem here is the fact, that both of the formats contain one specific field (EcoSpold the field “country code” / Sirii SPINE “comments”) that has no homologue in the other format – thus making it difficult to transfer the information documented in these respective fields to the other format.

Publication:

This part of the descriptive information is the most difficult part concerning the data exchange between the two examined formats. Main reason for this is the fact that in Sirii SPINE the whole information is stored in just one comment field, while EcoSpold contains a couple of different, very specific fields concerning the publication behind the respective dataset. Thus, while the exchange from the Swiss to the Swedish system is possible without the loss of any information (but with the loss of the structure within this information), an exchange the other way round is much more difficult.

4.2 Allocation topic

A topic on the border of the descriptive information and the flow data is the topic of “allocation”. While in the Swedish system it is clearly part of the descriptive part, in the Swiss ecoinvent database, such information is part of the flow data. This is maybe one possible explication for the differences between the fields about this subject in the two examined data formats (see table 2).

Both formats hold fields to document (format specific) default answers as well as a text/comments sub field on the method of allocation at a unit process. But with this, the compatibility on the subject is already complete. Furthermore Sirii SPINE contains fields for information on allocation rules for material recycling as well as system expansions, for which there is no equivalent in the database ecoinvent. This is due to the fact, that the ecoinvent philosophy (i) doesn’t use any types of benefits for materials that are recycled and thus, has no need for respecive specific rules, and (ii) has been developed for the documentation of LCI data on a unit process level – thus avoiding the possibility for an expansion of any kind of system.

All in all, the Sirii SPINE structure may be described as a format containing an overall, qualitative approach on the documentation of methods of allocation. Ecoinvent, due to the fact that it contains datasets on a unit process level, has not only qualitative information about the respective allocation procedure, but also quantitative data in the sense that allocation factors are applied to each specific flow.

4.3 Comparison of the flow data exchange

Having a look into the two examined data(exchange)formats shows for both cases also in the case of the actual flow data different fields that have to be filled in. Again, these different aspects have been listed (see table 2) and the respective exchange scores (according to chapter 3.2) established.

Table 2. Important aspects in the flow data of a LCI dataset and its exchange compatibility

Aspect of data set	Data exchange	
	Sirii to ecoinvent	ecoinvent to Sirii
Inputs (resources)	3	2
Inputs (technosphere process)	1	1
Output (emissions, waste)	2	2
Output (product(s))	3	2
Uncertainty information	-	3
Allocation	3	2

From table 2 it is obvious that the exchange of the flow data results in much more loss of information compared to the above described descriptive information. Apart from the inputs from technosphere, no other aspect examined got the score “1” for either of the two directions. This is mainly due to the differences in the philosophy that is behind the respective system. The two systems can therefore be characterized as following:

- Ecoinvent: The general methodology doesn’t take into accound recycled materials (cut off rule applied). All exchanges with nature are not only distinguished in the usual compartments (resources, emission to air water soil), but each of these compartments is further subdivided (e.g. emissions to air are divided into: low population density, low population density long-term, high population density, upper stratosphere and troposphere, unspecified). Each number contains not only the mean value, but also a quantified uncertainty indication.

- Sirii ED Network: Fields allows application of other rules than “cut off” for recycled materials. For exchanges with the nature only the usual compartments are distinguished. Further flows (Input of residues, intermediate emissions, exploitative impact, resource consumption) are included. The documentation of uncertainty information is not foreseen.

In summary, these differences in the philosophy or methodology of the two data(exchange)formats leads to the fact that it is very very difficult for a Sirii SPINE dataset to be integrated into the EcoSpold format without additional information as well as the loss of parts of the information. The other way round, it is less the problem of how to integrate the data, but the fact that the sub-compartment information is lost, resulting in the above shown score.

4.4 Effects on the data quality

According to all the points mentioned in the chapters before, there is no possibility in the present form of the two data(exchange)formats to transfer data between the database ecoinvent and the Sirii ED Network without the loss of at least part of its information. Thus, this implies also a loss in quality of the data due to fact that the integrality of the information can not be exchanged.

The Sirii SPINE format is mainly intended for the documentation and exchange of environmental data , and therefore contains a lot more of comment (means free text) fields. Thus, it is easier to include additional information from an EcoSpold dataset into the Swedish format than the other way round. Nevertheless, such an integration affects the quality of the data as e.g. an integration of the uncertainty information in an ordinary text field results in the loss of the relation of this information with the flow data of the dataset. This means that an exchange of such a dataset back into EcoSpold results in a different, less detailed dataset compared with the original EcoSpold dataset (e.g. the uncertainty information of the flow data is lost).

On the level of the actual flow data, the differences between the two examined formats are even more important. Here the translation from a ecoinvent dataset into the Sirii ED Network results in the loss of all information about the different compartments that ecoinvent distinguishes for the resources as well as the emissions, due to the fact that Sirii knows just one category each time. A sequence ecoinvent – Sirii – ecoinvent destroys thus all efforts of the Swiss Centre for Life Cycle Inventories concerning a more detailed presentation of e.g. emissions to air (by distinguishing the different sub-compartments). The other way round (i.e. Sirii – ecoinvent – Sirii) such a sequence doesn't lead to a decrease of the quality of the flow data, as ecoinvent has also a unspecified category in the different emission types. All this is not only a problem of different data(exchange)formats, but much more of the general philosophy used for the data collection and presentation – i.e. what types of emissions are taken into account, what rules are used for the nomenclature of the emissions, etc. But within the STSM representing the base of this paper, this topic hadn't been examined in details.

4.5 Ways for improving the compatibility

Having in mind a Pan-European LCI/LCA format for data documentation and exchange, our comparison shows that further efforts are necessary. All such efforts should fulfill the following requirements in order to lead to a common format:

- being for each single aspect based on the most detailed format so far established in Europe;
- taking into consideration possible differences in the philosophy behind the various formats / systems;

As mentioned above, besides that more general work on the level of the format, a lot of harmonization work has to be done also on another level – the general framework for LCI/LCA studies – e.g. concerning the naming of inputs and outputs. Although first efforts into this direction have been done by a SETAC-Europe LCA working group a couple of years ago [6], there is still a lot of open questions in this field. The main findings of the mentioned SETAC working group have been taken into account for the ecoinvent database. The Sirii ED Network on the other hand side is not actively establishing datasets, but more a collection point for such data – thus has less influence on the general methodology applied for the data. This is one reason that the comparison shows much more problems in the area of the flow data compared with the problems detected for the meta information.

5 CONCLUSIONS & OUTLOOK

This first comparison of two formats for LCA/LCI data documentation and exchange has shown that several common points exist between the formats.

If we exclusively consider the contents of the data documentation formats and exclude the fact that the systems were created for slightly diverging purposes we find that both formats, in one way or another, contain similar information. The aspects of meta information that are considered important are the same for both formats. This is a good start! In the way of a successful meta data exchange stands a few obstacles that may be over won by modifying one of the two formats.

On the level of the actual flow data, the differences between the two examined formats are more important. All this is less the problem of different data(exchange)formats, but much more of the general philosophy used for the data collection and presentation. All these discrepancies between the formats result in the loss of significant information, and thus the loss of quality, when attempting to exchange a dataset from one format to another. As long as there is no harmonization e.g. about how much of information is part of the name of an emission and how much of these information is part of separate fields within the format, it is very difficult to define the field structure of a common format. Thus, it is crucial for the further efforts of harmonization, that first all these open questions concerning the general framework (nomenclature, but also topics like allocation, benefits of recycled materials, etc.) are solved.

But all such efforts need strong coordination at a higher level, *at least* on European level. Possible starting points for the coordinated work in this area could be e.g. the working group "data base" of COST Action 530 – the framework for the STSM behind this comparison work here – or the EC's Joint Research Centre (JRC) efforts of Thomas Rydberg concerning a European LCI database initiative.

In a future step, a comparison of both formats with the ISO standard 14'048 shall be done. Due to the limited time frame of the STSM, it was not possible to do this important comparison so far. A first comparison of EcoSpold and ISO 14'048 has already been done by the ecoinvent team [7] – showing that in principle the Swiss format is in accordance with the ISO requirements, although there are a lot of further fields in the ISO 14'048 format due to the fact that this format is foreseen for a much broader use compared with the Swiss EcoSpold format. An in-depth examination of the influence on the data quality has not been established yet for the comparison EcoSpold – ISO 14'048.

5.2 Acknowledgements

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A APPENDIX

Figure A.1 fields within the meta information of the EcoSpoldformat (the "x" designs required fields)

Superior grouping	Second grouping	ID	Description	
PROCESS INFORMATION	Dataset Information	200	number	x
		204	timestamp	x
		201	type	x
		208	impactAssessmentResult	x
		202	version	x
		207	internalVersion	x
		203	energyValues	x
		205	languageCode	x
		206	localLanguageCode	x
	Reference function	400	datasetRelatesToProduct	x
		401	name	x
		404	amount	x
		403	unit	x
		490	local name	x
		493	infrastructureProcess	x
		495	category	x
		497	localCategory	x
		496	subCategory	x
		498	localSubCategory	x
		494	infrastructureIncluded	
		402	includedProcesses	
		492	generalComment	
	Reference flow	502	CASNumber	
		499	formula	
		491	synonyms	
		501	statisticalClassification	
	Geography	662	location	x
		663	text	
	Technology	692	text	x
	Timeperiod	601	startDate	x
		602	endDate	x
		603	dataValidForEntirePeriod	x
		611	text	
MODELLING AND VALIDATION	Represen-tativeness	726	extrapolations	
		722	percent	
		724	productionVolume	
		727	uncertaintyAdjustments	
	Source	801	number	x
		802	sourceType	x
		1002	firstAuthor	x
		1003	additionalAuthors	
		1004	year	x
		1005	title	x
		1006	pageNumbers	
		1007	nameOfEditors	
		1008	titleOfAnthology	
		1009	placeOfPublications	x
		1010	publisher	
		1011	journal	
		1012	volumeNo	
		1013	issueNo	
		803	text	
	Validation	5616	proofReadingValidator	x
		5615	proofReadingDetials	x
		5619	otherDetails	
ADMINISTRA-TIVE INFORMATION	Data entry by	302	person	x
		304	qualityNetwork	x
		751	person	x
	Person	5800	number	x
		5808	countryCode	x
		5802	name	x
		5803	address	x
		5804	telephone	x
		5805	telefax	
		5806	email	
		5807	companyCode	x
	Data generator and publication	756	dataPublishedIn	x
		757	referenceToPublishedSource	x
		758	copyright	x
		759	accessRestrictedTo	
		760	companyCode	
		761	countryCode	
		762	pageNumbers	

Figure A.2 fields within the meta information of Sirii SPINE (the "x" designs the standard fields)

Superior Grouping		Sirii field	Subfields	
TECHNICAL SYSTEM	1	Name		x
	2	Type of technical system	Default answers	x
			Comments	
	3	sector	Comments	
	4	geographi-cal site location	Company	
			MailAddress	
			EMailAddress	
			Name	
			Fax	
			Telephone	
			Comments	
	6	description system content	Comments	x
	7	significant system data gaps	Default answers	x
			Comments	
	8	owner	Company	
			MailAddress	
			EMailAddress	
			Name	
			Fax	
			Telephone	
			Comments	
CHOICES	9	intended user	Default answers	
			Comments	
	10	general purpose	Default answers	
			Comments	
	11	detailed purpose	Default answers	x
			Comments	
	12	commissioner	Company	
			MailAddress	
			EMailAddress	
			Name	
			Fax	
			Telephone	
			Comments	
	13	original practitioner	Company	x
			MailAddress	
			EMailAddress	
			Name	
			Fax	
			Telephone	
			Comments	
	14	LCI/LCA reviewer	Company	x
			MailAddress	
			EMailAddress	
			Name	
			Fax	
			Telephone	
			Comments	
	15	functional unit, short description		x
	16	functional unit motivation and explanation		
	17	system boundaries to the env. System	Default answers	x
			Comments	
	18	system boundaries in time	From date:	x
			To date:	
			Comments	
	19	geographical coverage	Default answers	x
			Comments	
	21	allocation rules for material recylcing	Default answers	x
			Comments	
	22	description of allocations at a unit	Default answers	x
			Comments	
	23	description of system expansions	Comments	x
	24	other system	Comments	

Figure A.2 (Cont.) fields within the meta information of Sirii SPINE (the "x" designs the standard fields)

Superior Grouping		Sirii field	Subfields	
METHODS OF AQUIRY	25	time period during which data was acquired	From date:	
			To date:	
			Comments	
	26	type of method		
	27	description of method		
	28	what represents data		
	29	references		
	30	further notes		
	31	data quality	Default answers	
			Comments	
RECOMMENDATIONS	34	data representa-tiveness	Default answers	x
			Comments	
	35	data completeness	Default answers	x
			Comments	
	36	data technology coverage	Default answers	x
			Comments	
	37	data precision	Default answers	x
			Comments	
	38	further notes are		x
	39	when data was completed	Date	
			Comments	
GENERAL INFORMATION	40	original publication(s)	Default answers	x
			Comments	
	41	SIRII documentation performed by	Name	x
			MailAddress	
			Telephone	
			Telefax	
			emailAddress	
			Company	
	42	SIRII review		
	43	availability	Default answers	x
			Comments	
	44	copyright		

FLEXIBILITY FOR APPLICATION. MARKET MODELLING IN LCI DATABASES

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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 CONCLUSIONS

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.

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IDENTIFYING KEY PRODUCTS FOR THE BELGIAN FEDERAL PRODUCT POLICY

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ABSTRACT: This paper presents lessons drawn from a study carried out by Institut Wallon and Vito (Flemish Institute for Technological Research) in 2002 that was aimed to determine which categories of products would be a priority for product policy development at the level of the Belgian federal Government. This was based on the identification of the key product groups, consumed yearly in Belgium, that contribute most substantially to the damages to the environment over their entire life cycle.

The paper addresses primarily the “life cycle approach” methodology that has been developed and followed in the study. The constraints, the problems encountered and issues on data availability, consistency and quality are described.
Briefly, the similarities and differences with other existing work in this field are looked at and currently ongoing and future work discussed.
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Keywords: *product policy, IPP, life cycle approach, consumption patterns*

1 INTRODUCTION

The importance of sustainable production and consumption patterns has been emphasised during the World Summit on Sustainable Development held in Johannesburg in August 2002. This summit resulted in an Implementation Plan, which specifically recommends to *"Develop production and consumption policies to improve the products and services provided, while reducing environmental and health impacts, using, where appropriate, scientifically based approaches, such as life-cycle analysis."* Integrated product policy (IPP) is a new kind of policy that precisely targets production and consumption patterns in order to orientate them towards a goal of sustainable development.

This new approach has been envisaged by the European Union and the Commission has issued its communication on Integrated Product Policy [1]. In Belgium, the Federal Plan for Sustainable Development (2000-2004) explicitly mandated the Product Policy Service to elaborate a Master Plan on Product Policy.

In preparing the Master Plan, the willingness of the Public Authorities was to direct the policy instruments towards the most relevant products and linked environmental problems. For this reason the Federal Public Service (Health, Safety of food chain and Environment - DG Environment) commissioned a study to IW and Vito, with the aim to identify the products consumed in Belgium with the highest environmental impacts as generated over their entire life cycle[2].

This study is an illustration of the use of LCI data and of the implementation of a life cycle approach for the policy-making decision.

With this respect it is important to underline the fact that the study was undertaken and followed by an advisory board including different persons from the public administration. This enabled to make the study evolve towards transparent and understandable conclusions for the policy process. Transparency was ensured both in the presentation of the methodology and in the limitation of the analysis.

This papers briefly presents the methodology followed in that study and points out the main difficulties encountered. Then it compares the study with similar studies carried out in other countries and for the EU.

2 METHODOLOGY

Consistently with the approach of the product policy, the method implemented in the study was based on a life cycle approach. It was also oriented towards the precise concept of product category as defined in the Law on product standards adopted in Belgium in 1998 as "*a group of products that are intended for the same use (thus perform an identical function)*".

In order to fully meet these preconditions, clear scope definitions have been developed in the beginning of the study. They concerned the environmental impacts to be considered, the definition of products and the definition of the product system boundaries to be considered for a life cycle inventory of environmental input and outputs flows.

The **environmental problems** considered in the study were determined in such a way as to reflect the priorities defined in the four policy levels, i.e. the multilateral level, the European Union level, the Belgian Federal level, and the Belgian Regional levels.
This means that we considered :

- resource use (raw material, energy, water)
- emissions to air (greenhouse gases, acidifying substances, photochemical substances, organic persistent substances, ozone depleting substances, heavy metals)
- emissions to water (chemical demand in oxygen, heavy metals, eutrophying substances, organic persistent substances).
- Waste

Waste has been considered in the analysis as being the cause of impacts on biodiversity and health. The result on waste is based on the concept of “ultimate” or final waste going to landfill, after treatment (thus not following the European definition of waste).

Nevertheless, evaluating environmental impacts is a difficult task as it is subject to a high level of uncertainty. Indeed, it implies to evaluate the impact pathway of environmental fluxes first in terms of concentrations in the different media (air, water, soils) and then in terms of environmental damages (in terms of damages to human health and to loss of biodiversity). It was not possible to make this complete evaluation within the scope of this study. Instead we have limited the analysis to the quantification of the different flows from and to the environment as aggregated and expressed in proper equivalencies. For instance, we have quantified greenhouse gas emissions as expressed in terms of CO2 equivalent.

Regarding the **definition of products**, we sought to refer to the legal definition in the Belgian federal law on product standards, as : *“all physical movable goods and services that are brought on the market for private and/or public consumers”*: However this definition posed two main problems. Firstly, such a definition includes all that is man-made, traded on the Belgian market, ranging from a bolt, a battery, a sawn tree log, a paper napkin… to a process machine, a car, an airplane, an office building… Given the available time and budget for this study, we needed a more pragmatic definition and selection of products. Secondly, this definition would have led to impacts double counting as long as a life cycle approach was used.

As a result, we built a product list using the concept of “final products”, defined as “*products that require no additional transformation prior to their use by end consumers, either industrial or household*”. The list was organised into several levels : function classes (corresponding to consumption clusters), product categories (groups of final products that are intended for the same use; at this level the functional unit is defined), and final products. We also defined consumable and spare parts as intermediate products or materials that are used during the lifespan of a product.

For practical reasons, buildings (industrial or household) were not considered as final products, but rather the building components they consist of. Packaging was not allocated to the final products they actually pack, but was treated as two separate function groups: “industrial packaging” and “household packaging”.

Food products were not considered in the study because the Belgian product policy doesn't cover this category.

Function CLASS	***Remarks***
Building structure	*Related to construction of building*
Building occupancy	*Related to living (houses) or working (office buildings, production plants…)*
Furniture	
Electrical Appliances	*EEE related to food preparation and storage, laundry, bathroom, DIY tools*
Information & Communication	*ICT equipment and traditional information carriers (paper books, newspapers etc…)*
Leisures	*Includes audio- and video equipment, computer games, photography etc…*
Healthcare & Detergents	
Transport	Only passenger cars considered (no public transport or transport of goods)
Garden	Garden furniture, garden tools…
Packaging	*Considered as the final products*
Textile & Footwear	Besides clothes and footwear also housetextiles, bags/sacks etc…

Then we sought to define the product system boundaries in such a way as to meet two divergent constraints : on the one hand the time and budget for the study were such that it wouldn't have been feasible to perform complete and detail life cycle inventories for all products in the list. On the other hand, producing results with a sufficient level of relevance for the policy decision on key products, required to make scientific sound based decisions.

For this reason we defined the product system boundaries in a way that would guarantee that for the larger set of products, the larger fraction of environmental releases are accounted.

This was done by taking into account the following life cycle stages :

- the mining of resources and the manufacturing of all the materials that entered the final product composition (including the production of secondary materials), these two stages form the *production phase* ;
- the *use stage* of the product ;
- the *disposal stage* of the product (waste treatment processes such as landfilling and incineration).

On the opposite we did not take into account : the material forming stage (e.g. blow moulding); the product assembly stage (because data were not found for this stage) ; the distribution stage of products to end users.

Regarding inputs, the Life Cycle Inventory was second order; including material and energy flows, not accounted are infrastructure and auxiliary process materials.

3 DISCUSSION OF PROBLEMS ENCOUNTERED

The methodology used for the study was dependant on a large set of data of different types. This required to consult and use, for each of data type, different sources and in some cases, to make own estimations :

- For consumption data national statistical data, extrapolated EU-wide statistics to Belgium, and product-specific reports (packaging, cars) were available.
- For the product material composition : scattered published LCA studies and product-specific reports completed with rough estimates

- Product Lifespan we generally estimated
- LCI data : public databases such as BUWAL, APME, ETH, and commercial databases IDEMAT 2001, IVAM LCA DATA 3.0, ..etc.
- Waste treatment scenario's for disposed products were based on data from regional waste programmes and activity reports.

The conclusion of the data collection was such that we were able to derive quantitative results for the following environmental impacts : energy, raw materials, greenhouse gases, acidifying and photochemical substances emissions to air, oxygen depleting substances to water and waste.

3.1 Uncertainty on quantified emissions

A sensitivity analysis was made to evaluate the uncertainty of the results as stemming from the uncertainty on the basic data used (consumption, composition, emission factors). It led to the conclusion that the uncertainty is far from negligible as confidence intervals were expected to range from more than half to twice the estimates.

As a consequence results had to be interpreted as **orders of magnitude** and not as absolute levels of impacts.

3.2 Non quantified input and output flows

Besides the environmental flows quantified we failed to find reliable data to quantify the others ones (ozone depleting substances, heavy metals to water, organic persistent substances to air and water). An other limitation resulting from the methodological choice, especially to neglect the manufacturing (assembly) phase.

Persistent organic pollutants were impossible to quantify for two reasons. First, this substance family covers a wide range of molecules, e.g. pesticides, dioxins. For instance, 12 groups of molecules are targeted by the Stockholm Convention, 19 by the Aarhus Protocol, but persistent organic pollutants not covered by these two conventions and are being studied by the UNEP. In fact, as for toxic chemicals in general, the persistency of chemicals is not fully assessed yet. Second, given the large number of substances involved, the databases which where used to quantify emissions to air and water are not sufficiently exhaustive and consistent between each others.

The reliability of data found for **ODS and F-gases** emissions is low for two reasons : first data relate to a limited set of substances while ODS represent a large array of substances. Second, and probably most important, a large part of the emissions of ODS occurs in the use phase of specific products. Databases that were used didn't provide corresponding emission factors.

In addition, available data do not reflect the evolution over the last years with respect to the use of those substances. Indeed, as a consequence of the Montreal Protocol and its subsequent amendments, some substances (CF4) are completely forbidden. Others are being phased out and replaced by alternative substances. Some HCFC are being substituted by non chlorinated fluorinated substances (HFC). Hence there is a close link between these two types of substances when attempting to evaluate their emissions.

Among greenhouse gas emissions that we could quantify we included emissions of PFC resulting from the aluminium production and of SF_6 from magnesium production. On the opposite, it was not possible to find out emission factors for PFC from semi-conductors production. The same difficulty is valid for HFC emissions.

Emissions of **heavy metals** to air and water couldn't be quantified reliably neither. Indeed, only some of these metals are considered in LCI databases. It is also acknowledged in general that current national inventories on heavy metals emissions suffer from high uncertainty. This is due to the same reason for lacking or uncertain data in LCI database, i.e. difficulties to derive reliable process emission factors.

4 COMPARISON WITH OTHER STUDIES

Prior to the Belgian product prioritization study, in several other European countries similar studies have been executed a.o. for the Swedish Environmental Protection Agency, performed by Statistics Sweden [3,4]; for the Danish Environmental Protection Agency, performed by COWIconsult A/S [5]. In parallel with the Belgian study, the EC's DG Environment commissioned a study on the external environmental effects related to the life cycle of products and services, this was performed by O2 France and BIO Intelligence Service [6].

4.1 EU, Danish, Belgian studies - life cycle approach

The EU, Danish and this Belgian studies use a very similar life cycle approach. The same issues seem to be tackled during the process such as developing an operational definition of products, developing a product list and linking this with existing statistical information available on consumption, estimating product compositions, use aspects and disposal treatments.

The differences in results are mainly caused by differences in product definitions and (not)accounted products. In the Belgian study, only final consumption is considered, because most consumption by industry is considered as an intermediate process step in final product systems. Also, food and industrial transport were not in the scope of the project. The Danish study also considers supply to industry and no clear distinction is made between final products and intermediates.

Also, the "endpoints" or parameters by which the environmental load is determined, differ in all studies which has consequences for the ranking. Only the European study uses a method to aggregate the different impact categories, the other studies consequently have different ranking lists, because no aggregation of the different parameters takes place.

4.2 Swedish study – expanded input-output analysis (IOA).

This "bottom up" life cycle approach is quite different from the approach used in the Swedish study: these results have been achieved by the use of expanded input-output analysis (IOA). Extended Input-Output Analysis is a tool for environmental analysis of broad classes of sector activities, taking into account indirect effects in other sectors "in the life cycle". It has been used as a "top down" approach to organize all the production that is needed in order to provide for the consumption/use of products in Sweden. Consequently, the study is 'consumption' oriented, but uses statistical (national) 'sector' oriented data to model these impacts. Due to this, environmental impacts from processes are (probably) underestimated due to globalized product chains and different production processes applied abroad. The impacts during the use phase and the waste phase are not accounted since it can not statistically be connected to the sectors/product groups. This is also the main reason why i.e. cars or energy consuming household products are missing from the priority list; because they have their main impacts during the products use phase. The same is true for products having their main impacts during the waste phase, such as packaging.

Method	**Life CycLife cycle stages**	**Country**	**Endpoints / parameters**	**Scope Products**
Input-Output analysis	Cradle to 'final demand' gate (no use and waste phase)	Swedish	CO2, NOX, SO2, fuel and electricity use, use toxic chemicals *(no aggregation)*	Consumed products. Sector-oriented product list
"Bottom up"	Production, Use, Disposal	Danish	Loss of resources, energy consumption *(no aggregation)*	Consumed products (households + industry). "Industrial products", some semi-manufactured
		EU	External Costs *(aggregation)*	Consumed products (households), Dual product list: 1 sector-oriented, 1 final product systems
		Belgian	Resource use, Energy use, 3 impact categories related to airborne emissions, 2 to water emissions, waste *(partial aggregation)*	Consumed products (households). "Final product systems", some intermediates

Figure 12 : Comparison of different studies (method)

	Results
Swedish	(No individual ranking) - Petroleum products - Electricity, gas, steam, hot water - Buildings - Home sale and retail trade - Real estate activeness - Food and drinks - Land transports
Danish	Complete ranking: 1. Coal 2. Oil for combustion 3. Petrol 4. Natural gas 5. Ocean-going cargo ships 6. Compression-ignition engines …
EU	i.e. for global warming: 1. Building occupancy domestic 2. Personal car 3. Building occupancy commercial 4. Goods transport 5. Domestic appliances 6. Food from animals …
Belgian	See Figure 1,2

Figure 13 : Comparison of different studies (results)

4.3 Conclusions

All studies mentioned do not depict the environmental impacts of exported products. On the other hand, in the current globalized economy, the gross part of the life cycle emissions of consumed products are imported. This means that reductions in life cycle emissions due to product policy will not necessarily results in substantial national impact reductions. This raises some questions on the environmental goals that can be achieved by implementing a product policy.

A need exists for a harmonized and consistent product list and an operational definition of 'products' for this type of product studies.

Reasonable arguments exist why some intermediates should be considered separately in these studies i.e. packaging, consumables, building materials… Policies at the level of intermediates, rather than at the level of final products could be more effective and already product measures exist at the level of intermediates (i.e. packaging).

IOA is an interesting approach because of the clear link between product groups and sectors. On the other hand; the disadvantage is the limited geographical system of national IOA-tables. There is a need for a Europe-wide input-output table with environmental extension as a basis for practical applications, certainly when production and supply of products are globalized. Another disadvantage is that the production, use and waste phase of a consumed product group cannot be considered in one system, avoiding a holistic 'life cycle approach', neither are all impact categories considered. This should also be integrated in IOA-approach.

5 FUTURE WORK

Life cycle analysis has enabled to identify key final products in Belgium for the product policy in the country.

A step further which is now part of our studies is to analyse in detail the key product categories with the aim to identify the most promising measures in the framework of a product policy. To do that we are now implementing a life cycle approach, both to analyse impacts in more detail and analyse improvement strategies that could act simultaneously in such a way as to cover all the life cycle stages of the products. First conclusions from the project will be available by end of 2003 and final conclusions by end of 2004.

6 CONCLUSIONS

The Belgian study on the identification of key products for the Belgian federal product policy undertaken by IW and Vito enables to learn different lessons concerning the use of life cycle analysis in support to the policy making decision.

The close interaction between researchers and representative of the Government revealed extremely important as a way to guarantee that the study leads to operational conclusions as well as transparency regarding, the method, the results and their interpretation.

Existing LCI database provide a large set of data on process emission factors and enabled to derive significant results for the study. Based on these data as well as on other types of data, the bottom-up approach implemented in the study enabled to identify product categories having the highest impacts regarding a series of environmental impacts.

Emissions of Pollutants like POP's, ODS and heavy metals are more difficult to evaluate because of the lower quality level of LCI data.

In general, continuous improvement of quality and comparability of LCI data crucial for the development of analytical tools for the product policy if the analysis

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PROBLEMS OF DATA ACQUISITION AND QUALITY FOR ELECTRONIC PRODUCTS AND PROCESSES

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ABSTRACT: Eco-Design in the electrical and electronics industry is complicated by short product and process innovation cycles, complex product composition, and very large supply chains. The assessment of environmental impacts of products and processes has to be suited to these specific needs. Our experiences show that there are several traps considering the creation of product or process data inventories. Two problems are demonstrated using case studies: (1) Depending on the manufacturer, tantalum capacitors of the same electric specification show great differences in material content. (2) Depending on the electric specification, the material composition of the tantalum capacitors of one manufacturer varies while carbon-film resistors show hardly any change. The overall conclusions from these examples are that existing or generic data for the assessment of electronic products and processes have to be used very carefully and in general lead to great uncertainties regarding the results. Data quality indicators have to be established to quantify and communicate these uncertainties. This is especially important for decision support in eco-design processes, as the uncertainty of the environmental assessment might be as high as the effects of possible design changes.

Keywords: electronics, data requirements, data quality, screening assessment, case study

1 INTRODUCTION

Generally, Eco-Design in the electrical and electronics industry is complicated by short product and process innovation cycles, complex product composition, and very large supply chains. The assessment of environmental impacts of products and processes has to be suited to these specific needs.

Main requirements therefore include fast compilation of new product and process data, easy data management especially for updates and revisions, and rapid environmental assessment results based on very few data. These requirements often conflict with the desire for reliable and trustworthy results; hence decision support is affected.

There are different approaches to meet the main requirements, mostly involving screening assessment and iterative methods:

- qualitative or half-quantitative assessment,
- "educated guesses",
- generic data-sets,
- cut-off criteria,
- simplified impact assessment,
- specific (internal) environmental performance indicators

The Fraunhofer IZM Environmental Engineering Toolbox is a set of screening assessment indicators especially designed for eco-design of electronic products and processes [1]. Depending on the needs for decision support, indicators with different fields of view are selected. In contrast to other life-cycle assessment methods, the IZM EE Toolbox does not aim at the quantification and impact assessment of elementary flows to and from the technosphere, but rather utilizes product and process related data, e.g. material composition of the product or mass and energy balances of manufacturing processes, to estimate potential environmental impacts connected with these data. In this text, the Toxic Potential Indicator is used to estimate potential environmental hazards caused by the material content of a product. The hazard potential evaluation of a substance bases on data from material safety data sheets like risk phrases (R-Phrases), maximum allowable workplace concentrations, and water pollutant classes.

Over recent industrial projects, our departments gathered experiences in screening assessment of electronic products and their manufacturing processes, employing several of the above mentioned methods. We have been able to build up a database covering a variety of electronic components. However, our experiences show that there are several traps considering the creation of product or process data inventories.

2 PROBLEMS REGARDING PRODUCT DATA OF ELECTRONIC PRODUCTS

Electronic products may consist of a vast number of components of different manufacturers. A typical example is the bill of materials of the Ericsson SH888 GSM Cellular Phone [2], comprising 588 electronic components – including 21 ICs from 10 different manufacturers.

It has to be stressed, that the environmental analysis of the supply chain and production of all components mostly has to be finished within a time-frame of half a year, as often product and process innovations come into effect after this time.

Hence, a way has to be found to quickly analyze product and processes so that the amount of data already existing and suitable for the assessment, e. g. in form of generic data sets, and the amount of newly required data can be determined.

In the following, two examples illustrate the difficulties connected with this problem.

Example 1: Tantalum Capacitors of different manufacturers

Depending on the manufacturer, tantalum capacitors of the same electric specification show great differences in material content.

The general assembly of tantalum capacitors is shown in figure 1. The capacitors are grouped in case code series, in dependence of capacity and voltage area. Figure 3 shows different screening toxicity assessment results for three of the case codes. Critical materials are tantalum, nickel and silver, and in the case of manufacturer A's capacitors additionally antimony.

Though the fulfilled function is the same, there is great difference in the toxicity screening results between the capacitors from manufacturer A and B.

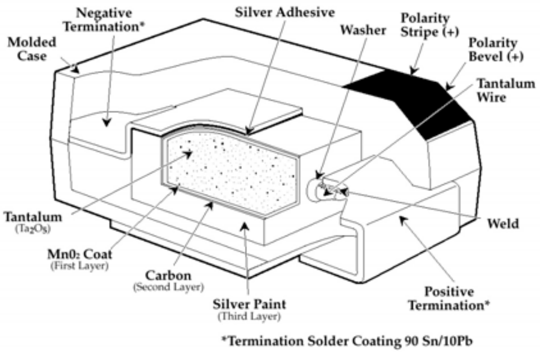

Figure 1. Schematic assembly of a tantalum capacitor [3]

Example 2: Carbon film resistors and tantalum capacitors of one manufacturer

Depending on the electrical specification, carbon film resistors show hardly any change in material composition while tantalum capacitors show varying composition.

The schematic assembly of carbon film resistors (figure 2) illustrates the working principle: the resistance depends only on the thickness of the graphite film with the skip scoring (5), the gage (3) and the width of the gaps (4). Due to the simple working principle, resistors from 47 to 4700 Ohm show hardly any change in geometrical size and material content.

In contrast to this behavior, the tantalum capacitors of one manufacturer show a greater dependency on the electrical specifications (see the first example, figure 3).

However, as a rule of thumb the material composition per manufacturer and case code could be estimated depending on the volume.

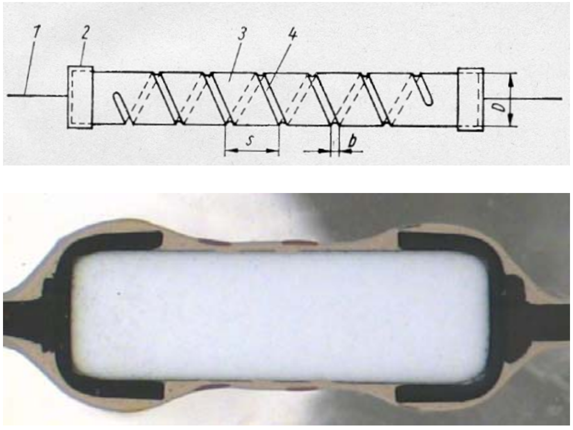

Figure 2. Schematic assembly and cross section of a carbon film resistor.

Conclusions from the examples in the context of generic product data inventories

The first example shows that even for standard electronic components manufacturers apply different technical solutions. For the generation of generic, component specific data, this implies the necessity of the compilation of the existing alternatives.

The second example illustrates that there exist some standard components for which generic data sets could be set up, while for others further data, like the electrical specifications, have to be known to select a fitting data set. Together with the first example it also shows that in some cases, like in the case of tantalum capacitors, rules of thumb might be identified to estimate material composition depending on this further data.

The overall conclusions from these examples are that:

1. Assessment of design alternatives in electronics requires detailed analysis of the bill of materials, as even material contents of standard components of the same electrical specification show significant differences.
2. Generic data sets and rules of thumb could be set up for *some* electronic components. However, data on the electrical specification and the manufacturer are needed for the selection of a fitting data set.

However, new practical questions arise from these conclusions: How are product and component data passed on along the supply chain? How are data quality information and requirements communicated?

The first question is currently discussed in context of the EU directives 2002/95/EC ("Restriction of the use of certain hazardous substances in electrical and electronic equipment", RoHS) and 2002/96/EC ("Waste electrical and electronic equipment", WEEE), as these require knowledge on the product material content to prove compliance with the restrictions on substances and for possible recycling pathways. A German standard is also in preparation [4].

The latter question will be discussed in the following section.

3 DATA QUALITY ASSESSMENT REGARDING ELECTRONIC COMPONENTS

As shown above, data on material content as well as technical, electrical, and geometrical parameters are necessary for the characterization of electronic components. For both data, quality has to be assessed. In the following, a proposition for a data quality indicator will be presented, basing on an approach by Philips Electronics, the SPOLD data format and work from SETAC [5], [6] [7]. The assessment bases on three columns: *reliability*, *completeness*, and *representativeness* of the data.

Data quality regarding material content can be divided into *reliability* and *representativeness* of single material data and the *completeness* of the overall component's list of materials. Reliability in this sense includes assessment of precision, statistical confidence, collection method, age of the data, and aggregations of single material data. Representativeness includes geographical, temporal, and technological scope of the data.

The completeness of the list is assessed regarding the coverage of data on all materials, suitability for the scope of the assessment, and completeness of the mass balance.

The list of other parameters should be assessed regarding its *representativeness* and usefulness for a unique description and identification of the component. The evaluation of this representativeness bases on the geographical, temporal, and technological scope. The technical and geometrical parameters are evaluated regarding their *reliability* and *completeness*. These terms are evaluated as described above.

Figure 4 gives an overview of the presented structure. The evaluation criteria for data quality parameters are shown in rounded boxes. The quantification method of these criteria varies, but results are always expressed on a scale from 1 (very bad) to 5 (very good). E. g., the value for coverage depends on the percentage of contained materials that have been actually analyzed: 99% = 5, 95% = 4, 90% = 3, less than 90% = 2, Uncertain = 1.

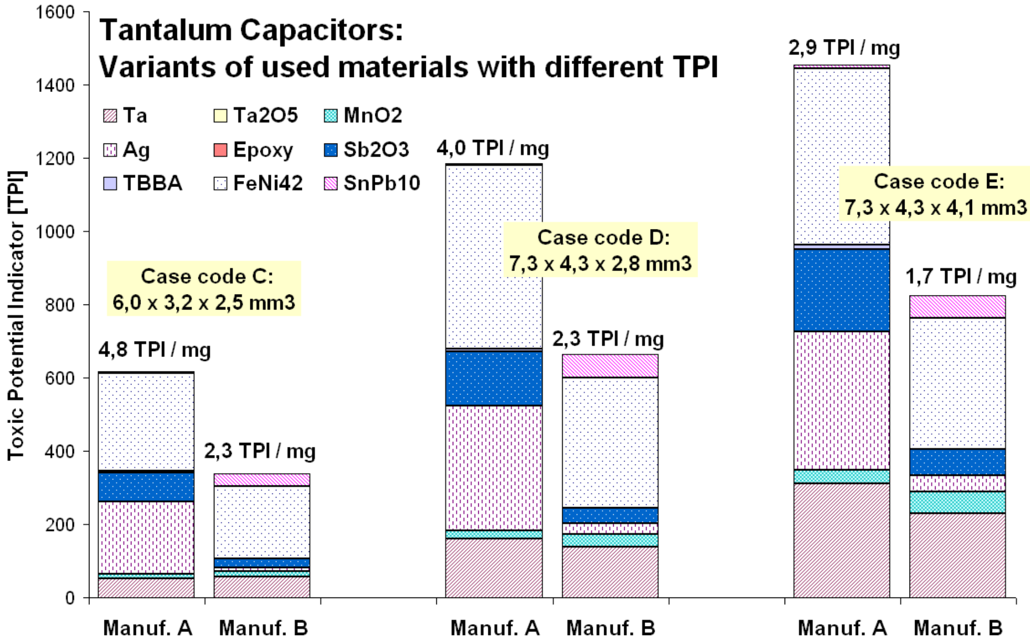

Figure 3. Screening toxicity assessment of three tantalum capacitor case codes of two manufacturers.

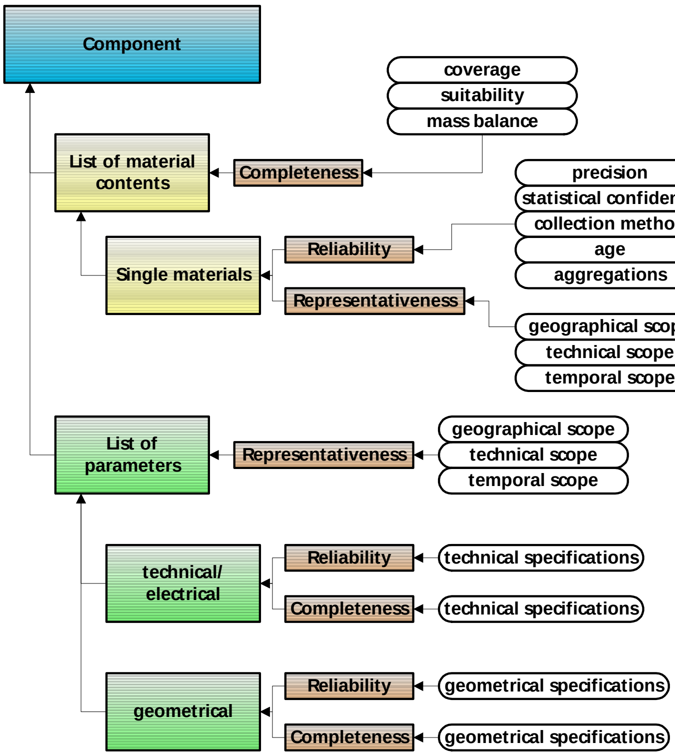

Figure 4. Structure for a data quality assessment regarding electronic components.

Hence, all criteria can be aggregated to data quality indicators, represented by the square boxes above. For example, the quality indicator for the reliability of the material list is the mean of the values for precision, confidence, etc. and can be combined with the quality indicator for the reliability of the parameter list to form the quality indicator for the reliability of the component's data.

This method supports the identification of data weak points and further requirements during simplified assessments on the basis of material content data. This is an important step to decrease uncertainty and to increase confidence when using assessment results for decision support in eco-design of electronic products.

4 CONCLUSION

Existing data or generic data for the assessment of electronic products and processes have to be used very carefully and in general lead to great uncertainties regarding the results. Data quality indicators have to be established to quantify and communicate these uncertainties.

This is especially important for decision support in eco-design processes, as the uncertainty of the environmental assessment might be as high as the effects of possible design changes; thus rendering no useful results. Pragmatic approaches and compromises between uncertainty due to the use of generic data and time-consuming acquisition of specific data will always have to be developed according to the situation and demands.

The upcoming efforts for a standardization of material declaration and supply chain management will be highly beneficial for life-cycle management. However, it is of vital importance to standardize data quality assessment methods and data quality criteria as well and to keep these methods scalable to the demands.

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DATA QUALITY ASSESSMENT METHOD FOR LCI-DATA OF THE DUTCH BUILDING INDUSTRY

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ABSTRACT: LCIA data from the Dutch MRPI® system, the EPD system of the Dutch manufacturers of building materials and products, are applied in LCA databases of software for building/construction calculations, such as Eco-Quantum. In view of the governmental initiative to standardise the LCA calculation method for buildings (which is however uncertain at the moment), the data quality has been identified as one of the most critical success factors for LCA. So far only little energy has been dedicated to the determination and assessment of data quality by the (international) LCA community. The MRPI foundation established a data quality assessment method for the LCI data used for MRPI®, based on existing methods. An approach is proposed for using the system within MRPI®, which will be tested in MRPI® practice in the next year. Furthermore, text proposals are provided to the Dutch standardisation organisation NEN, which should serve as input for the 'material based environmental profile for building' (draft standard NEN 7185, not published).

Keywords: data quality vs. transparency, integration of data with different appropriateness & quality

1 INTRODUCTION

The Dutch manufacturers of building materials and products (associated in the NVTB) developed an EPD system called Environmental Relevant Product Information (ERPI, in Dutch: MRPI). This system is implemented in 1999 and is managed by the MRPI foundation. One of the applications is to use the data in LCA databases of software for building/construction calculations, such as Eco-Quantum. In view of the governmental initiative to standardise the LCA calculation method for buildings (which is however uncertain at the moment), the data quality has been identified as one of the most critical success factors for LCA. The current manual for MRPI® requires a qualitative data quality description based on ISO 14040-41. A quantitative data quality assessment is regarded as essential for the MRPI® application.

So far, data quality assessment is not a hot topic in the international LCA community. Some systems are developed, but these are hardly put into LCA practice. Therefore, the MRPI foundation started a data quality project end of 2002, with the intention to establish a data quality assessment method for the LCI data used for MRPI®.

Goal of this project was threefold:

- to establish a system for a quantitative assessment of data quality of the (existing as well as newly collected) input data for LCAs of building materials and products (based on existing systems, adapted if necessary);
- to draft text proposals for the Dutch standardisation of the 'material based environmental profile for building' (draft standard NEN 7185, not published);
- to develop a protocol for using the data quality assessment system in the MRPI® system.

Two goals were defined for the application of the data quality assessment system in MRPI®:

- to make the quality of the data collected by the producer (the EPD owner) transparent;
- to make the quality of the LCA for MRPI® transparent in the discussions with the users of the MRPI®-LCIA data (such as the standardisation process and databases).

2 THE MRPI® SYSTEM

MRPI® is a so-called type III declaration. There is a MRPI® manual describing in detail how the LCA has to be carried out and how the content and lay out of the MRPI® sheet should be like. A third party review, according to an MRPI® procedure, must be carried out successfully after which the MRPI® logo can be used.

MRPI® is developed for manufacturers of building materials, products and elements. They take the initiative for the LCA. A cradle-to-gate (of the manufacturer) LCA is obliged; a cradle-to-grave LCA is allowed. The data from the producer have to be primary data. The other data can either be primary (from suppliers) or literature data.

In case of a cradle-to-gate LCA, the top-process is the process of the manufacturer. This can either be a unit process (in case of individual manufacturers) or a horizontally aggregated process (in case of branch LCAs).

The MRPI® manual [1] prescribes which data should be collected. Several checks are included to ensure a certain data quality. However, the data quality cannot be described quantitatively at the moment. This should become possible by a data quality assessment system.

The MRPI® datasheet contains information about the product and the product system studied in the LCA. The LCA results are presented as LCIA data (environmental profiles), according to the CML-2 method [2].

The LCA is reported in more detail in a separate report, which is subject to the review. Confidential (LCI) data are not reported but has to be documented in detail in case they have to be checked. If there are complaints, the MRPI foundation may do such a check.

3 APPROACH

The project is restricted to process data, i.e. (environmental and economical) inputs and outputs of a process. Modelling aspects, data treatment and calculation, such as goal & scope, system boundaries, allocation and impact assessment, are excluded.

3.1 Types of processes

Three types of processes are distinguished, in line with ISO 14048:

- *unit processes*
- *horizontally aggregated processes*
- *vertically aggregated processes*

The LCIA data on the MRPI® sheets concern a vertically aggregated process. The top-process of the manufacturer is either a unit process or a horizontally aggregated process, but is seldom presented separately.

3.2 Levels of process data

The following process data are defined:

- data *on substance level*: inputs en outputs: qualitative (name) and quantitative (value) description of environmental and economical flows;
- data on *process level*: process description, like the type of process and the whole of inputs and outputs;
- data on *system level*: data in their application (either a vertically aggregated process or a product system for an LCA).

3.3 Indicators

18 Data quality indicators were identified which could be important for the three type of processes:

- substance level: statistical representativity, source & verification, time-related representativity, aggregated substances (sum parameters), completeness, nomenclature;
- process level: completeness environmental flows, completeness economical flows, mass balance process, mass balance company, energy balance company, geographical representativity, time-related representativity;
- system level: geographical representativity, time-related representativity, technical representativity, uniformity & consistency, reproducibility.

3.4 Criteria

The approach was chosen to study existing data quality assessment systems first, and then decide if one of these systems is applicable for MRPI®. If not, the existing systems would be adapted. Six criteria were defined for the evaluation:

- the data quality system should be quantitative;
- it should make data quality transparent for data used in MRPI® and the Dutch standard for buildings (NEN 7185);
- the time consumption for the assessment should not exceed 10% of the time spent to data collection;
- producers should be able to apply the system to their own data (for other data: an LCA expert);
- a high degree of reproducibility;
- coverage of the identified data quality indicators.

4 EXISTING DATA QUALITY SYSTEMS

4.1 Types of data quality assessement

According to [3], the approaches for assessing the LCI data quality proposed during the last few years can be classified in two main categories:

- The first one uses a data quality indicator such as geographic representation, age of data etc.. A Pedigree matrix is used to quantify the data quality. The pedigree is an evaluative description of the mode of ‘production’. The pedigree is expressed by means of a matrix; the column represents the various phases of the production of information, and within each column there are modes, normatively ranked descriptions which are numerically graded.
- The second one represents the overall LCI quality in terms of uncertainty. The uncertainty of resulting inventory data of the system is obtained through the propagation analysis of uncertainties related to the raw data of each process.

[3] reports drawbacks of both methods. A drawback of the first method is that it does not provide a condensed index for overall quality of the LCI, but a set of quality scores. The second method is limited to only the uncertainty expressed by probability distribution or range of the inventory data and it does not take into account the other aspects of LCI quality. Results with a clear uncertainty analysis may have a low quality if the data used do not fit the objective of the study. Mixes of both methods are also developed to try to overcome these drawbacks.

4.2 Pedigree matrices

In our opinion, the most practical and applicable approach at the moment seems to be the Pedigree matrix. We studied and evaluated four existing systems:

- the ‘Pedigree matrix of Weidema’ [4];
- the ‘Pedigree matrix of Rousseaux et al’ [3];
- the ‘RIONED-procedure’ for quality assessment of LCA data for sewer pipes [5];
- the ‘AMPO-method’ for the assessment of data quality of environmental data [6], which is part of the Dutch draft Technical Specification (BRL) 5072 for insulation materials and roofing materials [7].

Furthermore, the results of the SETAC-Europe LCA Working Group ‘Data Quality and data availability’ [8], were studied.

4.3 Evaluation

We evaluated the methods on three aspects:

- *type of process that is assessed*
  All methods are suitable for the assessment of unit processes. They can also be applied to horizontally aggregated processes, although they are not specifically developed for it. The ‘Rousseaux matrix’, the ‘RIONED-procedure’ and the ‘AMPO-method’ include a calculation procedure for vertically aggregated processes. The calculation is a weighted sum of the data quality scores of the individual unit processes. It is interesting that Weidema mentions in [4] that Pedigree scores should not be regarded as representing ‘amounts’ and are

therefore not suitable for inter-comparisons and should not be added or aggregated.

- *indicators that are assessed*
  None of the four methods takes all identified indicators into account, but they include aspects that we excluded (like allocation and uncertainty calculations) or did not identify: 'representativity' for which the score is determined by being 'individual / branche / cluster' (the AMPO-method) and rules for the inclusion or exclusion of processes ('Rousseaux matrix' and 'RIONED-procedure'). The extra indicators were not convincing to us, so we did not adapt our list.
- *the level that is assessed (substance / process / system)*
  None of the methods explicitly discriminates between the levels. They comprise indicators on all three levels.
- *The criteria that were defined at the start of the project*
  Table 1 summarises our conclusions.

Table 1 Evaluation with regard to project criteria [9]

	Weidema	Rousseaux	RIONED	AMPO
quantitative	y	y	y	y
transparent	n[1]	n[2]	n[3]	n[3]
<10% time of data collection	y	n[4]	n[4]	n[4]
applicable by producers	n?	?	y	y
reproducible	n[5]	y	y	n
coverage	n	y	y	n

[1] No clear difference between unit processes and aggregated processes

[2] Vertically aggregated processes built up from unit processes

[3] Mainly for newly collected data. Aggregated processes built up from unit processes

[4] Probably high for aggregated processes

[5] Some indicators comprise more than 1 indicator. Several interpretations possible[4]

4.4 Conclusion

We concluded that the 'Pedigree matrix of Weidema' is relatively simple, but we were not happy with the reproducibility characteristics. The main drawback of the 'Rousseaux matrix' and the 'RIONED-procedure' is the time consumption and practical limitations (data quality of unit processes must be assessed first, and the unit processes are often not known in aggregated processes from literature). The 'AMPO-method' does not fulfil many criteria.

5 THE 'PEDIGREE MATRIX OF MRPI®'

The quantitative approach of the methods and their Pedigree score definitions were regarded as useful for our project. Therefore we decided to adapt the existing systems into a 'Pedigree matrix of MRPI®.

5.1 Characteristics

The adapted matrix has the following characteristics:

- separate matrices, but based on the same indicators, for unit processes, horizontally aggregated processes and vertically aggregated processes;
- distinction in substance level, process level and system level;
- the 'best' of the score definitions of the existing systems are copied. Some score definitions are adapted for use in MRPI® and NEN 7185;
- the assessment of vertically aggregated processes is based on consistency between the most important (qualitatively established) processes;
- including all identified indicators; no aggregations to come to one or a few score(s).

5.2 The results

The result are three Pedigree matrices (substance / process / system) per type of process (unit, horizontal, vertical). The description is very extensive. Part of it is shown as an example in table 2 at the end of the paper.

5.3 Cases

Cases were carried out by producers and LCA experts to test the 'MRPI® matrix' together with existing systems[5]. In spite of the extended matrices (more extensive than others but necessary in our opinion), the time consumption was limited (ca. 1-2 hours per data set) and regarded as acceptable. The testers experienced the differentiation of indicators and the resulting reproducibility as an important advantage over existing systems. Furthermore, the distinction into unit / horizontal / vertical processes was also regarded as positive with regard to interpretation.

Possible disadvantages of the 'MRPI® matrix' are the extensiveness and the fact that it is not (yet) internationally known.

6 APPLICATION IN MRPI®

6.1 Choices

The MRPI Foundation discussed the pro's and contra's of the four existing methods and the 'Pedigree matrix of MRPI®'. It was decided to start a pilot test in 2003 – 2004, in which MRPI® owners can test the new matrix for their own MRPI®. As a minimum, the system level must be applied for the vertically aggregated process (the MRPI® in fact) and either the unit process (individual producers) or the horizontally aggregated process (in case of branch MRPI®). It is recommended to apply the substance and process level, too. On the one hand you must know part of it to assess the system level, and on the other hand the MRPI foundation wants to know the experiences with these levels. After 2004 it will be decided which levels will be obliged to assess and if and

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[4] Our experience, although Weidema report that differences in interpretations are <10% [4]

[5] the 'Weidema matrix'and the 'Rousseaux matrix' were tested; there were not enough testers to include the RIONED and AMPO methods

how the data quality will be expressed in the MRPI® documents.

6.2 Review

The data quality assessment will be part of the MRPI® review. The assessment will be reported, except for the assessment on substance level (LCI), since this is confidential information. Suggestions are made to overcome this problem, but it will be decided after the test period how to deal with it.

6.3 Presentation and requirements

It is not sure yet if the data quality will be expressed on the MRPI® datasheet. It could be a possibility that the data quality is used for reviewing and/or data transfer only. Misuse, e.g. other parties using data quality requirements, should be avoided

Minimum data quality scores will not be required in the near future. The data quality assessment is developed for transparency reasons, not for strict requirements. However, on the longer term, requirements might be useful for rewarding the MRPI® logo, or in data transfer.

7 APPLICATION IN DRAFT NEN 7185

NEN 7185, the method for LCA of buildings, is based on requirements for unit processes. If requirements are not met, correction factors should be applied.

The manufacturers of building materials perceived this approach as not practical.

First drawback is that the data quality requirements are very strict. In terms of the developed data quality assessment method, the requirements are high. By using the ‘Pedigree matrix of MRPI®’, data quality requirements are easier to discuss, since it makes clear which options exist.

Secondly, the correction factors are regarded as time-consuming and sometimes not well argumented. The correction of non-complete environmental flows, for example, is based on a ‘√ formula’, but why a √ is chosen, is not clear. By using requirements for the Pedigree scores, correction factors could be avoided.

Text proposals to use the ‘Pedigree matrix of MRPI®’ in the text of the standard, are drafted. Requirements for the Pedigree scores are not suggested, but have to be established by the standardisation commission.

During the project, the standardisation process was stopped. It is unclear if the standardisation will continue, and if the text proposals will be used.

8 CONCLUSIONS

- Data quality systems for unit processes exist and can be applied, either modified or not, for unit processes and ‘top-processes’ in MRPI®. This implies for MRPI® that the data quality of the producer (owner of the MRPI® datasheet) is expressed explicitly instead of the current implicit requirements in the MRPI® manual.
- There are no data quality systems specifically for horizontally aggregated processes. This is developed within this project, to be applied to branch MRPI®.
- Data quality systems for vertically aggregated processes do exist, but they are not practical and time consuming in MRPI® practice. A data quality system is proposed, based on the systems for unit and horizontal processes, but with a more global character. This can be applied to an MRPI® dataset.
- During a test period it should be clear if the ‘MRPI® matrix’ is indeed practical.
- International discussions are welcome to optimise the method.

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More information: www.mrpi.nl

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Table 2 Part of the ‘Pedigree matrix of MRPI®’ (process level horizontally aggregated processes) [9]

PROCESS LEVEL HORIZONTALLY AGGREGATED PROCESSES						
To be assessed		The total of inputs and outputs (economical as well as environmental flows, except for the final product) as an average of a horizontally aggregated process				
Apply to		A process that is presented as a group average of a similar processes from different production locations				
Indicator	**Pedigree score**	**1**	**2**	**3**	**4**	**5**
COMPLETENESS						
Completeness environmental flows (NB: specific for the Dutch situation!)		All environmental flows from the LCA-2 guideline* have a value	All environmental flows that can be expected have a value	Some environmental flows that can be expected are missing, but it is expected that their relevance for the environmental profile of the process is limited	Some environmental flows that can be expected are missing, and are regarded relevant for the environmental profile of the process. Or the relevance is not known beforehand	Missing environmental flows are unknown
	Example	Value can also be zero (measured, calculated or based on arguments).				
Completeness economical flows		All input and output flows are qualified and quantified	All input and output flows are qualified. The flows that are expected to be relevant for the environmental profile of the process are quantified	All input and output flows are qualified. The largest mass and energy flows are quantified	The flows for which data are available are quantified	The completeness of the flows is unclear or unknown
	example	Flows = energy, waste. E.g.: Each additive is mentioned together with its amount.	Additives, comparable to the main product regarding production process and composition, are not quantified. Emission of water not quantified			
Mass balance on process level		>95% complete	90-95% complete	80-90% complete	70-80% complete	<70% complete or unknown
	example	Mass balance = ratio between the total mass of (raw) materials going into the process and the total mass of products+emissions+waste				
Mass balance on company level		The companies that represent >80% of the total production volume, have a mass balance per company that is >95% complete	The companies that represent >80% of the total production volume, have a mass balance per company that is >90% complete	The companies that represent >80% of the total production volume, have an expected mass balance per company that is >80% complete	The companies that represent >80% of the total production volume, have a mass balance per company that is >70% complete	The companies that represent >80% of the total production volume, have a mass balance per company that is <70% complete or unknown
	example	Mass balance = ratio between the total amount of used (raw) materials and the total mass of products+waste+emissions (purchase/selling, corrected for stocks)				
Energy balance on company level		The companies that represent >80% of the total production volume, have an energy balance per company that is >95% complete	The companies that represent >80% of the total production volume, have an energy balance per company that is >90% complete	The companies that represent >80% of the total production volume, have an expected energy balance per company that is >80% complete	The companies that represent >80% of the total production volume, have an expected energy balance per company that is >70% complete	The companies that represent >80% of the total production volume, have an energy balance per company that is <70% complete or unknown
	example	Ratio of the sum between the energy used by individual processes and the total energy consumption				

REPRESENTATIVITY					
Completeness of sites / geographical representativity	All companies in the group collected data for the LCA	A representative part of the group with regard to geographical differences of flows (e.g. transport distance, influence of temperature, differences in legislation). Different companies are equally (or weighted) represented in the average value	Part of the group that represents geographical differences	Random part of the group	Geographical differences not taken into account
Completeness of sites / technological representativity	All companies in the group collected data for the LCA	A representative part of the group with regard to `technological differences. Different companies are equally (or weighted) represented in the average value	Part of the group that represents technological differences	Random part of the group	Technological differences not taken into account

***** Handbook on Life Cycle Assessment. An operational guide to the ISO standards. Edited by Jeroen B. Guinée, CML, April 2002, Kluwer Academic Publishers, Dordrecht

INDUSTRY REQUIREMENTS ONTO LCI/LCA DATABASE

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ABSTRACT: LCA may be a powerful tool for industry to develop more eco-efficient products. However is the actual scientific detailed discussion about more sophisticated and complex models not very useful for industry practitioners. Beside an easy to use LCA the inclusion of costs is an essential measure to increase the utilization of lifecycle thinking in industry. This paper shows therefore the influence of different input data compared with different calculation models.

1 INTRODUCTION

Most of the big global acting companies have own internal experience and working groups which deal with LCA related topics. Some of these multinational companies do only monitor the international and scientific development of LCA whether it could influence their core business. Others have own LCA practitioners who are creating LCA-results for inhouse decision makers often for R&D. The BASF approach is to include LCA combined with costs into all relevant decision processes. Beginning with the R&D of new products, the investment decision, the marketing and the decision concerning political framework, the BASF tool eco-efficiency-analysis is widely used. Up to now more than 190 eco-efficiency analyses had been done for about 140 internal managers and about 50 externals. Within these externals a lot of BASF SME-customers were involved in these analyses. SME´s do not have the possibility to create own expertise in LCA. They normally use external consultants.

2 EXPECTATIONS AND NEEDS OF INDUSTRY MANAGERS CONCERNING LCA

Industry managers are used to make their decisions in combining different expert assessments. Normally these assessments are financial, technical, market and site related. Each of the experts has to give a well defined statement with concrete numbers and an overall assessment with clear recommendation. The inclusion of LCA results into decision processes must follow these regulations. The requirements for an broudly acceptable LCA tool are therefore.

- Quantitative results with a clear assessment
- Simple and impressing illustration of the results
- Scenario- and sensitivity analysis
- Short timeframe (2 month)
- Low costs for the analysis (<30.000 €)
- Combination of LCA with LCC

All of these requirements have to be fulfilled in order to disseminate LCA thinking in a big company. The board commitment is necessary in the initial stage of implementing the LCA program but it is absolutely not sufficient for a broad further use.

3 IMPLEMENTATION OF THE NEEDS INTO A LCA-PROCESS

To fulfill these needs of industry managers (which are nearly the same of politicians) BASF has developed the eco-efficiency tool in 1996. This tool combines a scientific based LCA (acc. ISO 14040 ff) with a direct cost calculation. The methodology of eco-efficiency is published in (LCA-Journal, Vol. 7, No. 4 2002, Peter Saling et al).

How does eco-efficiency fit to the requirements of decision makers: The results of an eco-efficiency-analysis are illustrated in the eco-efficiency portfolio, where the environmental impact is shown over the total cost. The inclusion of the cost is essential, as this is the starting point of all decisions. The environmental impact has to be shown as a single position in relation to the costs. As the eco-efficiency is only one tool within decision making, a clear statement of the LCA-practitioners is absolutely necessary.

The short needed timeframe requires the use of all accessible data. These data have to be divided into two categories. One is the real LCI data (e.g. eco-profiles for 1 KWh electricity, 1 kg Polypropylene, 1000 t/km road transport…)

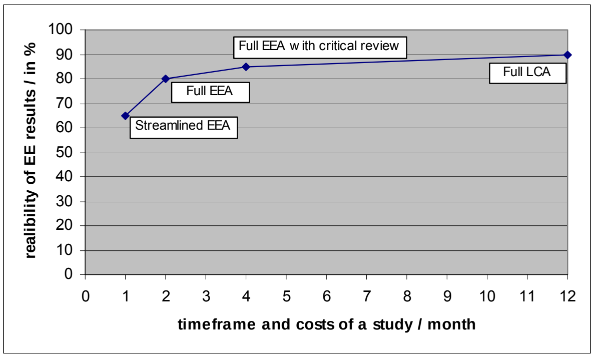
The other category is the technical data, coming from the system boundary (e.g. yield of a chemical reaction, additional fuel consumption of a car with increased weight, lifetime of a product, composition of a lacquer…) Nearly all of our sensitivity analyses have shown, that the quality of the LCI data is of minor importance for the overall result. The technical data however have a much higher importance onto the result. Practitioners, critical reviewer and LC-scientists should therefore focus much more onto these technical data than onto the LCI data and allocation rules. The scientific based focus onto the later ones does not improve the reliability of the LCA eco-efficiency results.

On the other hand, a small variation of the technical input data can sometimes change the result of an eco-efficiency completely and these input data can be influenced by the decision makers. They can for example start research programs for increasing the lifetime of a product or the yield of a process, or they can vary the composition of a product.

These opportunities which result in concrete actions are much more acceptable as a more scientific based discussion about the correct allocations rules or the discussion about the correct local electricity module.

In total the reduction of environmental impact is much more successful with the actions of the decision maker.

As of course due to the lack of time and normally absence of a single data base a lot of LCA-sources have to be used. These data are not completely consistent. But as that inconsistency is not relevant for the overall results it does not make sense to increase the financial and time efforts for an improvement. A typical situation is, that the first results coming from a streamlined LCA combined with a streamlined cost analysis do not differ a lot from the final results. Also if a critical revue is additionally done, the overall results do not change significantly. With different benchmark studies, where very expensive external LCA-studies where compared with internal BASF eco-efficiency-analyses-studies for the same topic a quantitative relation between the effort and the reliability of all results could be evaluated.

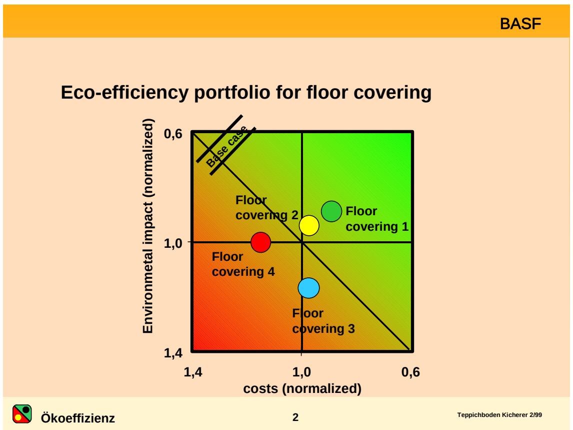


The above shown empirical diagram shows, that with about 25% of the financial effort more than nearly 80% of the final result can be obtained. Or with other words, for the same amount of money 4 eco-efficiency-analyses can be made instead of one full LCA, with an absolutely sufficient reliability.

Another prejustice is, that weighting factors can change the overall results. In that case, to, the sensitivity analysis shows only a slight impact to the interpretation and the ranking of the opportunity.

4 TYPICAL RESULTS

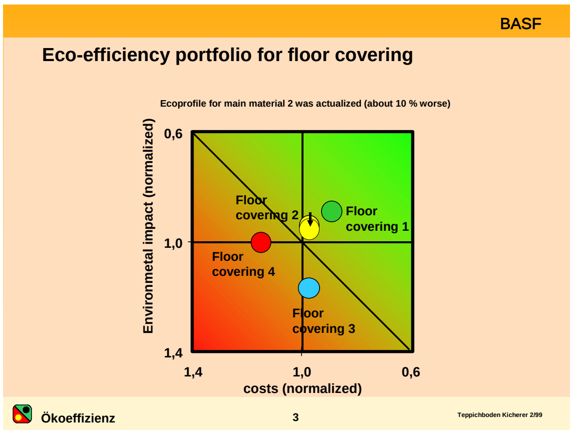
In figure 2, 3, 4, 5 and 6 these effects are shown. Figure 2 shows the initial portfolio of a study, where different floor coverings were compared. Material 1 is a most eco-efficient (largest distance from the diagonal line) followed by material 2. Material 3 and 4 have similar eco-efficiency.


BASF

Eco-efficiency portfolio for floor covering

Ökoeffizienz 2 Teppichboden Kicherer 2/99

In figure 3 an actualized eco-profile for material 2 is included. In the base case an estimation was used as a correctly calculated APME eco-profile was not available at that time. The figure 3 shows, that the interpretation of the portfolio remains the same, even with an about 10% worse eco-profile. The influence of correct LCA versus streamlined calculation is therefore low

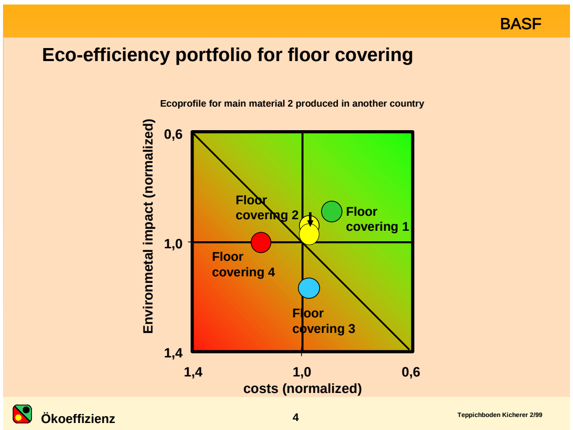

BASF

Eco-efficiency portfolio for floor covering

Ecoprofile for main material 2 was actualized (about 10 % worse)

Ökoeffizienz 3 Teppichboden Kicherer 2/99

Figure 4 shows another sensitivity analysis. In the base case the eco-profile from a German plant was used for material 2. As BASF is also operating a plant for that material in US with another technology, a sensitivity analysis was carried out. The portfolio shows, that the local effect onto the results is also minor. The ranking is still stable.


BASF

Eco-efficiency portfolio for floor covering

Ecoprofile for main material 2 produced in another country

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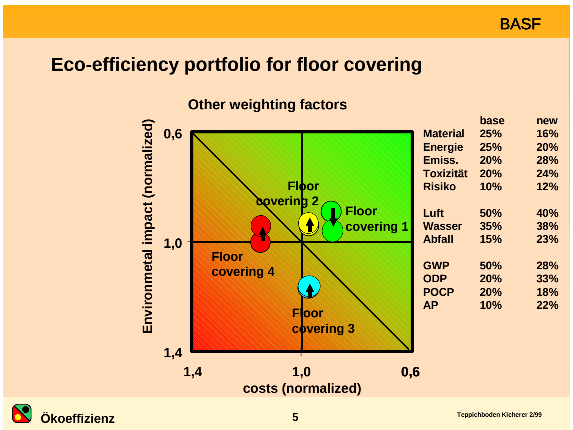
Eco-efficiency-analysis is using a weighting scheme for ecological assessment. A variation of that weights can be seen in figure 5.



BASF

Eco-efficiency portfolio for floor covering

Other weighting factors

	base	new
Material	25%	16%
Energie	25%	20%
Emiss.	20%	28%
Toxizität	20%	24%
Risiko	10%	12%
Luft	50%	40%
Wasser	35%	38%
Abfall	15%	23%
GWP	50%	28%
ODP	20%	33%
POCP	20%	18%
AP	10%	22%

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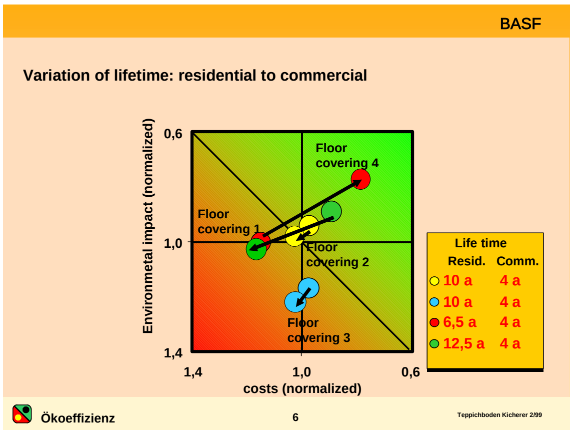
The positioning of the points are changing, but the overall results remain constant.

Material 1 is still the most eco-efficient followed by 2, 3 and 4 are less eco-efficient.

The most dramatic change can be seen in figure 6, when the technical input data are varied.



BASF

Variation of lifetime: residential to commercial

Life time	Resid.	Comm.
○	10 a	4 a
●	10 a	4 a
●	6,5 a	4 a
●	12,5 a	4 a

Ökoeffizienz 6 Teppichboden Kicherer 2/99

The original lifetimes of the products come from a small market survey. In the residential use the coverings are used according to their technical lifetime. In the commercial use floor coverings are more often used according to fashion requirements and therefore they will be replaced more often although they are still usable.

In the commercial case the covering 4 is the most eco-efficient followed by covering 2.

It could be shown that the market and technical skills are the most important aspects for influencing the eco-efficiency result. Therefore 2 decisions had been drawn. The material 4 was mainly sold in commercial application and for the material 2 a R&D program was launched to increase the lifetime in residential application.

5 CONSEQUENCES

It could be shown, that the main influence factors for the results of eco-efficiency-analyses are technical and market data. The more scientific based discussion about preciseness of LCA data has only a small input onto the practical use of LCA tools in decision making.

A very practical approach for LCA is necessary and reliable enough for industrial and political purpose. The biggest effort should therefore be done to increase the utilization of these tools. Managers in companies need clear and defined results. It is nearly no use for them to be involved in scientific and sometimes philosophic discussions. But with tools like eco-efficiency they have the possibility to use their power for daily decisions which will improve the environment.

DATA COLLECTION AND QUALITY FOR CP IMPLEMENTATION: THE EXPERIENCE OF THE CENTRE IN UGANDA

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ABSTRACT: UNIDO Cleaner Production Programme has established more than 30 National Cleaner Production Centres and Programmes in developing countries, with the main focus on fostering the implementation of Cleaner Production practices, mainly through environmentally sound technologies and productivity increase. When addressing companies, the services delivered by the Centres generally start from the conduction of an in-plant assessment, for the definition of the CP potentials. The Uganda Cleaner Production Centre, within the Eco-Benefits programme, trained the company staff in the conduction of their in-plant assessments and in the collection and evaluation of environmental data. This information, which originally has been used to identify the CP measures to be implemented in order to improve the companies' environmental performance, has been elaborated in order to go one step forward. Environmental, production and economic indicators stimulated the company to rethink and redesign its products, in order to achieve reduction of costs and emissions, together with the customers' satisfaction.
Besides the well-established data collection aiming at the conduction of in-plant assessment, the NCPCs and NCPPs started to define data collection procedures for life cycle analysis and for the calculation of macroeconomic indicators.

Keywords: Cleaner Production – NCPCs/NCPPs – In-plant assessment – Ecodesign

1 UNIDO CP PROGRAMME

UNIDO has achieved long-standing experience in promoting Cleaner Production (CP), by establishing, since 1992, National Cleaner Production Centres (NCPCs) and Programmes (NCPPs) in 31 developing countries and countries with economies in transition.

The main activities performed by the Centres and Programmes are based on the following services, which are strongly interrelated and support each other:

- *Awareness-raising and information*, for the promotion of CP and of the NCPCs/NCPPs and for the creation of CP networks at national and international levels;
- *CP Training programmes*, with the organization of workshops / seminars or combined with in-plant assessments for companies;
- *Technical Assistance and In-plant Assessments* to identify the CP potentials and CP related measures, which may be combined with assistance for the implementation of environmental management systems, health and safety issues and labor and social issues;
- *EST Development and Transfer*, facilitating the formulation of CP investment projects and fostering the development of partnerships or cooperation projects;
- *Policy Advice*, as the sustainability of CP requires effective policy instruments, which may be based on regulatory or economic measures, information based strategies or voluntary programmes.

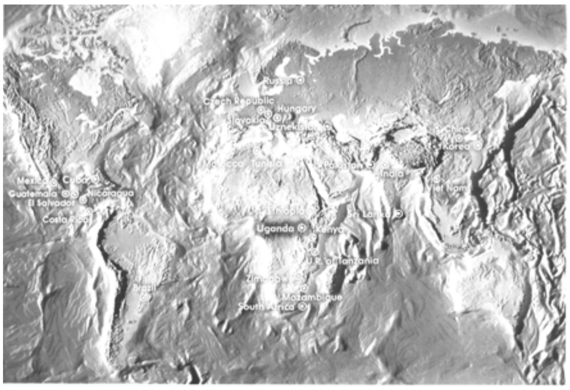

Figure 1 – Distribution of UNIDO NCPCs and NCPPs

2 NATIONAL CLEANER PRODUCTION CENTRE (NCPC) IN UGANDA

2.1 Cleaner Production in Uganda

Cleaner Production is still a new concept in Uganda. Many industries still use old technologies in their production process and end-of pipe solutions to manage wastes and emissions. Environmental standards have been defined on the assumption that compliance will be achieved by using end – of – pipe solutions. Many industries, especially the small and medium sized, claim that they cannot afford to invest in cleaner production.

After the establishment of the National Environmental Management Authority (NEMA), a body that coordinates, supervises and monitors environmental management in Uganda, a number of regulations have been put in place.

Notable among these is the National Environment (Waste Management) Regulations (1999), in which the regulation n.5 emphasizes the need for enterprises to implement cleaner production measures in order to prevent pollution and minimize waste generation.

2.2 The activities of the Centre

Uganda Cleaner Production Centre (UCPC) has been established in October 2001 and is hosted by Uganda Industrial Research Institute (UIRI) in the Nakawa Industrial Area. The UCPC is a joint project of the government of Uganda and UNIDO and is operated under the guidance of an Executive Board and an Advisory Board, where key national stakeholders from the private sector, NEMA, government, research institutions, universities are represented.

The objective of the UCPC is to introduce Cleaner Production practices in Uganda, providing advice, technical assistance and training.

3 ECO-BENEFITS PROGRAMME

The UNIDO NCPC coordinated the Eco – Benefits programme, a 10 – months programme with the objective to provide company staff with comprehensive know – how and on the job training in Cleaner Production, with the purpose of enabling them to keep on improving continuously, once they have built their own in-house capacities when the programme has ended. During the training, the UCPC experts provide technical assistance and supervision, but the practical activities are entirely left with the participants. Companies, who successfully complete the whole programme, receive a Cleaner Production award.

The first ECO-Benefits programme involved six companies, from the food (sweet, sugar and fishery) and packaging sectors: the participants completed their training in March 2003. The second programme started in October 2002, with companies from the food (fishery and dairy) and electronic (batteries) sectors. [2]

3.1 Main objectives of the programme

The organization, conduction and participation in the Eco-Benefits programme can bring important outcomes both for the UCPC, as the successful conduction of this project will serve as a demonstration of the potentials of CP, and for the participating companies. The main achievements have an impact at national level too:

- Strengthening of the economic situation and of the competitiveness of companies in Uganda by introducing Cleaner Production;
- Achievement of sustainable industrial development and thus improvement of the ecological situation in Uganda;
- Support of an increasing number of companies from different sectors, aiming at becoming more efficient and hence remaining competitive;
- Delivery of comprehensive know-how and on the job training in CP to selected company staff.

The programme and its results are promoted by the NCPC, during a public ceremony for the delivery of the awards and through the publication and distribution of a brochure.

3.2 The phases of the programme

The Programme includes the following phases:

PHASE A: *guided CP assessment phase*, based on 9 workshops, during which the companies undertake a step – by step CP Assessment, based on material and energy flow analysis (duration: 2 – 3 months)

PHASE B: *implementation phase*, starting with the presentation of the CP Assessment Report, to obtain the full commitment of the management, and involving the implementation of the identified CP measures, which may cover the areas of efficient material use, energy efficiency, improved health and safety, legal compliance (duration: 4 – 5 months)

PHASE C: *evaluation phase*, consisting in the verification of the results achieved by the company made by experts of the NCPC, based on a certification and licensing scheme from the Centre (duration: 1 – 1.5 months)

PHASE D: *Eco – Benefits Certificate* and promotion of successful companies participating in the programme.

From the beginning of the programme, participants are requested to go back to their companies and start conducting their in-plant assessments. Based on the results of this activity, the implementation of the first CP measures identified will have to start. This approach aims at achieving immediate implementation of the theory illustrated during the workshop.

4 DATA COLLECTION FOR IN-PLANT ASSESSMENT

4.1 In-plant assessment

The entire process of the in-plant assessment during phase A of the programme is developed with the targets of providing to the assisted companies:

a. Identification, characterization and quantification of waste streams and thus environmental and economic assessment of loss of resources (material and energy);
b. Identification of easy to implement and low-cost CP options that enterprises can immediately implement, and
c. Preparation of investment proposals to financing institutions for undertaking medium to high cost CP measures that may require technology and equipment change.

The assessments have to be conducted in a systematic way to get results which prove to be consistent with those identified in the company's general plans. Therefore the in-plant assessment generally includes the following steps [2]:

a) Planning and organization;
b) Pre-assessment;
c) Assessment;
d) Feasibility analysis;
e) Implementation;
f) Monitoring.

4.2 Pre-assessment and data collection

Considering the target of the study, the attention will be focused on the step b of the in-plant assessment, as in this phase the impact of data availability and quality can be felt. It generally includes four important tasks:

1) Compiling and preparing the basic information;
2) Conducting a walkthrough;
3) Preparing an eco-map;
4) Carrying out preliminary material and energy balances.

Compiling and preparing the basic information:

This first task includes the preparation of the Process Flow Diagram (PFD), listing all operations from the receipt of raw materials to the storage / dispatch of final products. Basic information which refers to each step of the process includes the operating conditions under which the operations are developed and all their inputs and outputs. The latter refers to raw, intermediate and final products, water and steam, wastewater, air and solid waste emissions and are treated as notes on the PFD or attached tables.

The PFD has to describe start up, shut down and maintenance conditions, as well as operations related to seasonal products and production related changes.

Conducting a walkthrough

This always proves to be the most effective technique to get updated and reliable information on the process. The walkthrough is conducted in different operative conditions in order to get the most complete indications related to the process and follows the production process, covering, as well, all support utilities (boilers, power generators, storage tanks, refrigeration plants).

Preparing an eco-map

Eco-mapping is a simple and practical tool to represent visually issues of concern, as well as good practices.

They include the following themes: water consumption and wastewater discharge, energy use, solid waste generation, odors, noise and dust, safety and environmental risks.

Carrying out and developing preliminary material and energy balances

This operation is conducted as a basic inventory tool, which allows for quantitative recording of material and energy inputs and outputs.

The material and energy balances are normally prepared using secondary data, supported by the information recorded during the walkthrough. Water and energy bills paid give indications of the consumption levels.

On the output side, production figures or orders received over a certain period of time are an estimate of average production. Obtaining figures on waste and emissions is generally more difficult. Only when specific measurements are requested by the controlling bodies, concentration data for water and air pollutants exist, from which the calculation of the emissions in mass can be made. Data on mass or volumes of solid waste are more frequently available, as they are used for economic purposes. Often, approximate calculations will have to be used, based on “typical” values given in the literature, paying attention to the territorial and social context in which these figures have been calculated.

At this level, mass and energy balances require the availability of at least three months of data and the calculation of monthly averages. Effective quantifications are converted in SI units and associated costs need to be provided.

4.3 Assessment phase and first data verification

The first verification of the information collected during the preliminary mass and energy balance will take place in the assessment phase, in case substantial discrepancies will be identified. This operation is actually offering a first opportunity to evaluate the quality of the data collected during the in-plant assessment. Immediate changes can be put in place, but require rediscussing the assumptions behind the numbers, conducting measurements, and making whatever revisions are necessary to the data used for inputs and outputs.

An additional element, which should be included in the mass and energy balance, is the economic evaluation of the streams. The most difficult information to be gathered is related to the evaluation of the costs of the materials lost or the waste streams that have been identified in the balance. Experience has shown that this could be the most important information in convincing of the value of cleaner production and securing their commitment for the next steps.

While assigning the monetary value to the materials or waste streams, the following information is included:

- The cost of raw materials / intermediate products / final products lost in the waste streams (e.g., the costs of unexhausted dye in waste dye liquor);
- The cost of energy in waste streams, in terms of the energy consumed to heat or chill them;
- The cost of treatment / handling / disposal of waste streams, including tipping or discharge fees;
- The costs incurred in protecting the workers and maintaining safe working conditions (e.g., shop floor exhaust systems);
- The potential liability costs from a possible accidental spill, discharge, or leakage.

These costs are determined for each major waste stream. Specific costs (i.e., costs per unit mass / volume of a waste stream) are also determined for computation of the savings obtained by reducing or avoiding waste streams. Obviously, the reduction and controls of high-cost waste streams is the most interesting focus of the assessment from an economic point of view.

4.4 In-plant assessment in a company in Uganda

This entire process has been applied to all the companies participating in the Eco-Benefits programme, during the nine sessions of the workshop. One of the companies, the MAKSS Packaging Industries Ltd., founded in 1994, manufactures corrugated cardboard boxes, conducting in-house the entire process, including design and artwork creation.

One of the preliminary operations of the process, the collection of data and the preparation of mass and energy balances, required the joint effort of 19 staff members, from different sectors (from production to quality and human resources).

The results of the assessment brought to the identification of the areas where higher potentials for CP implementation are foreseen: waste reduction and energy / material losses control.

The company immediately defined and started the implementation of the CP measures which could directly address these issues:

- Implementation of good housekeeping measures to reduce water consumption;
- Reduction of contamination of waste water, by repairing leaks and spillages;
- Reduction of the furnace oil consumption, with the inclusion of a pre-heating step in the process:
- Reduction of energy consumption through maintenance of the equipments:

- Efficient use of paper and reduction in the generation of solid wastes.

The management understood the positive impact coming from the implementation of CP and fully committed itself to support the CP team. Further developments have already been included in the environmental programme and consist in the adoption of additional CP measures.

4.5 Eco – design: one step beyond the in-plant assessment

After the positive achievements of the CP programme at the end of the in-plant assessment, the company decided to further improve its environmental performance.

Supported by the information and data collected for the mass and energy balance, the company decided to redesign its product in order to better respond to the environmental optimization of the process, keeping in mind the customer satisfaction.

This redesign process was based on the definition of the five steps of the product life and on the identification of the environmental impact deriving from them. The data collected during the in-plant assessment has therefore been reorganized for this evaluation and related to the following categories: use of raw material, manufacture, distribution, product use, end of life. [3]

The results of this process, together with intensive discussions with the different customers (flower producers, fruit and vegetable exporters etc.) for finding out their requirements and adapting the design of the products, brought to the definition of redesigned boxes, which allowed to reduce costs and environmental impacts at the same time.

As a first output of the programme the following new products were launched:

a) a self locking box for transportation of bundles of roses from the flower farms via air to the European market. The new box could offer:

Resource efficiency: 167 g reduction in weight (-12% of the original weight);

Improved production process: The production of the box involves one production step less since the bottom is 3 ply instead of 5. The box is self-locking and does not require any tape or staples.

Cost reduction: The box is sold at a cheaper price to the customer; air cargo charges (approximately 1.5 USD/kg to Europe) are less since it is lighter.

Functionality and costumer satisfaction: This design offers better ventilation for the flowers, so the product is more protected: the flowers are in better shape and consequently have higher value.

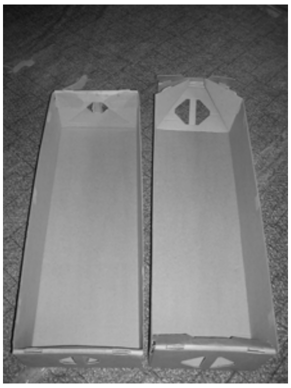

Figure 2 – Ecodesign box for flower export

b) a one piece box for 5 kg fruits transportation. The advantages of this redesigned box are:

Resource efficiency: 60 g reduction in weight (-10.7% of the original weight);

Improved production process: The production of the box involves one production process less since the MAKSS EcoDesign box is a one-piece box. Off-cuts are utilized to make pads for other boxes;

Cost reduction: The box is sold at a cheaper price to the customer; air cargo charges (approximately 1.5 USD/kg to Europe) are less since it is lighter;

Functionality and costumer satisfaction: Stability and ventilation are excellent. Easy locking system saves time of clients. A one-piece box is easier to handle, less space is needed for packing.

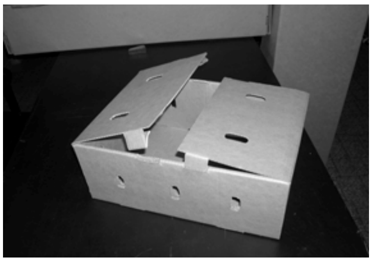

Figure 3 – Ecodesign box for fruit export, 5 kg

5 FURTHER DEVELOPMENTS

5.1 Preparation of databases and networking

The solutions already adopted by the NCPCs and NCPPs for the conduction and the evaluation of the in-plant assessments are important achievements to capitalize on. For this reason, UNIDO is planning to strengthen the existing network of the NCPCs and NCPPs to share the methodology adopted during the collection and validation of the environmental data.

Therefore, with the purpose of sharing the experiences and the tools, a unified approach for the delivery of this service has been identified. The information collected, together with the achievements deriving from the implementation of the CP measures, is to be compiled in a unified format (Technical Report form) and then included in the UNIDO NCPC database. This tool is available for consultation.

5.2 Availability of information at macro level

The activity of UNIDO Centres and Programmes contributes to the achievement of the goals identified in the United Nations Millennium Declaration. These goals are not simply addressing the performance of the companies, but require the definition of the impact of the activity of the UN organizations on the global social, economic, industrial and environmental context.

In order to be able to quantify this contribution, the Centres and Programmes will have to develop new indicators, besides the ones they are currently using at company level, where the effect of their services can be transferred at an broader prospective and show how they can contribute to the following goals:

Goal 7: Ensure environmental sustainability in a competitive economic context;

Goal 8: Develop a global partnership for development.

In addition to that, the compliance of their activities to the Johannesburg Declaration and its Plan of Implementation will have to be evaluated. They will achieve the objectives of this Declaration by emphasizing the importance of cleaner production and eco-efficiency on the way towards sustainable patterns of production and consumption.

5.3 Life cycle approach to CP

Based on the experience already concluded by the NCPC in Uganda, the procedure for collecting in-plant information is under revision in order to broaden the approach to CP.

The definition of the best CP options to be implemented will not simply focus on the process or on the production line, but will require a rethinking of the entire process and life cycle of the product.

For this reason, additional steps will be included in the information collection and evaluation process, starting from the research of additional information on the raw materials, on the use of the product itself and on the customer requirements and ending with the consequences of the disposal of the wastes generated.

Through this new and broader approach, the weakest points in the entire life cycle will be addressed and, therefore, more significant improvements will be achieved.

6 REFERENCES

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7 ABBREVIATIONS

CP	Cleaner Production
EST	Environmentally Sound Technologies
NCPC	National Cleaner Production Centre
NCPP	National Cleaner Production Programme
NEMA	National Environmental Management Authority
PFD	Process Plow Diagram
UCPC	Uganda Cleaner Production Centre

GERMAN NETWORK ON LIFE CYCLE INVENTORY DATA

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ABSTRACT: Reliability of LCA results crucially depends on the availability and quality of LCI data. In order to provide high-quality LCI data for background systems in LCA but also for a larger variety of possible application fields harmonization strategies for already existing data sets and data bases are required.

In view of the high significance of life cycle inventory data as a basis of major fields of action within a sustainability strategy, the German Helmholtz Association under the leadership of the Forschungszentrum Karlsruhe (FZK) has taken up this issue in its research programme. In 2002, the FZK conducted a preliminary study on "Quality Assurance and User-oriented Supply of a Life Cycle Inventory Data" funded by the Federal Ministry of Education and Research (BMBF). Within the framework of this study, a long-term conception for improving the scientific fundamentals and practical use of life cycle inventory data was developed together with external experts. The focus is on establishing a permanent German **"Network on Life Cycle Inventory Data"**. This network shall integrate expertise on life cycle assessment in Germany, it shall harmonise methodology and data, and it shall use the comprehensive expert panel as an efficient basis of further scientific development and practical use of LCA. At the same time, this network shall serve as a platform for cooperation on an international level.

Current developments address methodological definitions for the initial information infrastructure. As a novel element user needs are differentiated in parallel according to the broad application fields of LCI-data from product declaration to process design. Case studies will be used to define tailored interfaces for the data base which have to encounter different quality levels.

Keywords: data integration, appropriateness

1 INTRODUCTION

The methodological approach of life cycle assessment (LCA) comprises an integrated view on the process chain from production to use and disposal of a product ("from cradle to grave"). This approach is increasingly applied in environmental policy - e.g. the EU-Communication on integrated product policy – as well as in industry for product and process development. LCA serves as a means of decision support in order to identify control mechanisms for a sustainable development. Moreover, LCA will be used to an increasing extent for business to business and consumers' information in accordance with the new EU requirements for the so-called Ecolabel Type III.

Data on material and energy flows entering and leaving technical processes as well as for process chains like energy production, represent an essential prerequisite of LCA. Reliability of the results from LCAs crucially depends on the quality of the life cycle inventory (LCI). In order to provide high-quality data, infrastructure for quality assurance and scientific backup of data collection and data processing is required.

In view of the high significance of LCI-data as a basis of major fields of action within a sustainability strategy, the Helmholtz Association under the leadership of the Forschungszentrum Karlsruhe (FZK) has taken up this issue in its research programme. In 2002, the FZK conducted a preliminary study on "Quality Assurance and User-oriented Supply of a Life Cycle Inventory Data" funded by the BMBF. Within the framework of this study, a national, long-term conception for improving the scientific fundamentals and practical use of LCI-data was developed together with external experts. The focus is on establishing a permanent German "Network of Life Cycle Inventory Data". This network shall integrate expertise on life cycle assessment in Germany, it shall harmonise methodology and data, and it shall use the comprehensive expert panel as an efficient basis of further scientific development and practical use of LCA. At the same time, this network shall serve as a platform for cooperation on an international level like the EU Cost-action 530 or the Life Cycle Initiative by UNEP/SETAC [1].

2 OBJECTIVES

The German Network is still in the start-up phase which is basically focused on fund raising and contouring the organizational framework. It is understood as central platform for all groups involved in the supply and use of LCI-data from science to industry but also policy and governments up to consumer counselling and the interested public (figure 1). Core element of the activity is the "virtual institute" that is going to be established until 2006. The "virtual institute" will be a formal alliance of scientific institutions with a central organisation and coordination at the Forschungszentrum Karlsruhe. As important element this virtual institute fosters the development of a central data pool. A web portal (currently in German only) has already been set up to manage the various dialogue processes with interested parties.

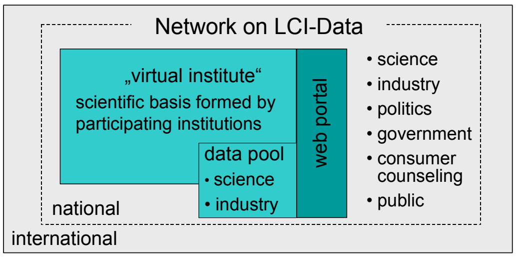

Figure 1: German Network on LCI-data

Within the "virtual institute" the participants agreed on three central objectives for this long lasting activity:

- the scientific validation, generation and continuous update of data for life cycle analyses
- the use of life cycle data for scientific decision support with respect to sustainable production and consumption in varying application areas
- further methodological development of life cycle analyses within the research area material flows and sustainability.

These aims shall be reached by an overarching scientific research programme, which can be understood as scalable framework for data acquisition and application as well as methodological developments.

3 SCIENTIFIC WORK PROGRAMME

As a result of the preliminary study a work programme has been set up which was revised and specified in intensive discussions. The programme is designed for the next three years and consists of three interdependent parts (figure 2):

- Supply of LCI-data
- Application of LCI-data
- Methodology

Within each part several themes are identified. The identification of the themes follows the priority setting within the preliminary study and prevails a snapshot of current concerns and important issues. Each theme is at the same time the name of a corresponding working group (WG). Each working group is represented by a scientist within the overarching WG Methodology which also has a coordinating function for the different themes and cross-cutting issues.

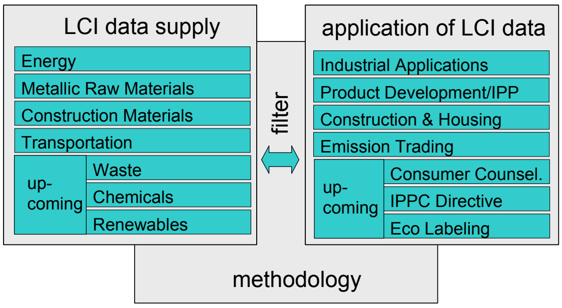

Figure 2:Themes of the scientific work programme

Upcoming themes have already been identified as areas for further activities, but they are not supported by working groups so far.

3.1 Supply of LCI Data

The main task for the working groups within this part of the work programme is to establish data acquisition schemes, guaranteeing the generation and continuous update of data together with responsible institutions. Each theme is characterized by a specific combination of involved scientific, industrial and governmental bodies. In commodity-specific themes like Construction Materials or Metals industry associations and in many cases market competitors are sitting at the same table. The lack of consistent and comparable data is of major concern here.

Within the service orientated themes Energy and Transportation public data is available oftentimes already in a variety of models. Harmonization and modelling choices oftentimes collide with market positions of competitors. Between the themes overlaps occur which require careful coordination to avoid double work.

3.2 Application of LCI Data

Similarly to the supply side the structure and themes of the application part are a result of the preliminary study. A common objective of the four working groups is to establish clear recommendations and the definition of user needs in the different application fields. Within the network, application of LCI-data does not necessarily mean to support LCAs only but rather to support, promote and broaden the application range of life cycle data. Within the scope of these working groups also criteria for the appropriateness of data are to be developed.

3.3 Methodology

The WG Methodology has an overarching position as all methodological choices and approaches within the separate themes have to be integrated within a continuous workflow. Therefore this working group is shaped like a steering committee with representatives of the different WGs. Within this WG overarching and general issues are discussed and fed into a structured discussion process. By means of a guideline for data capturing and maintenance consensual issues are codified and contentious issues are fed into a discussion process.

4 DATA QUALITY INDICATORS AND LCI-APPLICATIONS

Data quality of LCI-data and its continuous improvement is a central target of the network activity which is not an isolated initiative but rather an integrative science platform. Important documents which have been compiled in the LC community like the conceptual framework for a Quality Assessment [2] or the Code of Life Cycle Inventory Practice from the SETAC Workgroup on Data Availability and Quality [3] are fully taken into account. Also of crucial importance are already operating LCI-data base projects like the Swiss ecoinvent data base or the Swedish information system SPINE@CPM.

Data quality as super ordinate term has a broad meaning for LCAs in general pointing at the complex interdependencies between goal and scope, inventory modelling, impact assessment and interpretation. A generic isolated quality management for LCIs is undoubtedly dependent on a specification of framework conditions.

As captured in the Code of Life Cycle Inventory Practice quality is mentioned beginning with the list of recommended exchanges[6] via inventory modelling up to an evaluation framework for uncertainty in LCI [3].

Nevertheless LCI-data quality is relative, not only according to preceding and pursuing phases of an LCA but also according to different value choices. During a workshop on LCI-quality in 1992 the participants assigned preferences for selected data quality indicators (DQI) considering study type, objective and level of detail [2] (table 1). This rather subjective value choice illustrates, that “high quality” may not be a single attribute for neither a unit process nor a data set.

Rather it should be considered as a level of appropriateness of a given selection of data for a specified application.

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[6] Exchanges are used according to [3] replacing the term *intervention* in the ISO-framework.

Table 1: Use of qualitative DQIs in relation to study type, objective and level of detail [2]*

Qualitative DQIs	**Type of Study**			**Study objective**			**Level of Detail**	
	Single Product / Plant	Product Group	Regional / National / Inter-national	Ecolabeling	Product related decision (internal)	Pollution Prevention (Public Policy)	Screening	Detailed
Representativeness	Y	N/Y	N	N	Y	N	N	Y
Transparency	Y	N/Y	N	N	N/Y	N	N	N
Peer Review	N	Y	N	N	N	N	N	Y
Consistency	N/Y	N/Y	N	N	N/Y	N	N	N
N/Y: Some variability exists among practioners/studies. *these ratings reflect the circumstances at the time of the workshop (October 1992)								

This suggests rather the management of the variety of use cases and corresponding quality requirements than striving for single and absolute scores.

4.1 Towards Appropriateness

In order to establish a flexible matrix of data sets, unit processes and levels of appropriateness the elaboration and specification of quality criteria and indicators is a core element in central WGs of the network:

1. Guidelines for data capturing (WG Methodology): documentation and specification of quality criteria.
2. Review of data sets (WGs data supply): internal review on quality but also quantification of DQIs.
3. User needs (WGs application fields): definition of appropriate data set properties and rule based filters which also have to encounter DQIs.

Due to the organizational structure common criteria and commitments which are inevitable for the scope of the project are established jointly by the WG Methodology. Mandatory elements for a unit process data documentation are currently:

- kind of data (measured, literature etc.),
- age and timeliness of data and
- precision of data.

Elements for discussion are:

- additional quantitative DQIs
- treatment of data gaps and zeros
- treatment of different estimation techniques (conservative, optimistic etc.)
- lists of recommended exchanges

Another important area for discussion is the documentation of system data and appropriate DQIs as well as a comprehensive 3rd party review scheme.

The thematic WGs on the data supply side provide an opportunity to extend common elements of the quality documentation and assessment with specific measures and criteria. It is considered important, that sectors like metals or energy are able to define additional criteria, which allow a specific assessment of each background system. As example the degree of accordance between the year of the study and the year of collection of the obtained data suggested by Weidema [4] is an important DQI. But the interpretation of this degree might be different among different sectors and their specific dynamics, but also according to the different data update periods. The involvement of industry representatives in these WGs promises the input of actual data about sectors but also primary data sources.

As these technical WGs also provide a feedback which criteria and corresponding DQIs are meaningful and accessible within data acquisition and reporting, the WGs responsible for the application of LCI data play an essential role to bridge the gap between the technical LCI-part and real life application fields. The broad scope covered by these WGs suggests, that a single and uniform DQI-scheme will not match these needs. The approach here is, to design application specific filters which contain rules for the treatment of different data quality levels depending on the desired decision context.

To focus the discussion within and between WGs case studies are inevitable within the network. Currently cases are studied within three WGs.

4.2 Case Studies

Main initial focus of the network activity is not a novel data acquisition campaign but rather the re-use and “recycling” of existing data and the establishment of a framework for continuous data supply and quality maintenance. In order to identify key-issues, case studies are carried out currently. Their connecting element is the harmonisation of existing data sets with different origins.

Harmonisation in this stage means to understand and document the differences in data sources within a common framework. Data harmonisation is an inevitable prerequisite for data integration. Normalisation of data, which would require recalculation and additional data collection is currently out of scope.

4.2.1 Energy

Within the WG Energy it is aimed at selected energy carrier systems (coal, natural gas, etc.) for the German energy mix. Overall objectives comprise:

- Harmonisation of LCI data for electricity generation, including full process chains for energy carriers and power plants
- Method for updating of basic data
- Handling methodological questions

Taking hard coal as example different coal properties, different regions of origin, different technologies for coal extraction and coal preparation have to be taken into account. These technical considerations are encompassed by the assessment of the underlying sources used within the compared models.

In order to assign different efficiencies and emission factors of mine power plants in Germany and in foreign countries a variety of existing data quality criteria (exchanges, age, representativeness, etc.) will have to be merged and interpreted. The resulting model for electricity generation and its pre-chains serves as starting point for the recommendation of a harmonised and continuous data update scheme.

4.2.2 Construction and Housing

The WG Construction and Housing deals with the variety of application cases for LCI-data within this relevant and complex sector from materials selection up to the design of buildings. Different user scenarios are used to determine necessary information and their presentation for planers and architects. This case study can be seen as a first "filter"-concept for the rule based treatment of LCI-data.

4.2.3 Metals

The WG Metals is responsible for the harmonisation of existing data on metal production. According to their quantitative importance a subset of metals has been selected (Fe, Al, Cu, Zn, Mg). Within a pilot study a roadmap towards a harmonisation is to be developed. As suitable metal aluminium was chosen, which might be characterized by an extraordinary data availability from different sources. Preliminary results endorse that the specification of distinct quality criteria and indicators is difficult. Beneath the "classical" differences like regional or temporal system boundaries or scope definitions the representativeness varies due to different data acquisition schemes and editors within the three reference data sources:

- The environmental profile report for the Aluminium industry [5] is based on questionnaires covering the European Aluminium industry. An expert panel and extensive external reviewing lead to a condensed table of exchanges designed for the utilisation in LCI's
- The investigations of the Federal Agency for Geosciences and Resources (BGR) on material flow and energy requirements for the production of selected mineral commodities [6] is focused on a limited spectrum of exchanges and is also based on questionnaires and an international survey.
- The results of the Collaborative Research Centre (CRC) 525 [7] as a joint scientific programme between institutes of the Aachen University of Technology and the Forschungszentrum Jülich are based on an extensive literature review, own field work and laboratory experiments and reveals a detailed view not only with attributional but also consequential modelling elements.

Even if the BGR and CRC 525 studies were not conducted as standardised LCIs they represent typical primary data sources exemplary for a vast variety of non-LCA sources which are to be considered in the scope of the network activity. The determination of "appropriateness" as central criteria for future data acquisition and utilisation depends on how these structural differences are captured with criteria and DQIs.

5 CONCLUSION

The German network on Life-Cycle Inventory data is understood as co-operative approach for the continuous supply of LCI-data within a broad scope of potential applications. Key characteristics of the networking activity are:

- the integration of stakeholders from scientific institutions, consultants, commodity industries and governmental institutions
- the central co-ordination of sector- and application specific working groups
- the joint development of research strategies and collaborative programmes.

Visible activities are:

- active participation within ongoing international initiatives (EU-Cost 530; Life-Cycle Initiative).
- the web-portal, which is continuously adapted to the need of its users since start up in July 2003
- national and international workshops
- case studies

Future key prospects comprise:

- the development of a sustainable business model
- the establishment of an information infrastructure matching the needs for continuous supply of assessed LCI-data for background systems.

Within this scope it is inevitable to determine differences and similarities with "mature" projects like the Swiss ecoinvent data base or the Swedish information system SPINE@CPM.

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