# GaBi Modelling Principles

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# Content

Content ... ii
List of Figures ... iv
List of tables ... iv
List of abbreviations ... v
1 System Modelling Principles ... 1
1.1 Introduction ... 1
1.2 Goal definition ... 1
1.3 Functional unit ... 2
1.4 System boundaries ... 2
1.4.1 Definition of system boundaries for the creation of the LCI database ... 3
1.4.2 Cut-off rules ... 4
1.4.3 Infrastructure ... 6
1.4.4 Transports ... 7
1.4.5 Waste ... 7
1.4.6 Biomass ... 9
1.4.7 Other renewable energy sources ... 9
1.5 Types and sources of data ... 9
1.5.1 Source of data ... 10
1.5.2 Primary and secondary data ... 10
1.5.3 Units ... 10
1.5.4 Data selected for an LCI ... 10
1.5.5 Production and consumption mix ... 11
1.6 Data quality requirements ... 13
1.6.1 Reference time and reference area ... 13
1.6.2 Technology coverage ... 13
1.6.3 Data aggregation ... 14
1.6.4 Precision, completeness, representativeness ... 15
1.6.5 Consistency ... 16
1.6.6 Uncertainty ... 16
1.7 Data categories ... 17
1.8 Data collection ... 17
1.8.1 Quality check and validation of collected data ... 18
1.8.2 Treatment of missing data ... 19
2 System Modelling Features ... 20
2.1 Site dependency ... 22
2.2 Parameter ... 22
2.3 Allocation principle ... 23

2.4 Recycling ... 25
2.5 Generic Module ... 26
2.6 Special modelling features for specific areas ... 26
2.6.1 Energy ... 27
2.6.2 Transport on road ... 30
2.6.3 Metals and steels ... 33
2.6.4 Chemistry and plastics ... 33
2.6.5 Construction ... 35
2.6.6 Renewables ... 38
2.6.7 Electronic ... 41
2.6.8 End-of-life ... 44
2.7 Internal critical review and review of plausibility ... 47
2.7.1 Plausibility and technical quality of the base process ... 47
2.7.2 Important material and energy balances must add up on the base process level (e.g. metal content balance ore/ product; energy balance etc) ... 48
2.7.3 Plausibility of emission profiles (Ratio input-output) ... 48
2.8 Documentation ... 49
2.8.1 Nomenclature ... 49
2.8.2 Documentation of flows ... 49
2.8.3 Documentation of LCI data sets ... 50
3 References ... 52

# List of Figures

Figure 1: Example for a product system for LCA purpose ........ 2
Figure 2: Overall system boundaries for the manufacturing phase of "diesel" ........ 3
Figure 3: Detailed breakdown of the processes crude oil exploration and crude oil production 3
Figure 4: Difference between "production mix" and "consumption mix" demonstrated at the example of power generation ........ 12
Figure 5: Hierarchical structure of the processes and plans ........ 21
Figure 6: Atmospheric distillation as exemplary situation for allocation (simplified) ........ 24
Figure 7: Natural gas production in Germany ........ 28
Figure 8: Natural gas supply for Germany ........ 29
Figure 9: German power grid mix ........ 29
Figure 10: Consumption mix of Epoxy resin in Germany ........ 35
Figure 11: Schematic life cycle of a building ........ 36
Figure 12: Recycling in LCAs for construction products, using metal as an example ........ 38
Figure 13: Nitrogen in the agrarian system ........ 39
Figure 14: Time factor in the agrarian system ........ 40
Figure 15: Creation of a model for an electronic product – modular structure ........ 43

# List of tables

Table 1: Most important emissions of the average diesel at refinery in GaBi databases 2006 [4] per kg diesel referring to the exemplary impact categories AP/EP/GWP/POCP of CML [5]. ........ 6
Table 2: General procedure for material specific waste treatment process ........ 8

# List of abbreviations

| | |
|---|---|
| AP | Acidification Potential |
| ADP | Abiotic Depletion Potential |
| ELCD | European Reference Life Cycle Data System |
| EoL | End-of-Life |
| EP | Eutrophication Potential |
| FAETP | Freshwater Aquatic Ecotoxicity Potential |
| GWP | Global Warming Potential |
| HTP | Human Toxicity Potential |
| LCA | Life Cycle Assessment |
| LCI | Life Cycle Inventory |
| LCIA | Life Cycle Impact Assessment |
| MAETP | Marine Aquatic Ecotoxicity Potential |
| ODP | Ozone Depletion Potential |
| POCP | Photochemical Ozone Creation Potential |
| TETP | Terrestric Ecotoxicity Potential |

# 1 System Modelling Principles

This document is a result of the team work between PE International GmbH and LBP – University of Stuttgart. It aims to highlight important aspects which should be taken into consideration in a Life Cycle Inventory (LCI) Database study as well as report experiences based on the last 18 years from these groups in this field.

## 1.1 Introduction

This chapter gives an overview of the most important methodological aspects during the complete process of creating an LCI model as a basis for an LCA analysis. This process contains the following steps:

- Phase 1: Definition of the database
- Phase 2: Data collection and system modelling
- Phase 3: Quality checks
- Phase 4: Documentation

The methodical guidelines represent an important basis for the consistent creation of a model and thus the development of the database and consequently evaluation. They address the important points but are not exhaustive. Since going from theory to practice always requires interpretation and experience, certain responsibility will be kept by the practitioner in any case.

## 1.2 Goal definition

The results of a LCI study as a rule are related to a respective question or questions. Therefore, the goal definition is of central importance. In simple terms - the efforts to find an answer and the quality of the answer must be balanced with the complexity and the importance of the research, study or project question.

In most cases the complexity of the answer or result interpretation is strongly depending on the degree of general validity of the answers. Systems and system behaviour of very special circumstances is much simpler to describe than systems of under general circumstances with possible variations of boundaries.

Defining this question is the task of the goal and scope definition phase. According to the ISO 14044 [3] the following points are documented in the goal definition:

- Intended application,
- Reasons for carrying out the study,
- Intended audience and
- Whether the results are intended to be used in comparative assertions.

## 1.3 Functional unit

Following the goal definition, the functional unit has to be defined. The functional unit is a "quantified performance of a product system for use as a reference unit" in a life cycle assessment study (ISO 14044 [3]). It should be representative to the goal of the study and should allow the comparison of similar systems, processes or products, if needed.

Depending on the product, used functional units in the GaBi databases 2006 are basically physical SI-units related to the amount of product e.g.: 1 kg, 1 MJ, 1000 kg, 1 $m^3$. The functional unit of each process is defined within the process. The choice of the SI-unit does not influence the results of a comparison, if all compared systems can be described in the chosen SI-unit.

## 1.4 System boundaries

Within this sub-chapter the basis for the data collection as well as for the system modelling (building up the LCI dataset) is given. It defines what will be included in the study under investigation: a 'gate to gate', a 'cradle to gate' or a 'cradle to grave' analysis. The system boundaries can be a subject of adjustments due to the iterative process of conducting an LCA.

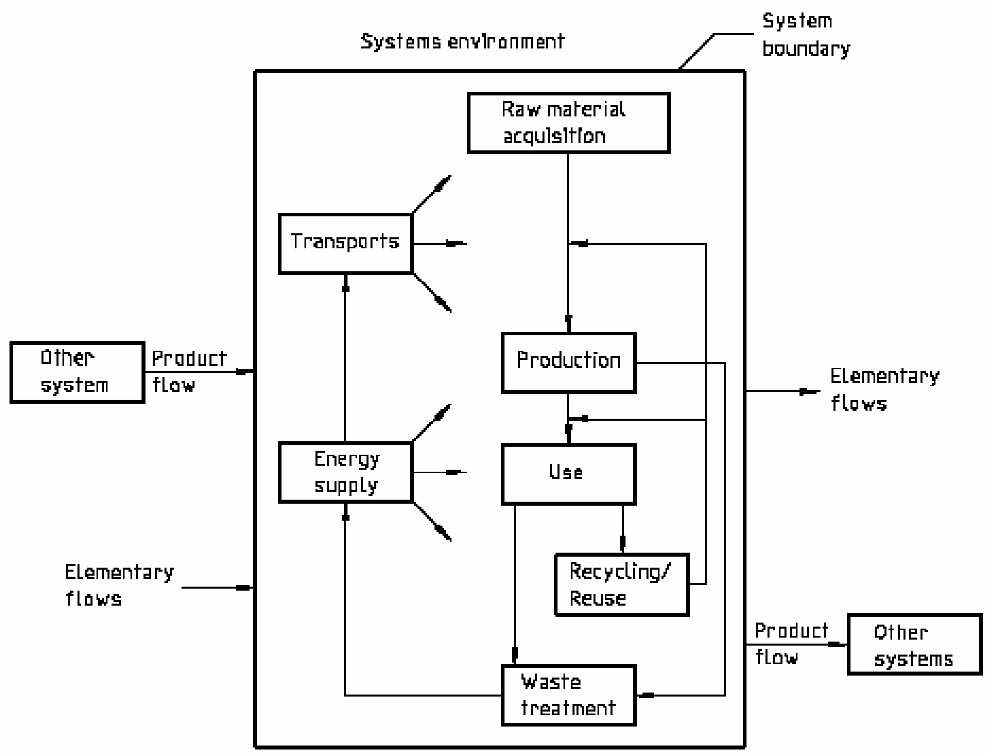
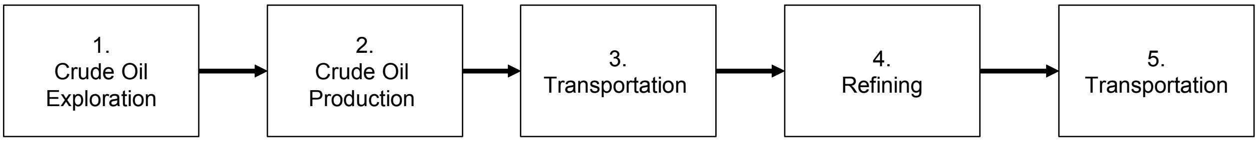



**Figure 1: Example for a product system for LCA purpose**

The basic terms and definitions have to be given, which should cover at least the definition of the major terminology used to describe a basic product system covering objects like systems, processes and flows based on ISO 14040 [2].

## 1.4.1 Definition of system boundaries for the creation of the LCI database

Within this section inclusions and exclusions within the generation of a specific inventory is specified. Therefore an example is given focusing the production route e.g. diesel fuel. Figure 2 shows a general overview of the system boundary to be considered.




1. Crude oil Exploration
2. Crude oil Production
3. Crude oil Transport
4. Refining
5. Transport of refined products, e.g. diesel fuel

**Figure 2: Overall system boundaries for the manufacturing phase of "diesel"**

Furthermore a more detailed breakdown of the identified major process is needed. Figure 3 is outlining the crude oil production and exploration process steps in detail.

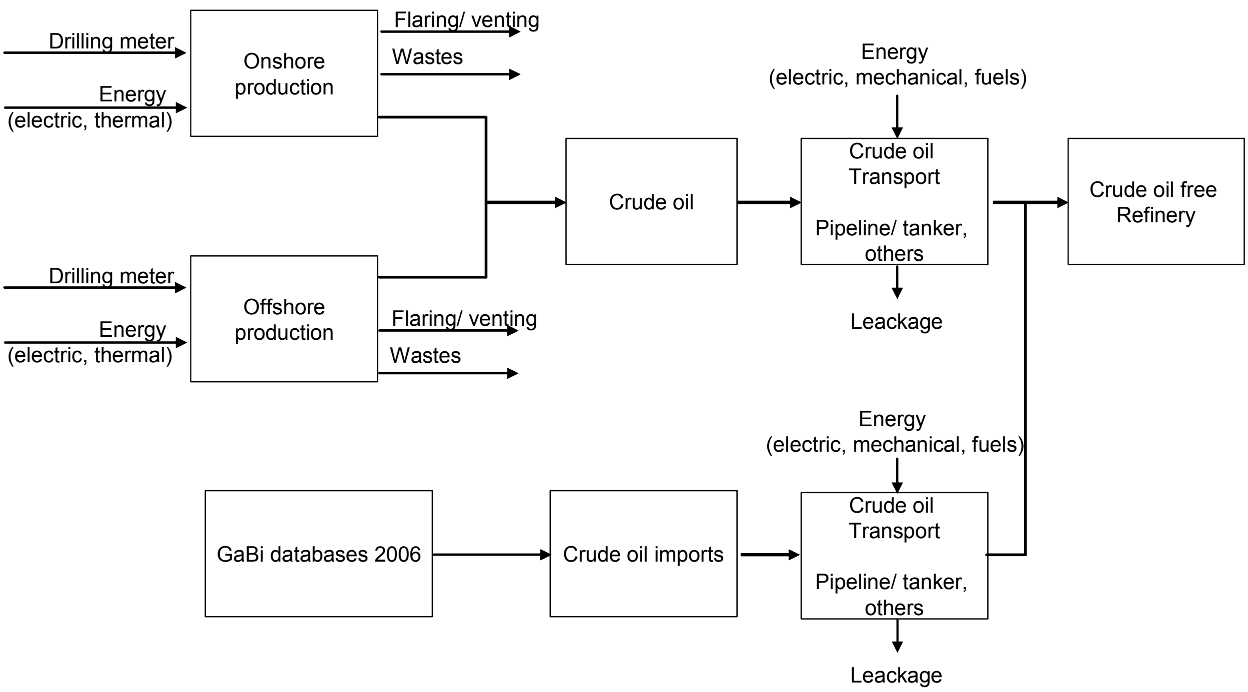



**Figure 3: Detailed breakdown of the processes crude oil exploration and crude oil production**

In this manner all commodities are analysed and result in a transparent description of the system boundaries. Certainly, a set of general definitions and rules how to set the system boundaries helps to minimise effort needed within this step and also give as good as possible guidance for this procedure. In practice "pre-modelled" cradle-to-gate datasets can be used for certain parts of the system to keep a balance of "sufficient system boundaries" and "sufficient time effort". But it is to keep in mind that those "pre-modelled" cradle-to-gate datasets have initially to be set-up in detail and maintained as described, before those can be used in other product systems.

### 1.4.2 Cut-off rules

Cut-off rules are defined to provide practical guidelines during the process of identifying the process chain under study in order to create a model of a specific product system. The ISO 14044 [3] mentions some criteria used to decide which inputs are to be included: a) mass, b) energy and c) environmental significance.

As a general rule, the mass- and energy balances of unit processes should always be respected. Unit processes should reflect actual physical and thermodynamical laws.

In the following description some frequently used cut-off criteria are listed and some examples are shown that a "straight forward" application of these rules can lead to problems within the definition of the system boundaries. Therefore the definition of the system boundaries using cut-off rules should essentially be done by experts:

- knowing the respective process chain technically, and
- knowing the field of environmental effects caused by the related material and energy flows.

Only this combined knowledge will lead to a meaningful definition of the system boundaries. Therefore system boundaries and cut-off rules are indeed essential elements preparing data collection. In the following, practical cases of cut-off rules are listed.

On the unit process level **(input side)** the following major rules are applied:

- cut-off of any input 1 % according to mass and energy, and
- expert-judgement according to ecological impact relevance of inputs less than 1 %.

This is especially important for processes with a high amount of different substances flows or large material flows, such as pesticide in agriculture or with concrete, as even small amounts (<1% mass) can be summed up in total, they are important due to their relative environmental relevancy in comparison to the main mass flows.

Therefore a technical and environmental understanding of the process is needed by the user. Otherwise suitable cut-off criteria are hard to define without uncertainty.

As a general principle of the unit processes, everything that is available or known, should be reported, even if it falls below the 1%. Whether, the cut-off criterion is applied or not is then rather a matter on system (or plan) level.

The suitable application of cut-off rules on the input side defines the amount of relevant included upstream process-chains.

On the output side the cut-off rules are mainly defining the degree of detail in terms of by-products, emissions and wastes.

On the **output side**, the procedure is as follows:

1. All known by-products are recorded (primary data is first choice).
2. All known emissions are recorded (primary data is first choice).
3. In case no data is available, emissions from similar processes or suitable literature data is used.
4. Alternatively with technological engineering know-how emission data can also be calculated over reaction equations and mass-energy balances.
5. Optionally, gaps in the data are identified and provided with a worst-case scenario (for example legal limit).
6. The ecological relevance of the individual emissions are calculated with the data categories described above (individually per category a sensitivity analysis is recommended. Sensitivity analyses are supported by actual software solutions and can therefore easily be done during this process). A check is carried out, as to whether temporarily entered literature values and estimated emissions produce important contributions.
7. If so the relevant emissions need to be investigated in detail (maybe iterative step of primary data acquisition needed as most representative values are the primary data sources of the actual process.

Hence the 7 points above may guide through possible steps of a data acquisition considering cut-off rules. But if the data of concern is not known but possibly unsuitable for cut-off an iterative step of primary data collection has to be applied or respective uncertainties are to be reported.

The fundamental problem is to establish the ecological relevance of emissions in order to assess the contribution of one particular emission, the total effect of all emissions must be known (and this has perhaps most often not even been measured completely; however the most contributing emissions are considered to be known). This criterion should therefore be seen as an indicator for which emissions are crucial according to the existing working-categories. The following sample calculation aims to develop a feeling for this, making the procedure easier.

**Sample Calculation from the Energy Sector for Diesel:**

As can be seen in Table 1, neither a cut-off below 1% mass fraction, nor a cut-off below 1% energy fraction makes sense in the example used, as most pollutants with significant effects on the environment would then be excluded. To avoid this, every potentially occurring substance must be estimated (e.g. concerning substance contents in fuel or emission limit values for exhaust), so that its relevance to working-categories (incl. possible margins of variation) can be ascertained and finally assessed, as to whether detailed data research is useful.

**Table 1: Most important emissions of the average diesel at refinery in GaBi databases 2006 [4] per kg diesel referring to the exemplary impact categories AP/EP/GWP/POCP of CML [5].**

| | | | | | AP | EP | GWP | POCP |
|---|---|---|---|---|---|---|---|---|
| | kg | % | MJ | % | % | % | % | % |
| Total emissions to air | 5,95E-01 | 100,00 | - | - | - | - | - | - |
| Exhaust | 1,83E-01 | 30,78 | - | - | - | - | - | - |
| Steam | 1,06E-01 | 17,83 | - | - | - | - | - | - |
| Carbon dioxide | 3,02E-01 | 50,73 | - | - | - | - | 99,29 | - |
| Nitrogen oxides | 8,78E-04 | 0,15 | - | - | 25,86 | 97,52 | - | 5,61 |
| Sulphur dioxide | 1,76E-03 | 0,30 | - | - | 73,88 | - | - | 19,23 |
| Carbon monoxide | 4,16E-04 | 0,07 | - | - | - | - | - | 2,56 |
| Nitrous oxide (laughing gas) | 6,97E-06 | 0,00 | - | - | - | - | 0,71 | - |
| Group NMVOC to air | 8,74E-04 | 0,15 | - | - | - | - | - | 72,60 |
| Ammonia | 3,27E-06 | 0,00 | - | - | 0,26 | 0,98 | - | - |
| Waste heat | - | - | 1,29 | 100,00 | - | - | - | - |
| Total emissions to fresh water | 0,00834863 | 100,00 | - | - | - | - | - | - |
| Chloride | 5,82E-03 | 69,75 | - | - | - | - | - | - |
| Chemical oxygen demand (COD) | 8,00E-05 | 0,96 | - | - | - | 1,50 | - | - |
| Particles to fresh water | 2,13E-03 | 25,49 | - | - | - | - | - | - |
| Sulphate | 3,04E-04 | 3,65 | - | - | - | - | - | - |
| Sulphide | 1,26E-05 | 0,15 | - | - | - | - | - | - |
| Waste heat | - | - | 0,056 | 100,00 | - | - | - | - |

In summary a general rule can be stated: **"Only cut-off what can be quantified"** (see point 1 to 7).

This makes system boundary definition and the choice of cut-off criteria quite demanding for users that have limited knowledge or access to the relevant technical background data.

Therefore two principal requirements are needed to prevent rude or unsuitable cut-off.

1. Experience, as a comparable system has been modelled before and the important aspects are already known, approved and possibly even reviewed.
2. Time, as if no experience related to the system under study exists, this experience has to built up

## 1.4.3 Infrastructure

Infrastructure is a question of cut-off criterion: if relevant, the infrastructure is also taken into account. Since infrastructure in most cases is not relevant (assuming mass production and a long use phase) it can be excluded from the scope of the system boundaries in most of the cases, as the inclusion would not significantly change the result. This has been proven in many cases over the last 2 decades of LCA history (see point 2 of chapter 1.4.2).

Nevertheless these aspects need to be kept in mind if mass production is not taking place or the production system is rather exclusively described by the infrastructure (e.g. at the production of electricity by wind power converters). Therefore an estimation of the relevance of infrastructure should be checked (this can be done e.g. based on a worst case material composition of the infrastructure for example).

### 1.4.4 Transports

Whether transport must be considered or not is a question of cut-off criterion as well:
As a general rule the transportation processes are to be included due to consistency. However transportation processes, including fuel production and utilization, is in principle only to be included if the process in the considered system is know as to be relevant due to

- weight of material or product to be transported and
- distance of transportation.

If in doubt, it is recommended to include the transportation process in the model. In general the LCI database should be build up using the same source for transportation processes.

### 1.4.5 Waste

Waste treatment is integrated over the whole system during modelling, where the treatment is known. That means that e.g. for waste, which should be disposed, incinerated or landfilled related processes are integrated. In the case of GaBi databases 2006 [4] these aspects are prepared as models (inert matter landfill, domestic waste landfill, hazardous waste landfill underground/ above ground, waste incineration of domestic waste, waste incineration of hazardous waste). Hence the waste fractions of the processes must be identified by its composition.
There are many products which are considered legislatively a waste, but which have to be treated as products in life cycle analysis, as those are not leaving the system boundaries. Waste going to any kind of reuse or recycling is allocated or substituted, if a considerable positive market value (a product) exists. It should be noted that the same market value is applied at the point where the waste (or waste products) accumulates and at the point where the waste is recycled. For a suitable modelling feedback from the both side (producer of waste product and user or processor of waste product) is necessary. Waste to be recycled without a market value will stay (virtually) as waste in the producer process and is documented as such. The user of the waste product may process the waste without burden of the previous operation. All allocations must be documented.

In case that specific information is not available, a standard procedure is adopted at the GaBi databases 2006 [4]. Following the EU rules and goals on recycling and waste treatment

- any secondary material that already has a recycling market is treated as recycled according to the market share (see examples in following table).
- all waste generated within the EU that has a calorific value is treated in an incineration plant (see selected examples).
- all other waste goes to landfill (see selected examples):

**Table 2: General procedure for material specific waste treatment process**

| Material | Waste treatment Process |
|---|---|
| Mixture of plastics | Incineration |
| PVC waste | Incineration |
| Wood | Incineration |
| Aluminium waste | Recycling |
| Steel waste | Recycling |
| Coating and sealing | Recycling |
| Glass, concrete, stones | Inert landfill |

The above description is a definition which was drawn for the GaBi databases 2006 [4]. Each case should be analysed separately in order to decide how to define the general integration/ modelling of waste treatment.

In addition the treatment of waste water should be included in the modelling. As in the case of waste treatment (incineration and landfill) the composition of the waste water must be determined in order to make the individual adaptation of the waster water treatment process possible (see chapter 2.6.8). Within the GaBi databases 2006 [4] all waste water is modelled until release to river or sea. In case the water is treated with related consumption of energy and chemicals leading to lower emissions to nature; in case of untreated water with higher emissions respectively.

### 1.4.6 Biomass

Suitable biomass is also an important aspect that should be taken into consideration in the modelling of a system accordingly. This means, especially carbon dioxide, water, solar primary energy and the land use categories are addressed, if biomass is considered in the GaBi databases 2006. Doing this, mass balance consistency is assured as for example, biomass incineration releases $CO_2$ which was uptaken shortly before.

The solar primary energy of biomass is exactly the amount of solar energy, which has been converted by the biomass (hence the calorific value). The efficiency of conversion does not play a role, as the source (sun) can be understood as infinite.

### 1.4.7 Other renewable energy sources

For hydropower, wind power and geothermal power the related primary energy demand has to be calculated and accounted for as well. Otherwise product systems using this energy sources, would generate end energy without primary energy use. However, the value and burden of the use of 1 MJ renewable primary energy is certainly not comparable with 1 MJ of fossil primary energy, because the availability of the fossil resources is limited.

This report will not discuss the topic further, but will give practical guideline to prevent “double counting” as well as “perpetuum mobile”.

1 MJ electricity from wind power is produced using (virtually) 2,5 MJ of primary wind power (this is an efficiency of 40 %). If the efficiency is not a matter, as the primary energy from wind is considered as infinite, 1 MJ primary wind power is used to produce 1 MJ electricity from wind power (see biomass).

For 1 MJ electricity from hydro power (virtually) 1,15 MJ of primary hydro power is used (this is an efficiency of 87 %).

For 1 MJ electricity from geothermal power (virtually) 1,98 MJ of primary geothermal power is used (this is an efficiency of 45 %).

## 1.5 Types and sources of data

Data to be used for an LCI depends highly on the goal and scope of the study. Also, one has to keep in mind, which impact assessment method will be adopted for the evaluation, as this will also influence the type of data to be collected. Or vice versa, the available data may influence the choice of impact assessment method.

### 1.5.1 Source of data

Despite of the fact that all possible data sources should be checked, primary data from industry should be the preferred option. In case of unavailability or missing access to such data, similar or comparable data should be used: reports with industry participation, industry publication, etc. Other options could be: literature or expert judgement. (please refer to chapter 1.8.2 for more possibilities).

### 1.5.2 Primary and secondary data

There are numerous types of data that can be acquired for conducting LCI studies, and it is important to distinguish between primary and secondary data.

***Primary data*** are those obtained from specific facilities as a primary source of information. This data is measured or calculated for this particular facility.

***Secondary data*** are those included in the product system life-cycle inventory that have been obtained from published sources. Examples of secondary data sources include published literature, other LCI studies, emissions permits, and general government statistics (e.g. mineral industry surveys, Bureau of Labor statistics, and Energy Information Administration data).

All data should be identified as being either primary or secondary as part of routine data documentation. The most representative and reliable data should always be used, with the proviso that critical reviewers should be able to verify that the data is updated and that it reasonably represents relevant aspects of the unit process under study.

### 1.5.3 Units

All data should be presented in metric (SI) units. Where conversions are required from imperial or non SI units, the conversion factor must be clearly stated and documented.

### 1.5.4 Data selected for an LCI

It is important to clearly define the kind of data which will be covered by creating an LCI dataset for a system. Therefore it is necessary to have a clear understanding of all material and energy flows connected to the product system. Also it is meaningful to have this definition done comprehensively to focus on the impact categories and evaluations methods which will be taken into consideration. In this way, consistency among different data sets provided by different groups is also assured. Below a listing of some commonly used impact categories and evaluation methods. Nevertheless this list must be considered specifically under each user's goal and scope. ´

- **Input-dependent quantities**
  - Abiotic Depletion
  - Primary energy non-renewable (is entered as an additional quantity)
  - Primary energy renewable (is entered as an additional quantity)
  - Demands on natural space (surface)
- **Output-dependent quantities**
  - CML 2001 Categories (GWP 100, ODP, AP, EP, POCP, HTP, TETP, FAETP, MAETP) [5]
  - TRACI categories [6]
  - EDIP 2003
  - Disposal space (volume)
  - Others

Further assessment methods are:
  - Ecoindicator 99 [9] or 95 [8]
  - Impact 2002+ [10]
  - UBPs [11]
  - EPS [12]
  - Others

### 1.5.5 Production and consumption mix

In general two different levels of information can be understood as:

a) "**production mix**": this approach focuses on the domestic production routes and technologies applied in the specific country/region.

b) "**consumption mix**": this approach focus on the domestic production and imports taken place. This approach represents the situation which exists for every commodity in the specific country/region in a day to day situation.

Figure 4 shows the differences between the two principle approaches. To explain the two approaches an example focusing the generation of electrical power is selected. The example is set up on the principle that electrical power available within Country C (for example) is generated by running different types of power plants. The energy carriers necessary for the operation of the power plant will be supplied by domestic resources as well as by imports from different countries. It is likely that besides the supplies for the power generation also electric power might be imported as well.

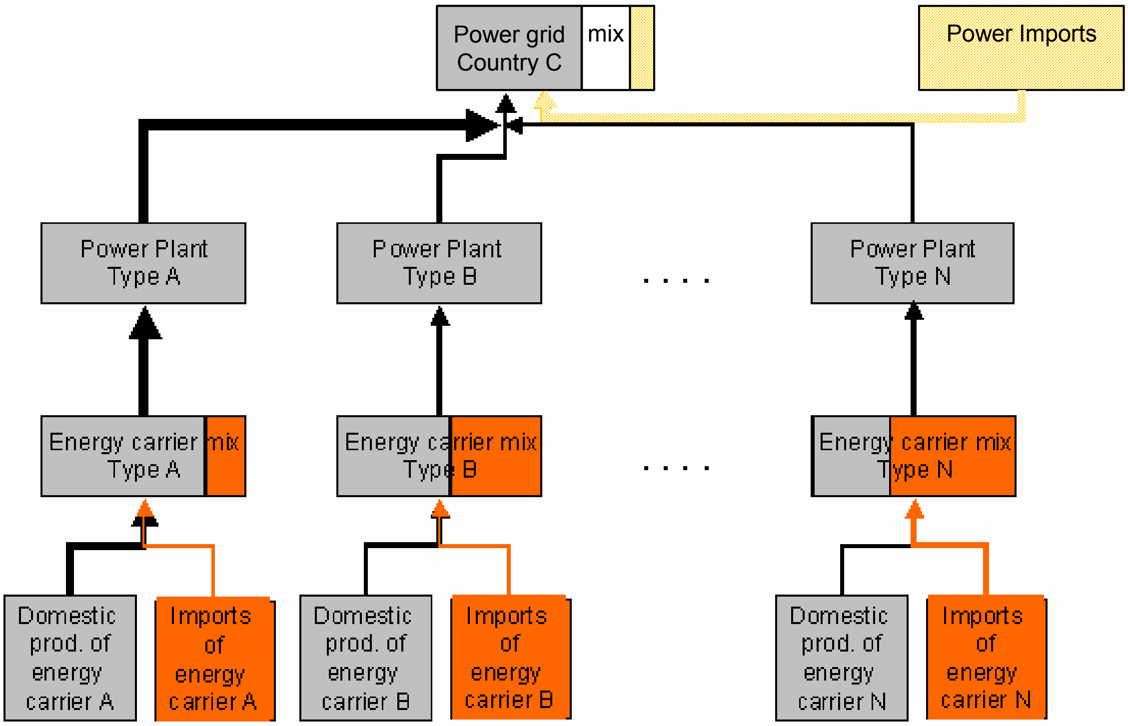



**Figure 4:** **Difference between "production mix" and "consumption mix" demonstrated at the example of power generation**

The part of the Figure 4 which is coloured in bright grey represents the domestic part of the production represents the "production mix" approach.

All parts of the supply chain of the power generation process coloured in orange (dark grey) represent the imports of supplies for the power generation (imports on energy carriers). Imports on end consumer level (imported power) are illustrated by yellow colour (criss-cross yellow line). The "consumption mix" includes the "production mix" as well as all information regarding the imports. The inclusion of the imports in the LCI data requires country specific information about the generation of supplies and whether final products are available or will be gathered during a data collection. Not included in this example is the export as the reverse of import.

It is obvious that for every commodity of the database a screening of the existing situation focusing the relation on domestic production and imports has to be done, since this will be different for every commodity. As the GaBi 2006 Database is dedicated to be used mainly by persons requiring consumption mixes, most of the products represent the consumption mix by country.

## 1.6 Data quality requirements

### 1.6.1 Reference time and reference area

Reference time and Reference area have to be defined as one of the basis setting for the database creation process. Here the focus is to select the most up-to-date year possible keeping in mind that different industries have different reporting systems and innovation cycles. If data might come from governmental agencies also their delay in publishing data must be considered.

Regarding the reference area please compare with the section of chapter 1.4 discussing the definition of system boundaries.

### 1.6.2 Technology coverage

The intent is to develop industry average data for the range of technologies currently in use for specific unit processes. If more than one technology is used for the production of a certain product system in an industry, data should be collected for the full technology range and reported separately with the market proportion served by that technology. If it proves impossible to produce anonymous data by averaging from plants using similar technology or if there are confidentiality agreements in force to prevent disclosure then results can be aggregated to produce weighted averages, with the relative contribution to the market by each technology type used as the weights. Data by technology type should also be separately reported unless confidentiality agreements with manufacturers prevent its disclosure.

Where distinctly different technology pathways are used to produce the same materials/products/commodities, then these may need to be kept distinct and not aggregated – the average values would not be representative of any of the technologies. Examples include:

- Electricity from different pathways
- Steel making: electric arc, basic oxygen furnace, HiSmelt
- Blast furnace or electro-refined metals
- Wet or dry process cement clinker production

There may also be a rationale for regional production models for commodities which are predominantly traded just within a local region.

- Electricity, gas and petroleum products
- Wood panels and timber products
- Cement , aggregates and sand
- Waste management services

For some low impact materials, transport is the dominant impact in their production and transport distances and modes may crucially affect the LCI results with sometimes counter-intuitive outcomes. For example:

- Aggregates shipped long distances by sea from coastal quarries may have lower net impacts than apparently more local sources travelling by road haul.

All technology or region specific models should document the following information where it is available:

- Location, Geography, Climate and Land use
- Environment issues and International Agreements
- Natural Resources and Hazards
- Economy and Industry Infrastructure and Logistics
- Fuel and energy, Infrastructure and Transportation

### 1.6.3 Data aggregation

The aggregation of datasets is necessary in order to secure the privacy of confidential information (such as name of data provider), but still enable to use the most accurate and up-to-date information; further to make the handling of datasets feasible for both experts and users.
Some systems have a complex character. Thus they are only understandable for LCA experts and experts of the related technology. In order to make the handling for non-experts possible and feasible as well, some complex and often used datasets need to be aggregated in a representative way. An example is the aggregation of electricity mix for a specific country, which is used in most of the industrial LCI models. This is indeed a complex model, consisting of a huge amount of processes and parameters. The users want to have assured the transparency of the information concerning this model, which demand can be fulfilled with a transparent documentation of the dataset. However they do not have an interest in dealing within the details of the model (except for the case the user belongs to the energy provider or wants to deal with the effects of the parameters within the electricity mix). Therefore an aggregation of datasets is suitable and meaningful for a wide range of users.
An LCI study benefits from the availability of datasets or databases. In order to establish a database, with high quality, the use of primary colleted data from industry is necessary (primary data). Usually, such kind of direct data can only be colleted under confidentiality. Also, for this purpose the implementation of data aggregation is meaningful. Basically there are two aggregation types:

- Horizontal aggregation and

- Vertical aggregation.

The horizontal aggregation is applied for the creation of a representative process for a production of a certain product by taking different technologies into account. In this case either the consumption or the production situation must be taking into account (see “production and consumption mix” chapter 1.5.5). The upstream or downstream processes are not integrated in this step of aggregation

The vertical aggregation is carried out by considering certain technological route. In this case the upstream and/ or downstream processes are included in the aggregated dataset.

The vertical aggregation of the horizontally aggregated dataset can be applied as well.

### 1.6.4 Precision, completeness, representativeness

The items precision, completeness and representativeness provide specific details to the data used and should be included in the documentation.

**Precision**

Precision determines the variance of data, e.g. whether measured, calculated or estimated. In this case, the GaBi databases 2006 [4] the following procedure is adopted:

- **Measured:** Values measured directly by LCA practitioner, producer or project partner. Values from reports, which were measured and allowed for publishing, can be also considered as measured.
- **Literature:** Values obtained from literature which are explicitly not stated, whether the value was measured or estimated.
- **Calculated:** The values were calculated e.g. stoichiometric calculated.
- **Estimated:** Expert judgement e.g. referring to comparable products/ processes or legislations.

**Completeness**

Completeness provides information regarding the percentage of flows that are measured, estimated or recorded as well as unreported emissions. In the GaBi databases 2006 [4] the following procedure is adopted:

- **"all flows recorded":** the whole process is covered due to complete access to process data or the process was modelled in a very detailed form. Processes in which the cut-off rules were applied and checked can also be considered as complete.

- **"all relevant flows recorded":** the relevant flows of the process are covered. When all flows cannot be recorded, this is the next option, which still enables reasonable good quality of results in terms of evaluation.
- **"particular flows recorded":** only particular flows are recorded. It must be clear that in this case some important flows can have been left aside, so that only medium quality of data can be achieved. If possible, further research should be performed.
- **"some relevant flows not recorded": i**f good quality is desired, this case should not occur. In case no data is available, reasons for using this kind of data should be documented.

**Representativeness**

Information about data representativeness is assessed qualitatively and reflects to which extent the data set represents the reality, being data e.g. completely, partly or not representative. The technical representativity is stated in the documentation, the regional representativity is documented by country short name in the process and the time representativity is documented as well in the process.

## 1.6.5 Consistency

Consistency refers to the uniformity of the data, methodology and procedure adopted in the study. At the latest in the plausibility check (chapter 2.7) this should be checked through mass and energy balance, methods used, etc. The GaBi database 2006 [4] is consistent since all datasets follow the same methodology as described in this report. The database uses consistent data sources, background system (e.g. transport, energy processes) etc. as presented in chapter 2.7.1.

## 1.6.6 Uncertainty

Uncertainties can be present in different ways in the inventory of a process:

- Uncertainties in the measurement, process or time variations, mean values from literature,
- Assumptions made based on missing data or process conditions,
- Approximations or estimations, e.g. in use of background processes for materials and energy,
- Completeness of the flows, e.g. in case not all relevant flows were captured,
- Errors in terms of modelling or
- Human errors.

Although it is not always easy to quantify this uncertainty, as in many cases just one value for each process step in the inventory is available, whenever possible, it should be quantified and documented. Methods for uncertainty estimations such as Monte-Carlo Simulation can be used. All references and assumptions must be documented.

As a general rule: Due to the extreme complexity of life-cycle-models and the high amount of measurements, calculations, estimations and external data sources a "real" difference in terms of "better" or "worse" option should only be interpreted, if results vary more than 5 %.

## 1.7 Data categories

Data categories refer to the classification of the database content. Its main objective is to enable a better structure of the database as well as provide guidance on the datasets within the database. For instance, the following types of categories can be used:

- Process categories (e.g. energy carriers, materials, etc.),
- LCIA method categories (e.g. human health, natural environment, etc.),
- Flow categories (e.g. emissions to air, resources, etc.),
- Flow property categories (e.g. technical flow properties, chemical composition, etc.),
- Unit group categories (e.g. technical unit group, impact unit group, etc.),
- Contact categories (e.g. organizations, working groups, etc.),
- ...etc.

Using diesel as an example for a process category, a possible classification could be: energy carriers (process top category) → crude oil bases energy carriers (process sub-category) → Diesel at refinery (data set).

## 1.8 Data collection

The data collection is the basis for all following steps of analysing the gathered data and the use of this data for the set-up of the process models which will be the basis for the inventory calculation. This means that the quality of the dataset will be dependent on the success and the level of quality resulting from data collection. Therefore a unique procedure is defined how to do the data collection. Such a procedure should cover the following aspects:

- Try to understand firstly the core production technically.
- Identify the general situation on the manufacturing phase of a product system to be analysed (e.g. how many producers exist, what are the applied technologies, etc.).
- Identify the essential single process steps which are dominating the manufacturing phase of a certain product system (the modelling expert must be familiar with the

technologies). In case that industry has given a commitment to provide data than this process should be done in cooperation.

- Create a questionnaire which explains the reason for data collection and also describes the data need on process level (Golden rule: the questionnaire should be as detailed as possible but not more than necessary and very objective, which means to stay on a realistic level which can be supported by the data source but also fulfils the needs of the LCI project). A flow chart of the process also helps to have a good overview from where which data comes from. It also facilitates the understanding of the questions. Try to fill in as much information as the data collector already knows. That gives the data supplier the feeling that the data collector has informed himself and of having less work.
- Hand over the questionnaire to the data supplier, possibly this is taking place during a personal meeting to explain the procedure in detail and to make sure that the questionnaire is understood correctly, or by e-mail with a telephone conference.
- Check of the returned data applying general rules which focus on consistency and overall quality of the gathered data. This should include:
    - mass and energy balance,
    - emission balances,
    - plausibility check focusing the general process characteristics and
    - others
- Provide feedback to the data supplier and also use this additional conversation to clarify challenging matters if any existing from analysing the provided data.

For the process of data collection different techniques can be used which differ in type of technique and also effort to prepare. The following type of data collection can be used:

- Printed paper version,
- Electronically Word® or Excel® Document,
- Specific macros (e.g. GaBi 4 data process recording tool) or
- Web based applications (e.g. GaBi 4 web questionnaire).

Within this section also aspects can be listed which give tips what to do if there is an inconsistent or even missing data set. This procedure was also adopted in the work done at the GaBi databases 2006.

### 1.8.1 Quality check and validation of collected data

During the process of data collection, experts can prepare a check-list of general points that should give evidence if the data quality requirements are fulfilled. As mentioned above, this includes: mass and energy balance, emission balances, plausibility check, but also whether all processes steps and inputs and outputs are included. In the presence of return flows inside the process and/ or waste, it must be checked the procedure adopted by the data provider. This is also part of the data collection.

In case of anomalies, problems should be checked with the data provider. It should be clarified whether this is a common problem with the specific process or any special case.

Apart from this technical check, aspects covered by the data quality requirements (Chapter 1.6), data sources (Chapter 1.5) modelling principles such as goal and scope (Chapter 1.2), functional unit (Chapter 1.3) and system boundaries (Chapter 1.4) must be checked in order to assure consistency over all data collected.

After this internal check as well as documentation check, once the quality level is achieved and all points are checked, data is validated and can be used for modelling.

### 1.8.2 Treatment of missing data

Data gap is a common problem of LCA practitioners. This can happen due to unavailability of data from data provider, no measurement performed for all emissions, no access to data due to confidentiality reasons, etc. In this case it is up to the expert team to decide which procedure to adopt.

The goal is just to close the gap as efficient as possible, without mistakes.

There is no standard rule for this problem as each case should be analysed separately, but the following measures can be taken:

- Literature: reports, papers, books, etc. can be checked.
- Average value from similar processes.
- In case of chemical reactions, often a good estimation can be provided by the stoichiometry and estimation of the reaction's yield.
- Estimation based on similar processes/ technologies or in the case of cross-boundary situation, consider the situation of countries with similar boundary conditions.
- Expert judgement (but this should be based on one or more aspects of the above).

In any case, according to the ISO 14044 [3] the procedure adopted for the treatment of data shall be documented.

# 2 System Modelling Features

The system modelling starts with editing gathered data to the selected software system.

In the case of the software system GaBi 4 the system is organised in modules. This means that: plans, processes and flows as well as their functions form modular units.

The basis of modelling using GaBi 4 is the object type flow. A GaBi 4 flow is a representative of an actual material or energy flow. Flows are used by processes and represent the link between processes within a life cycle.

GaBi 4 processes are representative of actual processes, technical procedures or groups of procedures. They roughly correspond to the term “unit process“ in ISO 14044 [3].

Plans are used in GaBi 4 to assemble processes in the product system. Essentially, plans are the process maps which visually depict a stage or sub-stage in the system.

In this way, for each modular unit, a clear defined nomenclature is necessary to specify new flows, processes and plans.

- Flows

  Example: A flow needs to be specified by the following aspects:
  - Name (most commonly used or according to existing systems)
  - CAS code
  - Abbreviation (e.g. polypropylene → PP)
  - Chemical formula (e.g. carbon dioxide → $CO_2$)
  - Relevance to a certain impact category should be indicated
  - Other technical aspects like calorific value, element content, …
  - Reference unit

In general a software system used for the system modelling should already have a substantial list of predefined elementary flows, so that ideally only new product flows need to be created. Following ISO 14044 [3], elementary flows (mostly resources, emissions and wastes) refer to the material or energy flows entering or leaving the system being studied that has been drawn or released into the environment without human transformation. Product flows refer to flows entering or leaving other product system. This approach has proven its effectiveness at PE and LBP-GaBi during the creation of several LCA databases within the last 2 decades. At the moment a commonly accepted nomenclature for flows used for LCI purpose is not available. However a European or global standard nomenclature would be desirable.

- Processes

  Example: a process needs to be specified by the following aspects:
  - Specification of the country

- Name (mostly the name of the product created → which is also the functional unit of the process analysed)
- Addition to the name (e.g. polyamide 6 granulate (PA 6)
- Indication if production technology if several technologies exist to produce the material
- More detailed information on the region which is described by the process data (e.g. South Germany)
- Reference year
- Data quality and its completeness

- Plans

  Example: A plan should be named like the process created.

Goal is a consistent naming of the flow, the related process and the related system plan.

GaBi databases 2006 [4] has already integrated elementary and product flows for more than 2500 datasets and the respective used flows are documented directly in the process headline.

Also since the combination of processes and plans in e.g. GaBi 4 affects the result analysis (not the overall LCI result) a clear definition how to do this should be defined. The processes and plans have a build up a structure as exemplary presented in the following figure.

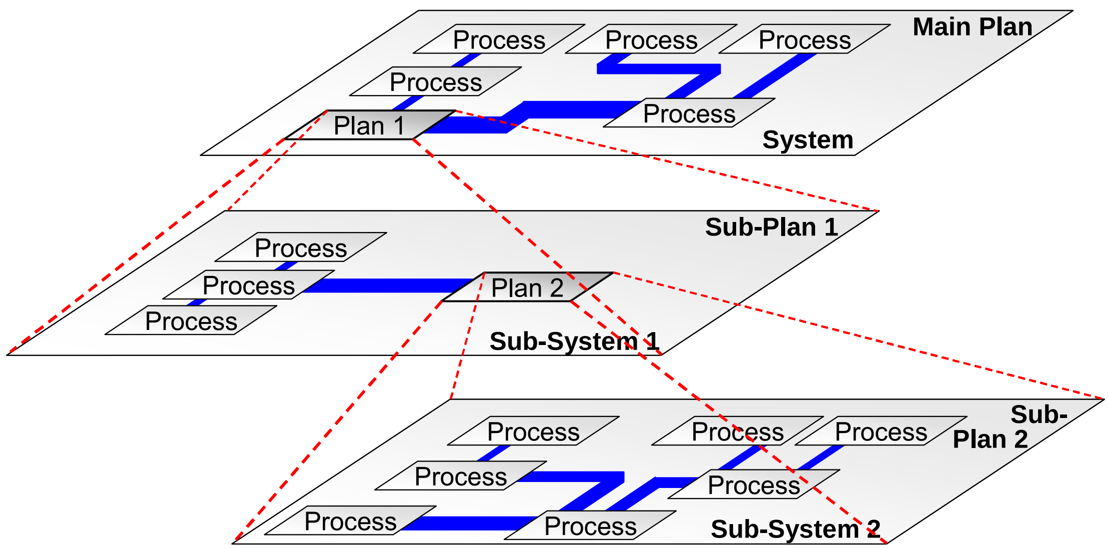



**Figure 5: Hierarchical structure of the processes and plans**

## 2.1 Site dependency

Regarding site specific information, GaBi adopts the following modelling rules:

- Site-specific data needs to be collected, the complete modelling should also keep this level, i.e. if data is received from a German particle board producer, the respective thermal energy and binding material process used by the company should be used. In case thermal energy is not produced by the company, then the German thermal energy should be used.
- In case power is produced by the company but no access to such data is possible, an estimation of the power supply of the company should be made based on the data provided by the company.
- If no estimation can be made, before using a general dataset, it should be checked in the database available, whether power supply for specific situations is available, e.g. cogeneration in the chemical industry. If available, this option should be used.
- If no information is available concerning the use of own power supply or external power supply, then a general country grid mix should be used.
- If no specific information nor reliable data, nor information about the source of the used materials is available, country specific consumption mix is to be used as basis.

## 2.2 Parameter

In this context a parameter is a variable within a data set, allowing the variation of process input and output flows detached from a strict relationship between input and output flows (scaling). Thereby parameters can be used to calculate flow quantities (e.g. due to the characteristics of a used substance) based on technical conditions, e.g. efficiency of power plant using energy carrier properties or e.g. sulphur dioxide emissions in dependency of the sulphur content of the used fuel or on other parameters.

A typical application of parameterised models (processes) is the modelling of transportation processes. For instance is it possible to calculate the $CO_2$ emissions by means of a mathematical relation in dependency of the travelled distance, the utilization ratio and the specific fuel consumption of a truck (see chapter 2.6.2 for more details).

Parameters should be used in LCI processes with a high level of variation, such as transportation processes or in processes which should be easily adaptable for the user.

## 2.3 Allocation principle

Allocation respectively system expansions are used to effectively handle so-called co-products. This aspect in LCA is often the reason for discussion, despite the fact that often just one useful allocation rule is applicable and often the relevance of different allocations is rather an academical question than a real difference in the result. If there is a significant influence on the results due an allocation, a sensitivity analysis shows transparently the effects and enable related result interpretations.

The ISO 14040 series says that allocation is to avoid if possible and system expansion should be used.

This is rather not to interpret in way that system expansion is the favourite approach. But in most cases it is quite easy to show that system expansion is not applicable. Hence allocation and system expansion are equally favoured.

Nevertheless the system expansion approach often results that the final inventory than will have single flows included which can hardly be integrated into the interpretation of the analysed system. Therefore results are often confusing to technical experts (e.g. people who have provided data but which are not LCA experts) if they are analysing an LCI representing the field of expertise enlarged by data from totally different fields.

The solid technical interpretation of the results gets weaker and less transparent.

Measures described in the ISO standard such as system expansion or further detailing the system until only single output processes are used to avoid allocation will only be applicable to a limited degree. Therefore the applicability of those are checked as a first step

Experiences from research institutes or industry have shown over time that allocation using the appropriate allocation keys proves to be a suitable tool for distributing environmental burdens to a specific product; especially using scenario calculation and sensitivity analysis to quantify influences of changing allocation keys.

For example, applying system expansion increases the efforts for data collection massive and in most cases it is not possible to reflect the actual situation of a process step by replacing a multi output process by multiple single output processes in a feasible and technical meaningful way.

As soon as multi-output unit processes (e.g. refinery) are part of the system under consideration, it is necessary to implement allocation. That means to distribute the in- and outputs (resources, intermediates; emissions) to the different products of the processes since it is neither wanted and nor that all of these products are defined in the functional unit.

Following the ISO 14040 series, an allocation is always necessary if the allocation of a process with two or more outputs (e.g. combined heat and power generation, atmospheric distillation;

see Figure 6) can't be avoided by dividing the multi output unit process into single output processes or by extending the product system (which is daily practice mostly the case as mentioned before). It is then necessary to determine which allocation key is used to partition the environmental burdens of the product system to the different products. This is also applicable to the recoverable process wastes. Physical properties (e.g. mass, work potential, calorific value) but also economic criteria (e.g. market value) are suitable allocation keys according to the ISO 14040 series. It is important to select the allocation criteria keeping in mind the *original intention of the process* and the system boundaries specifying which in- and outputs are associated with the functional unit. The choice of allocation method needs to be documented and sensitivity analysis for evaluating the impact of the allocation is to be conducted if necessary.

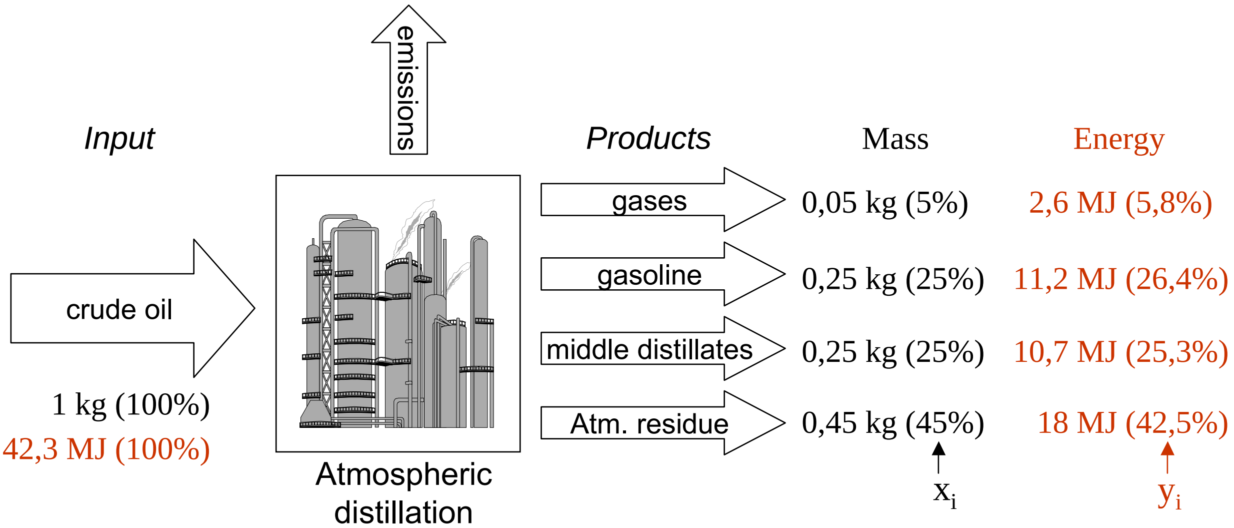



**Figure 6: Atmospheric distillation as exemplary situation for allocation (simplified)**

Figure 6 gives an exemplary situation for allocation. It shows the variation of the allocation keys (mass or energy) leading to a different distribution (factors $x_i$ and $y_i$) of the inputs (raw material resp. crude oil) and emissions from the process step on each product.

The used allocation keys will reflect the initial purpose of producing a certain product, which means the main burden, will be allocated to the main product of the process in question. Each choice of an allocation key will be justified and will be documented.

Figure 6 gives a simplified allocation example. In reality, a refinery is a complex system incorporating a multitude of multi-output processes. To allocate the material and energy inputs along with the process-specific emissions to the different products of an actual refinery in a way as feasible and accurate as possible, a hybrid allocation approach is chosen. The actual allocation of the needed crude oil will be done considering the energy content of the product (to avoid perpetuum mobile effects). The energy related emissions and the needed energy input (electricity, thermal energy) is considered over the product output mass (mass allocation).

The applied two step allocation rule ensures, that on the one hand the environmental burden is modelled accurately according to the needed effort to process the oil and intermediates in the related process steps (more mass processed → more burden and more process steps → more burden), on the other hand the respective crude oil is in a realistic relation to the energy content of the product, which is important for the use phase of the refinery products (e.g. as fuel in busses).

For allocation it is important to comply with the closing condition for mass (m) and energy H (enthalpy H = heating value h* mass m) for the unit process under consideration

$$\frac{\sum_{Input} m_{input}}{\sum_{Output} m_{output}} = \frac{\sum_{Input} m_{input} \cdot h_{input}}{\sum_{Output} m_{output} \cdot h_{output}} = 1$$

When allocating by mass or by energy, in- and output flows of a process are leaving the system boundaries. This seems to lead to mistakes, e.g. the energy balance for a mass allocated process isn't correct or there is a defect of mass for an energy allocated process. But looking at the unallocated process it becomes clear that there is no calculation error. The reason is that the other mass and energy flows are no longer a part of the product system and therefore they are not considered in the balance. They are considered in other products system using these flows.

Making the balance over a whole company, region or nation the allocated values sum up correctly to the e.g. totals of the company, region or nation again. Hence allocated burdens are a systematic part of a consistent total, which enables to understand the life-cycle easier.

## 2.4 Recycling

Regarding recycling two main cases can be mentioned: closed loop recycling and open loop recycling.

Closed loop recycling involves the recovery or reuse of material in an identical secondary use. For example, the reuse of PET bottles or the recovery of PET granulates from bottles to produce new bottles.

Open loop recycling corresponds to the conversion of material from one or more products into a new product, involving a change in the inherent properties of the material itself (often with quality degradation). For example the reuse of coke PET-bottles as water bottles or the use of the PET-bottles granulate to produce cloths.

**Allocation beyond Lifecycle limits (Open loop and Closed loop Recycling)**

With allocations beyond lifecycle limits with durable products the time aspect must be taken into account and the situation of production nowadays must be separated from that of future recycling. For production, the current average market situation must be assessed (ratio of primary material to recycled material). In parallel, the recycling potential reflecting the "value" of the product following treatment can be presented. The product part required for current secondary production should be deducted beforehand (see 2.6.5).

## 2.5 Generic Module

Some industrial processes or natural systems are highly complex. The complexity is not only characterised by the amount of required materials and processes, but also by their non linearity among each other. Complex systems can be often found in different fields: electronic, agrarian, construction fields, etc. If the required materials and processes are the same for several different systems, the model can be adapted for each purpose – as far as the complex relation is the same and integrated in the model.

In this way, the approach of a Generic Modul is applied to manage complex product models and gives the opportunity to provide transparent and summarised results within an acceptable time. This is realised by forming flexible models with parameter variations, including readily modelled materials and parts. These parameters allow the variation of system models based on technical dependencies. The parameter variation offers the possibility to adapt the models to specific product properties or modelling design scenarios without the need of forming entirely new models.

Generic Modules are used for single processes, system parts or the complete manufacturing of a product. By variation of significant parameters each single module of the product chain can be varied. By implementing the entire manufacturing into a modelled Life Cycle all effects to each Life Cycle phase can be recognised depending of the different variations.

## 2.6 Special modelling features for specific areas

In the following paragraphs specific modelling issues are addressed for selected areas, which were used in the GaBi databases 2006 [4]:

- Energy,
- Transport on road,
- Metals and steels,
- Chemistry and Plastics,

- Construction,
- Renewables,
- Electronic and
- End-of-Life.

### 2.6.1 Energy

Due to its specific situation in different regions and the related complexity, the modelling of the energy supply takes place in three levels:

- Supply of different sources of energy (e.g. different energy resources)
- Creation of country specific mixes for each single energy carrier (e.g. natural gas mix Germany)
- Supply of the final energy by transformation to electricity, thermal energy and steam.

For this detailed modelling, the technical processes necessary during supply of renewable and non renewable sources of energy as well as the analysis of the power plant technology used in each case for the production of energy are required.

**Supply of Energy Carrier**

The supply of an energy carrier includes the exploration, if necessary, the production and the required processing. Figure 7 shows the natural gas production in Germany as an example to clarify how in principle the energy carrier supply is modelled for all. Among the considerations are the need for auxiliary materials for the drilling during exploration of the gas fields, the energy demand for exploitation of the energy carriers as well as further consumption and losses, e.g. venting and flaring of gas during the production.

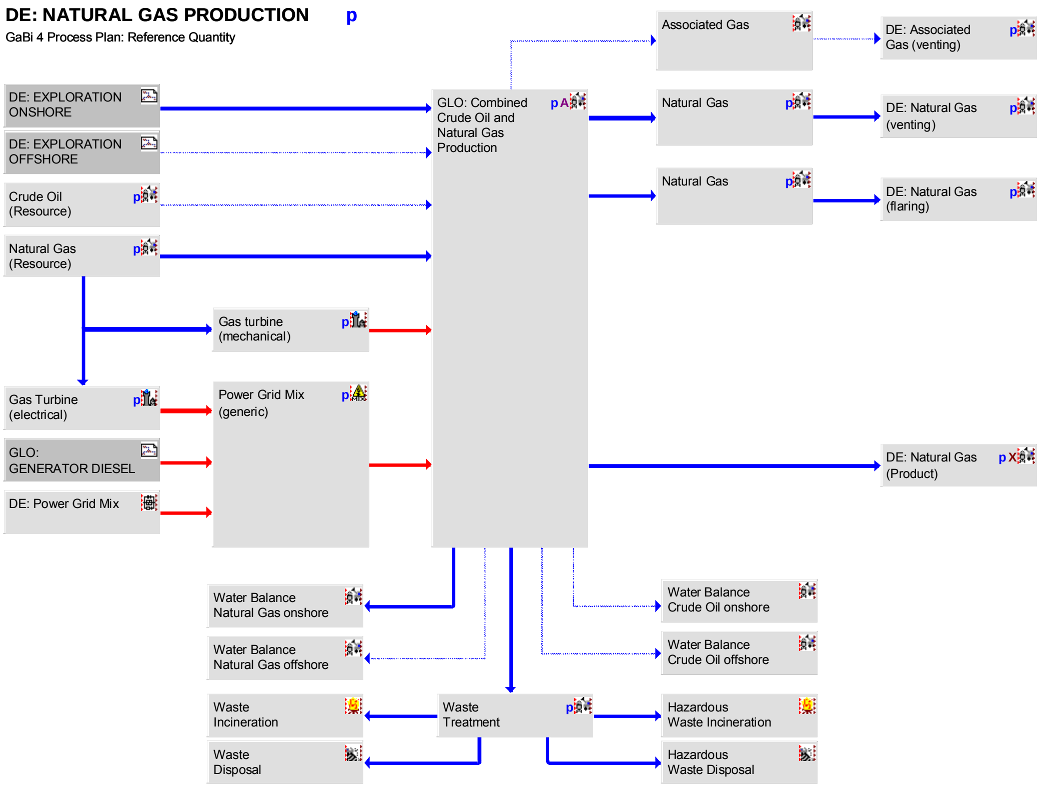



**Figure 7: Natural gas production in Germany**

For the combined crude oil and natural gas production for all in- and outputs an allocation key by energy (calorific value) is chosen, except for:

Crude oil input is completely allocated to crude oil.

Natural gas input is completely allocated to natural gas.

Vented petroleum gas and waste water from crude oil exploration are allocated to crude oil.

Vented natural gas and waste water from natural gas exploration are allocated to natural gas.

## Energy Carrier Mix

The western industrial nations depend mainly on fossil fuel imports. The supply of the sources of energy, natural gas, crude oil and coal in all relevant countries in the world are to be analysed.

So-called "import-mixes" for the individual countries according to the import/export statistics for the individual sources of energy are set-up. Figure 8 shows exemplary the natural gas supply for Germany.

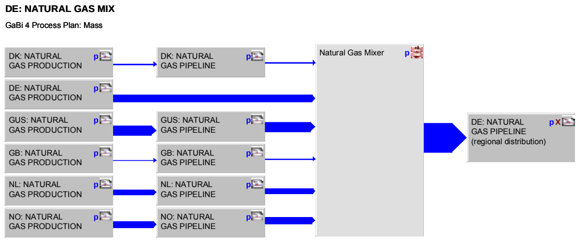



**Figure 8:** **Natural gas supply for Germany**

## Production of Final Energy

Using energy sources in power plants alternative final energy such as electricity, thermal energy and/or steam etc. is produced. The country-specific power station technologies (efficiency of the fuel use, exhaust-gas recycling plants etc..) are to be considered.

A generic modelling of the power stations enables consideration of both fuel-dependent (e.g. $CO_2$) and fuel technology dependent (e.g. $NO_X$, polycyclic aromatics) emissions, including the effects of emission reduction measures (e.g. flue gas desulphurisation).

Thus the mass and energy flows including the auxiliary materials (e.g. lime for desulphurisation) are considered during the energy conversion. Also, the emissions of the power plant and the material and energetic losses are taken into consideration. Figure 9 shows the modelling of the German power grid mix.

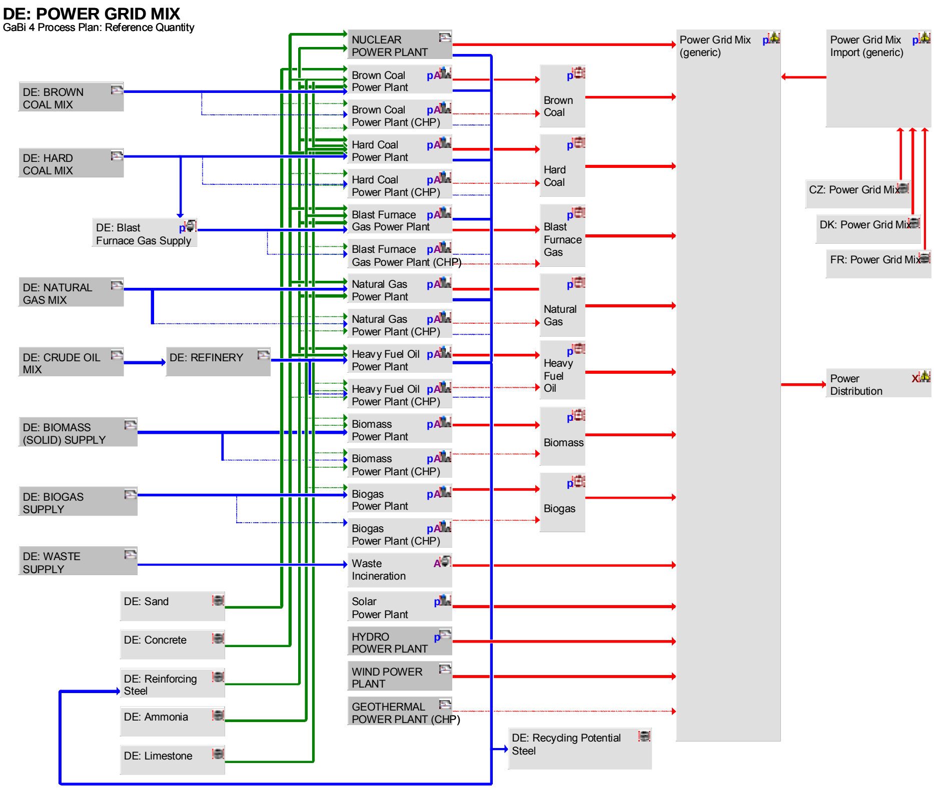



**Figure 9:** **German power grid mix**

Within fossil power plants an allocation by market value is done for the product power (main product), gypsum, boiler slag and flue ash – latter ones are desired by-products with market value remaining from flue gas cleaning or residues from combustion processes. In combined heat and power plants power and heat are allocated by exergy.

## 2.6.2 Transport on road

Transportation systems are comprised of the use phase containing the fuel demand and released emissions. The functional units are chosen as following:

- transportation of 1 kg cargo over a distance of 100 km for heavy vehicles processes.
- 1 vehicle kilometre for passenger car process. For the case of car the manufacturing and end of life phase can be connected to the utilization model.

Adaptable parameters in the datasets are: distance, utilization ratio, share of road categories (urban/interurban/motorway) and if required sulphur content in fuel and total payload.
Due to the fact that transportation processes are very specific for each situtation, these processes are delivered as parameterised processes for individual adaption.

**Calculation of emissions**

Basis for the emission calculation for both heavy vehicles and passenger car is the emission factors of the literature [13].

<u>For heavy vehicles</u>

With the assumption that the utilization ratio behaves linearly (see [14]), the Emissions factors (EF) [g/km] are referred to 1 kg cargo as the following equation:

$$Emission = \frac{EF_{emp} + (EF_{loaded} - EF_{emp}) \cdot Utiliz\_ratio}{Net\_load \cdot 1\,000 \cdot Utiliz\_ratio} \quad \left[\frac{g}{km \cdot kg}\right] \qquad \textbf{(1)}$$

| | |
|---|---|
| $EF_{emp}$ | Emission factor for empty run [g/km] |
| $EF_{loaded}$ | Emission factor for loaded run [g/km] |
| Utiliz_ratio | Utilization ration referred to mass [-] |
| Net_load | Maximum payload capacity [t] |

The payload and utilisation ratio are variable parameters, which can be set individually by the dataset user.

For passenger cars and heavy vehicles

The total emissions for each pollutant referred to 1 kg cargo and the transportation distance is to calculate based on the driving share (urban $IO_{share}$ /interurban $AO_{share}$/motorway $AB_{share}$), the specific emissions ($IO_{Em}$, $AO_{Em}$, $AB_{Em}$) in [g/(km*kg)] and the distance [km].

$$Totalemission_X = \left(\left(AB_{share} \cdot AB_{Em}\right) + \left(AO_{share} \cdot AO_{Em}\right) + IO_{share} \cdot IO_{Em}\right) \cdot Distance \qquad \textbf{(2)}$$

| | |
|---|---|
| $x$ | Index for a specific pollutant [-] |
| $AB_{share}$ | Driving share on motorway [%] |
| $AB_{Em}$ | Motorway specific emissions [g/(km*kg)] |
| $AO_{share}$ | Driving share on interurban road [%] |
| $AO_{Em}$ | Interurban specific emissions [g/(km*kg)] |
| $IO_{share}$ | Driving share on urban road [%] |
| $IO_{Em}$ | Urban road specific emissions [g/(km*kg)] |

For $CO_2$ emissions the calculations bases on the emission factors according to equation [13] and [14], whereas a constant relation of 3,175 kg $CO_2$/ kg diesel for the fuel consumption is assumed. With a medium density of 0,832 kg/l (diesel) a relation of 2,642 kg$CO_2$/l (diesel) results, and a medium density of 0,742 kg/l (gasoline) a relation of 2,356 kg$CO_2$/l (gasoline) results.

For $SO_2$, a complete stoichiometric conversion of sulphur, which is contained in the fuel, and oxygen into $SO_2$ is assumed. The sulphur content in the fuel is a variable parameter, which can be set individually by the user.

$S + O_2 \rightarrow SO_2$

$$EF\_SO_2 = \frac{x\_ppm_S}{1\,000\,000} \frac{kg_S}{kg_{Diesel}} \cdot \frac{64 g_{SO2}}{32 g_S} \cdot Fuel\_consumption \frac{kg_{Diesel}}{kg_{Cargo}} \quad \left[\frac{kg_{SO2}}{kg_{Cargo}}\right] \qquad \textbf{(3)}$$

| | |
|---|---|
| $EF\_SO_2$ | Emission factor for $SO_2$ |
| $X\_ppm_S$ | Mass share in fuel |

The emission factor for laughing gas (nitrous oxide, $N_2O$) is assumed to be constant for each emission class and each category of driving road. The emission factor for ammoniac ($NH_3$) is set as constant throughout all categories.

**The following systems and emissions are excluded from the model:**

- Vehicle production (for passenger cars the integration is possible due to existing valuable flow),
- Vehicle disposal (for passenger cars the integration is possible due to existing valuable flow),
- Infrastructure (road…),
- Noise,
- Diurnal losses and fuelling losses,
- Evaporation losses due to Hot-Soak-Emission,
- Oil consumption,
- Cold-Start Emissions,
- Emissions from air conditioner (relevance < 1% see [15]) and
- Tire and brake abrasion.

**Representativeness**

Concerning representativeness the emission classes from "Pre-Euro" to "Euro 4" are covered. The technologies are representative Europe wide and can be adapted for worldwide locations with some little restrictions. There is a need to identify the corresponding emission classes.

The referring locations are Germany, Austria and Switzerland. However due to the similarity of the vehicle structure and the same emissions limit values, the models are representative for entire EU. With some little restrictions the model can be assigned worldwide to other countries. Attention should be paid to the fact, that the impreciseness increases with the increase of the deviation of the vehicle structure, which deals as basis, as well as the road categories and the utilization behaviour – an adaption can be carried out by setting the driving share (AB/AO/IO) as well as the utilization ratio and sulphur content in the fuel for individual conditions..

The reference year of the data set is 2005, thus representativeness is given for the period of 2000 to 2010.

Modification of the age structure of vehicles for each emission classes leads to changes of the emission profile. The validity of the data set is given for about 5 years (until 2010). Prognoses in [13] based on comprehensive time series, report that there is no change of emission profiles within a certain size class, emissions class, and road categories. Only the different composition of the total vehicle fleet results some changes between 2005 and 2010.

### 2.6.3 Metals and steels

The sources of metals are metal ores which often contain several different metal components. Therefore the production of one metal is usually accompanied by the production of other metals as co-products. For instance the production of nickel is accompanied by the production of cobalt, other platinum group metals and sulphuric acid.

In order to share the environmental burdens caused by the production of a certain metal, the allocation is a suitable and applicable method.

The metal contained in metal ores can have totally different properties concerning its physical specification and its value. Therefore the choice of the appropriate allocation key is important. For metals the market price of metals is a suitable allocation key. Since the market price can vary from year to year – in extreme cases with a factor of 100% or more – the allocation key and thus the allocated environmental burdens change significantly. Therefore, and to keep the consistency among the different metals, for the modelling the average market prices for each metals covering several years (e.g. 10 years) are chosen.

Attention has to be paid to the types of products/materials, which are taken into account for the allocation. Usually the market price for the concentrate or metal ore cannot be determined. The suitable method is to calculate it then on basis of the metal content and the value of the pure metal.

### 2.6.4 Chemistry and plastics

Chemical and plastic products provide an important basis for many other industrial fields. In electronics, automotive, construction fields etc, chemicals and plastics go into the system as input materials. Therefore it is important to achieve a high quality in the modelling of the processes in these fields.

For the modelling of a chemical plant, the following information was investigated as minimum:

- name of the reaction route (there is often more than one, even with the same reactants; so the route should definitely be documented)
- stoichiometric equation
- rate of yield (be careful, whether it is given as % mole or % mass and which reactant it refers to)
- maximum pressure ($P_{max}$) and maximum temperature ($T_{max}$) of the process conditions
- a short description of the plant or a process flow sheet.

**Modelling**

Chemical and plastic processes produce a variety of products. For each material several different processing technologies are often available. For example for the production of polypropylene "polymerization in fluidised bed reactor" and "vertical stirred reactor" are the mainly applied technologies. Therefore for each relevant technology, an individual process model was set up.

In case of chemical and plastics, it is not meaningful to apply Generic Modules as the specification of the technologies differs significantly. Country specific models are required additionally, since the chemical and plastic products are traded worldwide. This means that a chemical or plastic material which is provided in a certain country can be imported from other countries. For the creation of country specific models, the country specific technology was identified, its efficiency, local data were collected and the country specific upstream data was integrated.

Especially chemical processes have often a co-product system. In this case, the method of allocation was applied. Even though exceptions are available, usually "market price" and "energy content" is used as allocation key. Most often there is even no significant differences in both allocation keys for organic synthesis as the efficiency of many processes are characterised by the energy of their products.

For those processes were waste and/or waste water have an environmental relevance – depending on the amount and type of the containing pollutants – the treatment system (landfill, incineration and/or waste water treatment) are integrated into the model. The choice of the treatment technology (landfill or incineration) is up to the country specific situation.

**Production and consumption mix**

As the users of the dataset are usually not able to determine the exact technology for the production of their upstream materials, a representative production mix or consumption mix should be provided. For this purpose the market or consumption share was determined, beside the dataset for each relevant technology. Especially in the case of chemicals, in which different production routes are possible, the technology mix represents the distribution of each technology inside the reference area.

For instance, the production of standard polypropylene in Germany is based on polymerisation in fluidised bed reactor and on vertical stirred reactor. They have a share of each 50 % in 2001. For standard polypropylene the two main process models are mixed according to their share in industrial application to an average polypropylene data set.

The consumption mix considers the trade of the material. Figure 10 shows an example of a mix for the consumption of epoxy resin in Germany for the reference year 2003. As can be seen, the epoxy resin, which is consumed in Germany, is produced in Germany (53,4 %), in Switzerland (20,3 %), The Netherlands (9,1 %), Italy (8,5 %), Spain (4,5 %) and in Belgium (4,2 %).

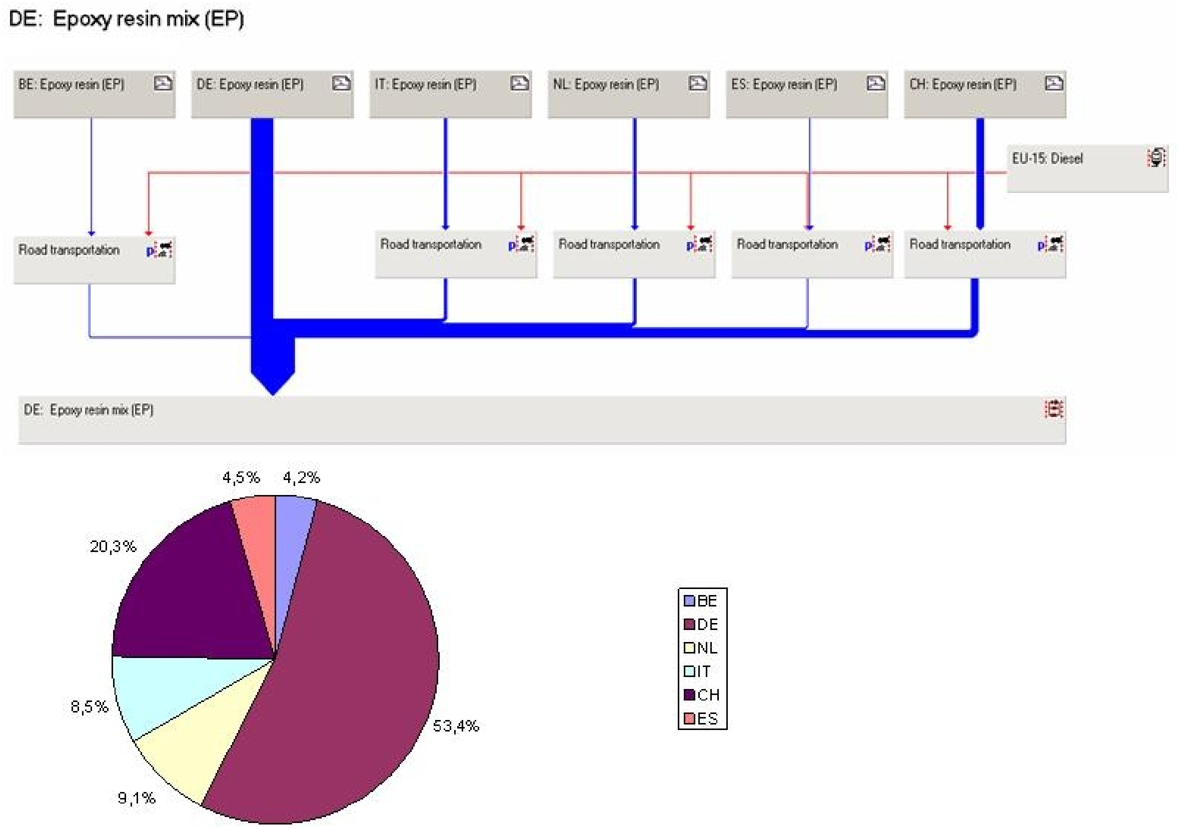



**Figure 10: Consumption mix of Epoxy resin in Germany**

## 2.6.5 Construction

The construction sector uses extensive quantities of natural resources, raw materials and energy. Within the European Union, the construction sector is responsible for a share of 10 % of the gross domestic product (GDP) and creates about 7 % of the total employment. Considering their entire life cycle, buildings and construction products are responsible for the consumption of approximately 40 % of the total European energy consumption, as well as for the consumption of approximately 40 % of natural resources [1].

The anthropogenic material flows that are caused by the life-cycle of buildings contribute in many environmental categories to the impact potentials. In order to describe a building during the whole life-cycle, various information are required concerning the depletion of mineral resources (mining and production of building materials), depletion of energetic resources and release of pollutants (construction material production and transport, energy supply of production and during utilization of the building, etc.), land use (e.g. of a quarry and surface sealing by the building) and waste treatment (construction, use, renovation, demolition).

To structure these data sets, the life cycle is systematically divided into several unit-processes, forming a chain, respectively a network that represents the mass- and energy flows caused by a building from cradle to grave.

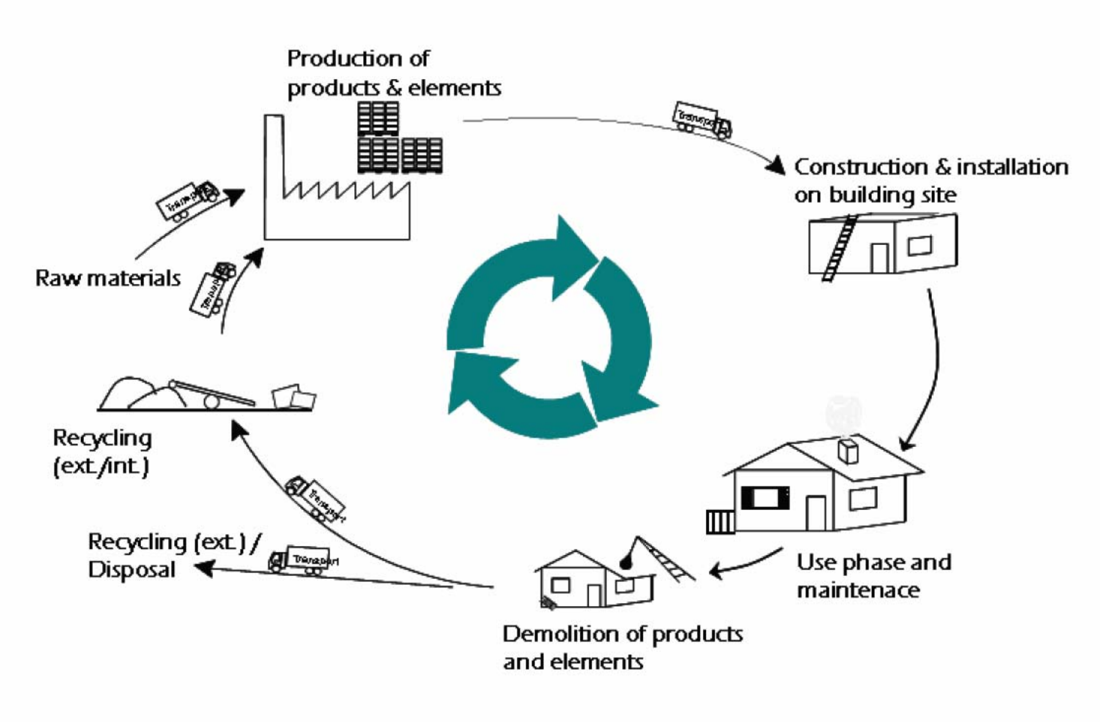



**Figure 11: Schematic life cycle of a building**

Every construction material is produced in order to fulfil a function within some sort of building or construction. Accordingly, analysing individual construction materials should not be done without employing a functional unit that considers the function of the construction material or without considering the construction where it is intended to be used. The functional unit should always include the performance of a material within a building. Simple comparisons on mass basis are misleading.

The general data (e.g. transport, energy supply) that is used to model the production of construction materials has to be comparable, as it is true for system boundaries and methodological key points (like cut-of-criteria and allocation rules), as it may influence the result considerably. For GaBi construction materials cradle-to-gate life cycle inventories (LCI), the standard GaBi background system is used.

The GaBi databases 2006 [4] for construction materials covers the most relevant construction materials, as well as more specialised materials used in the construction of buildings, roads or subsurface constructions. It divides into mineral products (including concrete and concrete products, bricks, sandlime, natural stones, etc. as well as mineral insulation materials such as rockwool or glass wool), metals (construction), polymers (for construction, including insulation materials such as PUR, EPS or XPS), wood for construction, cement and gypsum / mortar products, coatings and paints, etc. The database also holds several ready-to-use building components such as windows with different dimensions and different frame types. These windows are based on a generic, parameterised window model that is capable of ‘assembling’ windows by adjusting parameters. Such a window model allows for the efficient generation of additional windows, if required.

As said above, the life cycle inventories of construction materials are – as are the underlying construction materials themselves – set up in order to meet a functional demand within a building or other construction and therefore life cycle analyses in the construction sector have to consider the intended function. At the LBP-GaBi and PE International GmbH working group, a generic building model has been developed in order to meet the demand for analysing construction materials, as well as construction elements and entire buildings within the respective context. This building model served as the methodological basis for the life cycle analysis of the European residential buildings stock and, since then, has constantly been under further development in order to meet the need of building planners, architects and engineers to assess the life cycle performance of existing or planned buildings. The building model contains not only the construction and frame of the building, but also heating, cooling and technical appliances.

One special feature in the construction sector is the use of a ‘recycling potential’. The recycling potential quantifies the environmental burdens that could be avoided by the use of recycled materials in comparison to the production of new materials. Since metals currently present the highest re-use rate among other construction materials, metals are used as example to explain this concept below.

**Allocation beyond life cycle limits (open loop and closed loop recycling)**

As a durable product, for metal, and steel in particular, the time aspect must be taken into account and the situation of production nowadays must be separated from that of future recycling. Taking steel as example, this means that the scrap which is treated in the End-of-Life (EoL), initially saturates the upstream lifecycle steps (production, use). In an ideal world (e.g. with a high recycling rate and simultaneously a low proportion of secondary scrap in the inputs of the production and use phase), the secondary steel would remain left over and would exceed the system limits. This flow is linked to the recycling potential of an inverse production process, i.e. secondary steel is still left over, a certain credit (inverted process) is received. However, as steel is needed from an external source to saturate the secondary steel requirement in the production and use phase, the flow to the inverse process is negative. (Negative flow + inverse process yields the production of additional steel).

Let's put the explained example into numbers:

For the production of 1000 kg of metal product, currently 80 % primary material and 20 % secondary material are used. The production therefore comprises 800 kg primary production and 200 kg secondary production. Assuming that the secondary production presents 10 % losses, 220 kg of scrap are required for this process and therefore 780 kg of scrap are available for the secondary production as recycling potential. From this amount, considering the losses in the secondary production, 702 kg of secondary material can be produced. The recycling potential is therefore calculated from the "avoided production" of 702 kg of primary material.

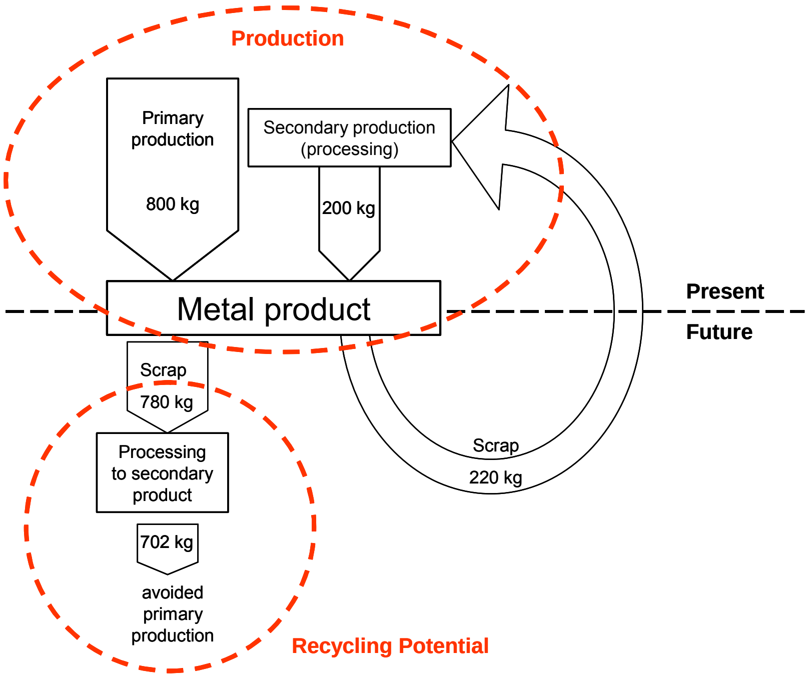



**Figure 12: Recycling in LCAs for construction products, using metal as an example**

## 2.6.6 Renewables

From the modelling point of view, agrarian processes are production processes like industrial processes. But there are significant differences between agrarian systems and industrial processes, which are for instance:

- No sharp technically determined border to the environment
- Complex and indirect dependence of the output (harvest, emissions) from the input (fertilisers, location conditions etc.)
- The variety of different locations
- Small scale soil variability within and between locations

- The large amount of production facilities (farms)
- The variety of agricultural practices
- Variable weather conditions within and between different years
- Great variation in pests and parasites, diseases, weeds
- Different crop rotations (to consider especially in LCA´s for annual crops)

Central points which characterise the agrarian model are:

- **Nitrogen:**

  Concerning Nitrogen many forms of Nitrogen are involved in the agrarian system, which are coupled over mass balance. The N-based emissions affect the result of an environmental analysis significantly. Thus the LCA relevant emission is the small difference between the large input and outputs. The challenge to integrate the nitrogen component in the model is, that important figures (like $N_2O$) are often known only imprecisely. The $N_2O$ volatilisation (and possible global warming implications) is today one of the largest uncertainties in modeling agrarian systems.

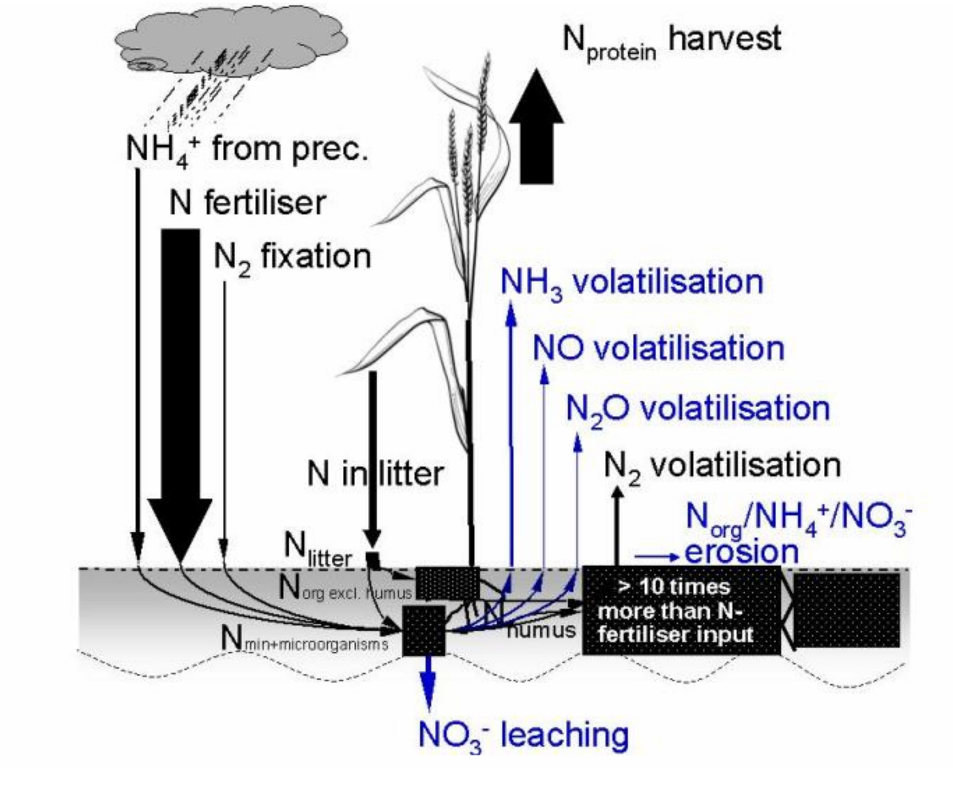



**Figure 13:** **Nitrogen in the agrarian system**

- **$CO_2$ uptake in biomass and storage of renewable energy in the biomass:**

  The $CO_2$ uptake in biomass is a further central point. The product bound $CO_2$ has directly to be accounted as 100% on the input side comparable to $CO_2$ emissions into air on the output side. The $CO_2$ quantities from renewables emitted during later stages in the life cycle (e.g. burning, composting, etc.) have to be accounted as emissions to air. This means that over the life cycle of a renewable, all bound $CO_2$ is released as $CO_2$ at a later stage.

  Other carbon emissions (e.g. $CH_4$ and CO) which are released into air during biomass production, its conversion and its end of life have to be considered as well.

  Finally the storage of renewable energy in agro-products (finally sun-light) has to be considered as "lower calorific value" on the input side, to avoid a perpetuum mobile effect, if renewables are used as energy source.

- **Time factor:**

  Time factor is an important parameter, as natural events can have different effects depending on which stage of the life cycle of the plant it occurs, e.g. during seeding or growing time (please refer to Figure 14).

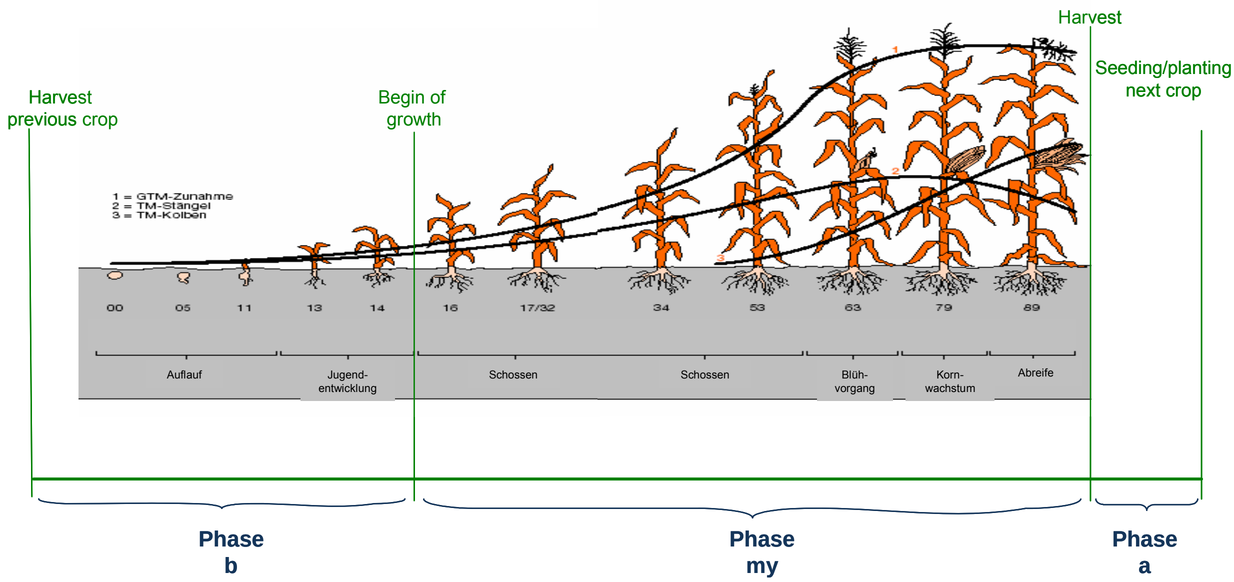



**Figure 14: Time factor in the agrarian system**

For the purpose of modelling and finally analysing agrarian production, a new computing model is required. In order to create an agrarian model, which can be applied for any agrarian and plantation product of the world and which operation effort is feasible, the model requires a complex, variable usable and highly parameterised systems and many background processes.

The mixed balance model with different implicit mapped compartments and simplified time solution delivers consistent and exact results.

In addition the effects of crop rotation and periods with limited plant growth can be involved into the model.

GaBi databases 2006 [4] contains aggregated datasets for agrarian products, which were set-up with the above described agrarian model.

### 2.6.7 Electronic

The specific characteristic of the electronic and electro-mechanic components is the complexity, the large numbers and the variety of part components. Considering the existing part components, more than 10 million components can be counted. An electronic subsystem (e.g. PWB - Printing Wiring Board) is often equipped with several hundreds of different components.

There is the demand to make datasets for electronic components available, sine electronics are applied in various fields such as automotive, houses, consumer products, information and communication systems etc. However it is either from the point of time or of resources by far not possible to create for each of the 10 million electronic components a dataset manually. The challenge here is the selection, which datasets to take and how to deal with this huge amount of parts and how to reduce the numbers of datasets by providing the representativeness of those datasets.

In order to make statement about the representativeness of an electronic component, the whole scene needs to be understood. The long experience of GaBi working group in electronic business enables the determination of the representative components, simply by having analysed hundreds of electronic boards and the application of always, often and rarely used components. Beside the experience, which components are representative, the know-how of typically contained materials and the most significant steps of manufacture of the components is important. To know, what steps for manufacture are significant, in order not to get lost in details and to avoid endless chains of data acquisition, which is practically not possible, other technical fields can help. So either similar technical processes or comparable technical fields in which the identified manufacturing processes are applied for other purpose, support the determination of relevance and provide the knowledge of orders of magnitude – is it significant or not, is it to consider for the dataset or not - concerning environmental impact. Only the interaction of all three conditions experience, knowledge about similar processes and the knowledge concerning market situation, make the identification of relevant and representative components, with their technologies and materials possible.

Even though not all electronic components can be covered with the restriction of representativeness, the most relevant causes of environmental potentials from groups of similar or typical electronic components can be identified, when having investigated a certain amount of products. Thus for example the difference in environmental impacts is possible to identify for example between semiconductors and resistors or between active components (e.g. semiconductors, diodes and discrete transistors) and passive components (e.g. capacitors, resistors, inductions) in general or even by comparing different types of technologies (e.g. SMD (surface mount device) or THT (Through hole technology)). The more knowledge is gained the better and easier it is to identify, which fields and components of electronic products cause significant and less significant environmental impacts.

Thus a prerequisite, in order to make the modelling of representative electronic products, subsystems or components possible, the environmental knowledge and the availability of huge numbers of materials is necessary, such as metals, plastics and ceramics, since electronic products can consist of most elements of the periodic table, and a broad range of many technical manufacturing processes and their environmental causes are necessary to know, such as sputtering, lacquering, sintering, winding, soldering, clean room condition, etching, electrolysing, vacuum metal dispersion and many more.

**Modelling**

Based on the necessity to model and assess electronic systems with justifiable effort, GaBi working group developed the modular-system based on Generic Module system. The target is to establish a Generic Module for each group of electronic components, e.g. resistors, ceramic capacitors or substrates.

The Generic Model of a typical electronic system follows a hierarchical structure. The system is divided into several subsystems. Also the subsystems themselves are modelled on the basis of the Generic Modules, as presented in 2.5.

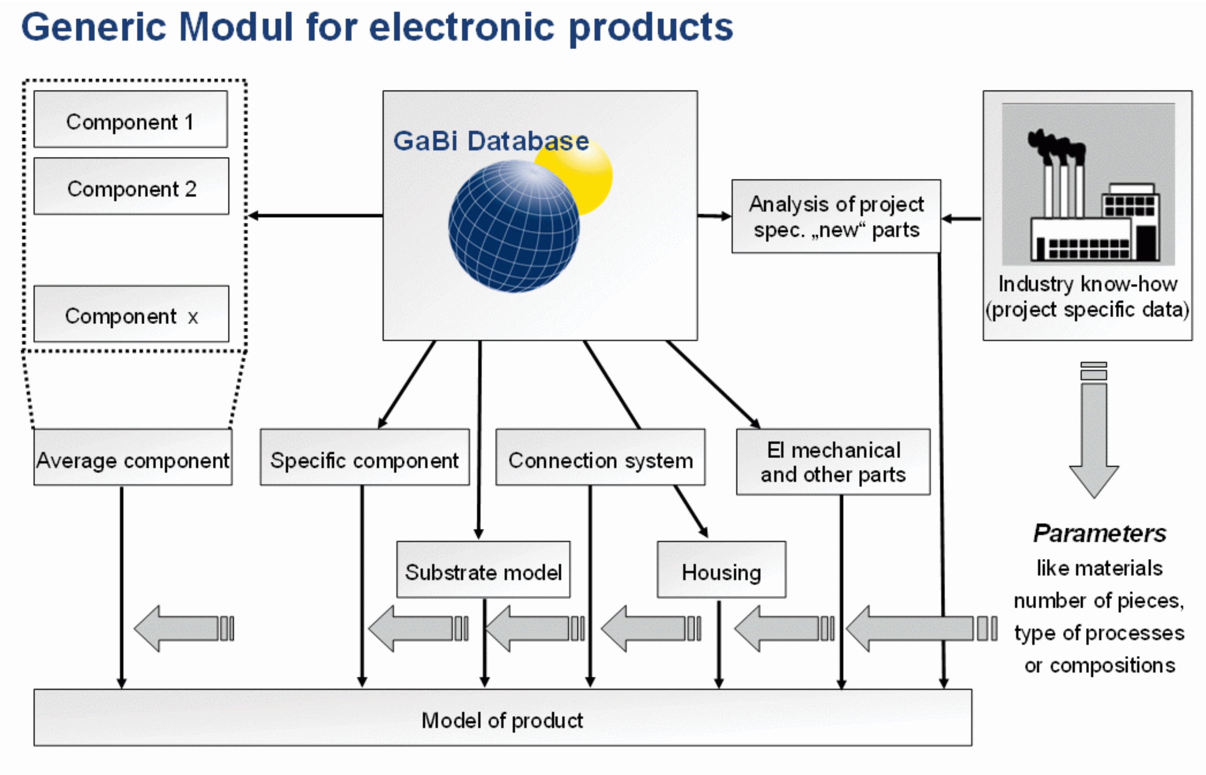



**Figure 15: Creation of a model for an electronic product – modular structure**

Technical systems form the basis for highly-flexible modules. With few variable parameters such as size, number of layers and type of finishing in the case of a PWB, these modules can be flexibly adapted to a specific case. If no respective data for a component are available, the pre-defined parameter-settings can be chosen. These are set to market-average components.

After the determination of the representative components and their relevant technologies, for several often used typical electronic subsystems a Generic Module is created: housing, substrate, connection system, electronic components and electro-mechanical and other part:

Housing: Typical housings are made by injection moulding of plastics (e.g. PC/ABS) or are metal housings, e.g. from aluminium die casts or steel sheets. The models contain all relevant preliminary process steps. For plastic housings it is crude oil extraction, production of plastic granulate and the injection moulding itself, including the respective demand for auxiliaries, energies and transport in each process step.

Substrate: The substrate is the PWB without components and connection system. PWB's are modelled depending on the number of layers, size, weight and composition (e.g. content of copper, glass fibres, TBBA or Au/Ni finishing). If this is not available, pre-defined average compositions may be used as described above.

Connection system: Usually solder pastes, formerly mainly SnPbAg, today typically lead free are used (different solder systems are regarded in a similar manner).

Electronic components: A huge database containing the material contents of the main groups of components such as resistors, capacitors, coils, filters, transistors, diodes etc. is available. As thousands of different components may be contained in electronic products, several representative average components are built.

Electro-mechanical and other parts: This subsystem contains models of switches, plugs or shielding and other non-standard parts such as displays, keys or sensors.

The Generic Modules enables the individual adaptation of a module. As variable parameters the significant functional units are used depending on the subsystem: e.g. piece for components, area for boards and assembly lines, kg for solders and electro-mechanics.

GaBi database contains aggregated datasets for components, which base on the above described Generic Modules. Further own dataset can be set up easily by using the Generic Modules.

### 2.6.8 End-of-life

To ensure consistency and models with high efficiency, the end-of-life processes concerning incineration, landfill and waste water treatment have been generated by means of three generic models:

1. Waste incineration model
2. Landfill model
3. Waste water treatment model

These models follow the general rules of modelling principles. All models represent standard technologies and are based on parameterised unit processes. For the generation of datasets (e.g. DE: Polyvinylchloride to incineration), the models are specified according to the dataset conditions. This embraces e.g. country or region specific background datasets, country specific or region specific process efficiencies and specific input information about the characteristic of the waste and waste water.

**Incineration model**

The elementary and system flows from the incineration plant and the auxiliaries as input are allocated according to the elementary contents in the waste input, which cause the emission or auxiliary demand.

The energy products are allocated according to the heating value of the specific input. The energy demand of the waste incinerator is allocated to the specific input, e.g. the electricity demand for the slag treatment is allocated to the input responsible for the slag.

The incineration model is build for the described technology and verified with measured data from different German incinerators. The heating value of the input can be specified or can be calculated based on the elementary specification of the input. The material flow in the plant is calculated using individual transfer coefficients for every element and stage of the incinerator. So main substances are traced thought the model.

For the input specification in the model the following elements and compounds can be used: Ag, Al, AlOx, As, ash, Ba, Br, C_Carbonat, C_HC, Ca, Cd, Cl, CN, Co, Cr, Cu, F, Fe, H, $H_2O$, Hg, J, K, Mg, Mn, N, Na, NH4, Ni, O, P, Pb, S, Sb, $SiO_2$, Sn, SO4, Ti, Tl, V, Zn.

The modelled emissions to air in the flue gas of the incinerator are: As, Ba, Cd, Co, CO, $CO_2$, Cr, Cu, dioxins, HBr, HCl, HF, HJ, Hg, Mn, $N_2O$, $NH_3$, Ni, NMVOC, $NO_x$, particles, Pb, Sb, Sn, $SO_2$, Tl, V, Zn. In addition slag, boiler and filter ash and recycled metals are modelled. Some of the elements respectively tracked substances leaving the system are input dependent. That means there is a stoichiometrical correlation between input and output. For other input the relations are depending on the used technology. The output of these substances are a function of the used technology and therefore independent of the specific input. Hence, the input dependent part is linear the technology dependent is constant in a certain range. Input dependent parameters are for example the input of C, H, Cl, F, S, N and metals and the emissions caused by these elements. The amount of slag, boiler and filter ash produced is also input dependent.

The element composition of the co-incinerated waste fraction is recorded in the documentation. Technology dependent parameters are for example CO, VOC and dioxin emissions, use of adsorbent and the composition of slag, boiler and filter ash.

**Landfill model**

The elementary and system flows from and to the landfill site are allocated to the elementary content in the waste input. The amount of generated landfill gas is only allocated to the organic carbon content in the waste input and represents an average landfill gas composition.

The auxiliaries as input (e.g. energy for compacting, materials for the landfill construction) are allocated to the mass of the waste input. The inert landfill sites do not generate landfill gas, nor is the leakage technically treated before going to the receiving water.

The landfill model is parameterised to allow generating different datasets according to the waste input and region / country specifics. Important parameters and parameter sets are:

- any waste input to be disposed (from elementary composition)
- different technologies for the sealing and cap (layers)

- differing surrounding conditions (e.g. precipitation)
- rates and treatment routes of collected landfill gas and CHP efficiencies and rates (combined heat and power production)
- rates of leakage collection and treatment efficiencies (COD and AOX)
- transfer coefficients of the substances in the landfill body over the regarded time (default 100 years)

The waste input can be specified by its elementary composition (27 elements) and additional waste specific information (e.g. inert substances content, non-degradable carbon and nitrogen content).

The landfill body calculates – based on element specific transfer coefficients - the amount of this substance going to leakage collection and soil. The transfer coefficients also depend on the inert fraction of the waste.

The amount and types of materials for the cap and sealing of the landfill site are adapted to specific situations (background processes, thickness of layers rates of leakage collection), where relevant and applicable.

The collected leakage is either going to a technical treatment (to minimise the organic compounds in the waste water) or directly to the receiving water (landfill site for inert waste). In case of technical treatment of the leakage, the generated sludge is dried and disposed of in an underground deposit.

If landfill gas is produced when disposing organic matter, its treatment route is adapted to the country or region specific situation. The shares can go directly to air (emission), to flare or to a combined heat and power unit (CHP), producing electricity. For simplification reasons, the landfill gas composition is only representing the average useable landfill gas. Its amount is calculated over the time where it is produced. The amount is only depending on the organic carbon content in the waste composition.

**Waste water treatment model**

The elementary and system flows from and to the waste water treatment plant are allocated to the elementary content in the waste water input.

The waste water treatment plant is modelled according to an average treatment technology for waste water from chemical industry. It contains mechanical, biological and chemical treatment steps for the waste water (including precipitation and neutralisation), and treatment steps for the sludge (thickening, dewatering, drying, conditioning and incineration). The outflow goes directly to the receiving water (natural surface water). The waste water composition to the plant represents an average outflow of a chemical industry commodity to the treatment plant with organic and inorganic substances or derivates from this average composition (see documentation "waste water composition"). The process steps are taking average elimination and transfer coefficients into account. The sewage passes through the bar screens for rag removal. In this section, automatic bar screen cleaners remove large solids (rags, plastics, etc.) from the raw sewage. Next, the sewage is transported to the grit tanks. These tanks reduce the velocity of the sewage so that heavy particles can settle to the bottom. In the separator suspended particles such as oils, fats are removed. The settlement tank can remove the larger suspended solids. $FeSO_4$, and $Ca(OH)_2$ are used as precipitant agents in the mixing tank to remove metals. $Ca(OH)_2$ and $H_2SO_4$ to regulate the pH value. The primary clarifiers remove the suspended solids from the mixing tank prior to discharge to the aeration tanks. The aeration tanks provide a location where biological treatment of the sewage takes place. The activated sludge converts organic substances into oxidised products, which is settled out in the secondary clarifiers. Phosphoric acid is used as nutrient for micro-organisms. The cleared overflow in the secondary clarifiers goes to a natural surface water body (stream, river or bay). The settled solids, from the settlement tank, the primary clarifiers and secondary clarifiers, are pumped to the primary thickener where the solids are thickened (water content thickened sludge 96 %). The sludge is pumped to filter presses for dewatering, which use chemical flocculants to separate the water from the solids (water content dewatered sludge 65 %). Next, the sludge is getting dried with thermal energy (water content of dried sludge 25 %). The content from the screen and grit chamber is mixed with the dried sludge and is fed into the incinerator, which produces energy (electricity and thermal energy) for the wastewater treatment plant.

## 2.7 Internal critical review and review of plausibility

A critical review is required by the ISO 14040 ff norm when the study is intended to support a comparative assertion to be public available. It should be performed by interested parties, not involved in the project, but expertise in LCA and if possible involved in the field investigated (not necessarily).

Plausibility in this sense here deals with the support for data collection and systematic error tracing in inventories. It checks incorrect or missing values/ flows (type faults, conversion/ unit errors).

### 2.7.1 Plausibility and technical quality of the base process

A possible checklist for the final check of collected data could be:

- Data source, reliability of the sources, representativity of the souces.

- Technical conditions (is the state of the art presented, are the conventional processes represented, etc.).
- Is the process a stand-alone process or integrated into a large production facility?
- Calculation method (average, aggregation of data, etc.).
- Whether all technically relevant process steps are compiled.
- Plausibility of type and quantity reactant/product and by-product/ waste.
- Plausibility of emissions (relation between in- and outputs, comparison to similar processes).
- Plausibility of circulating flows.
- Plausibility of the amount of auxiliary material.
- Plausibility of the application possibility for parameterised processes.
- All flows considered? Or still any missing?
- Efficiency/ stoichiometry check of chemical reactions; monitoring of the rate of yield (almost must-be >80%; should-be > 90%).
- Energy source is always included; if not electricity or steam, check if incinerated
- (incineration processes) or (partly) converted into products (stoichiometry).
- Inputs for exhaust air purification (lime, NH3, etc.); Are the quantities plausible?
- Do by-products accumulate? Or are these used internally?
- Allocation performed or system expansion, in case the model includes co-products.
- Is waste reused or disposed of? If disposed of, to landfill or incineration. If re-used, does it return to the process or any recycling process considered?

### 2.7.2 Important material and energy balances must add up on the base process level (e.g. metal content balance ore/ product; energy balance etc)

- Energy balance: net calorific value (sum of renewable and non-renewable)
- Mass balance
- Element balance (also check for raw material recovery)

### 2.7.3 Plausibility of emission profiles (Ratio input-output)

The basic principle is to avoid gross faults, both too high and (rare) too low values and/ or missing emissions. The plausibility and fault checking must therefore take place on the unit process level. Per process type there are typical emissions and/ or statements to be derived. The following checks result from these, which should assist the systematic fault check. But these checks do not replace expert knowledge, data collection or one's own reasoning!

## 2.8 Documentation

Documentation is essential in order to assure the transparency of the data sets as well as to clarify the scope of the datasets and the possible applications.

This chapter describes the content and the comprehensiveness of the applied documentation format. Thereby recommendations to mandatory and optional information, which are either based on international standards such as ISO 14040, ISO14044 and ELCD or on the experience of PE and LBP-GaBi are accounted for. The requirements of ISO 14040 [2] and 14044 [3] are considered. Within this chapter the documentation of flows and LCI datasets is highlighted.

The metadata documentation of the data sets in "GaBi Databases 2006 [4]" is in line with the documentation recommendations of the "European Reference Life Cycle Data System" (ELCD) Conformity Rules 1.0.1 of the European Commission's European Platform on Life Cycle Assessment, while not strictly meeting them in every case.

### 2.8.1 Nomenclature

Nomenclature is a very important issue when choosing flow and process names. In case a new process or new flow should be created as it is not available in the database, consistency with existing processes or flows should be kept. This is a very important aspect as each data provider follow different rules.

### 2.8.2 Documentation of flows

The documentation of flows outlines an important component of the documentation of processes and LCI results. Because of this integral part and especially due to the large influence of the flow properties to the LCIA results, the documentation of flows should be paid a certain attention.

In the following it is distinguished between mandatory and optional documentation items.

**Mandatory items:**

- General flow information:
    - Name of flow, including specifying information like sulphur content
    - Category/ subcategory of flows, e.g. resource/ non renewable resource
    - Reference flow properties, e.g. net calorific value (MJ)
    - Type of flow, e.g. elementary flow, product flow
    - Flow properties and LCIA factors e.g. 1 kg $CO_{2eq}$
    - Language, e.g. English

- Documentation in terms of usage in database:
    - Administrative information, e.g. data set generator, modeller
    - Intended application, e.g. Life Cycle Inventory data for the national database
    - Publication and ownership, e.g. access restrictions

**Optional and often helpful are the following items:**

- Synonyms of flow names, e.g. power, electricity
- CAS numbers
- Valid location of the flows, e.g. region Western Europe
- Field for general comments to add further information

### 2.8.3 Documentation of LCI data sets

In accordance to the documentation of flows, the documentation of the LCI data sets can be described as follows. The mandatory content of the documentation comprises the points listed below:

**Mandatory items:**

- General Data set information:
    - Name of Process or LCI result, including specifying information like electricity at 220V
    - Category/ subcategory of the process or LCI result, e.g. energy carriers/ electricity
    - Reference flow and reference unit, i.e. functional unit, e.g. 1 kWh electricity
    - Reference year, e.g. 2007
    - Representativeness country (geographical code), e.g. DE
    - Description of product system/ process technology
    - Reference to included datasets, e.g. linkage to other datasets
    - Technological applicability
    - In case of parameterised processes the mathematical relations (including name of parameter, formula, mean-, minimum- and maximum values), e.g. distance within transportation datasets
    - Type of dataset, e.g. LCI result, unit process
    - Data source(s), e.g. literature source, personal communication, measured, calculated, etc.
    - Data completeness, e.g. cut-off rules, applied extrapolation principles

  - Type of review, e.g. internal, external review
  - Coverage of review, e.g. inventory, documentation, LCI method
  - Consistency and conformity, e.g. in terms of nomenclature, methodology, documentation
  - Inputs and outputs flows, e.g. type of input and output flows including their amount
  - Representativeness technology, e.g. best practice, pilot plant
  - Language, e.g. English
- Documentation of methodological assumptions:
  - Allocation rules, e.g. market value allocation is applied in the process refinery
  - System expansion principles
- Documentation in terms of usage in database:
  - Administrative information, e.g. data set generator, modeller
  - Intended application, e.g. Life Cycle Inventory data for the national database
  - Publication and ownership, e.g. access restrictions

**Optional and often helpful are the following items:**

- Synonyms of process or LCI result name, e.g. electricity, power
- Field for general comments to add further information
- Date until data set is valid, e.g. 2010 (based on expert judgement)
- Modelling constants, e.g. all calculation of the LCI results refer to net calorific value
- Time representative description, e.g. annual average
- Data selection and combination principles
- Use advice, e.g. use by electricity customers without own electricity generators or transformers
- Data treatment and extrapolations principles, e.g. dealing of data gaps
- Flow chart, pictures, diagrams

# 3 References

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