



GaBi Database & Modelling Principles 2012

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PE INTERNATIONAL
SUSTAINABILITY PERFORMANCE

Authors:

Dr. Martin Baitz, Dr. Cecilia Makishi Colodel, Dr. Thilo Kupfer, Julia Pflieger, Dr. Oliver Schuller, Fabian Hassel, Morton Kokborg, Dr. Annette Köhler, Alexander Stoffregen

with contributions of the PE expert teams:

Energy, Transport, Metals, Chemicals and Polymers, Construction, Renewables, Electronic, End-of-Life, Water

PE INTERNATIONAL AG

Hauptstraße 111 – 113
70771 Leinfelden – Echterdingen
Germany

Phone +49 711 341817 – 0
Fax +49 711 341817 – 25

E-Mail info@pe-international.com

Internet www.pe-international.com

List of Contents

List of Figures	5
List of Tables	7
Abbreviations	8
1 Introduction and aim of document	9
2 GaBi LCA database framework	10
2.1 GaBi Database concept and management.....	10
2.2 GaBi Database development, maintenance and update	12
2.3 Structure of the Master Database contents	13
2.4 Standardisation, compliance and application issues of LCI databases	20
2.5 Databases in reference networks, standards and principles	21
2.6 GaBi LCI Team.....	22
3 Methodological framework	24
3.1 Definition of tasks in database work	24
3.2 Goal.....	24
3.3 Scope	25
3.3.1 <i>Function and Functional Unit</i>	26
3.3.2 <i>Definition of terms within system boundaries</i>	26
3.3.3 <i>System boundaries for the creation of standard LCI cradle to gate datasets</i>	27
3.3.4 <i>Cut-offs</i>	34
3.3.5 <i>Gap closing</i>	35
3.3.6 <i>Infrastructure</i>	36
3.3.7 <i>Transportation</i>	38
3.3.8 <i>Water</i>	38
3.3.9 <i>Wastes and recovered material or energy</i>	46
3.3.10 <i>Aspects of biomass modelling</i>	47
3.3.11 <i>Aspects of primary energy of fossil and renewable energy sources</i>	48
3.3.12 <i>Land Use Change</i>	49
3.4 Sources and types of data.....	52
3.4.1 <i>Primary and secondary sources of data</i>	52
3.4.2 <i>Unit process and aggregated data</i>	53
3.4.3 <i>Units</i>	53
3.4.4 <i>LCI data and supported LCIA methods</i>	53
3.4.5 <i>Production and consumption mix</i>	54
3.5 Data quality issues	56
3.5.1 <i>Technology and region coverage</i>	56
3.5.2 <i>Data aggregation</i>	57
3.5.3 <i>Precision, completeness, representativeness</i>	59
3.5.4 <i>Consistency</i>	60

3.5.5	<i>Uncertainty</i>	60
4	System Modelling Features	66
4.1	Data collection.....	66
4.1.1	<i>Quality check and validation of collected data</i>	67
4.1.2	<i>Treatment of missing data</i>	67
4.1.3	<i>Transfer of data and nomenclature</i>	67
4.2	Geographical aspects of modelling.....	69
4.3	Parameter.....	70
4.4	Multifunctionality and allocation principle.....	70
4.5	Generic Modules as background building block.....	71
4.6	Special modelling features for specific areas.....	72
4.6.1	<i>Energy</i>	72
4.6.2	<i>Transport</i>	77
4.6.3	<i>Mining, metals and metallurgy</i>	82
4.6.4	<i>Chemistry and plastics</i>	84
4.6.5	<i>Construction</i>	88
4.6.6	<i>Renewables</i>	90
4.6.7	<i>Electronics</i>	94
4.6.8	<i>Recycling or End-of-Life measures</i>	97
5	Review, documentation and validation	104
5.1	Review procedures and check routines.....	104
5.1.1	<i>Technical information and documentation routines in GaBi</i>	104
5.1.2	<i>Important material and energy balances</i>	105
5.1.3	<i>Plausibility of emission profiles and avoiding errors</i>	105
5.2	Documentation.....	106
5.2.1	<i>Nomenclature</i>	106
5.2.2	<i>Documentation of Flows</i>	107
5.2.3	<i>Documentation of LCI process data</i>	107
5.3	Validation.....	109
6	Literature	110
Supplement A	Description of result and impact categories.....	115
Supplement A 1	Primary energy consumption.....	116
Supplement A 2	Waste categories.....	117
Supplement A 3	Global Warming Potential (GWP).....	117
Supplement A 4	Acidification Potential (AP).....	121
Supplement A 5	Eutrophication Potential (EP).....	123
Supplement A 6	Photochemical Ozone Creation Potential (POCP).....	125
Supplement A 7	Ozone Depletion Potential (ODP).....	127
Supplement A 8	Human and eco-toxicity, USEtox.....	129
Supplement A 9	Resource depletion.....	132
Supplement A 10	Particulate matter formation (PM).....	134
Supplement A 11	Normalization.....	135
Supplement A 12	Weighting.....	135
Supplement B	Background information on uncertainty.....	137

List of Figures

Figure 2-1:	GaBi Database concept embedded in 3 pillar solution approach.....	10
Figure 2-2:	Database Management at PE INTERNATIONAL	11
Figure 2-3:	Hierarchical system in GaBi	13
Figure 2-4:	Aggregated dataset in GaBi	14
Figure 2-5:	Polymerisation subsystem in GaBi Master DB.....	15
Figure 2-6:	Tetraflourethylene subsystem in GaBi Master DB.	16
Figure 2-7:	R22 subsystem in GaBi Master DB.....	17
Figure 2-8:	Chlorine production mix in GaBi Master DB.....	17
Figure 2-9:	Chlorine membrane technology production in GaBi Master DB.	17
Figure 2-10:	Refinery model in GaBi Master DB.	18
Figure 2-11:	Crude oil import mix and country specific oil extraction in GaBi Master DB.....	18
Figure 2-12:	Power plant models of the Grid Mix modelling in GaBi Master DB.	19
Figure 2-13:	German Natural Gas Mix in GaBi Master DB.....	19
Figure 2-14:	German Natural Gas production in GaBi Master DB.....	20
Figure 2-15:	GaBi DB in the international context of databases and frameworks.	22
Figure 2-16:	GaBi LCI Expert Teams and the core LCA content team.....	23
Figure 3-1:	Graphic representation of different (sub-) system boundaries	26
Figure 3-2:	Generic example product system of a dataset development	27
Figure 3-3:	Application water flows in open-loop and closed-loop cooling systems in various industrial settings	42
Figure 3-4:	Application water flows in once-through cooling and cooling towers in energy/electricity generation	44
Figure 3-5:	Application water flows in hydropower generation	45
Figure 3-6:	Ad hoc example of a simple plan system including different processes and water flows.....	45
Figure 3-7:	Difference between "production mix" and "consumption mix" (for power generation).....	55
Figure 3-8:	Principle graphical explanation of the relation of completeness, precision	58
Figure 4-1:	Hierarchical structure of the processes and plans	69
Figure 4-2:	Conventional natural gas production in Germany	73

Figure 4-3:	Natural gas supply for Germany	74
Figure 4-4:	US, East electricity grid mix	75
Figure 4-5:	Parameterized US Coal gas CHP power plant.....	76
Figure 4-6:	Excerpt of the organic network considered in GaBi	85
Figure 4-7:	Consumption mix of Epoxy resin in Germany	86
Figure 4-8:	Example of PVC resin - compound- part.....	88
Figure 4-9:	Schematic life cycle of a building	89
Figure 4-10:	Nitrogen in the agrarian system	92
Figure 4-11:	Creation of a model for an electronic product - modular structure via Generic Modules	96
Figure 4-12:	Exemplary incineration model with in GaBi (here average European domestic waste treatment with dry offgas cleaning).....	99
Figure 4-13:	Details of incineration and dry offgas cleaning in GaBi incineration model	100
Figure 4-14:	Exemplary landfill model in GaBi (here commercial waste composition for certain geographic example regions).....	101
Figure 4-15:	Exemplary wastewater treatment model in GaBi (here municipal wastewater for German circumstances).....	103
Figure 5-1:	Example documentation in GaBi (excerpt) [GABI 2012]	108

List of Tables

Table A:	Background system boundaries.....	28
Table B:	Relevancy of infrastructure of a natural gas power plant in GaBi Master DB (selected representative sample power plant).....	37
Table C:	Publicly available example value for a medium size gas power plant.....	37
Table D:	Publicly available example values for CO ₂ for a gas power plant	37
Table E:	General treatment procedure (if no specific information is available) for common materials/wastes	47
Table F:	General procedure for some hazardous waste flows	47
Table G:	Overview of the Land Use Change Indicator Units	50
Table H:	Overview of qualitative importance of “quality indicators” in GaBi DBs.....	56
Table I:	Coefficients of variation.....	64
Table J:	ILCD set of recommended impacts.....	116
Table K:	Normalization references	135
Table L:	PE Weighting 2012	136
Table M:	Chemical substance datasets available for various countries in GaBi	138
Table N:	Chemical substance datasets available for various technology routes in GaBi	140

Abbreviations

AP	Acidification Potential
ADP	Abiotic Depletion Potential
B2B	Business-to-Business
B2C	Business-to-Customer
CHP	Combined Heat and Power Plant
DeNOx	NOx emission reduction
DeSOx	SOx emission reduction
DB	Database
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
IEA	International Energy Agency
IPCC	International Panel on Climate Change
ILCD	International Lifecycle Reference System
KEA	Cumulated Energy Approach (Kumulierter Energieaufwand)
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MAETP	Marine Aquatic Ecotoxicity Potential
MSW	Municipal Solid Waste
NDA	Non-Disclosure Agreement
ODP	Ozone Depletion Potential
POCP	Photochemical Ozone Creation Potential
SCR	Selective catalytic reduction (DeNOx type)
SNCR	Selective non catalytic reduction (DeNOx type)
TETP	Terrestrial Ecotoxicity Potential
WtE	Waste-to-Energy

1 Introduction and aim of document

Consistency, Relevancy, Quality, Continuity are the main drivers in the GaBi database. The GaBi databases contain over 300 person-years of direct data collection and compilation. PE staff with an experience of over 1000 person-years contributes constantly to the management and development of the GaBi databases.

The goal of “GaBi Database and Modelling Principles” is to transparently document the environment, background, important aspects and details of the GaBi databases, as well as the basis of the models.

Furthermore, the database management is described – an important aspect of professional databases in practise – as well as update and maintenance procedures and strategies.

Finally, important, general, methodological aspects and branch- or expert-specific methodological aspects are documented.

This document is the basis of all GaBi databases, the professional database and the extension databases, as well as all data-on-demand datasets.

2 GaBi LCA database framework

Successful, continuous and effective database provision needs

- a professional database concept and management,
- consistent and central database development,
- database maintenance as well as frequent and efficient update routines.

To enable a flexible use of the database content in different Life-Cycle- related applications, Life-Cycle Management tasks and professional decision situations, the data should be suitable and adaptable to different schemes and standards of industrial and professional practise and should most importantly reflect the real supply chain and technology situation. Well-educated and broadly experienced teams of different branches and expert groups with broad experience in their areas of expertise are important.

The methods and methodological choices used have been selected to reflect the supply networks in the most appropriate way. "Method follows reality."

2.1 GaBi Database concept and management

The database concept is embedded into the solution concept of PE INTERNATIONAL. This Master DB concept is one core pillar of our three pillar solution approach, which is accompanied by engineering consulting knowledge and a professional software environment.

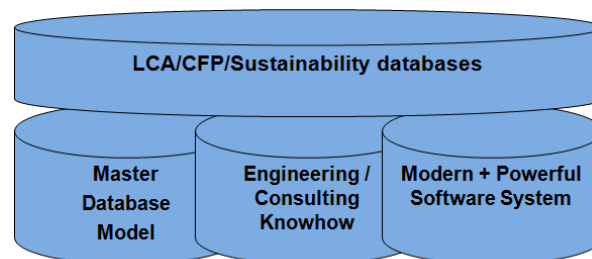


Figure 2-1: GaBi Database concept embedded in 3 pillar solution approach

Database development at PE involves experts on LCA methodology, with technical expertise (see Chapter 2.6 for details on the different teams), as well as knowledge of the supply chain. Relevance checks and routine quality assurance checks are applied. The generation of new data follows a standard procedure with "cascade quality checks" and is embedded into the GaBi Master DB concept.

Internal entry quality checks: Newly generated data first passes a purely internal quality check, by two LCA experts with engineering skills at PE INTERNATIONAL, in a dependent internal review, before entering the database environment.

Internal resulting quality checks: Depending on the type of data and its intended use, field of expertise and the sources providing the data (internal or external sources and/or organisations), a second check or validation by our cooperative partners LBP University of Stuttgart and Fraunhofer IBP or other independent organisations are undertaken, as an independent internal review.

External resulting non-public quality checks: Data, which is generated together with industry or associations for distribution with GaBi databases into the professional LCA user community (e.g. Eco-profile-type data or other representative averaged industry data of different companies or an individual dataset of single companies), undergo an additional quality check by the respective data providers or selected neutral third party organisations, as an independent external review or third party review.

External resulting public quality checks: The dataset and systems, which are provided with our software and databases for public use to a broad user community, are constantly used, compared, benchmarked, screened and reviewed, and the results are published in various external, professional and third party LCA applications in industry, academia and politics. User feedback via the online GaBi forum or direct via user information is standard in the maintenance and update process of the databases and leads to consistent quality, constant control and improvement of data, if knowledge or technology improves, or industrial process chains develop and change, as independent public or “cloud” reviews.

The Database Management at PE INTERNATIONAL protects private and project-related information of customers and clients, while enabling customers and clients to best benefit from the general, usable part of the internal information and knowledge and expertise pool of PE.

Any information that leaves the PE internal database area needs release permission and is centrally distributed.

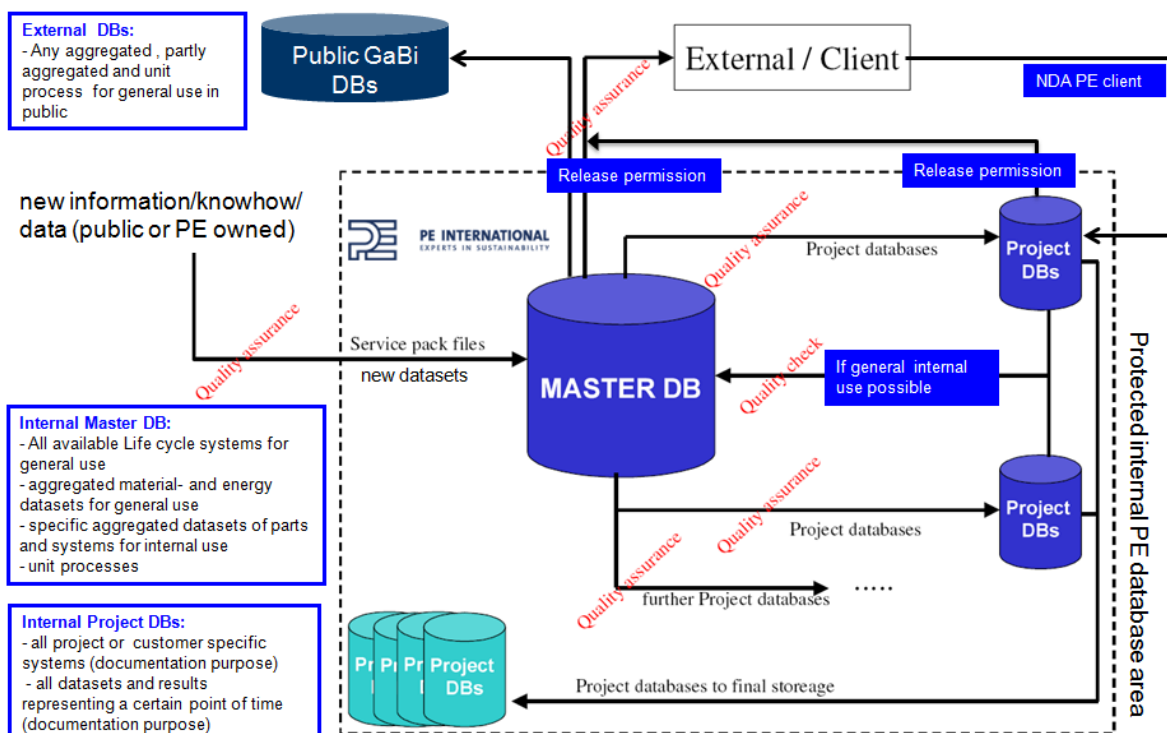


Figure 2-2: Database Management at PE INTERNATIONAL

Any confidential project or customer-related information is protected by a “Non-Disclosure Agreement (NDA)” and securely separated from any publicly available database.

2.2 GaBi Database development, maintenance and update

After observation of the LCA developments over the last 20 years it becomes obvious that the motivation to start using LCA approaches two decades ago is industry-driven. Naturally all data should ideally be “industry borne,” meaning the data are validated or sourced from or within industry to ensure the proper representation of real circumstances. So “data” is a typical topic for LCA work with and in industry.

The need for sound methodological approaches within database and LCI modelling has attracted the academic world and later, standardisation bodies.

LCA databases began appearing in the early 1990s - some with software systems. GaBi was the only pioneer having both database and software system at hand from the beginning, opening up synergies and unique possibilities.

LCA Databases are growing in relevance. GaBi databases evolved and established LCA in daily use early within research and industry. Only professionally managed, maintained and updated databases continue to be relevant in practise.

Maintaining and updating databases is an important, although time- and management-intensive task. Accuracy of data, new (practical, proven) methods and user needs are just three examples that need constant attention. And constant attention requires a consistent group of people taking care of specific topics and branches.

- New scientific findings, new data and technologies and new methods need constant database development.
- Decisions for development of new products based on LCA and optimisation or investment depend on reliable results, applicability and continuity in daily practise.

GaBi database development combines the important aspects of these requirements. The GaBi database employs proven “best practice” data and approaches. New scientific methods and data are applied only after feasibility checks to reduce risks of wrong (product or process) decisions. “Best practice” is based on the “latest science.”

The GaBi database work is considered to be done “for practice with information from practise” and therefore considers the “critical success factors” in professional LCA applications. GaBi data is therefore not just any randomly available data, but rather best practise data.

We have access to raw data sources developed by PE and in-house engineering expertise, which enables PE to develop and deliver within scope, on time, with high quality and provide guidance towards suitable data and data selection. A standard format for all LCI datasets is mandatory for all PE-owned data.

PE considers its data to be “Industry-borne” as we aim for stakeholder involvement and validation on data developments with suitable contacts, sources and published industry data. PE always welcomes feedback, constructive criticism and suggestions for improvement.

We model real supply chains for inter-sectoral use for all B2B and B2C relationships. The data reflect specific and up-to-date technology and technology routes for individual branches. Region-specific background systems are combined, wherever suitable and possible, with local/regional process technology information. Individual, user-specific modification, adaptation and extension on local situations with customer-owned data or parameterised data are possible. Individual data on demand can be constructed according to the same routine for best consistency.

The ultimate goal is to attain flexibility in the application of our data to address different topics and allowing flexible assimilation between political and industrial decision contexts. In other words the same database can be used in making a quick decision or in an intensive investment decision.

Regarding development, maintenance and update environment, a suitable group structure (see Chapter 2.6 for details) with different responsibilities at PE is in place. There is a direct relationship between software and database development, which supports practical and relevant solution pathways, seeing as many issues deal with both fields.

Maintenance and support routines are installed and updates are regularly conducted with the least possible user effort required including smart database/software updates with automated addition of new standard LCI or LCIA data.

2.3 Structure of the Master Database contents

The Master Database is the core data knowledge memory and contains about 10,000 generic plan systems, each with one or more unit processes and several sub-systems.

In some cases single cradle-to-gate systems involve several thousand individual plan systems and tens of thousands of individual processes tracing back to the resources.

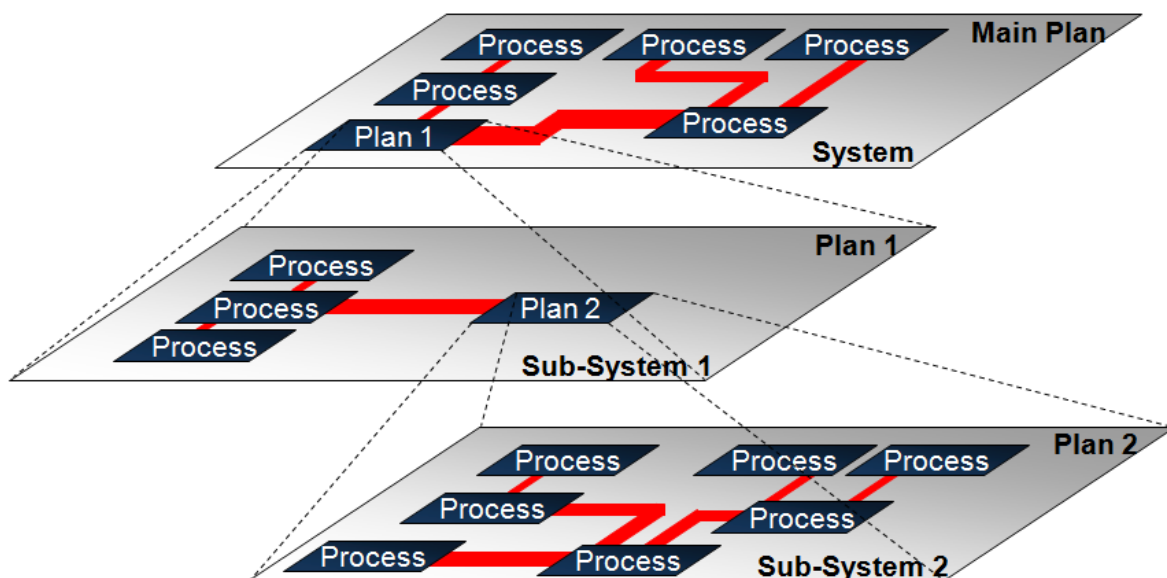


Figure 2-3: Hierarchical system in GaBi

Each PE-owned, aggregated process provided in the public available databases has a corresponding plan system, unit processes and sub-systems with sub unit-processes in the Master Database.

Huge systems result, which are hardly manageable without suitable LCA software support. In principle it would be possible to display all sub-systems of all processes and plans of the complete Master DB. The resulting document would probably have about a quarter of a million pages¹. This is one main reason why GaBi and its corresponding Master database were developed: To be able to transparently and simply manage and use large process chain systems of real supply chains.

¹ Rough estimate assuming two screenshots per page.

The graphical display for this document is therefore limited to an example. It aims to transparently document the structural background of the Master Database. Further publicly available process chain and technology information on all datasets and systems is covered in the documentation.

We offer to share more details and process chain knowledge through bilateral business relationships.

The publicly-available databases contain plan systems, unit processes, partially aggregated processes and aggregated processes.

DE: Polytetrafluoroethylene granulate (PTFE) Mix PE [Plastic production] -- DB Process

Object Edit View Help

Name DE Polytetrafluoroethylene granulate (PTFE) Mix PE agg - LCI result

Parameter

Parameter	Formula	Value	Minimum	Maximum	Standard	Comment
Parameter						

LCA VF LCC: 55,4 EUR LCWE Documentation

Completeness All relevant flows recorded

Inputs

Flow	Quantity	Amount	Unit	Trz Standar	Origin	Comment
Air [Renewable resources]	Mass	84,5	kg	0 %	(Calculated)	
Antimony [Non renewable elements]	Mass	9,89E-010	kg	0 %	(No statement)	
Barium sulphate [Non renewable resou]	Mass	2,44E-013	kg	0 %	Literature	
Basalt [Non renewable resources]	Mass	1,83E-006	kg	0 %	Calculated	
Bauxite [Non renewable resources]	Mass	0,000372	kg	0 %	(Literature)	
Bentonite [Non renewable resources]	Mass	0,00438	kg	0 %	Literature	
Biotic Production [Transformation]	Biotic Production	0,00011	kg/a	0 %	Literature	
Biotic Production [Occupation]	Biotic Production	0,0657	kg	0 %	Literature	
Calcium chloride [Non renewable resou]	Mass	2,49E-011	kg	0 %	Literature	
Carbon dioxide [Renewable resources]	Mass	0,81	kg	0 %	(Literature)	

Outputs

Flow	Quantity	Amount	Unit	Trz Standar	Origin	Comment
Polytetrafluoroethylene granula	Mass	1	kg	X 0 %	Measured	
High radioactive waste [Radioactive w	Mass	9,39E-006	kg	* 0 %	Literature	
Low radioactive wastes [Radioactive v	Mass	0,00015	kg	* 0 %	Literature	
Medium radioactive wastes [Radioacti	Mass	7,63E-005	kg	* 0 %	Literature	
Radioactive tailings [Radioactive wast	Mass	0,00721	kg	* 0 %	(Calculated)	
1,1,1-Trichloroethane [Halogenated o	Mass	1,13E-012	kg	0 %	Estimated	
1,2-Dibromoethane [Halogenated org.	Mass	8,13E-018	kg	0 %	Literature	
1,3,5-Trimethylbenzene [Group NMVC	Mass	2,02E-017	kg	0 %	Estimated	
Acenaphthene [Hydrocarbons to fres	Mass	2,81E-010	kg	0 %	Literature	
Acenaphthene [Hydrocarbons to sea	Mass	1,71E-009	kg	0 %	Literature	
Acenaphthylene [Hydrocarbons to fre	Mass	1,06E-010	kg	0 %	Literature	
Acenaphthylene [Hydrocarbons to sei	Mass	5,79E-010	kg	0 %	Literature	
Acetaldehyde (Ethanal) [Group NMVO	Mass	9,47E-007	kg	0 %	(Calculated)	

System: No changes. PE-GaBi Last change: System, 23.10.2012 09:26:13 GUID: {1d892f94-5e26-4248-a15...}

Figure 2-4: Aggregated dataset in GaBi

Aggregated processes are often the only way to provide relevant, suitable and up-to-date information of industrial sources to the LCA user community. Many users consider aggregated processes the best way to reliably and representatively model existing background systems.

PE has added value from unit process data collection and compilation, including verification of technical realistic boundaries, to country-specific supply chain modelling.

Opening the first level of the related polytetrafluorethylene production in the Master database shows the polymerization step with the respective unit process in the centre. Upstream sub-systems are shown on the right (in the unit process only technical flows are visualised; elementary flows such as resources or emissions are not visualised, but definitely physically and mathematically present in the individual unit processes).

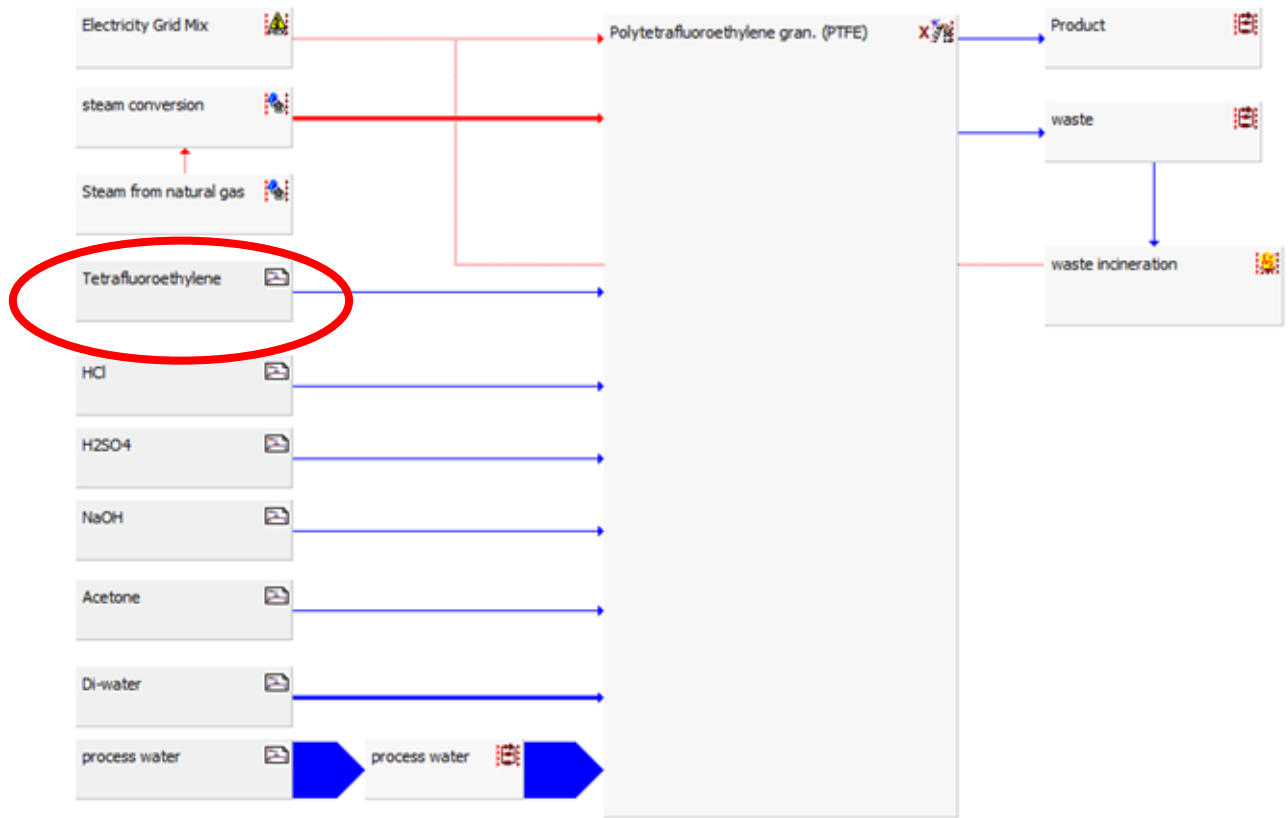


Figure 2-5: Polymerisation subsystem in GaBi Master DB

We follow one single upstream pathway from Tetrafluorethylene (indicated by the red circle; details are shown in the next figure)...

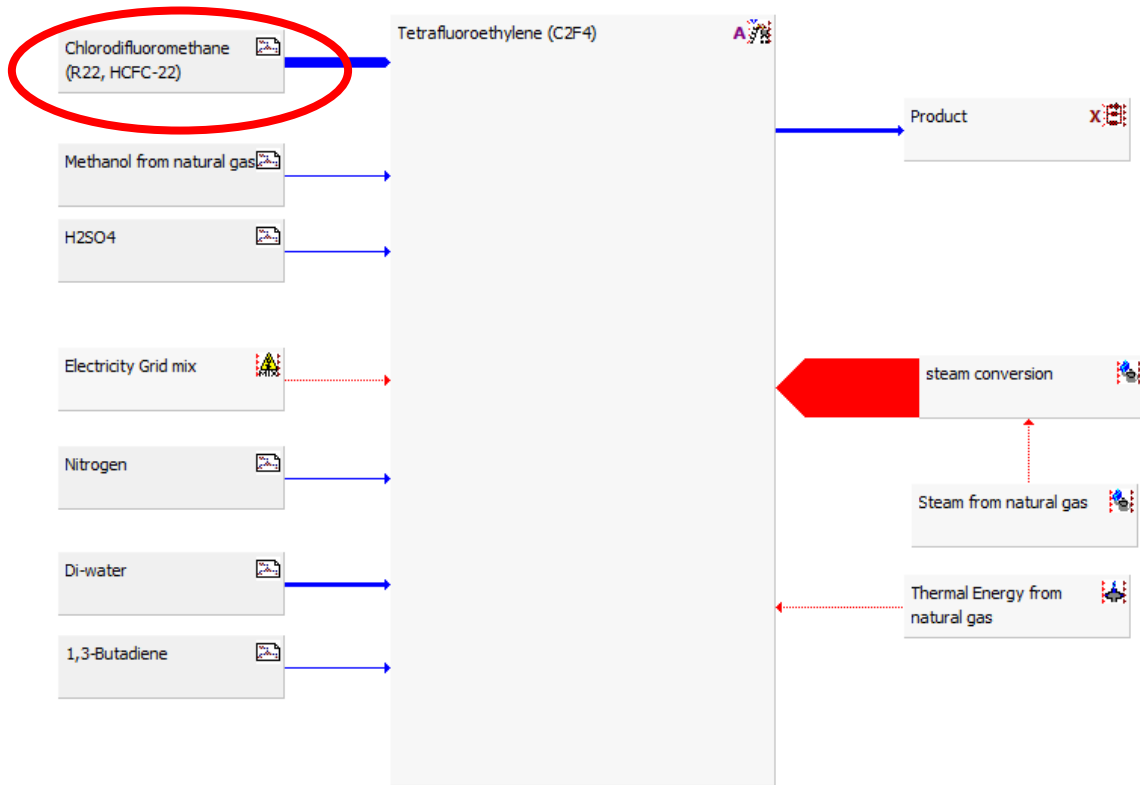


Figure 2-6: Tetrafluorethylene subsystem in GaBi Master DB.

...to R22 details and chlorine mix details (marked in red)...

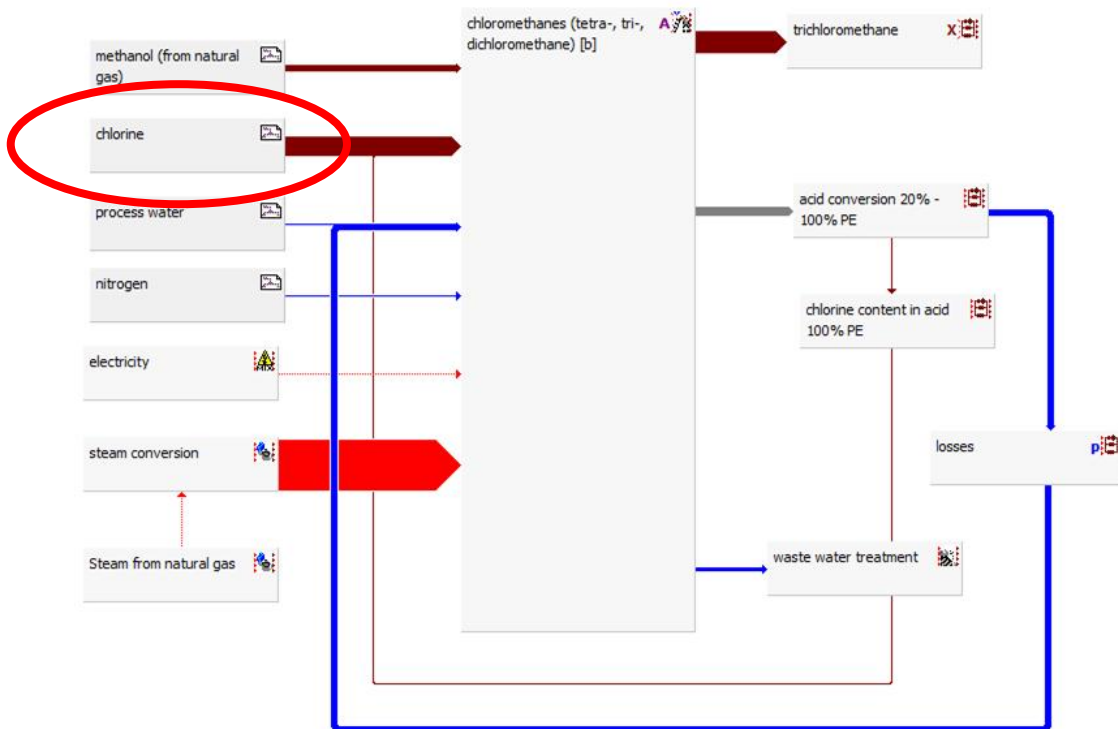


Figure 2-7: R22 subsystem in GaBi Master DB.

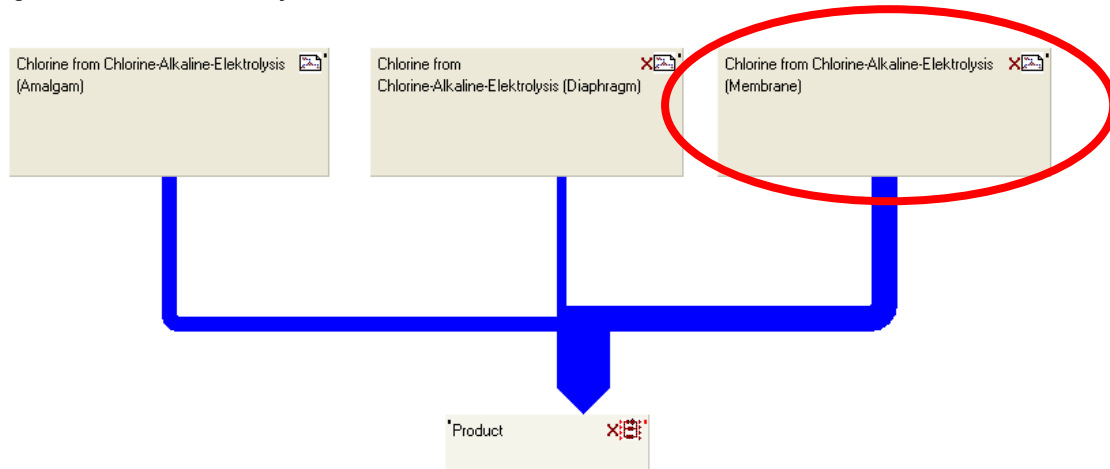


Figure 2-8: Chlorine production mix in GaBi Master DB.

... then to chlorine membrane technology details (marked in red) and back to rock salt mining.

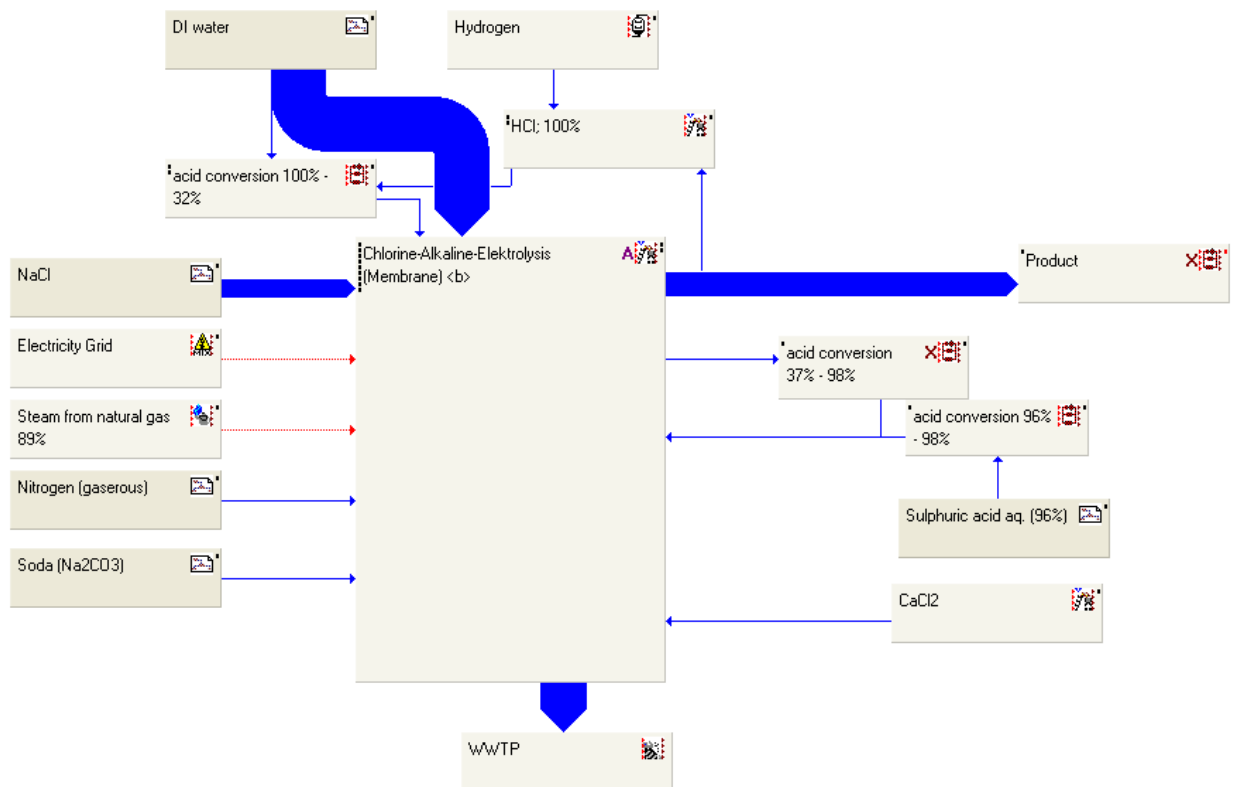


Figure 2-9: Chlorine membrane technology production in GaBi Master DB.

The previous example showed the journey from polymer back to rock salt. The following example gives insight to the fossil fuel and organic process chain. Starting with the various refinery products diesel, gasoline, naphtha and gases on the right side....

GaBi LCA database framework

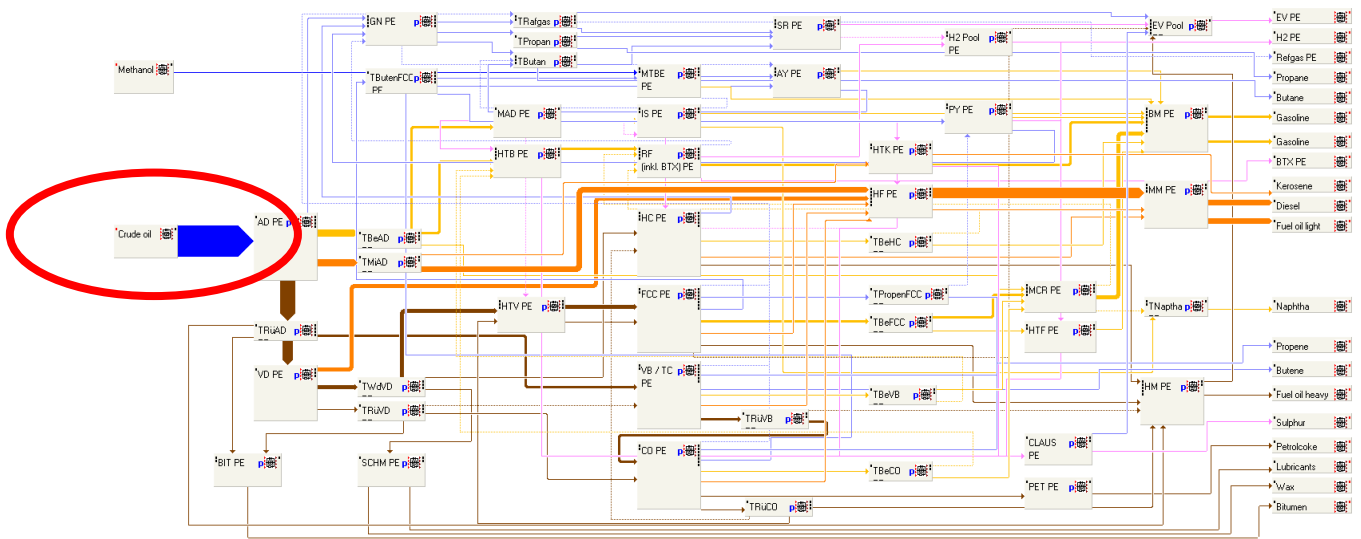


Figure 2-10: Refinery model in GaBi Master DB.

... the refinery products progress through the different refinery stages to the crude oil input on the left...

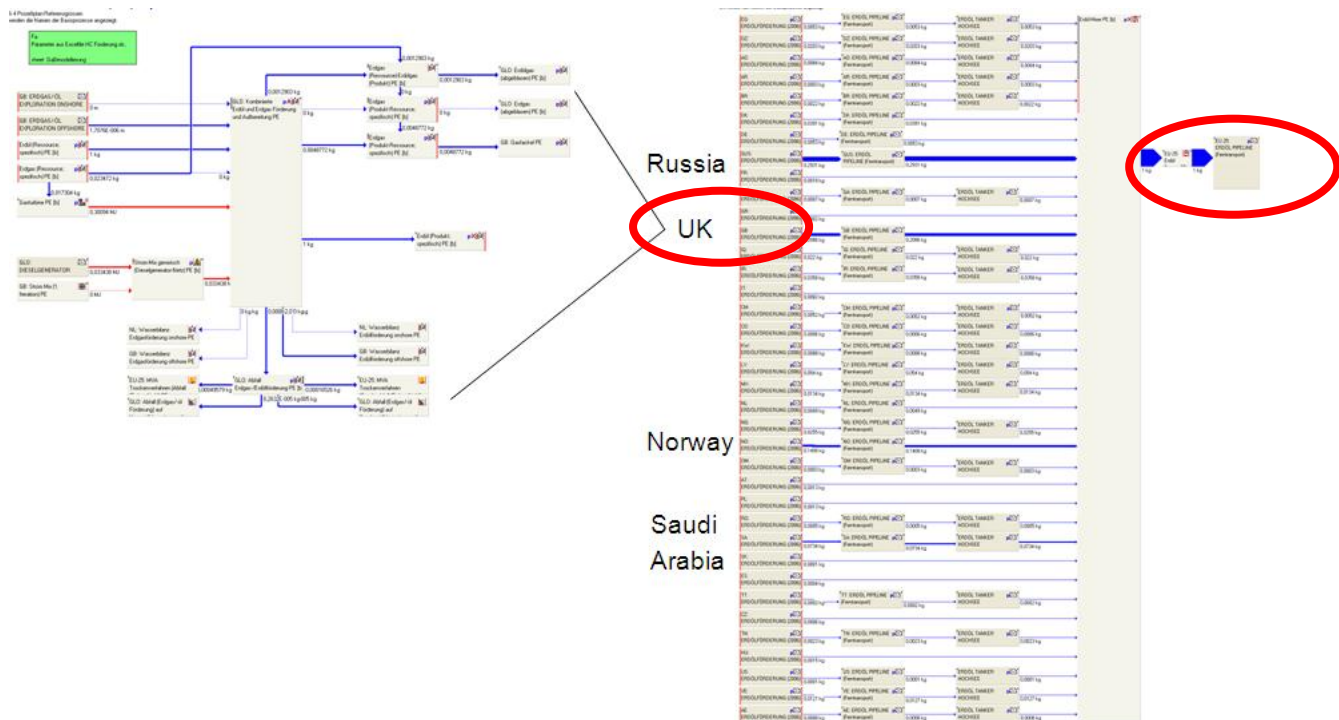


Figure 2-11: Crude oil import mix and country specific oil extraction in GaBi Master DB.

...and from the right side of crude oil import mix to country-specific oil extraction and the bore hole at the source.

The last example shows the electricity modelling in GaBi Master Database.

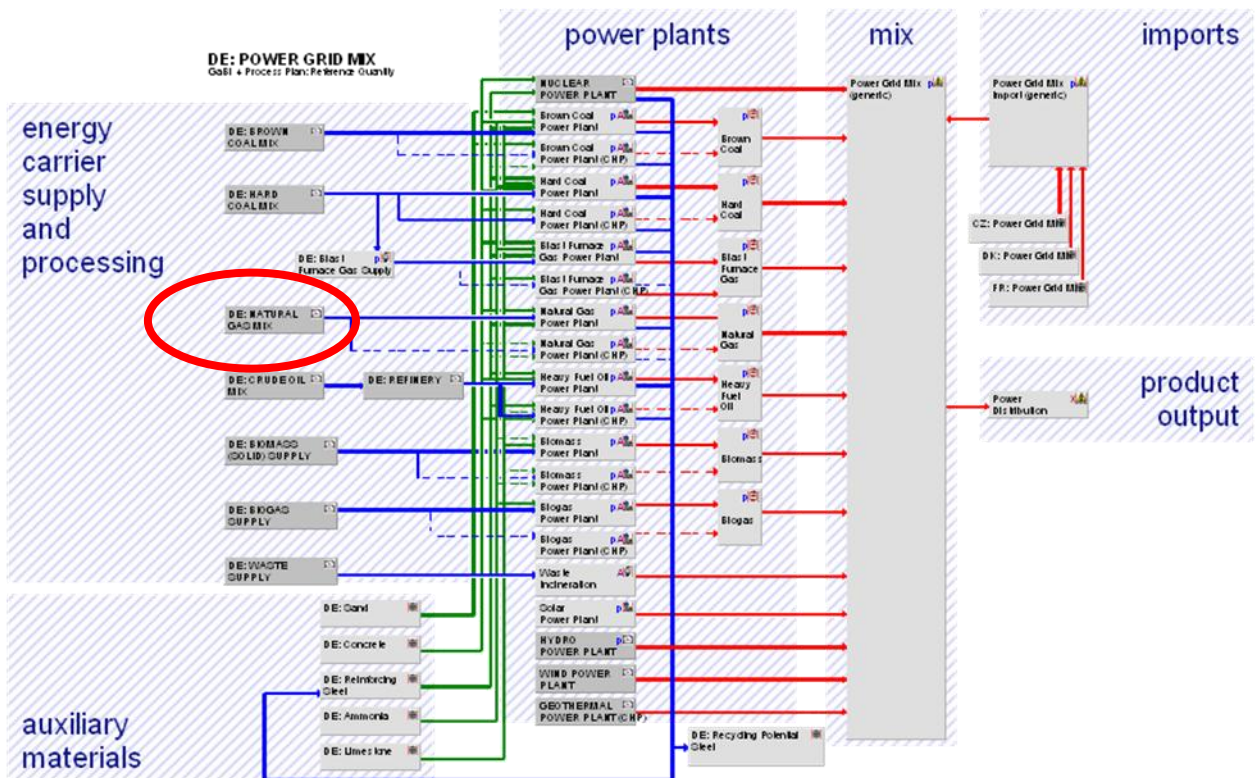


Figure 2-12: Power plant models of the Grid Mix modelling in GaBi Master DB.

The output which results on the right side of above screenshot is 1 kWh of electricity. On the right next to the hydro, wind, waste and nuclear power plants, the necessary fuels (hard coal, lignite, oil and natural gas)...

DE: NATURAL GAS MIX

GaBi 4 Process Plan: Mass

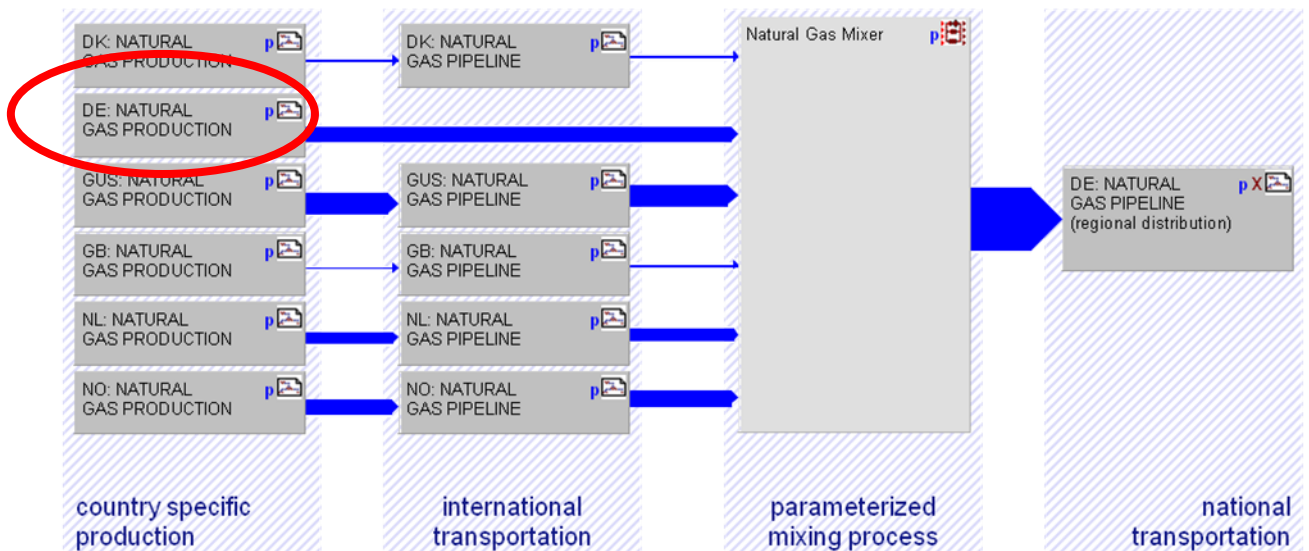


Figure 2-13: German Natural Gas Mix in GaBi Master DB.

...which are provided by the German consumption and import mix of natural gas...

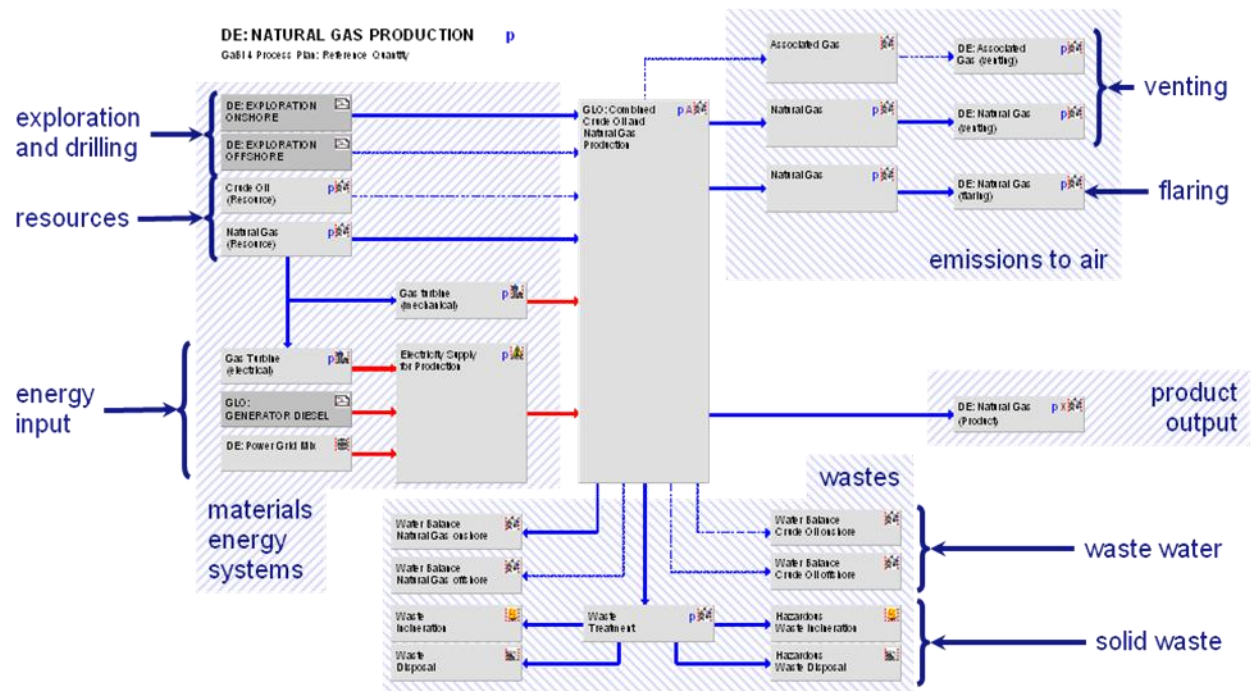


Figure 2-14: German Natural Gas production in GaBi Master DB.

...can be traced all the way back to the natural gas production at the source.

The above screenshots represent only a very small amount of the total process chain network involved in the chosen PTFE example.

In summary we can conclude that a pre-calculated dataset integrates a large amount of valuable information, which would otherwise be barely manageable.

Thousands of pre-modelled, real world subsystems and engineering information are included. Data collection time, industry research and compilation and consistency checks create real B2B supply chains. Knowledge of technical aspects of supply chains has been documented, along with the approximately 300 person-years work on the database and content.

2.4 Standardisation, compliance and application issues of LCI databases

The customer or case specific foreground model must be compliant to the desired approach in first instance. GaBi supports in various ways due to its flexible modelling features.

GaBi Databases are developed for use within different situations and applications as upstream, downstream and background data and seek to be in line with relevant existing standards, reference documents and best practise documents.

In this context we primarily consider:

- LCA / LCI / LCIA: [ISO 14040 : 2006, ISO 14044 : 2006]
- Ecolabels [ISO 14020 : 2000] , Typ II [ISO 14021:1999], Typ III [ISO 14025:2006], Environmental product declarations (EPD) [ISO 21930:2007], [ISO 15804], Institute

Construction and Environment [IBU 2011], Fiches de Déclaration Environnementales et Sanitaires (FDES) [NF P 01 010 : 2004]

- Greenhouse Gases / Carbon Footprint: [ISO 14064-1:2006], [ISO 14067], GHG Protocol Corporate Value Chain (Scope 3) [GHGPC 2011] and Product Life Cycle [GHGPP 2011], [PAS 2050:2011]
- Carbon Disclosure Project (CDP)
- Environmental Management ISO 14001, EMAS II, EMAS III
- Database reference systems and guidelines: ILCD reference system [ILCD 2010], SETAC/UNEP Global Guidance on databases [UNEP/SETAC 2011], Eco-profiles and Environmental Declarations, PlasticsEurope [PLASTICSEU 2011]
- CDP Water Disclosure and Water Footprint Network Manual

Because LCA is a multi-function/multi-application method, the GaBi data is generally developed to be used consistently within the aforementioned framework (please visit also <http://www.gabi-software.com/international/solutions/> for further details). It may be possible that some frameworks defined in certain specific applications result in contrary requirements, that one single background dataset cannot match both by default. Therefore the GaBi system supports and allows for specific addition/modification/adaptation of the dataset.

2.5 Databases in reference networks, standards and principles

GaBi databases are known to be of practical relevance and therefore are often used to support different initiatives, industry or national databases and schemes. And vice versa, initiatives, industry or national databases and schemes influence GaBi databases. This coexisting symbiosis enables practicability, applicability, compatibility and distribution of data within the relevant professional frameworks. The following graph illustrates the dependencies within this coexisting symbiosis.

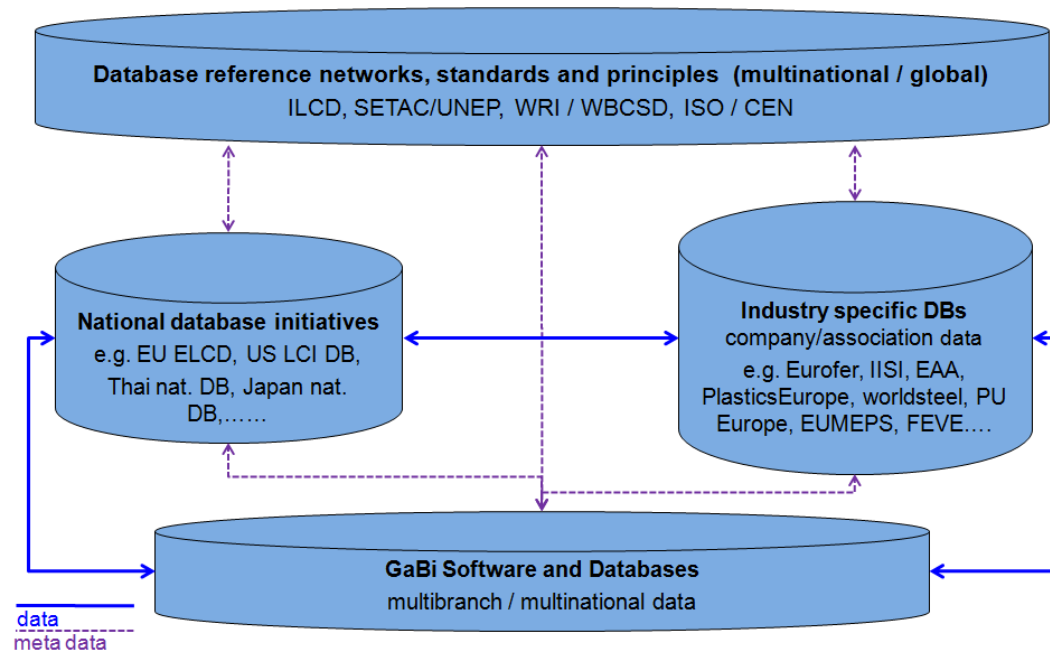


Figure 2-15: GaBi DB in the international context of databases and frameworks.

Potential data and metadata flows are visualized among the different professional frameworks.

2.6 GaBi LCI Team

GaBi databases result from the teamwork of 10 expert teams and one core content team. Each expert team is responsible for modelling its specific system, as well as documenting the generated LCI. Each team requires experts which have a solid background in the following fields:

- Technical knowledge specific to the given industry branch
- Performing LCAs and specifically having experience in analysing technical production routes
- Good understanding of the analysed production technologies applied for material production and/or power generation
- Sensitivity to the industry's current state and having an appropriate understanding of the role of LCA within industry
- Self-directed work in effective cooperation with industry

The coordination of all expert teams is the task of the core content team.

The content team provides the technical platform and methodological guidelines to all expert teams to ensure a consistent and synchronized database in the end. It also serves as an interface to clients, to the market and to the scientific community to receive feedback on the existing database, to make sure the GaBi databases are in line with the development of methodologies and the demands of the market, as well as to constantly improve the internally-used work flow and guidelines. In this way consistency throughout all GaBi databases can be assured.

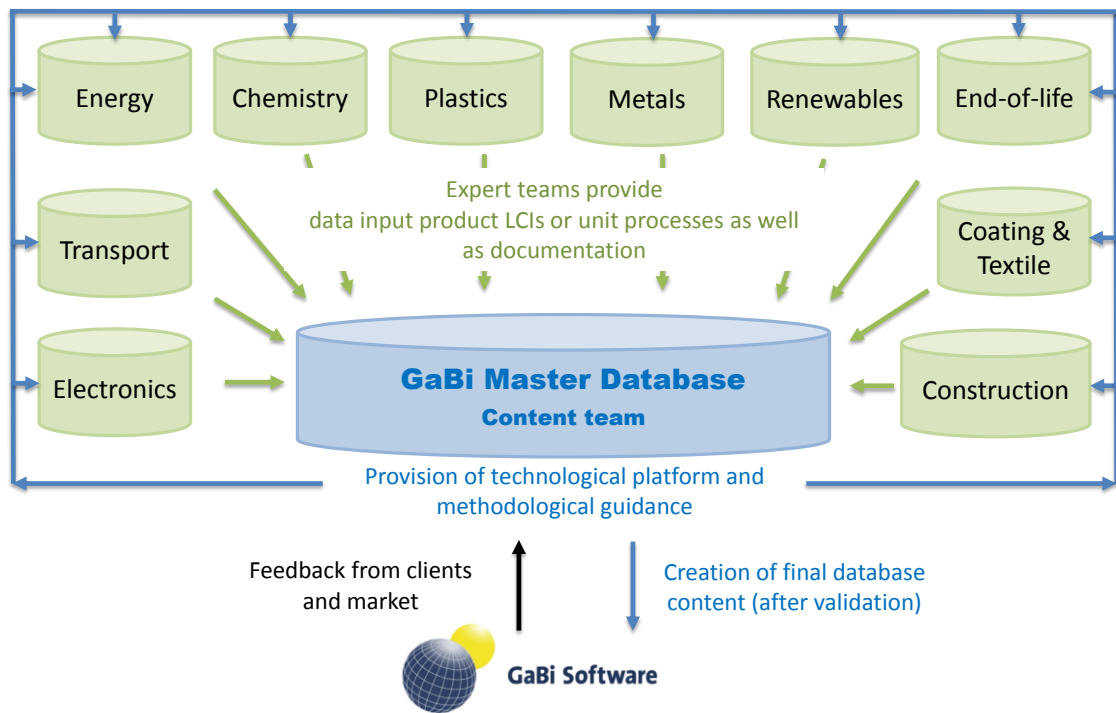


Figure 2-16: GaBi LCI Expert Teams and the core LCA content team

3 Methodological framework

This chapter summarises important methodological principles, which are applied in GaBi database modelling and are utilised if new datasets are developed or existing datasets are updated for Life Cycle Inventory (LCI) purposes.

3.1 Definition of tasks in database work

Database work can be separated into the following categories:

- Data and database development and set-up
- Data and database maintenance

In Data and Database development new LCI data and databases are produced using suitable raw data sources and appropriate methodological approaches to set-up new data the first time in line and consistent to existing data.

Data and Database maintenance keeps existing LCI data and databases constantly up-to-date in terms of (relevant and practically proven) evolutionary aspects of data formats, flow formats, flow hierarchies and methodological findings and to correct possible errors. Data and Database maintenance further involves frequent upgrades on new technological background information of unit processes, upstream technology information and technology routes, consumption and production mix figures for commodities, new impact factors, as well as all new combined software-database functions that enable the use of generic data in a broader, more flexible and extended way.

For any of the above mentioned tasks in database work we use the phrase "modelling".

These modelling processes follow principally the known steps of an LCA and contain the following main steps:

- Goal, Scope and System boundaries
- Data collection/validation/check and system modelling
- Data quality requirements and checks
- Documentation and publication

The "GaBi Database and Modelling Principles" are the basis for consistent database work. These guidelines address the important points but are not exhaustive. Transferring theory into practise requires interpretation and experience and, as a result, a degree of responsibility is held by the practitioner.

3.2 Goal

The results of an LCA study, as a rule, are related to a specific question. Therefore, the goal definition of an LCA study is of vital importance.

In the development of generic and representative (single) datasets, deciding on the goal of the dataset is of vital importance.

The main goal of all datasets in GaBi is to reflect the reality of our industrial and business networks and to be as flexible as possible to address all different aspects.

GaBi datasets therefore incorporate best available practise and information from internal or external sources. Consistency is important in that all sources used fit with each other and verify the final resulting data with existing data and our engineering knowledge.

Concerning the ISO standards [ISO 14044 : 2006], the goal of GaBi data can be understood as follows:

- Intended application: All practical life cycle-related applications that aim to maintain links towards or are based upon the ISO 14040/44 series.
- Reasons: Not applicable in the generic data context. Reasons to be specified within context of the system.
- Intended audience: All LCA practitioners in industry, research, consulting, academia and politics that aim to base their individual work on relevant data based in reality.
- Comparative assertions: No comparative claims are intended or supported on solely an inventory level from the database level. The databases are a consistent compilation of different datasets per functional unit, but direct comparison on the database level is not appropriate because proper (user case-specific) modelling is needed. The user is, however, able to take data and set up comparative assertions disclosed to public, which is its own responsibility.

3.3 Scope

The scope of the dataset and data systems depend on the type of dataset requested (see Gate to Gate, Cradle to Gate and Cradle to Grave²).

In most cases the complexity of the answer or result interpretation is strongly dependent on the degree of desired general validity of the answer or result interpretation.

Models of specific circumstances tend to be described with less complex systems, fewer possible varying circumstances or sensitivities that must be addressed. However, specific circumstances often call for more specific data.

Models of general circumstances tend to be described with more complex systems, because more possible varying circumstances or sensitivities must be addressed. Circumstances that are more general enable the use of more generic data.

In other words: For specific results or a specific company product, specific foreground primary data from the related company is needed. For general results concerning an average product, generic background data can be suitable and for unspecific results, such as sector-related results, even more general data (such as I/O table-type LCA data) can be used.

To avoid misinterpretation due to the use of data and datasets, the type of data and its boundaries, the specific product systems and its upstream technology routes must be documented and understood. The GaBi dataset and the related documentation of the GaBi dataset provide the necessary information to avoid misinterpretation.

² To avoid confusion by using any “vogue terms” of non-standardised concepts and visions the well-known and established term “Cradle to Grave” is used. The broadly used “Cradle to Grave” approach is able to include all kind of End-of-Life options and recycling options. So the “Cradle to Grave” approach is used to model all kind of cycles and recycling issues and is not used in contrast to any other method, as all aspects of technical and natural cycles e.g. like carbon, water and nutrients can be covered.

3.3.1 Function and Functional Unit

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 : 2006]. It should be representative of the goal of the dataset/data system and should allow the comparison of similar systems, processes or products, if needed.

In GaBi datasets the goal of functional unit is always defined as the related output product flow. Depending on the product, the functional units used in the GaBi databases [GABI 201] are essentially physical metric [SI]-units related to the amount of product, e.g. 1 kg, 1 MJ, 1000 kg, 1 m³. 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, seeing as all compared systems can be described in the chosen SI-unit.

3.3.2 Definition of terms within system boundaries

Within this sub-chapter the different bases for the data collection and system modelling (building up the LCI dataset) is described. The system boundary defines what is included in the dataset and depends on the kind of dataset: a ‘gate to gate’ unit process, a ‘cradle to gate’ aggregated or a ‘cradle to grave’ aggregated dataset.

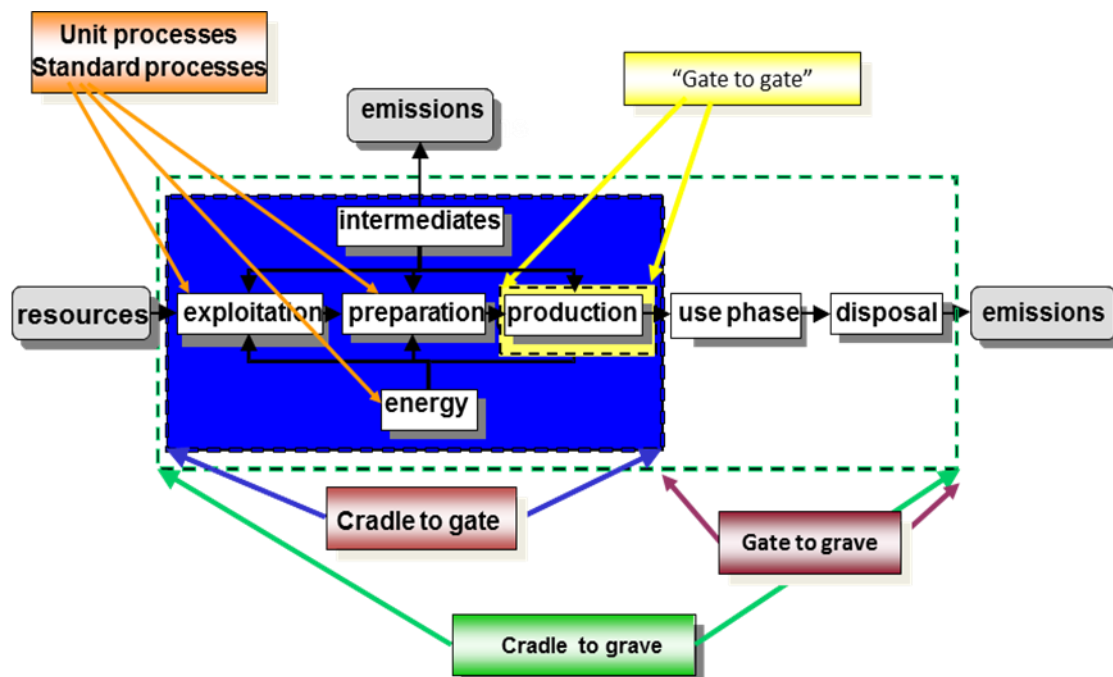


Figure 3-1: Graphic representation of different (sub-) system boundaries

Figure 3-1: Graphic representation of different (sub-) system boundaries

is a pictorial representation of the system boundary definitions.

- **Gate to Gate:** All company or site-related activities from material acquisition or procurement, beginning at entrance gate through all the production steps on site, until final commissioning steps before leaving the site gates again.
- **Cradle to Gate:** All activities from resource mining through all energy and precursor production steps and on site production, until final commissioning steps before leaving the site gates.

- **Cradle to Grave:** Cradle-to-Gate extended through the use, maintenance and the end of life (disposal, recycling, reuse) of a product.

During development of a dataset the system boundaries can be subjected to step-by-step adjustments due to the iterative nature of data system set up and validation procedures.

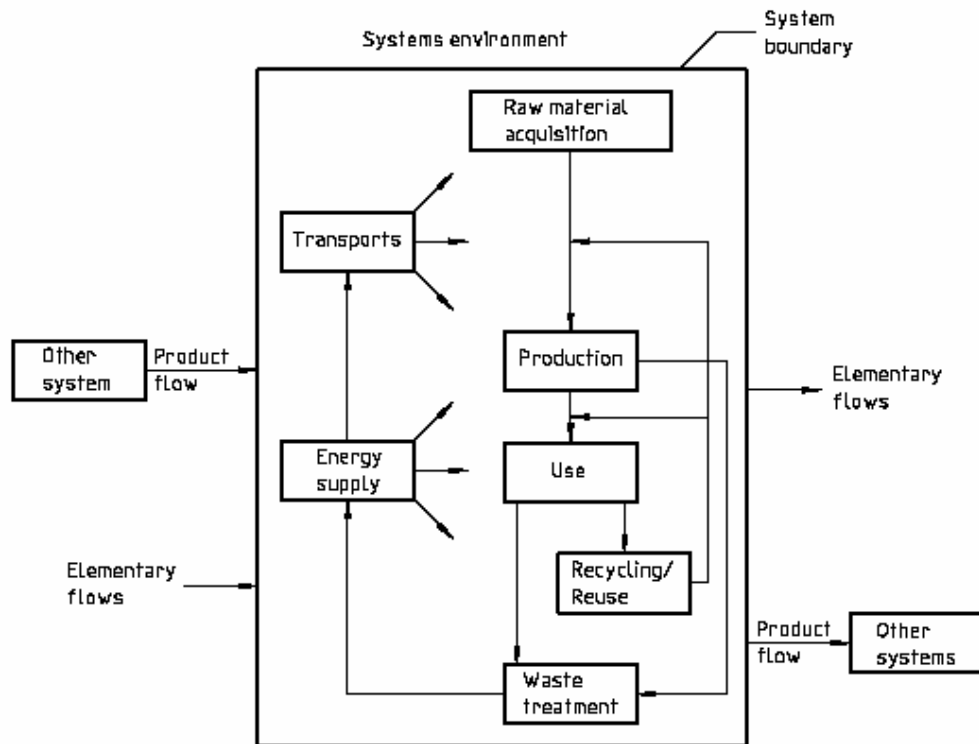


Figure 3-2: Generic example product system of a dataset development

Figure 3-2 gives an example of an example product system. Elementary flows enter and leave the system environment, as do product flows to and from other systems. Included within the system environment are different transports, energy supply, raw material acquisition, production, use, recycling/reuse, and waste treatment, depending on system boundaries. The respective system boundaries are defined by the type of dataset.

3.3.3 System boundaries for the creation of standard LCI cradle to gate datasets

Within this section the system boundaries for the generation of standard life cycle inventories are described.

System boundaries are defined by the included and excluded processes of the foreground and background systems.

The foreground system boundaries are described in the documentation of the GaBi dataset (<http://www.gabi-software.com/international/databases/>).

The background system boundaries of the GaBi datasets are described in the following tables.

The models are set-up over hundreds of engineering parameters in the software, which would be difficult to list, thus is one reason why GaBi relies on the combined software-database approach to couple functionality

with precision. PE offers the opportunity to share more details and process chain knowledge under bilateral business relationships. In the following tables the system boundaries of the main operations in the background system of GaBi dataset are documented.

Table A: Background system boundaries

	within system boundary³	outside system
Crude oils and natural gases	primary, secondary and tertiary production per country	offshore supply vessels, onshore drilling transports and some minor drilling chemicals
	onshore processes of exploration and drilling per country	
	offshore processes of exploration and drilling per country	
	resource extraction	
	venting and flaring emissions	
	drilling meter length	
	generators (diesel/gasoline) and electricity	
	thermal and mechanical energy	
	water use and wastewater treatment	
	waste and hazardous waste treatment	
	share of spilled crude oil from well testing	
	share of vented natural gas from well testing	
	bentonite and barium sulphate use	
	infrastructure	
see also http://www.gabi-software.com/international/databases/		

³ If relevant in the context of the country- or technology specific data system

Table Background System Boundaries (continued)

	within system boundary³	outside system
Coals and Lignites	open pit operations per country	production of conveyers and mining vehicles
	under ground operations per country	
	soil removal and digging	
	overburden	
	mining trucks and excavators	
	conveyors	
	water pumping	
	water use and wastewater treatment	
	air conditioning	
	explosives	
	dust and explosion emissions	
	specific pit methane, CO ₂ , chloride	
	fuels and electricity	
Power plants (electricity/heat)	all relevant combustion and off gas cleaning steps (see screenshot in Chapter 2.3) per country	construction processes of power plant
	power plant park per country	
	fuel characteristics per country	
	imports of other countries	
	all relevant emission country and technology specific	
	DeNO _x and DeSO _x units	
	electricity/heat shares	
	distribution losses	
	off gas treatment chemicals	
	infrastructure	
	see also http://www.gabi-software.com/international/databases/	

Table background system boundaries (continued)

	within system boundary³	outside system
Refinery operations	all relevant refining steps, approx. 30 different (see screenshot in Chapter 2.3) per country	Construction and infrastructure
	crude oil characteristics per country	
	H2 production in reformer and use	
	external H2	
	process water	
	all relevant refining emissions per country	
	desulphurisation and treatment	
	internal energy management	
	methanol, bio-methanol	
	product spectrum of 21 products per country	
	see also http://www.gabi-software.com/international/databases/	
Mining ores and minerals	ores concentrations and combined ore shares per country	production of conveyers and mining vehicles
	open pit operations	
	under ground operations	
	soil removal and digging	
	landfill overburden	
	mining trucks and excavators	
	conveyors	
	water pumping	
	water use and treatment	
	air conditioning	
	explosives	
	dust and explosion emissions	
	thermal energy propane	
	fuels and electricity	

Table background system boundaries (continued)

	within system boundary ³	outside system
Ore beneficiation	process chemicals	infrastructure and machinery
	fuels and electricity	
	thermal energy	
	process water	
	wastewater treatment	
	ammonium sulphate use	
	waste and tailings treatment	
	end of pipe measures and emissions	
Metal smelter, electrolysis and raffination	electricity specific per electrolysis	infrastructure and materials of facilities
	silica use, oxygen use	
	compressed air	
	coke and related reduction media	
	waste and slag treatment	
	hazardous waste treatment	
	auxiliary chemicals, caustics, chlorine, HCl, formic acid, soda, ammonia	
	thermal energy LPG, naphtha use	
	water use and wastewater treatment	
	see also http://www.gabi-software.com/international/databases/	
Chemical Synthesis, Formulations and Polymerisations	all relevant educts or monomers	some catalysts of confidential or patented composition and materials of reactors and facilities
	electricity specific per reaction type	
	thermal energy use or production	
	waste treatment	
	hazardous waste treatment	
	auxiliary chemicals	
	water use and wastewater treatment	
	purge purification of recycling (if any)	
	see also http://www.gabi-software.com/international/databases/	

	software.com/international/databases/	
Mineral processing and kiln processes	all relevant mineral inputs and fuels	infrastructure and materials of machinery
	electricity specific per kiln and operation type	
	thermal energy	
	waste and hazardous waste treatment	
	end-of-pipe operations	
	auxiliary chemicals	
	water use and wastewater treatment	
	particle and combustion emissions	
	see also http://www.gabi-software.com/international/databases/	
Agrarian products and renewables	CO ₂ uptake, sun light and nitrogen balance	farm infrastructure and materials of machinery
	rain water, irrigation water, water pumping	
	individual pesticides per crop	
	individual fertilizers per crop	
	land use and reference systems	
	fertilizing effects of by-products	
	tillage and all related soil preparation	
	tractor and all related machinery	
	transports to field border / farm	
	electricity and fuels for cultivation	
	electricity and fuels for harvesting	
	see also http://www.gabi-software.com/international/databases/	

Table background system boundaries (continued)

	within system boundary³	outside system
Electronic products and components	NF-metal and precious metal materials	infrastructure and materials of machinery
	polymer and resin components	
	Solders	
	housing and frames	
	fire retardant	
	printed wiring boards	
	processing and assembly	
	Etching and processing chemicals	
	see also http://www.gabi-software.com/international/databases/	
Water supply	water withdrawal and pumping	infrastructure and materials of machinery
	mechanical and chemical (pre-) treatment	
	chemicals for processing (ClO ₂ , O ₃ ,...)	
	electricity and thermal energy technology specific	
	reverse-osmosis and membrane technology	
	see also http://www.gabi-software.com/international/databases/	
EoL water treatment	mechanical and chemical (pre-) treatment	infrastructure and materials of machinery
	chemicals for processing (ClO ₂ , O ₃ ,...)	
	sludge and slag treatment (fertilizer or incineration)	
	see also http://www.gabi-software.com/international/databases/	
EoL incineration	waste input specific (composition, calorific value)	infrastructure and materials of machinery
	fuels, co-firing, combustion, boiler, SNCR/SCR	
	active filter, end-of-pipe, DeSO _x	
	chemicals, water	
	Efficiency and energy recovery (electricity/heat)	
	Combustion calculation incl. all relevant emissions	
	see also http://www.gabi-software.com/international/databases/	

	software.com/international/databases/	
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All datasets of commodities and products are modelled within the foreground system boundaries described in the documentation and within the background system boundaries described above. For any of the PE-owned datasets, the underlying plan systems are accessible in the Master database and PE can grant access rights (e.g. for review purposes) under bilateral contracts. PE Master database content is valuable, privately-financed information, developed, collected and compiled with a tremendous amount of resources and costs with no public funding. It is therefore not possible to grant free public access to the Master DB in its totality.

3.3.4 Cut-offs

Cut-off rules are defined to provide practical guidelines to be able to omit specific less relevant process chain details, while creating a specific product system. The ISO 14044 : 2006 mentions three criteria used to decide which inputs are to be included: a) mass, b) energy and c) environmental significance.

There are three different types of cut-offs:

1. A known input or substance is not connected to an upstream process chain due to lack of information
2. A known inconsistency in a mass or energy balance with a known reason
3. An unknown or known inconsistency in a mass or energy balance with an unknown reason

The GaBi database has very few cut-offs of type 1). The only two reasons for cut-offs of type 1) are starting conditions (at the very beginning of the supply chain) or confidentiality reasons of competitive formulations/substances (see table in Chapter 3.3.3). Due to the magnitude of the database content, most information is available or can be developed. If a substance for which no LCA data exists is needed and is not available as a dataset, the GaBi Master database uses information for a chemically/physically-related substance and creates a worst case scenario for the substance causing the gap. If the influence of the worst case scenario on the overall result is smaller than 5%, the worst case scenario can stay (gap-closing insignificantly overestimates to the actual value, precautionary principle). If the influence on the result is higher, more information is gathered or the sensitivity quantified.

The GaBi database has acceptable cut-offs of the type 2), if the environmental relevance on the overall result can be justified as small. An example of a justifiably small environmental relevance is a known inconsistency in a mass or energy balance with known reason, such as missing or imprecise quantified mass information in the input. These can be minor variations in moisture content or minor amounts of diffuse water input, reaction or combustion air, which is directly taken from the atmosphere and normally not quantified in a “bill of material” or process flow chart. Known inconsistencies in a mass or energy balance with known reason on the output side can be undocumented “emissions” or energy flows such as evaporated water, used air, “clean” off-gas streams or off-heat. These cut-offs are acceptable, if their quantification would raise the effort drastically and marginally improve the overall results.

All GaBi unit processes seek to reflect actual physical and thermodynamic laws and the mass balance of the key substances and fuels in the input must best match the product, waste and emission output. As a general rule in GaBi unit process modelling, the mass and energy balances are closed and cut-offs are avoided. Projects and data collections with industry and associations showed that on the unit process level mass balance inconsistencies of less than 1% are achievable with practically feasible effort.

On the unit process level of GaBi datasets, a best practise value of < 1% cut-offs (or unknown omissions, sources or sinks) is applied for flows that are less environmentally-relevant.

Diffuse emissions (which are normally calculated or estimated according to local regulations) are considered, if there is any indication that they are relevant in the respective process. Many processes limit or virtually prevent diffuse emissions by using specific sealing technologies or by operating with pressures below atmospheric condition (which can prevent unwanted substances to leave the system).

Unintentional cut-offs (mistakes) or forced cut-offs (non-closable gaps) of type 3) (unknown or known inconsistency in a mass or energy balance for unknown reasons) are due to missing information or due to a mistake. If cut-offs must be applied in the foreground system, they are mentioned in the dataset documentation in GaBi <http://www.gabi-software.com/international/databases/> and limited as much as possible or practicably feasible. If reviews, validations or usages of the Master database reveal unintentional cut-offs, these are documented in the “GaBi database bug forum” and corrected with the next appropriate maintenance activity within the GaBi database maintenance and service schemes.

Straightforward application of mass-% cut-off rules can lead to significant inaccuracies, if no possibilities exist to properly quantify the environmental relevance properly (e.g. on the basis of comparable existing systems). Therefore, the definition and use of cut-off rules should essentially be done or validated by experienced LCA professionals who

- know the respective process chain technically, and
- know the field of potential environmental effects caused by the related material and energy flows that are intended to be cut-off.

Only this combined knowledge ensures proper application of cut-off rules. Therefore, cut-off rules are indeed essential elements when preparing, collecting and validating data. These rules are especially important for processes with a large amount of different substance flows (such as pesticides in agriculture) or systems that employ large material flows of less environmental relevance and few minor mass flows of substances with potentially high impact (such as heavy metals in a mineral mass production process or precious metals in catalyst production). In such cases even small amounts (<1% mass) can sum up to relevant cut-offs due to their environmental relevancy in comparison to the main mass flows.

It can be concluded that the best rule for cut-offs is: “Only cut off what can be quantified.” The definition of useful cut-off criteria is therefore quite complex for those stakeholders and users who have limited access to the relevant technical background data.

3.3.5 Gap closing

Suitable application of cut-off rules on the input side defines the amount of relevant and included upstream processes and process-chains. The possibilities to avoid cut-offs were discussed in Chapter 3.3.4.

This chapter documents gap-closing possibilities on the output side, primarily for “data on demand” requests. “Data on demand” are datasets, which are additionally ordered and developed on request and enhance the standard database content.

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

On the output side, the procedure is as follows:

- All known by-products are recorded (primary data is the first choice, if applicable).
- All known emissions are recorded (primary data is the first choice, if applicable).
- In case no data is available, emissions from similar processes or suitable literature data are used.
- Emission data can alternatively be calculated overreaction equations, mass-energy balances, known efficiencies and yield figures with adequate engineering expertise.
- Optionally, gaps in the data are identified and provided with a worst-case scenario (such as legal limit, which is in most cases higher than the actual value).
- The ecological relevance of the individual emissions of concern (and their sensitivities) is quantified with software. Sensitivity analyses are supported by GaBi software solutions and can therefore easily be done during data collection and validation process.
- If the contribution is less relevant, the worst-case scenario may remain. If the contribution is relevant, the emissions of concern must be investigated in detail (maybe an iterative step of primary data acquisition needed).

The seven steps above are used in any customer specific “data on demand requests,” as well as for any new internal or external datasets, whose goal is to be consistent with the rest of the GaBi data and where the first choice, primary data, cannot be used.

3.3.6 Infrastructure

The integration and omission of infrastructure in LCA systems are closely related to its respective relevance within the system, which can significantly differ.

Infrastructure is relevant for processes which show comparatively fewer direct emissions during operation but involve material-intensive infrastructure per product output. This is the case for some renewable resource-based operations like hydropower plants (mainly reservoir), wind converters (blades, tower, gear) and geothermal power plants (turbines halls, well equipment). For wind converters the majority of all established impacts (> 90%) are from infrastructure because virtually no relevant emissions appear in the use phase. For hydro and geothermal power plants the impact of infrastructure can be up to 80%, in our experience. The impacts of storage hydropower plants especially depend upon the latitude of the site of the reservoir. The degree of relevancy of degrading organic matter in the reservoir of warm climates can reduce the infrastructure’s relevance, such as in the case of hydro, as far down as 20%. For geothermal power plants the kind of geological underground situation (rocks, soil) may influence the share of impacts concerning infrastructure and maintenance.

The relevancy of infrastructure of mainly fossil operated power plants is significantly lower; according to our records much less 1% across some main impacts. We will document the relevancy of fossil operations in two ways: Based on non-public LCA data of the GaBi database and based on an internet public domain calculation.

GaBi Master DB:

Table B: Relevancy of infrastructure of a natural gas power plant in GaBi Master DB (selected representative sample power plant)

	natural gas	emissions + chemical supply	mainly concrete + steel	EoL, recycling
	fuel supply	operation	infrastructure	others
Acidification [kg SO ₂ -Equiv.]	79.7%	20.3%	0.06%	0.02%
Eutrophication [kg Phosphate-Equiv.]	60.1%	39.8%	0.05%	0.02%
Global Warming [kg CO ₂ -Equiv.]	21.7%	78.2%	0.02%	0.004%
Photoch. Ozone Creat. [kg C ₂ H ₄ -Eq.]	83.6%	16.3%	0.05%	0.02%
Fossil Primary energy [MJ]	99.9%	0.1%	0.02%	0.003%

Larger plants with large throughput and longer life times tend to have lower impact shares in infrastructure/operation than smaller plants with shorter life times.

Public internet sources:

The above given evaluation can be cross-checked (e.g. by interested parties without access to LCA data) taking publicly available power plant information from many internet sources. We consider the following figures of a medium power plant as a public domain example:

Table C: Publicly available example value for a medium size gas power plant

Cross check	Example value (considered as public domain)
Operation time	30-50 years
Installed capacity (electrical)	400-500 MW
Emissions Operation	400-450 kg CO ₂ emissions / MWh electricity output
Total emissions Operation	40-90 Mio. t CO ₂ over the life time of the power plant

Furthermore, we considered the following main material intensity of a power plant for the cross check of a public domain example (see various public and easily accessible internet sources).

Table D: Publicly available example values for CO₂ for a gas power plant

Cross check	Example value (considered as public domain)
Steel infrastructure	2000 t to 4000 t steel per 1 Mio kWh electricity output
Concrete infrastructure	16,000 – 20,000 t concrete per 1 Mio kWh electricity output
Asphalt infrastructure	1000 t to 2000 t asphalt per 1 Mio kWh electricity output

Considering additional publicly available CO₂ intensity factors of the ELCD database (<http://lca.jrc.ec.europa.eu/lcainfohub/datasetCategories.vm>), for the aforementioned materials the infrastructure is responsible for about 60000 to 80000 t CO₂, which amounts to about 0.09%-0.15% of the CO₂ emissions of the operation (neglecting the supply of gas and recycling possibilities of the power plant materials). If the gas supply and recycling are also included, the CO₂ intensity of infrastructure would be further reduced and a distribution similar to GaBi model above could be expected.

Summary:

As a consequence the degree of relevance of infrastructure is strongly case-specific. Even if one considers the side effects of construction of vehicles and machinery as several factors more impact-intensive than the material supply for infrastructure, infrastructure and construction would still have very low relevance for fossil-fuelled power plants.

Huge conversion processes show the most likely comparable characteristics (of high throughput and long life times), so we consider the infrastructure for those operations as very low in relevance for a background database⁴.

Regardless of the degree of relevancy, all energy datasets in GaBi databases (fossil and renewable) include the power plant infrastructure for consistency.

3.3.7 Transportation

As a general rule all known transportation processes have been included to remain consistent. Pipeline, ocean vessels, river boats, trucks, railroad and cargo jets are used as parameterised processes, meaning they are scaled and parameterised according to technology, distance, utilisation, fuel type, road type, river or sea conditions and cargo specifications.

Transportation processes, including fuel production and utilisation, is especially relevant if the process in the considered system is known to be relevant due to:

- Weight of material/product to be transported or
- Distance of transportation.

If an LCI database is structured into many sub-systems of producing and consuming systems, the transportation system should be modelled in the respective and consuming system. This ensures the generic use of the same producing system in other applications while reflecting specific transportation situations in the consuming plan system.

3.3.8 Water

Water use is understood as an umbrella term for all types of anthropogenic water utilisation. Water use is generally differentiated in consumptive water use (i.e. water consumption) and degradative water use.

Freshwater consumption describes all freshwater losses on a watershed level which are caused by evaporation, evapotranspiration (from plants), freshwater integration into products and release of freshwater into sea (such as from wastewater treatment plants located at the coast line). Freshwater consumption is therefore

⁴ Be aware: This documentation relates to a background database. For a specific goal and scope of a specific study it can of course be important to consider infrastructure (maybe even in the foreground system).

defined in a hydrological context and should not be interpreted from an economic perspective. It does not equal the total water withdrawal, but rather the associated losses during water use. Note that only the consumptive use of freshwater (not sea water) is relevant from an impact assessment perspective because freshwater is a limited natural resource. Sea water is plentifully available and therefore not further assessed in the life cycle impact assessment.

Degradative water use, in contrast, denotes the use of water with associated quality alterations, in most cases quality degradation (e.g. if tap water is transformed to wastewater during use). Quality alterations are not considered (fresh) water consumption. Also noteworthy is that the watershed level is regarded as the appropriate geographical resolution to define freshwater consumption (hydrological perspective). If groundwater is withdrawn for drinking water supply and the treated wastewater is released back to a surface water body (river or lake), then this is not considered freshwater consumption if the release takes place within the same watershed; it is degradative water use.

In a GaBi balance the above terms can be understood as:

Fresh water use = total fresh water withdrawal = water (river water) + water (lake water) + water (ground water) + water (rain water) + water (fossil groundwater)

Fresh water consumption = total freshwater use – total fresh water release from Technosphere = water vapour + water (incorporated in product inputs) – water (incorporated in product outputs) + water (fresh water released to sea)

Furthermore, new and different water flows are being introduced for hydropower (e.g. “water (river water from technosphere, turbinized)”) and a new approach to consider cooling water is implemented, which takes into account the latest developments of assessing thermal emissions to the aquatic environment.

Additionally applied water flows in GaBi database to enable consistent modelling of water:

- “Water (fresh water)”: This is a composite flow. Individual water elementary flows shall be documented (river/lake/ground water) and given priority. Use this flow only in very exceptional cases if the former is not possible.
- “Water (fossil ground water)⁵”: The consideration of fossil groundwater is important because the use of fossil water directly contributes to resource depletion which is specifically addressed by some LCIA methods.
- “Water (surface run-off)”: Note that surface run-off is differentiated in surface run-off from soil (considered as resource elementary flow) and surface run-off from technosphere (considered as technosphere flow). Surface run-off from a landfill surface can be represented by the flow “water (wastewater, untreated)” due to the pollutant load included in the flow.
- “Water (tap water)”: We used the term “tap water” as general term encompassing tapped water with different qualities. It includes non-drinking-water quality water and high-quality drinking water produced from groundwater and/or surface or seawater by desalination.

⁵ Fossil water or paleowater is groundwater that has remained sealed in an aquifer for a long period of time. Water can rest underground in “fossil aquifers” for thousands or even millions of years. When changes in the surrounding geology seal the aquifer off from further replenishing from precipitation, the water becomes trapped within, and is known as fossil water.

- “Water (wastewater, untreated)”: This flow is generally treated in a Wastewater Treatment Plant, connected to a wastewater treatment plant module.
- Water vapour: Note that only water vapour stemming from evaporation (not steam) is used as a term here. Steam is an output from a process and therefore a technosphere flow.
- Resource flows from technosphere: Water resource flows from the technosphere are introduced in order to facilitate complete water mass balances on the level of plan systems including foreground processes and aggregated background data (supply chains).
- Water (evapotranspiration)⁶: Evapotranspiration can be an output from either rain water or/and irrigation water stemming from e.g. rivers or lakes.
- Water (brackish water): Brackish water has more salinity than fresh water, but not as much as seawater. It may result from mixing of seawater with fresh water, as in estuaries, or it may occur in brackish fossil aquifers.

Examples of how water was addressed in GaBi databases:

- Process using process water as input:
 - Input flow: Apply “water (process water)” and connect flow to a water treatment/supply module (see Figure 3-6)
 - Output flow: Apply “water (waste water, untreated)” and connect flow to a wastewater treatment plant module (see Figure 3-6)
- Process using tap water as input:
 - Input flow: Apply the appropriate GaBi dataset for tap water production (see Figure 3-6)
 - Output flow: Apply “water (waste water, untreated)” and connect flow to a wastewater treatment plant module (see Figure 3-6)
- Process using cooling water as input:

Note that for cooling water we distinguish between use in 1) general production processes and 2) energy/electricity generation. Waste heat released to the water environment will also be properly recorded (see Figure 3-3) as both the information on the volume of released cooling water and the incorporated waste heat are necessary to perform the subsequent LCIA. Different technologies for cooling are differentiated as outlined below.

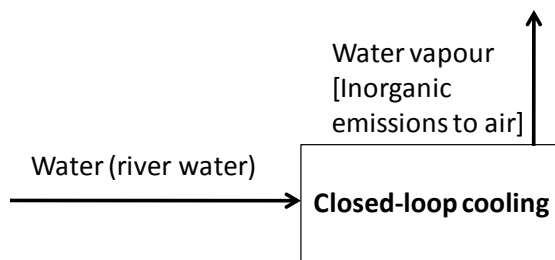
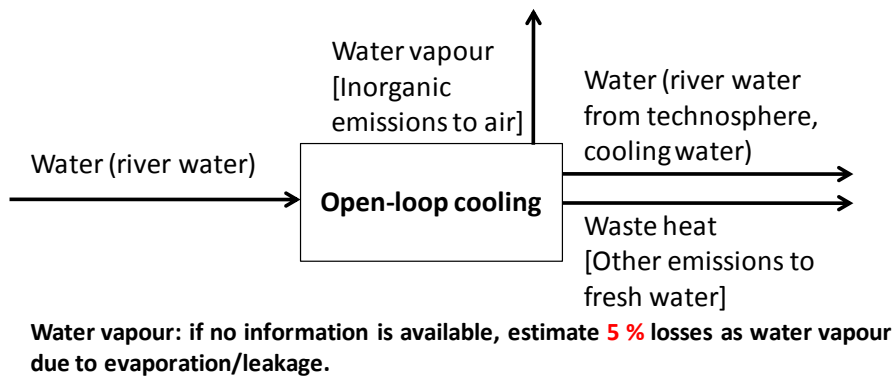
1) General production process (in different industrial settings):

Open-loop and **closed-loop cooling** are differentiated (see Figure 3-3).

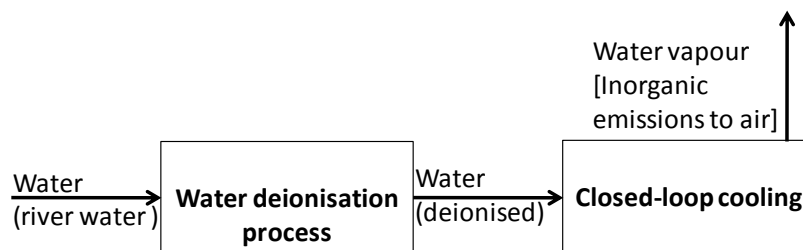
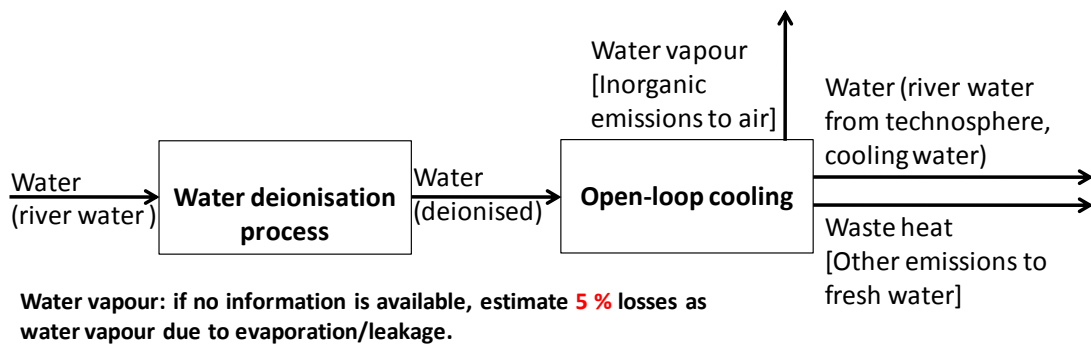
- Input flow: Identify whether the cooling water input is...
 - directly withdrawn from the environment (e.g. from a river or lake) → then apply the appropriate water resource flow (e.g. “water (river water)”).

⁶ Evapotranspiration (ET) is a term used to describe the sum of evaporation and plant transpiration from the Earth's land surface to atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and waterbodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapour through stomata in its leaves.

- taken from a connected upstream water treatment process (e.g. water deionisation) → then apply the appropriate water technosphere flow/operating material (e.g. “water (de-ionised”).
- Output flow: Identify whether the cooling water output is...
 - directly released to the environment (e.g. back to the river the cooling water was withdrawn from) → then apply the appropriate resource flow from technosphere (e.g. “water (river water from technosphere, cooling water”). Consider also water vapour and waste heat, if applicable.
 - released as wastewater to the sewer system → then apply the flow “water (waste water, untreated)” and connect flow to a wastewater treatment plant module. Consider also water vapour and waste heat, if applicable.



Water vapour: if no information is available, estimate 5 % losses as water vapour due to evaporation/leakage.
 Note that the amount of water vapour lost equals the amount of the resource input “water (river water)” due to the closed-loop set-up.



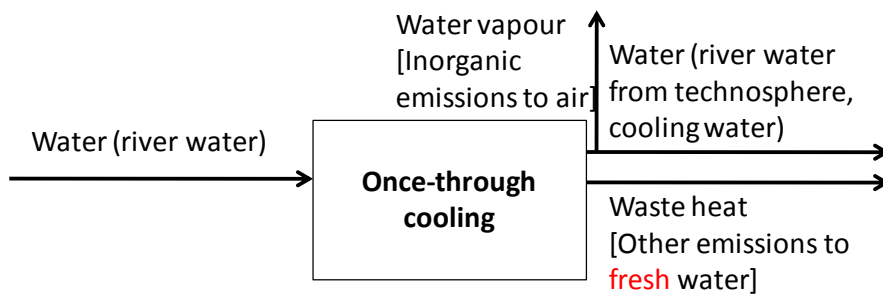
Water vapour: if no information is available, estimate 5 % losses as water vapour due to evaporation/leakage.

Figure 3-3: Application water flows in open-loop and closed-loop cooling systems in various industrial settings

2) Energy/electricity generation:

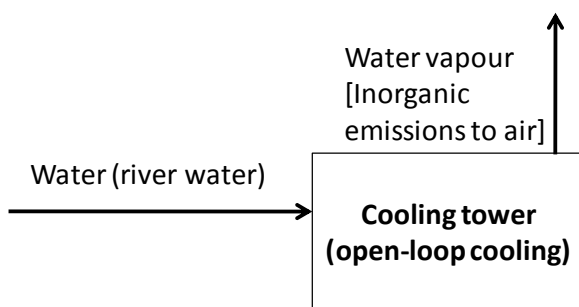
Once-through cooling and cooling towers (also denoted open-loop cooling in electricity production) are distinguished (see Figure 3-4).

- Input flow: Identify which water source is used for cooling (e.g. river water, lake water) → then apply the appropriate water resource flow (e.g. “water (river water)”).
- In the case of cooling plants located at the coastline and using sea water for cooling purposes, consider a desalination process as an additional water treatment process and apply the appropriate water technosphere flow/operating material (e.g. “water (desalinated, deionised)”).
- Output flow: Apply the appropriate resource flow from the technosphere according to the water source used for cooling (e.g. “water (river water from technosphere, cooling water)”). Consider also water vapour and waste heat, if applicable.

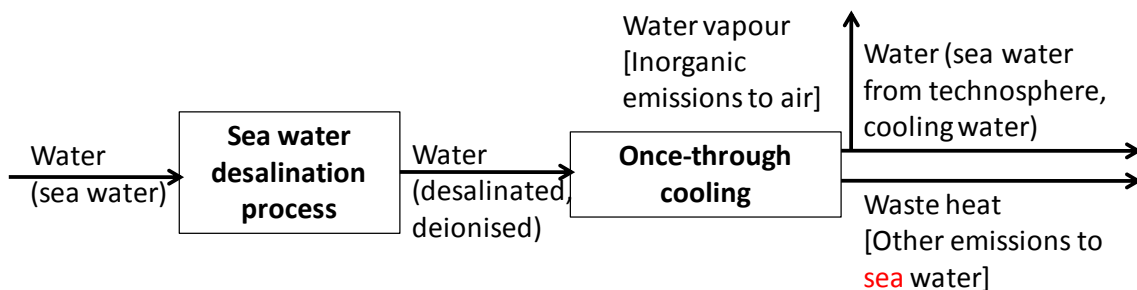


Water vapour: if no information is available, estimate **1 %** losses as water vapour due to evaporation of heated cooling water from the river after release (Goldstein R., Smith W. 2002).

Waste heat embodied in the cooling water release according to heat balance.



Water vapour: Amount of evaporated water equals amount of the resource input "water (river water)".



Water vapour: if no information is available, estimate **1 %** losses as water vapour due to evaporation of heated cooling water from the sea after release (Goldstein R., Smith W. 2002).

Waste heat embodied in the cooling water release according to heat balance.

Output flow "water (sea water from technosphere, cooling water)" denotes the origin of the water applied for cooling, namely the sea, and at the same time indicates that the cooling water is released back to the marine environment (assumption!).

Figure 3-4: Application water flows in once-through cooling and cooling towers in energy/electricity generation

- Use of water in hydropower generation:

For hydropower generation the following four generation technologies are considered: run-of-river power station, pump-storage and storage power stations, and tidal/wave power plants. See the following graphs (Figure 3-5) for instructions for inventorying the appropriate water flows.

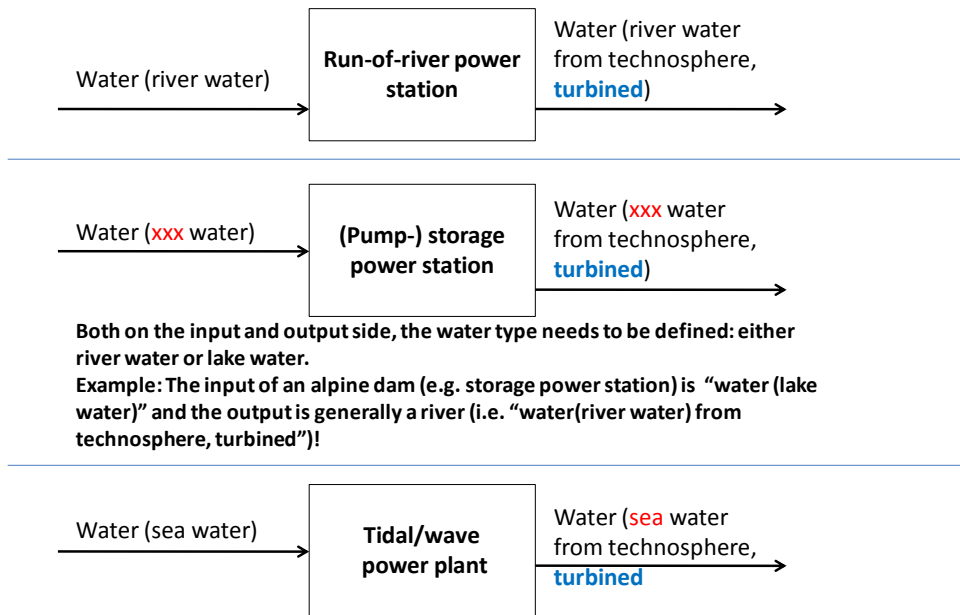


Figure 3-5: Application water flows in hydropower generation

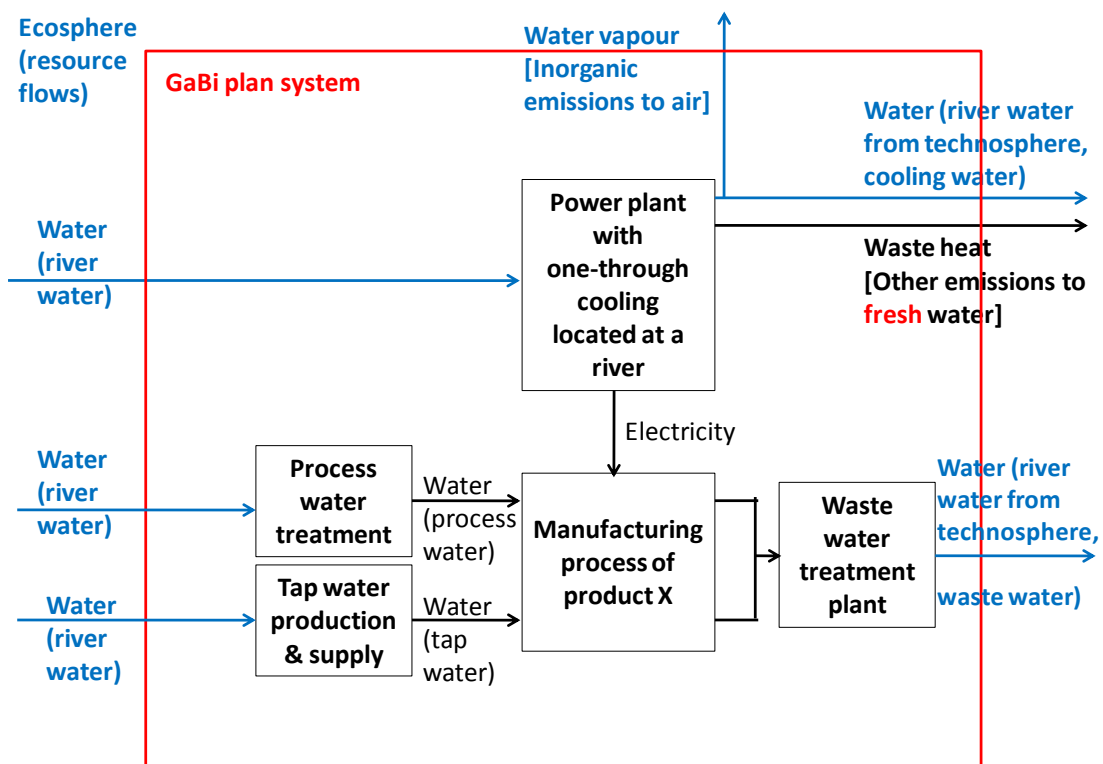


Figure 3-6: Ad hoc example of a simple plan system including different processes and water flows

For the GaBi background database water that has been treated generally (chemically or physically deionised/decalcified) is used for process and cooling water purposes, which reflect the standard case. Untreated water (tap or even surface water) is only used where it is explicitly known that it was used.

3.3.9 Wastes and recovered material or energy

Waste volumes or masses are known and commonly used to describe the environmental relevance of outputs of processes. Waste volumes or masses are not an environmental intervention. The environmentally relevant intervention occurs in the incineration, treatment or landfill after waste is turned into emissions like landfill gas or water leaching.

According to ILCD [ILCD 2010] all product and waste inputs and outputs should be completely modelled until the final inventories exclusively show elementary flows (resources in the input and emissions in the output).

Therefore waste treatment is integrated throughout the whole system during modelling wherever possible and known to occur⁷. For all known treatment pathways (e.g. for regulated waste with calorific value) the incineration and landfilling processes of the residues are integrated.

Different waste treatment options are provided in the GaBi databases (inert matter landfill, domestic waste landfill, hazardous waste landfill underground / above ground, waste incineration of domestic waste, waste incineration of hazardous waste). The waste fractions of the processes are identified by the composition and their appropriate treatment and the respective GaBi process applied.

“Waste” going to any kind of reuse or recycling is modelled in loops or allocated/substituted, if a considerable positive market value (a product) exists.

There are many products which are legislatively considered a waste, but which must be treated as products in life cycle analysis. 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 suitable modelling feedback from both sides (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.

Standard procedure (general waste treatment)

In the case that specific information is not available for the respective situation, a standard procedure is adopted according to secondary material markets.

- 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 and can be disposed with municipal solid waste (MSW), is treated in an incineration plant (see selected examples).
- If case-specific treatment is specified and known, and the waste cannot be mixed with MSW, specific treatment is modelled.
- All other waste (mainly inert waste) goes to landfill.

⁷ Due to the integration of treatment pathways for known waste or residue streams it might be possible that (intermediate) waste flows are deleted from existing plan systems (because those are now modeled further).

Table E: General treatment procedure (if no specific information is available) for common materials/wastes

Material/waste	Treatment Process
Mixture of plastics	Incineration, waste to energy
Polyofefin and PVC	Incineration, waste to energy
Wood	Incineration, waste to energy
Aluminium, non ferrous metals	Recycling
Steel	Recycling
Coating and sealing	Incineration, waste to energy
Glass, concrete, stones	Inert landfill

Standard procedure (Hazardous waste treatment)

Hazardous waste streams are often hard to define as default in a background database, because, depending on various options to mix different waste streams, several disposal options exist. Hazardous waste streams in the upstream chains are modelled according to their specific fate, if it is known (e.g. in tailing ponds). Hazardous slags/sludges are treated via vitrification, incapsulation and landfill. If unspecific hazardous waste streams appear, a worst-case scenario (precaution principle rule) is used. The worst-case scenario models incineration, vitrification, macroencapsulation and the inert landfill of the remains. Carbon-rich and carbon-free hazardous waste is differentiated, as are other emissions which occur in incineration.

Table F: General procedure for some hazardous waste flows

Kind of waste	treatment	treatment	treatment	final treatment
Slag/Sludge		Vitrification	Macroencapsulation	Inert Landfill
Non-specific source	Incineration	Vitrification	Macroencapsulation	Inert Landfill

If hazardous waste treatments become relevant, a check must be performed to determine if specific data for the treatment pathway is available.

3.3.10 Aspects of biomass modelling

The carbon cycle in LCA can be defined as: CO₂ in atmosphere → CO₂ intake/H₂O/sunlight/surface → plant growth → harvested biomass → biomass use as fuel or matter → CO₂ combustion/decomposition → CO₂ intake in atmosphere → ...

Depending on the situation one can understand “biomass” as a certain status at different points in the cycle: As a plant, as harvested biomass and as a renewable product.

The definition of “biomass resource” is therefore somewhat arbitrary and can be chosen according to the given goal and scope.

Biomass in GaBi is further modelled towards carbon dioxide, water, solar primary energy and the land use [GaBi 201]. This modelling assures mass balance consistency especially of the carbon-balance, for example,

biomass storage in the product and fuel and the incineration or decomposition releases of CO₂, which had been released previously.

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

3.3.11 Aspects of primary energy of fossil and renewable energy sources

Energy evaluation in the GaBi database is based on the principle of “cumulated energy approach (KEA)” or often also referred to as embodied energy. The primary energy needed to supply certain materials or energies often serves as indicator of the energy efficiency. The indicator can be misleading, if renewable and non-renewable energy sources are compared or summed and not separately interpreted. Renewable and non-renewable energy sources must be interpreted separately, as implemented in the GaBi database. The interpretation is usually done in LCA reporting practise. A combined evaluation of the primary energy (renewable and non-renewable figures) may be required.

It is relatively common to compare non-renewable energy production procedures with a uniform parameter like the calorific value of the primary energy needed to provide a certain usable energy. However such a uniform parameter does not intuitively exist for renewable energy sources like hydro and wind or for nuclear energy. Different approaches exist (technical efficiency⁸, physical energy content method with virtual 100% efficiency for renewables⁹, substitution approach to avoid renewable efficiencies with virtual thermal fossil efficiencies for renewables¹⁰) to define or compare the „primary energy demand“ of a related usable energy form.

The IEA states¹¹: “Since these types of energy balances differ significantly in the treatment of electricity from solar, hydro, wind, etc., the share of renewables in total energy supply will appear to be very difficult depending on the method used. As a result, when looking at the percentages of various energy sources in total supply, it is important to understand the underlying conventions that were used to calculate the primary energy demand”.

In principle the method of the technical efficiency differentiates between renewable and non-renewable primary energy needs, while others do not.

ISO 14040 frameworks do not call for an explicit method for the aggregation/separate representation of the primary energy.

The ILCD framework [ILCD 2010] does not call for an explicit method either, but a recommendation is given for a differentiation between non-renewable energy resources and renewable energy resources.

In GaBi consequently the method of the technical efficiency with differentiation between non-renewable energy resources and renewable energy resources is applied as it illustrates the situation adequately, comprehensively and transparently. This is especially important in countries with significant portions of renewables in the

⁸ See Richtlinie, VDI 4600, 1997: VDI 4600 Kumulierter Energieaufwand - Begriffe, Definitionen, Berechnungsmethoden.

⁹ See International Energy Agency (IEA) (Hg.): Methodology of International Energy Balances. Unter Mitarbeit von Karen Treanton. Paris, France, 2001. Online verfügbar unter <http://www.iea.org/work/2001/stats/Balance4.pdf>, zu-letzt geprüft am 2010-09-07.

¹⁰ See Murtishaw, S.; et al.: Development of Energy Balances for the State of California. Lawrence Berkeley National Laboratory. Berkeley, USA, 2005. Online verfügbar unter <http://escholarship.org/uc/item/6zj228x6>, zuletzt geprüft am 2010-09-07.

¹¹ International Energy Agency (IEA) (Hg.): Energy Balances of Non-OECD Countries 2010. Paris, France, 2010.

grid (e.g. Norway, Austria and Denmark). The international trade of energy is accounted for individually to avoid a virtual efficiency of 100% for imported electricity, which is relevant for countries with a high share of imported energy

The value and burden of the use of 1 MJ of renewable primary energy is not directly comparable with 1 MJ of fossil primary energy, because the availability of the fossil resources is limited and depletion occurs. The topic cannot be discussed in detail here, but the guidelines will help to prevent “double counting” as well as “perpetual motion.”

1 MJ of electricity from wind power is produced using (virtually) approx. 2.5 MJ of primary wind energy (an efficiency of approx. 40%, due to usable kinetic energy of wind).

For 1 MJ of electricity from hydropower (virtually) 1.15 - 1.25 MJ of primary hydro energy is used (an efficiency of 80 - 85%, due to usable kinetic energy of water).

For 1 MJ of electricity from geothermal power (virtually) 5 – 6.5 MJ of primary geothermal energy is used (an efficiency of approx. 15 - 20%, due to energy content of usable temperature gradient).

For 1 MJ of electricity from nuclear power approx. 2.5 - 3.3 MJ of primary nuclear energy is used (an efficiency of approx. 30 - 40%, due to energy content of used fissile material).

For 1 MJ of electricity from photovoltaic approx. 10 MJ of primary solar energy is used (an efficiency of approx. 10%, due to the usable part of the solar radiation).

For 1 MJ of electricity imports the specific efficiency of the import country is applied.

3.3.12 Land Use Change

Apart from the classical impact categories like GWP, AP, EP and POCP, land use as an environmental issue is widely considered to be important and constantly gains attention in the Life Cycle Assessment (LCA) community, especially for agrarian products, forestry and sealed areas.

In the software and database system GaBi 6 land use parameters are integrated. The methodology behind integrated land use parameters is based on the dissertation of Martin Baitz [BAITZ 2002] and subsequent work that was carried out at the University of Stuttgart, Chair of Building Physics (LBP), Dept. Life Cycle Engineering (GaBi; former Institute for Polymer Testing and Polymer Science) and PE INTERNATIONAL AG [Beck, Bos, Wittstock et al. 2010]. According to Baitz 2002, a set of indicators has been defined to model land use aspects in LCA and incorporate them into the software:

- Erosion Resistance
- Mechanical Filtration
- Physicochemical Filtration
- Groundwater Replenishment
- Biotic Production

These land use indicators are calculated for several land-intensive processes with the support of the LANCA tool (Land Use Indicator Calculation Tool) based on country-specific input data and the respective land use types. A detailed description of the underlying methods can be found in Beck, Bos, Wittstock et al. 2010.

The values calculated according to these methods are then integrated into the GaBi 6 database and software, and aggregated over the process chain to form environmental indicators that are representative for the entire life cycle of many of the aggregated processes in the GaBi database system. Land use can be considered an additional aspect in LCA to extend its environmental impact evaluation.

Country-specific input data for the tool has been derived from the ISRIC database [ISRIC WISE 2002] for the input parameters of humus content, skeletal content, declination and effective cation exchange capacity and from the [Mitchell 2003], TYN CY 1.1 dataset for precipitation, summer precipitation and evapotranspiration. For the input parameter of “distance to groundwater,” a default value (0.8-10m) is used.

For the calculation of indicator values, indicator qualities Q must be calculated for the state and land use types of the land before transformation (t_1), during use (t_2 and t_3) and after regeneration of the land (t_4) [Beck, Bos, Wittstock et al. 2010]. At this stage it is assumed that the occupation phase is a static situation. Consequently, for all processes calculated t_2 and t_3 have the same land use type. For each indicator, occupation and transformation are calculated according to the following equations:

Occupation indicator value = $(Q(t_4, \text{ref}) - Q(t_{2,3})) \cdot \text{area used} \cdot \text{time of occupation}$

Transformation indicator value = $(Q(t_4) - Q(t_1)) \cdot \text{area used}$

The resulting units of qualities, transformation and occupation indicator values as used in GaBi are shown in Table G.

Table G: Overview of the Land Use Change Indicator Units

Indicator	Quality unit	Transformation Indicator unit	Occupation Indicator unit
Erosion Resistance	[kg/(ha*a)]	[kg/a]	[kg]
Mechanical Filtration	[cm/d]	[cm*m ² /d]	[cm*m ²]
Physicochemical Filtration	[cmol/kg _{soil}]	[(cmol*m ²)/ kg _{soil}]	[(cmol*m ² *a)/ kg _{soil}]
Groundwater Replenishment	[mm/a]	[(mm*m ²)/a]	[mm*m ²]
Biotic Production	[kg ² /(m ² *a)]	[kg/a]	[kg]

Positive occupation indicator values can be interpreted according to the following:

- Erosion Resistance (expressed by kg of erosion): kg of soil eroded in addition to naturally-occurring soil erosion due to the effects caused by the production of one functional unit
- Mechanical Filtration: amount of water that could not be filtered due to the effects caused by the production of one functional unit
- Physicochemical Filtration: amount of cations that could not be fixed to the soil due to the effects caused by the production of one functional unit
- Groundwater Replenishment: amount of groundwater, which could not be replenished due to the effects caused by the production of one functional unit

Biotic Production: amount of biomass not produced due to the effects caused by the production of one functional unit. Positive transformation indicator values (permanent impacts) can be interpreted according to the following:

- Erosion Resistance: kg of soil eroded in addition to naturally-occurring soil erosion per year in the time following the considered land use due to the permanent transformation impacts caused by the production of one functional unit
- Mechanical Filtration: amount of water that cannot be filtered in the time following the considered land use per day due to the permanent transformation impacts caused by the production of one functional unit
- Physicochemical Filtration: amount of cations that cannot be fixed to the soil in the time following the considered land use, due to the permanent transformation impacts caused by the production of one functional unit
- Groundwater Replenishment: amount of groundwater, which cannot be replenished in the time following the considered land use per year, due to the permanent transformation impacts caused by the production of one functional unit
- Biotic Production: amount of biomass that is not produced in the time following the considered land use per year due to the permanent transformation impacts caused by the production of one functional unit

Negative indicator values show the respective positive impacts.

According to BAITZ 2002, the reference situation “tref” is assumed to be the same as the situation “t4.”

With the integration of consistent land use information in the GaBi 6 database, it is possible to examine and to quantify the effects of a product or a process on the land. The resulting information refers to land quality parameters and is summable and scalable over the whole process chain.

Seeing as this is the first inclusion of such land use information into a database, there are some limitations to be mentioned:

- Land use information is only included in land-consuming unit processes.

- Entry data is often derived from databases where only country-specific values can be gathered. More site-specific values would enhance the accuracy of the results. These values are often difficult to obtain.
- Allocation of transformation effects, especially for agricultural processes, has not been done and is subject to further research.

The background data provides valuable information which can be used to compare and contrast different products on a country scale. For the comparison of foreground processes and land uses in their exact locations, indicator values can be calculated using LANCA and can be included into unit processes.

The land use database in GaBi 6 gives the user a good starting point in order to determine the main contributors to land use effects. Due to further development of the method and tools, and increasing data availability, similarly to other LCA data, land use data will be periodically updated to ensure currency of results.

3.4 Sources and types of data

Many sources and types of data exist. Whether the source or type of data is suitable is a matter of the goal and scope of the exercise, and the capability of the data modeller to turn raw data and process information into LCI data. The raw data and resulting LCI data used in the generic GaBi background databases seek to reflect the reality of a certain point in time as representatively as possible.

3.4.1 Primary and secondary sources of data

(Primary) data and information from industry sources is the preferred choice of GaBi raw data and background data, wherever possible and approved.

Primary data can be collected via the classical approach of collecting data from several companies producing the same product and averaging the resulting inventories. Primary data is obtained from specific facilities as a primary source of information. This data is measured, calculated or acquired from the bookkeeping of a particular facility.

Secondary data is obtained from published sources and used to support the set-up of the LCI. Examples of secondary data sources include published literature, environmental reports of companies or LCI and LCA studies, emissions permits and general government statistics (e.g. mineral industry surveys, Bureau of Labor statistics and Energy Information Administration data).

This secondary data of industrial operations is used to develop, calculate and set-up LCI data by experienced PE engineers with background in the technology and capability in the field, with the support of technical reference literature or branch encyclopaedias.

PE engineers are in constant contact with industrial companies and associations to update their knowledge about representative process-chain details and new technologies.

PE's developed capabilities and critical-constructive feedback from industry confirms PE's approach to model real process chain circumstances. Due to this process of continuously learning about industrial operations, we consider PE data the best available "industry-borne" data.

PE's strategy is proactive cooperation with industry. In the event of an unavailability of data, confidentiality or missing access to (company or process) specific data, PE can bridge the gap with developed capabilities and possibilities to generate generic data of comparable quality.

Publicly available information such as internet sources, environmental reports, scientific or application reports with industry participation, other industry publication or other LCI relevant literature is constantly screened and used for benchmark purposes. The quality of technical data of many publications varies considerably. The sole fact that the information is officially published or publicly available ensures neither the consistency nor quality of the content. The professional user of publicly available data should either know and trust the source, or be able to judge and ensure the quality.

All generic GaBi data seeks to directly involve feedback of users, companies and associations by validation or benchmarks with various industry or process information. PE offers and maintains a constant connection with suitable users and diverse information sources from industry.

3.4.2 Unit process and aggregated data

GaBi databases deliver unit processes, aggregated and partly-aggregated data and complete life-cycle (sub-) systems (plans), which include varying combinations of the aforementioned data. Any delivered dataset and system is based on suitable raw data and process chain data.

As stated in the “Global Guidance Document for LCA databases” UNEP/SETAC 2011 – to which PE contributed considerably with its expertise to reflect professional issues through the provision of a global software and multi-branch database - there exist many good reasons to provide and use any of the aforementioned datasets.

The main goal of GaBi data is to enable the utilisation of best available information from reliable and suitable technical sources. GaBi does not follow certain paradigms or patterns concerning data or data types. All data types are welcome, used and supported, if they are determined to be suitable.

The reliability and representativeness of the data source are important aspects to ensure the data’s appropriateness and quality. The possible level of (public) disclosure of data is subject to individual circumstances, the source and the proprietary nature of the information provider. In LCA and business practise many different circumstances related to ownership, rights, patents and property exist.

In practise anti-trust and competition regulations exist, aside from those dealing in the proprietary, which are properly maintained by GaBi database. It works to ensure compliance with related laws and regulations.

Regarding reliability and representativeness, unit process data must ensure that it technically fits within each other if used in one system. Random connection without a suitable check of technical consistency may lead to wrong results, even if unit processes are disclosed. The fact that a unit process for a certain operation exists, does not necessarily mean that it is technically suitable, up-to-date or appropriate. Background knowledge concerning the real B2B supply chains is essential.

Transparency is an important aspect. In aggregated processes GaBi databases ensure transparency through suitable documentation that covers all important technical facts. Parts of the Master Database are used to share more details and process chain knowledge under bilateral business relationships.

3.4.3 Units

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

3.4.4 LCI data and supported LCIA methods

It is important to clearly define the kind of data which will be covered by creating an LCI dataset for a system.

The GaBi LCI datasets are generally full-range LCI datasets. These datasets seek to cover all LCI data information, which are of environmental relevance in relation to LCA best practise.

The sum of input and output (like resources and emissions) are a compendium of 20 years of LCA work in industrial practise and the harmonised sum of all LCI interventions which could be measured, calculated or documented in LCA practise.

Important impact methodologies have influenced the flow list – and hence the data collection – seeing as GaBi considers the relevant impact categories and evaluation methods.

Basing the work on a harmonised and constantly growing flow list provides consistency among different datasets provided by different groups or branches. A list of the supported impact categories including a brief description is given as a supplement.

The GaBi database delivers full-range LCIs, which enables the use of any (existing and future) impact methods for which corresponding characterisation factors exist. For the following impact assessment methods GaBi delivers already implemented default values.

Input-dependent quantities

- Abiotic Depletion (elements and fossil)
- Primary energy non-renewable (entered as an additional quantity)
- Primary energy renewable (entered as an additional quantity)
- Demands on natural space (surface)

Output-dependent quantities

- CML 2001 (versions 2001 – 2010) categories (GWP 100, ODP, AP, EP, POCP, HTP, TETP, FAETP, MAETP) [CML 2001]
- TRACI categories [TRACI 1996]
- TRACI 2.1 categories [TRACI 2012]
- EDIP 2003 [HAUSCHILD 2003]
- USETox 2010 [USETox 2010]

Further assessment methods are:

- ReCiPe Endpoints and Midpoints [RECIPE 2012]
- Ecoindicator 99 [ECO-INDICATOR 99 : 2000] or 95 [ECO-INDICATOR 95 : 2000]
- Impact 2002+[IMPACT 2002]
- UBPs [UBP 2006]

3.4.5 Production and consumption mix

In LCA practise process chain networks working toward one common product contain different levels of representative situations:

- “production mix:”** This approach focuses on the domestic production routes and technologies applied in the specific country/region and individually scaled according to the actual production volume of the respective production route. This mix is generally less dynamic.
- “consumption mix:”** This approach focuses on the domestic production and the imports taking place. These mixes can be dynamic for certain commodities (e.g. electricity) in the specific country/region.

Figure 3-7 shows the differences between the two principle approaches. Electricity generation has been selected as an example to explain the two approaches. The electrical power available within Country C is generated by operating different types of power plants. The fuels necessary for the operation of the power plant will be supplied by domestic resources, as well as by imports from different countries. In addition to the domestic power generation, electric power might also be imported.

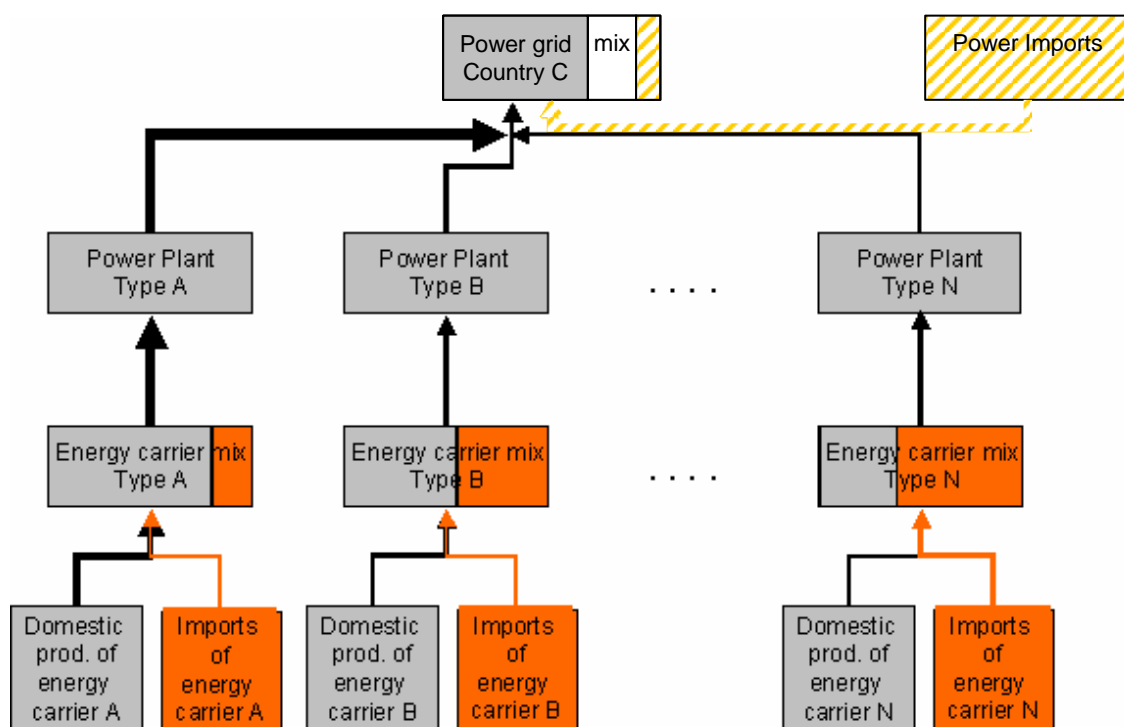


Figure 3-7: Difference between "production mix" and "consumption mix" (for power generation)

The part of the Figure 3-7 which is coloured in grey represents the domestic part of the production and represents the “production mix” approach.

All parts of the supply chain of the power generation process coloured in orange (dark grey if b/w print) represent the imports of supplies for the power generation (imports on fuels). Imports on end energy level (imported power) are indicated by a (yellow, bright grey) criss-cross. The “consumption mix” includes the “production mix” as well as all imports.

The GaBi database supplies both the electricity consumption and electricity production mixes. The inclusion of the imports in the LCI data requires country-specific information about supply generation and whether final

products are available or will be gathered during data collection. Not included in this example is the export as the reverse of import.

It is apparent that for every commodity contained in the database, a screening of domestic production and imports must be done, since this combination can be different for each commodity.

The GaBi 2012 database aims to provide consumption mixes wherever possible.

3.5 Data quality issues

Data quality is probably one of the most discussed issues of databases and most widely interpreted. For the development of the current GaBi databases the following importance of “quality indicators” can be stated.

Table H: Overview of qualitative importance of “quality indicators” in GaBi DBs

Indicator	indication of importance					
	less					more
credibility and source of data	■					
access to industry information	■					
relation of data to technology issues	■					
consistency	■					
representativeness of data	■					
age / validity of data	■					
transparency of documentation	■					
country/region specificness	■					
completeness of data	■					
precision of data	■					
transparency of final data set	■					
reduction/management of data uncertainty	■					
uncertainty of data	■					
public access of raw and unit process data	■					

Several methods and approaches have already been proposed, but no single approach so far can be established as the “best practice.” The GaBi data quality approach follows a golden rule: Be as precise and specific as needed, and as simple and applicable to all circumstances as possible. The following paragraphs address the important quality issues that arise in GaBi modelling.

3.5.1 Technology and region coverage

GaBi datasets aim to be technology specific. Various technologies may produce basically comparable products. GaBi datasets aim to provide

- the most likely “representative” case
- if suitable, a range of different technologies for the same product
- if suitable, the local consumption (or market) mix based on capacities

Where distinctly different technology pathways are used to produce the same materials/products/commodities, they are kept separate and the local consumption (or market) mix is additionally provided. Below are some examples of important technology differences:

- Electricity from different power plants (CHP, coal or gas, hydro, or wind)
- Steel making: electric arc, basic oxygen furnace, HiSmelt technology
- Blast furnace or electro-refined metals
- Wet or dry process cement clinker production

Plain average values for the above-mentioned processes (regardless of unit process level or aggregated level) would not be representative of any of the technologies.

There is also a rationale for regional production models for commodities which are predominantly traded within a certain 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 on 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 more local sources travelling by road.

Therefore, the GaBi databases focus on the most relevant aspects first, after screening and identifying the most important issues of a specific life-cycle model.

3.5.2 Data aggregation

The aggregation of datasets is often necessary and requested by users and providers of data in order to secure the privacy of confidential information. This enables the use of accurate and up-to-date information; further aggregation speeds up LCAs (and therefore lowers costs) as the handling of datasets and complete process chains becomes feasible for both experts and users.

Almost any LCI dataset is aggregated: Either on the unit process level (either several production steps are aggregated towards a unit process or different unit processes producing a comparable product are aggregated into an average unit process) or on the process chain level (different subsequent processes are aggregated). For a good description of the various types of aggregation see the UNEP/SETAC 2011 database guidance.

Some systems are characteristically complex and therefore only understandable for LCA experts and experts of the related technology. In order to make the handling for non-experts possible, some complex and often used datasets must be aggregated in a representative and applicable way to make them suitable for use in practise.

A prominent example is the aggregation of electricity mix data for a specific country; a complex background model, consisting of a large amount of processes and parameters (see Chapter 2.3 for details). The user has

access to information transparency concerning the underlying model and data in the documentation. Most users have an interest in accurate data and are less interested in power plant details, so an aggregation of datasets is suitable and meaningful for a wide range of users¹².

Two types of aggregation exist:

- horizontal
- vertical

The following figure describes the difference.

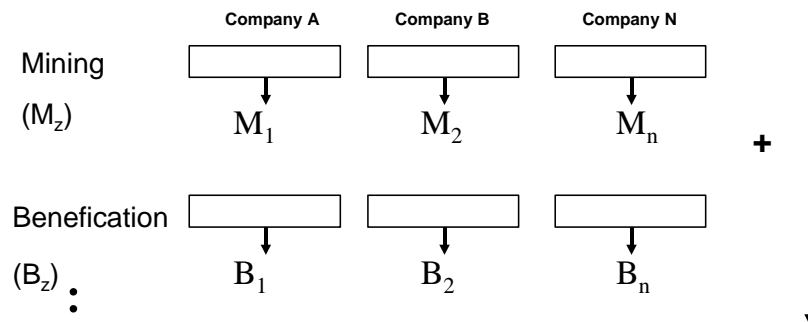


Figure 3-8: Principle graphical explanation of the relation of completeness, precision

The horizontal aggregation ($M_1+M_2+M_3+\dots$) and ($B_1+B_2+B_3+\dots$) is applied in the creation of a process for an average production step of a specific product by taking (different) technologies into account. The upstream or downstream processes are not integrated into this step of aggregation. The horizontal aggregation must be sure to lead to understandable and interpretable datasets, as technical information and upstream substances of different processes is aggregated and provided side by side (whilst never appearing in reality as one process). Not all unit processes of the same kind are automatically suitable for horizontal aggregation or are subject to easy misinterpretations.

The vertical aggregation ($M_1+B_1+\dots$) and ($M_2+B_2+\dots$) is carried out by considering a specific technological route and aggregating process chain parts that exist in reality. In this case the upstream and/ or downstream processes are included in the aggregated dataset.

Depending on the case, in GaBi databases vertical and horizontal aggregation are applied to the datasets.

¹² A power plant operator or energy provider may have another view on this and wants to deal with the effects of the power plant parameters within the electricity mix. However, users that are interested in their own foreground system behaviour should rather model on basis of their specific foreground situation and should take generic background data to set up their respective background system or use it as reference or validation. Specific results on foreground systems request specific foreground data.

3.5.3 Precision, completeness, representativeness

Each item's precision, completeness and representativeness provide specific details of the composition of the background data and are documented in provided datasets. The users can use these indicators to describe their own data in GaBi.

Precision

Precision determines the variance of data, whether it has been measured, calculated or estimated. In the case of the GABI 201 database, the following procedure is adopted:

- **Measured:** Values measured directly by the LCA practitioner, producer or project partner. Values from reports, which were measured and allowed to be published, can be also considered as measured.
- **Literature:** Values obtained from literature which are not explicitly stated, whether the value was measured or estimated.
- **Calculated:** The values were calculated, e.g. stoichiometrically.
- **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 the following procedure is adopted:

- **"all flows recorded":** The entire 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 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 reasonably 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 out, so only medium quality of data can be achieved. If possible, further research should be performed.
- **"some relevant flows not recorded":** If good quality is desired, this case should not occur. In the case that no data is available, reasons for using this kind of data should be documented.

The technical, geographical and time related-representativeness of the background process is also stated in the documentation and the process name. Aside from the description of the underlying background data the proper application of the data by the user (goal and scope dependent) and its respective documentation is also important. GaBi offers several possibilities to document the proper application of the background data in the user-specific case. This can be done on the plan-system level in GaBi, by indicating the technical, geographical and time-related representativeness.

Technical Representativeness

Information about data representativeness is assessed qualitatively and reflects the extent to which the dataset represents the reality of a certain process or process chain, e.g. completely, partly or not representative. GaBi data aims for best technological representativeness from the commission gate back to the resource extraction. Technology matters.

Geographical representativeness

The GaBi databases have a 4 level regionalisation approach.

- Transferring existing technology information into other countries by adapting the energy supply
- Adapting the important upstream processes with regional supply data
- Collecting technology mix information of used in the region to adapt the existing information
- Collecting and validating primary data in the regional industry networks

Inventory data that shows the necessary geographical representativeness for the foreground data, site or producer/provider specific data for the foreground system, supplier-specific data is used for the products that connect the foreground with the background system. Generic data of geographical mixes can be used also in parts of the foreground system if it is justified for the given case to be more accurate, precise and complete than available specific data (e.g. for processes operated at suppliers). For the background system average market consumption mix data can be used.

Time-related representativeness

The time-related representativeness indicates a reasonable reference value for the validity of the dataset. That means for unit processes the dataset is most representative for the indicated year. This year is neither the year of the most recent source that is used nor the year of the oldest one. The time at which the data collection occurred should be used as a reference.

In GaBi the 'most representative' year indicates the current year of the modelling or validity checking of the data, if our engineers did not have any evidence that something changed or developed in process technology concerning this production step.

3.5.4 Consistency

Consistency refers to the uniformity of the data, methodology and procedure used in the data set-up and database maintenance and additions. The GaBi database is consistent since all datasets follow the same methodology and principles as described in this document. The PE database content uses consistent data sources and background systems (e.g. transport, energy processes).

3.5.5 Uncertainty

Uncertainty in the LCA is often discussed from two different viewpoints: There is a scientific discussion on one side, as to which approach is the best to calculate something rather uncountable¹³.

And there is a discussion about practise, dealing with how to limit uncertainty of results and how to judge its importance regarding stability of results and proper decision support.

In GaBi database work PE INTERNATIONAL chooses the following approach to minimise uncertainty:

¹³ Not everything that can be counted counts and not everything that counts can be counted. Albert Einstein

1. Completing correct data collection (and close mass and energy balances).
2. Choosing a representative LCA data for the upstream and background data, which represent the actual technology
3. Understanding the technical processes and defining technical parameters that are uncertain
4. Completeness of the system (no unjustified cut-offs)
5. Consistent background data

Consistent data collection and background data are the basis to reducing uncertainty. In addition useful scenarios, sensitivity calculations and technical understanding of the LCA modeller (as well as the reviewer) ensure minimum uncertainty.

If LCA modeller and the reviewer have no indication how the identified technical parameters may perform or how the parameters are independent from each other, the Monte Carlo Analysis is an alternative. It allows the examination of consequences of random uncertainties for some selected technical parameters. The quality of the resulting “uncertainty statements” strongly depend on the selection of these technical parameters, which should be as representative (in terms of uncertainty) as possible.

In principle the Monte Carlo analysis should consider each parameter in the model which is uncertain (all inputs, outputs, parameters, impact values). This analysis is not yet implemented in GaBi. Challenges in this context are: broad methodological acceptance, availability of (useful) uncertainty information for all model parameters, implementation effort and probably the calculation performance.

Based on the above discussion, a practical approach to quantify the uncertainty issue was developed for the GaBi background database.

Quantifying uncertainty in GaBi

Uncertainty in LCA can be split into two parts:

- data uncertainty (the uncertainty of the modelled, measured, calculated, estimated) and data within each unit process
- model uncertainty (uncertainty introduced in the results of a life cycle inventory analysis due to the cumulative effects of model imprecision, input uncertainty and data variability)

Uncertainty in LCA is usually related to measurement error-determination of the relevant data, e.g. consumption or emission figures. Since the ‘true’ values (especially for back-ground data) are often unknown, it is virtually impossible to avoid uncertain data in LCA. These uncertainties then propagate through the model and appear in the final result. Small uncertainties in input data may have a large effect on the overall results, while others will be diminished along the way. This article addresses PE INTERNATIONAL’s recommendations for addressing the quantification of uncertainty in an LCA study, and how it can be done practically and with reasonable accuracy.

Quantifying the uncertainty of primary data points on company-specific processes can be relatively straightforward and easy for a company to calculate using the mean value and its standard deviation over a certain number of data points.

But quantifying the uncertainty in the background systems (hundreds of upstream processes including mining and extraction) and then performing error propagation calculation is typically neither practical nor feasible due

to the cost and time constraints in an industrial setting. In addition to put the issue in a general perspective, one should be wary of data with an extremely precise uncertainty value to each inventory flow, as these cannot be calculated with the accuracy that the value implies.

A common rule estimates that the best achievable uncertainty in LCA to be around 10%. This was supported by [KUPFER 2005] on the forecast of environmental impacts in the design of chemical equipment. The actual degree of uncertainty can vary significantly from study to study.

The overarching question that really must be answered is:

How robust is my overall result when taking into account the combined uncertainties?

The effort to come up with a reasonable estimate can be significantly reduced by following a two-step approach:

1. Understand the model structure and its dependencies

Keep it simple at first and start by setting up your model with values you have. Then **try to develop an understanding of the most relevant aspects of your LCA model**, i.e. those life cycle phases, contributors, or data points that have the largest impact on your result. This is usually done by a **contribution or 'hot spot' analysis** and a subsequent **sensitivity analysis**. Both of these functions are available to GaBi users in the LCA balance sheet through the Weak Point Analysis and the GaBi Analyst Uncertainty in the LCA is often discussed from two different viewpoints: There is a scientific discussion on one side, as to which approach is the best to calculate something rather uncountable¹⁴.

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sis and a subsequent **sensitivity analysis**. Both of these functions are available to GaBi users in the LCA balance sheet through the Weak Point Analysis and the GaBi Analyst.

Here is an example: The contribution or 'hot spot' analysis of an energy-using product may show that the use phase is dominating the life cycle greenhouse gas emissions, closely followed by the production of a printed circuit board and logistics. Sensitivity analyses may then show that the parameters that influence these contributors the most are the split between online and stand-by mode during use, the amount of precious metals in the circuit board and the distance from the Asian production facility to the local distribution centre.

2. Test the robustness of the model's results

The next step is to focus efforts on estimating the level of uncertainty of each of the identified key parameters. Do some more research to establish **upper and lower bounds** for the relevant parameters. The higher the uncertainty, the larger these intervals will be. It may even be possible to find data that allows for the **calculation of a standard deviation** in literature.

The combined effect of these uncertainties can then be assessed using the **Monte-Carlo simulation** available in the GaBi Analyst. By defining uncertainty intervals around the key parameters, the Monte Carlo simulation is able to **produce a statistical estimate (mean value) of the end result (e.g. X kg of CO₂ equivalents) as well as its standard deviation** across all simulation runs. To do this it simply draws random numbers from the defined intervals and calculates a single result using that set of numbers. By repeating this procedure a multitude of times (10,000 runs is usually a good choice), it will produce a probability distribution of 10,000 individual results. **The lower the standard deviation associated with it, the more robust or 'certain' your result is.** The resulting mean value is also closer to the 'real' value than the value obtained when doing a simple balance calculation based on the basic parameter settings.

To make the assessment even more robust towards any additional, unknown uncertainties, it is possible to **increase the ascertained intervals** around the key parameters by a specific **'safety factor.'** This will provide a sound estimate of the robustness of the model.

For more quantified results on uncertainty issues in LCA see Supplement B.

Coefficients of variation

As seen in the above discussion and from quantified results in Supplement B, the percentage maximum error can easily reach several orders of magnitude for the 'choose max' cases. These numbers can be misleading, though, since they heavily depend on the magnitude of the respective denominator, i.e. the minimum values. A more unbiased way to look at the variability across the evaluated datasets is to calculate the **coefficients of variation** across the absolute indicator results, which is defined as the **standard deviation divided by the modulus of the mean value**. When the modulus is used, the coefficient is always a positive value.

The following table displays the maximum coefficients of variation across datasets for each impact category separately. Again, **knowing the country of origin but not knowing the specific technology route can be worse** than the inverse case. The coefficients of variation are significantly higher for the latter case.

Table I: Coefficients of variation

Impact	known technology / unknown country of origin	unknown technology / known country of origin
--------	--	--

PED	32%	88%
AP	92%	98%
EP	63%	123%
GWP	47%	89%
POCP	86%	132%

This chapter answered two questions: First, how do I assess the uncertainty of my LCA model in GaBi, and second, how large are the uncertainties across different datasets assuming that either the country of origin or the technology route is not known?

While it is known from experience, as well as a recent PhD thesis, that the model uncertainty can scarcely be kept below 10% once the most appropriate datasets have been chosen, the uncertainty around this choice can be significantly higher. For most considered datasets, the relative error is between -75% and +250%, while the coefficient of variation is roughly between 90% and 130%.

Based on these results, the following conclusions can be made:

1. The appropriate choice for dataset is a higher concern for the uncertainty on the elementary flow level. The selection of the most representative technology route has a large influence on the resulting environmental profile. The most 'certain' dataset can introduce a massive error to your model if it is not representative to the process / product at hand.
2. When the most representative datasets have been identified and deployed, the next concern is about the accuracy of your model structure and parameter settings. Here the described functionalities of the GaBi Analyst can help you understand the dependencies and assess the overall effect on your results.

In Chapter 3 the methodological framework of goal, scope, types, sources and quality issues of data was addressed. In Chapter 4 the technical framework of system modelling is built upon this framework.

4 System Modelling Features

The GaBi software system was developed to support the complete work flow of LCA work: Starting at data collection, over life-cycle system modelling, data storage and handling, as well as interpretation.

Appropriate results call for appropriate system modelling and appropriate data. In the following chapter the technical framework of system modelling is described.

4.1 Data collection

Data collection is the basis for all following modelling steps: Analysing the gathered data, the use of this data for the set-up of the process models and as the basis for the inventory calculation. The quality of the dataset will finally depend upon the type, sources, consistency and appropriateness of data collection. A standardised procedure is therefore defined and applied for GaBi data collections:

- Understanding the core production technique.
- Identifying the generic situation of the manufacturing of the product system to be analysed (e.g. how many competitive producers exist, what are the applied technologies).
- Identifying the essential single process steps which are dominating the manufacturing phase of a certain product system. Ideally this process is done in cooperation with industry, validated or accompanied by experts of the related branch.
- Creating a customised data collection sheet. Golden rule: data collection should be as detailed as necessary and as efficient as possible; staying on a realistic level, which can be supported by the data source but also fulfils LCI quality issues. A flow chart of the process helps to have a good overview and to keep track in technical discourse.
- Inspection of the returned data applying general rules which focus on consistency and quality of the gathered data, which includes:
 - mass and energy balance
 - emission and substance balances
 - plausibility check focusing the general process characteristics (energy efficiency, yield, purge streams, residues, by-products, loop substances, recovered matter)
- Provision of feedback to the data supplier or validator.

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

1. Manual informal (generally not used in GaBi data collection procedures)
2. Manual predefined formats (Word® or Excel® documents)
3. GaBi process recording tool
4. Web based applications (e.g. GaBi 6 web questionnaire)

Collection types 3 and 4 comfortably support the user to integrate data consistently and while saving time into GaBi.

4.1.1 Quality check and validation of collected data

During the process of data collection, our experts prepare a check-list of general points that ensure the data quality requirements are fulfilled. As previously mentioned these methods include: mass and energy balance, emission balances, plausibility check, in addition to whether all relevant processes steps and inputs and outputs are included.

If anomalies occur, problems are iteratively checked with the data provider or the data-providing expert team within PE. The goal would be to clarify whether it is a data or methodological problem and whether it is a special case or a common issue.

Apart from this technical check, aspects covered by the data quality issues (Chapter 3.5), data sources (Chapter 3.4) or principles such as goal (Chapter 3.2) or scope like functional unit and system boundaries (Chapter 3.3) must be checked in order to assure consistency over all data collected. All data aims to represent the reality, but the kind and detail of needed data sources can differ.

After this check the data considered as “validated” and can be used for modelling in the GaBi framework.

4.1.2 Treatment of missing data

Missing data is a common problem of LCA practitioners (see also Chapter 3.3.5 for gap closing strategies). This can happen due to unavailability of data or missing access to data. In this case it is up to the expert team to decide which procedure to adopt.

The goal is to find the missing data and close the gap as efficiently as possible, without unacceptable simplifications.

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 can be checked (standard way, but often no LCA suitable information available)
- For chemical reactions, often an estimation can be provided by the stoichiometry and estimation of the reaction's yield
- Estimation based on similar processes/ technologies
- Expert judgement of a skilled person (supported by one or more above aspects).

The chosen procedure for the treatment of missing data shall be documented according to the ISO 14044 [ISO 14044 : 2006].

4.1.3 Transfer of data and nomenclature

The system modelling starts with the transfer of gathered data into the GaBi software system. GaBi 6 is organised into modules. Plans, processes and flows, as well as their functions, are formed into modular units.

The fundamental basis of modelling using GaBi 6 is the object type flow. A GaBi 6 flow is a representative of an actual product, intermediate, material, energy, resources or emission flow.

Elementary flows are resources and emissions that are released from unit processes directly into the environment without further treatment, causing a specific environmental impact.

Intermediate flows (material or energy) are technical flows between unit processes or a product flow leaving the final process for further use in a system.

Intermediate flows are used as the link between processes within a life cycle system.

Plans (or plan systems) are used in GaBi 6 to structure the processes in a product system. Essentially, plans are the “process maps” which visually depict a stage or sub-stage in the system and help to understand the technical reality behind the system.

A clearly defined nomenclature of flows is needed. GaBi 6 defines all known and used flows consistently by avoiding double entries (e.g. synonyms).

A clear and defined nomenclature is needed to ease or enable data transfer with other nomenclatures and systems (like e.g. ILCD 2010). Different nomenclature systems are proposed by academia and practice. No global standard nomenclature currently exists, because theoretical and practical approaches still call for different aspects.

For each modular unit a clearly defined nomenclature is necessary to specify flows, processes and plans. In the following the most important nomenclature aspects are listed.

Flows

- Name (most commonly used or according to existing systems)
- CAS code
- Abbreviation (e.g. polypropylene PP)
- Chemical formula (e.g. carbon dioxide CO₂)
- Technical aspects like calorific value, element content or impact category
- Reference unit (e.g. kg, MJ, Bq, Nm³)

The GaBi software system has a substantial list of consistently predefined elementary flows, so that ideally only new intermediate or product flows need to be created (look out for synonyms before creating new elementary flows).

Processes

- 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))
- Production technology (if several technologies exist to produce the material)
- Reference year
- Data quality and completeness

Plans

The name of the plan system should enable to understand its related system boundaries, the core technology route and the core location of the operation.

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

GaBi Databases [GABI 2012] have already integrated elementary and product flows for more than 8000 datasets and the respective used flows are documented directly in the process headline.

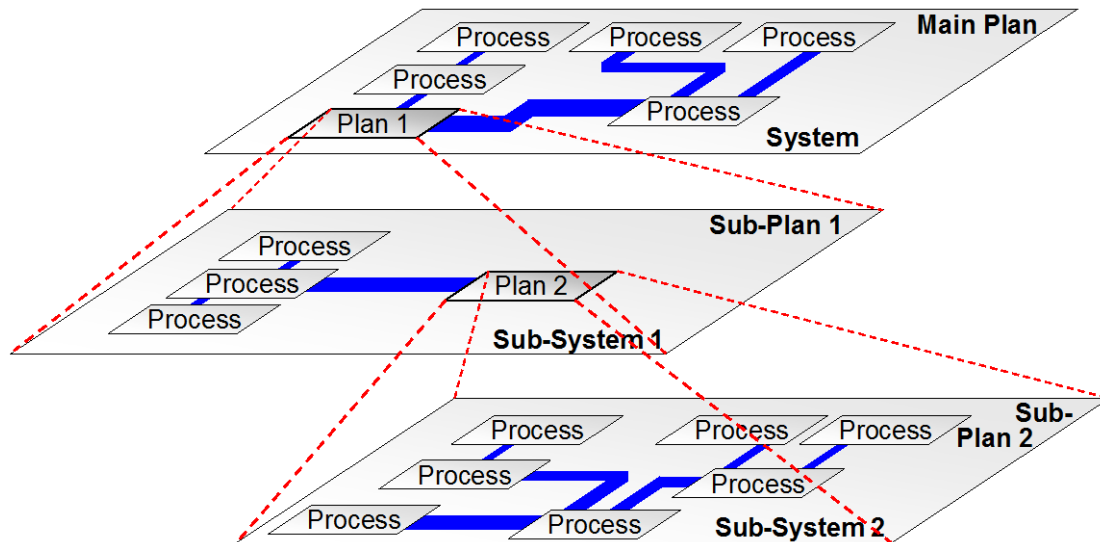


Figure 4-1: Hierarchical structure of the processes and plans

Since the efficient and flexible combination of processes and plans in GaBi affect the appropriate result analysis, a certain structure of the desired system should be known beforehand. The processes and plans can be individually structured (shown in the figure above) to represent any desired degree of detail.

4.2 Geographical aspects of modelling

To set data in the correct regional context is an important aspect of LCI modelling. Users in multinational companies, as well as national and international programs and requirements, call for realistic geographical representation. Realistic regionalisation is as dynamic as markets. The core issue of regionalisation is not the methodological approach, but rather the necessary background information on technology and the market situation.

Country-specific energy (pre-) chains are called for throughout the database (electricity, thermal energy, resources). The most relevant industry processes, including the technology route, in the respective region must be country or region-specific. If use phase or utilisation (losses or other performance issues) data are relevant, a country-specific situation is necessary. Recycling rates and waste (water) treatments may be adopted, as well as the crediting of materials and energies in EOL.

In GaBi database work and “data on demand” business a “4 level regionalization approach” is used, which depends on the goal and scope of the data and the relevance of the related measure on the overall result.

1. Transferring existing technology information into other country by adapting the energy supply

2. Adapting the important upstream processes with regional supply data
3. Collecting regional technology (mix) information to adapt existing information
4. Collecting and/or validating primary data in the regional industry networks

If a GaBi dataset is country-specific, at least level 2 is applied. For individual information please consult the respective documentation.

4.3 Parameter

Parameters are variables within a dataset, which allow the variation of process input and output flows to detach from a strict relationship between input and output flows (scaling). Parameters can therefore be used to calculate flow quantities (e.g. due to the characteristics of a used substance) based on technical conditions, such as efficiency of power plant using energy carrier properties or sulphur dioxide emissions depending on the sulphur content of the used fuel or other parameters.

A typical application of parameterised models (processes) is the modelling of transportation processes. It is possible to calculate the CO₂ emissions by means of a mathematical relation depending on the travelled distance, the utilisation ratio and the specific fuel consumption of a truck (see Chapter 0).

Important parameterised (background) processes are:

- crude oil, natural gas and coal extraction
- power plants
- refinery operations
- water supply
- wastewater treatment, recycling and incineration processes
- transports
- agricultural processes
- certain metal beneficiation and refining processes

Suitable parameterisation can reduce the error probability seeing as one individual (quality-checked) process can be applied in many generic situations.

4.4 Multifunctionality and allocation principle

GaBi modelling principles follow the ISO 14040 series concerning multifunctionality.

Subdivision for black box unit processes to avoid allocation is often possible but not always [ILCD 2010]. Subdivision is therefore always the first choice and applied in GaBi database work. This includes the use of the by-products in the same system (looping).

System expansion (including substitution) is applied in GaBi database work, wherever suitable. The system boundaries are the key issue. ISO says: "Expanding the product system to include the additional functions related to the co-products, taking into account the requirements of appropriate system boundaries [ISO 14044 : 2006]."

It is to carefully check, if the function of the system would be enlarged inappropriately. If this is the case and the explicit and unique function of the dataset is not clear anymore, the system expansion should not be applied.

In practise, system expansion can lead to the need for further system expansion because the additional systems are often multifunctional. In other cases the alternative processes exist only in theory or are of no quantitative relevance in practise. Another challenge is to identify the superseded processes, which will prove to be complex [ILCD 2010].

The aspects of a (virtually) enlarged system can cause interpretation and communication problems and needs special attention. The interpretation of the results can grow weaker and less transparent.

System expansion (including substitution) is applied, if it does not lead to misinterpretation or to an enlargement of the functional unit, because this would be in a conflict with the aim to provide single datasets with respective functional unit.

In GaBi database work system expansion is frequently applied to energy by-products of combined or integrated production, where direct use in the same system is not feasible.

Allocation is the third method to deal with multi-functionality. Allocation has long been discussed and debated, despite the fact that often only one feasible or useful allocation rule is applicable and the relevance of different allocation keys is frequently of rather low relevance on the results.

Identification of the most appropriate allocation key is essential and often intuitive. The inputs and outputs of the system are partitioned between different products or functions in a way that reflects the underlying physical relationships between them, i.e. they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system. Wherever possible, physical relationships are utilised to reflect meaningful shares of the burden.

Whereas physical relationships alone cannot be established or used as the basis for allocation, the inputs are allocated between the products and functions in proportion to the economic value of the products.

Sensitivity analysis of possible choices is helpful to justify a decision. Allocation always works and the sum of the allocated emissions is 100% of the actual total amount of emissions. Allocation is applied in GaBi, where subdivision and system expansion (including substitution) fail on the practical level.

If there is a significant influence on the results due to an allocation, a sensitivity analysis can transparently show the effects and enable interpretations of the results. Different datasets for the same product with different allocation keys may be supplied to document relevant sensitivity and to be able to choose the right one in a given goal and scope.

Our experiences from research and industry projects have shown over time that allocation - using appropriate allocation keys - is a suitable tool for distributing environmental burdens to specific products. Scenario calculation and sensitivity analysis to quantify the influences of changing allocation keys are particularly effective.

4.5 Generic Modules as background building block

Some industrial processes or natural systems are highly complex (see Chapter 2.3). Their complexity is not only characterised by the amount of required materials and processes, but also by their non-linearity in relating to each other. Complex systems can be often found in electronic products (many materials, parts and process steps), agrarian systems (natural processes interfering with technical processes with unclear bounda-

ries) and construction systems of complex use and secondary effects. If the required materials and processes are the same for several different systems, the model can be parameterised once and adapted for each purpose individually – as long as the complex relationship is the same and integrated in the model.

The generic module approach is applied to manage complex product models and provides the opportunity to produce transparent and summarised results within an acceptable timeframe. Generic modules comprise flexible models with parameter variations, including already-modelled materials and parts. These parameters allow the variation of system models based on technical dependencies (technically understandable and interpretable parameters). The parameter variation offers the possibility to adapt the models to specific product properties or modelling design scenarios without the need to create entirely new models.

Generic modules are used for single processes, system parts or the complete manufacturing of a product. Varying significant parameters allows each individual module of the product chain to be specified. By implementing the entire manufacturing process into a modelled Life Cycle, all effects to each life cycle phase can be recognised according to the different variations.

4.6 Special modelling features for specific areas

In the following paragraphs specific modelling issues are addressed for key areas, which are applied in the GABI 2012 database [GABI 2012]:

- Energy
- Road Transport
- Metals and steels
- Chemistry and Plastics
- Construction
- Renewables
- Electronics
- End-of-Life

4.6.1 Energy

Energy is a core issue because its supply and use influences the performance of most industrial products and services.

Energy supply systems differ significantly from region to region, due to individual power plant parks and individual energy carrier supply routes.

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

- Supply of different energy carriers (e.g. different energy resources)
- Creation of country-/ region-specific mixes for each single energy carrier (e.g. natural gas mix Germany, crude oil mix EU-27)
- Supply of final energy from conversion to liquid fuels such as gasoline and diesel fuel
- Supply of the final energy by conversion to electricity, thermal energy and steam

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

Supply of Energy Carriers

The supply of an energy carrier includes exploration and installation of the production site, production and processing. Figure 4-3 shows the natural gas production in Germany as an example to clarify how the energy carrier supply is modelled. Among the considerations is 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, such as venting and flaring of gas during production.

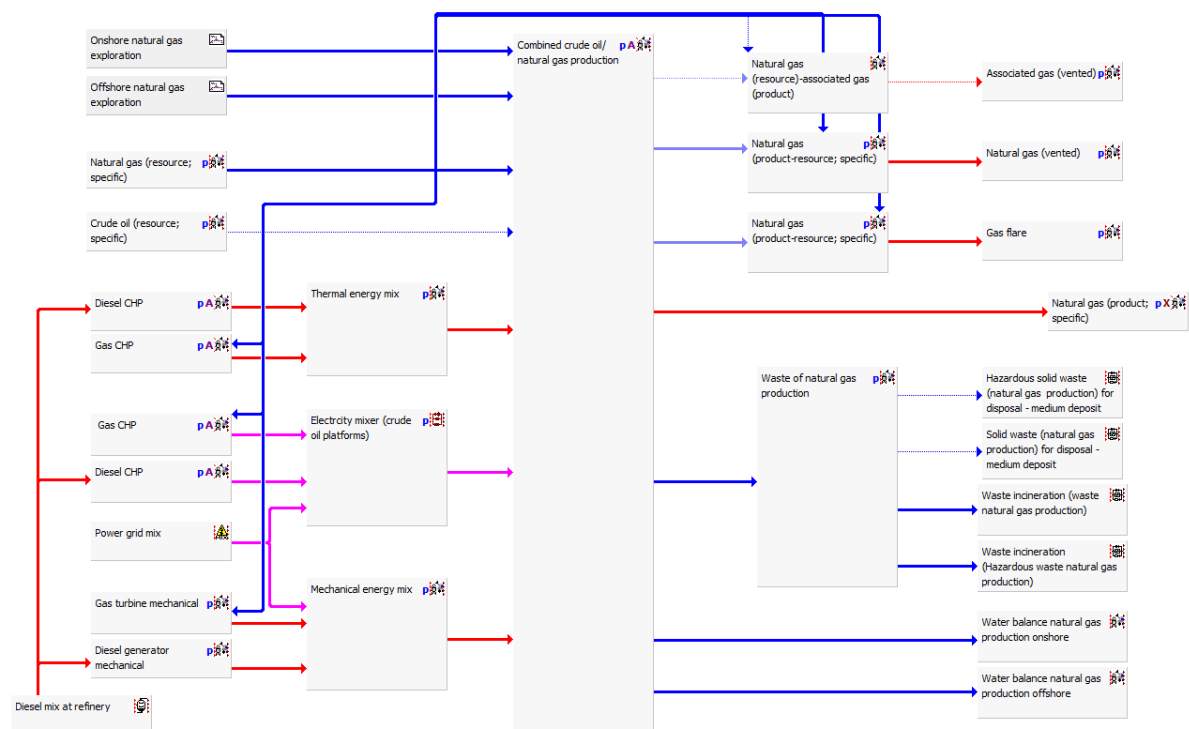


Figure 4-2: Conventional natural gas production in Germany

For the combined crude oil and natural gas production, allocation by energy content (based on net calorific value) is applied.

Associated gas and wastewater from crude oil production is allocated only to crude oil production. Vented gas and wastewater from natural gas production is only allocated to natural gas production.

Energy Carrier Mix

For the countries addressed in the GaBi Database, the energy carrier supply mixes (consumption mixes) have been analysed and modelled. The consumption mixes of the main energy carriers, natural gas, crude oil and hard coal, have been analysed and modelled in great detail to ensure the needed specification. The information about the different shares and sources are based on statistical information.

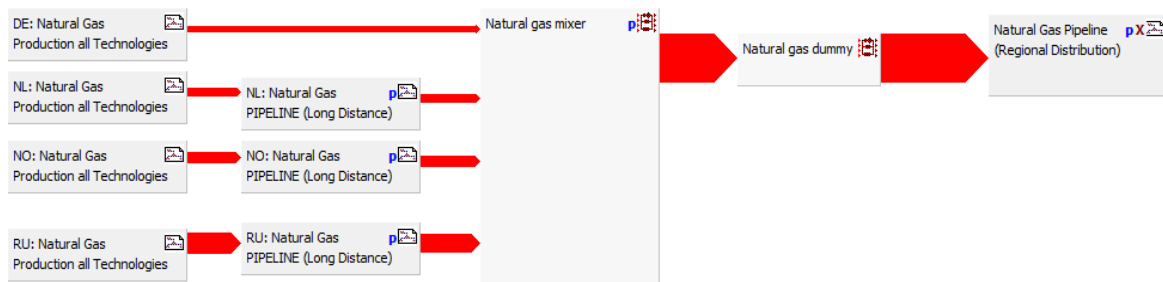


Figure 4-3: Natural gas supply for Germany

Production of electricity, thermal energy and steam

Through the utilisation of different energy carriers like gas, oil and coal in their respective power plants, electricity, thermal energy and steam is produced. The country-specific power plant technologies (efficiency of conversion, exhaust-gas treatment technologies and their efficiencies) are considered.

In addition direct and combined heat and power generation are considered separately, depending upon the country-/region-specific situation.

Generic modelling of the power plants enables consideration of both fuel-dependent (e.g. CO₂) and technology-dependent (e.g. NO_x, polycyclic aromatics) emissions, including the effects of emission reduction measures (e.g. flue gas desulphurisation).

Mass and energy flows, including auxiliary materials (e.g. lime for desulphurisation), are considered during the energy conversion. The emissions of the power plant and the material and energetic losses (waste heat) are also taken into consideration. Figure 4-4 shows the modelling of the US, East power grid mix.

US, East: Power grid mix 1kV-60kV
 GaBi 4 process plan: Reference quantities

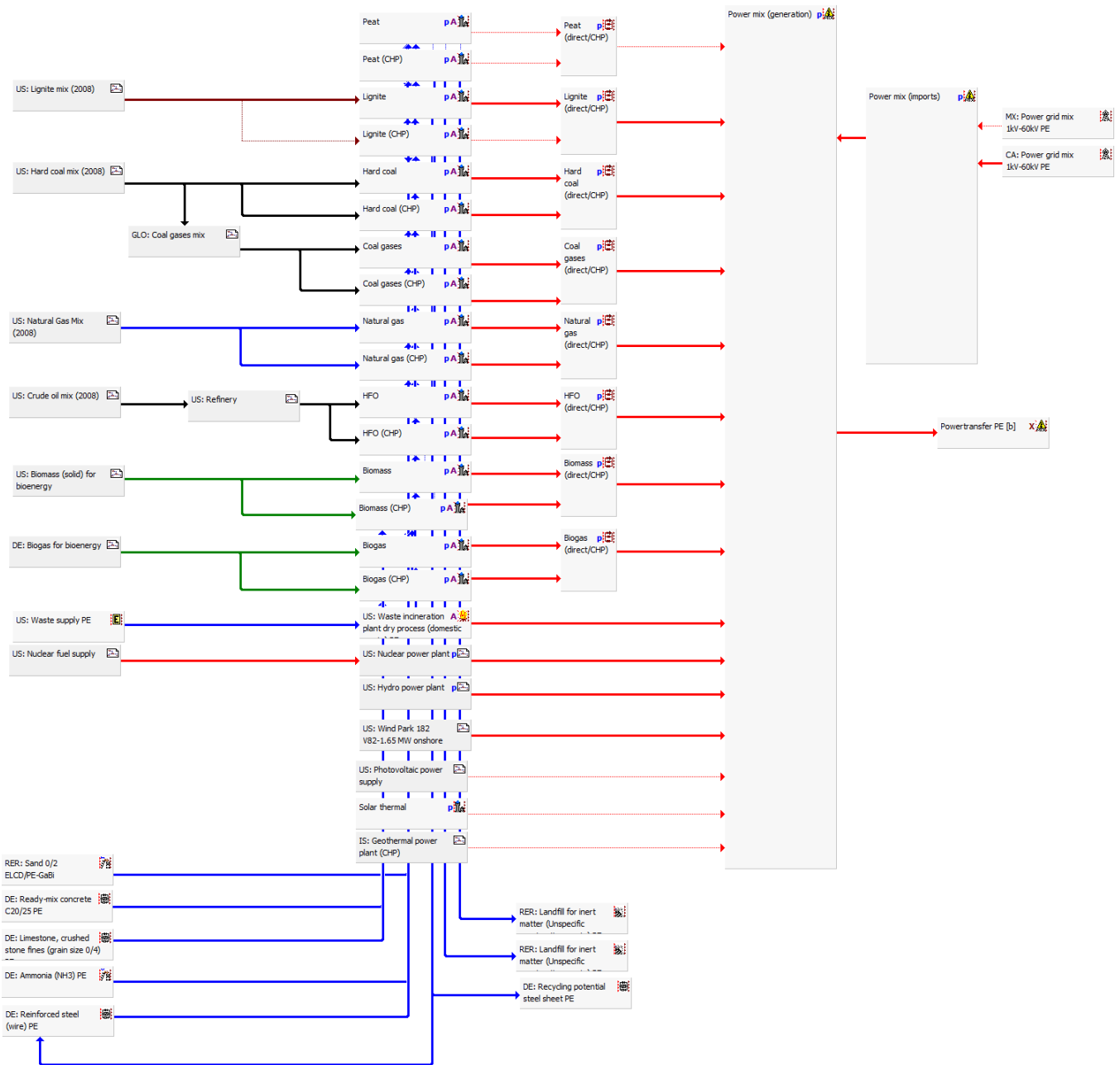


Figure 4-4: US, East electricity grid mix

The parameterised unit process models in the centre of the plan system are all comprehensive input-output relations based on several technology settings and calculation steps to represent the given regional technology. The following figure provides insight to the degree of engineering detail of the GaBi power plant models.

Free parameters

Parameter	Formula	Value	Minimum	Maximum	Standard	Comment, units, defaults
Stromverh		0,2269			0 %	[001] Fraction of generation of power to the fuel utilization (between 0 and 1)
eta		56,54			0 %	[002] [%] electrical efficiency (BAN with CHP) related to gross consumption
Eigenverbrauch	Coal gases'.Eigenverbrauch	0				[003] [%] own consumption of power plants related to gross production
O2_trockRauch	Coal gases'.O2_trockRauch	3,7647				[004] [%] CO2 content of the dry flue gas (default 3.7647%)
staub_emTJ	Coal gases'.staub_emTJ	1				[005] [kg] of particulate emission per TJin (default = 0.5 kg)
N2O_emTJ	Coal gases'.N2O_emTJ	0,1				[006] [kg] laughing gas emission per TJin (default = 2.05 kg)
CH4_emTJ	Coal gases'.CH4_emTJ	1,2				[007] [kg] of CH4-Emissionen per TJin (default = 1.4 kg)
NMVOC_emTJ	Coal gases'.NMVOC_emTJ	1,75				[008] [kg] NMVOC emissions per TJin (default = 1.75 kg)
NOx_vor	Coal gases'.NOx_vor	750				[009] [mg/m3 dry Flue Gas] NOx concentration before nitrogen removal plant (default =
NOx_nach	Coal gases'.NOx_nach	264,3				[010] [mg/m3 dry Flue Gas] NOx concentration after nitrogen removal plant (default = 1

Fixed parameters

Parameter	Formula	Value	Unit	Comment, units, defaults
Wärmeerz	1-Stromverh	0,7731		Rate of heat generation in fuel use
Phi_v	V_trockRauch/V_Verbrifststoc	1,1803		parameter
n	1+Phi_v*(O2_trockRauch/100)/(0,20938-(O2_trockRauch/100))	1,2587		Lambda (combustion air mass/stoichiometric combustio
energie_in	gas*Hu/1000000	1,7687E-006		[TJ] Energy content of the amount of natural gas used
Abwaerme	gas*Hu*(1-eta_net/100)	0,76866		[MJ] Waste heat per MJ power
Hu	f_q_convert('Coal gases, at consumer'; Mass; Energy (net calorific value))	8,2514		[MJ/kg] selections from flow
V_H2ORauch	(-0,00996785*V_Verbrifststoc+(CO_Vol*0,0238+H2_Vol*1,0231+CH4_Vol*2,1002+C2H0,44563	0		[m3] Water vapour in the flue gas per m3 natural gas
V_SO2Rauch	H2S_Vol/100*0,984859409	0		[m3] Sulfur dioxide in the flue gas per m3 natural gas
V_Verbrifststoc	(CO_Vol*2,38714982+H2_Vol*2,38416960+CH4_Vol*9,565680839+C2H4_Vol*14,42261,9315	0,97951		[m3] stoichiometric combustion air per m3 natural gas
Normvolumen	f_q_convert('Coal gases, at consumer'; Mass; Standard volume)	0,97951		[m3] Selections of the standard volume
gasm3	gas/Rho_Erdgas	0,20995		[m3] required gas amount for the production of 1 MJ p
V_O2Rauch	(n-1)*0,20938*V_Verbrifststoc	0,10464		[m3] Oxygen in the flue gas per m3 natural gas

Inputs

Alias	Flow	Quantity	Amount	Unit
m_Luftinput	Air [Renewable resources]	Mass	0,022056	kg
	Steel wire [Metals]	Mass	1,2697E-006	kg
	Concrete C20-25 [Minerals]	Mass	4,3323E-006	kg
	Ammonia [Inorganic intermediate products]	Mass	2,9338E-006	kg
gas	Coal gases, at consumer [Others]	Mass	0,0071634	kg
Wasser_in	Water (river water) [Water]	Mass	0,0027628	kg

Outputs

Alias	Flow	Quantity	Amount
Wärmeerz	Thermal energy (MJ) [Thermal energy]	Energy (net0)	0,016195
Stromverh	Power [Electric power]	Energy (net0)	0,016195
staub_em	Dust (PM2.5) [Particles to air]	Mass	5,9108E-0
NOxproMJ	Ammonia [Inorganic emissions to air]	Mass	2,9338E-0
NOx	Nitrogen oxides [Inorganic emissions to air]	Mass	5,3216E-0
NMVOC_em	Formaldehyde (methanal) [Group NMVOC to air]	Mass	2,1722E-0
NMVOC_em	Propane [Group NMVOC to air]	Mass	1,1378E-0
NMVOC_em	Acetaldehyde (Ethanal) [Group NMVOC to air]	Mass	2,0688E-0
NMVOC_em	Butane (n-Butane) [Group NMVOC to air]	Mass	2,3791E-0
NMVOC_em	Pentane (n-pentane) [Group NMVOC to air]	Mass	3,5169E-0
NMVOC_em	Acetic acid [Group NMVOC to air]	Mass	3,1031E-0
NMVOC_em	Benzene [Group NMVOC to air]	Mass	8,2775E-0

Figure 4-5: Parameterized US Coal gas CHP power plant

For the combined heat and power production, allocation by exergetic content is applied. For the electricity generation and by-products, e.g. gypsum, allocation by market value is applied due to no common physical properties. Within the refinery allocation by net calorific value and mass is used. For the combined crude oil, natural gas and natural gas liquids production allocation by net calorific value is applied.

Energy consumption by power plants themselves and transmission losses of the electricity from the power plants to the consumers are included in the analysis.

The difference of thermal energy and process steam

The GaBi database offers country-specific datasets for thermal energy and process steam by energy carrier. For example, the datasets "US: Thermal energy from natural gas" and "US: Process steam from natural gas 90%" are available for natural gas. In the GaBi databases all process steam and thermal energy datasets refer to the same functional unit of 1 MJ of final energy delivered ("at heat plant").

The difference between the two types of datasets is related to the conversion efficiency of the energy carrier consumed to the final energy (steam, thermal energy) produced by the conversion process (heat plant).

While the LCI datasets for process steam are provided with several conversion efficiencies, i.e. 85%, 90% and 95%, the thermal energy datasets are calculated with an efficiency of 100% by definition. The thermal energy datasets therefore represent emission equivalents of the energy carrier consumed in the conversion process.

For practical LCA modelling:

If the amount of fuel (energy carrier), which is converted to final energy, e.g. litres of heavy fuel oil or kilograms of coal consumed, is known, then use the thermal energy processes. In contrast, if the amount of final energy, e.g. MJ of process steam, is known, then use the process steam processes. The latter is also to be used if the process steam in MJ is further translated into kg of process steam.

In addition to calculating conversion efficiencies, both types of LCI datasets also consider the energy self-consumption by the heat plants. Due to this fact, the “overall process system efficiency” is in reality lower than the conversion efficiency (mentioned above). The conversion efficiencies of 100%, 95%, 90% and 85% should be documented accordingly as conversion efficiencies.

Summary of most important aspects applied in GaBi energy modelling

- Country-/region-specific resources extraction technology (primary, secondary, tertiary)
- Country-/region-specific power plant and conversion technology
- Country-/region-specific production and consumption mix of energy
- Country-/region-specific transport chains (pipeline, tanker, LNG tanker)
- Specific efficiencies and specific emission equivalents per fuel use
- Specific resource/fuel characterisation per region
- Qualities and characteristics of fuel properties used in power plant models
- Parameterised models for emission calculations (specific standards adapted)
- Country-/region-specific refinery technology
- Unit process modelling based on engineering figures (no black box unit processes)
- Modular energy data provision (separate upstream data, fuel data, consumption mix data, fuel specific electricity generation data, country grid mix data)
- Deep regionalisation of energy data on all levels and layers of the life cycle model
- Adaptable electricity grid mix data

These main aspects ensure a reliable background database and enable the GaBi user to use the best practise energy data.

4.6.2 Transport

Transport is the link between process chain steps at different locations. Road, Rail, Air, Ship and Pipeline transports are the main modes of transport; however, the GaBi background model contains other modes of transport such as excavators, mining trucks and conveyors.

Road transport

Transportation systems are found in the use phase, which contains the fuel demand and released emissions. The functional units are the following:

- transportation of 1 kg cargo over a distance of 100 km for truck processes
- 1 vehicle-kilometre for passenger car processes. In the case of a car, the manufacturing and end of life phases can be connected to the utilisation model.

Adaptable parameters in the datasets are: distance, utilisation ratio, share of road categories (urban/rural/motorway), required sulphur content and share of biogenic CO₂ in fuel and total payload (total payload only applies to trucks).

Due to the fact that transportation processes are very specific for each situation, these processes are delivered as parameterised processes for individual adaptation.

Calculation of emissions

The basis for the emission calculation for both trucks and passenger cars is emission factors from literature [HBEFA 2010].

With the assumption that the utilisation ratio behaves linearly (see [Borken et al 1999]), the Emissions Factors (EF) [g/km] for 1 kg of cargo can be calculated with the following equation:

$$Emission = \frac{EF_{empty} + (EF_{loaded} - EF_{empty}) \cdot utilisation}{payload \cdot 1\,000 \cdot utilisation} \quad \left[\frac{g}{km \cdot kg} \right]$$

EF_{empty}	Emission factor for empty run [g/km]
EF_{loaded}	Emission factor for loaded run [g/km]
utilisation	Utilisation ratio referred to mass [-]
payload	Maximum payload capacity [t]

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

The total emissions for each pollutant refer to 1 kg cargo (truck) and 1 km (passenger car) and the transportation distance is calculated based on the driving share (urban: share_{ur} / rural: share_{ru} / motorway: share_{mw}), the specific emissions (urEm, ruEm, mwEm) in [g/(km*kg)] and the distance [km].

Equation for trucks:

$$Total-Emission_x = ((share_mw \cdot mw_{Em}) + (share_ru \cdot ru_{Em}) + (share_ur \cdot ur_{Em})) \cdot distance$$

x	Index for a specific pollutant [-]
share _{mw}	Driving share on motorway [%]
mw _{Em}	Motorway specific emissions [g/(km*kg)]
share _{ru}	Driving share on interurban road [%]
ru _{Em}	Interurban specific emissions [g/(km*kg)]
share _{ur}	Driving share on urban road [%]
ur _{Em}	Urban road specific emissions [g/(km*kg)]
distance	Driven distance [km]

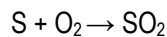
Equation for passenger cars:

$$Total-Emission_x = ((share_mw \cdot mw_{Em}) + (share_ru \cdot ru_{Em}) + (share_ur \cdot ur_{Em}))$$

x	Index for a specific pollutant [-]
share_mw	Driving share on motorway [%]
mw _{Em}	Motorway specific emissions [g/(km*kg)]
share_ru	Driving share on interurban road [%]
ru _{Em}	Interurban specific emissions [g/(km*kg)]
share_ur	Driving share on urban road [%]
ur _{Em}	Urban road specific emissions [g/(km*kg)]

For CO₂ emissions the calculations are based on the emission factors according to the previous equations, where a constant relation of 3.175 kg_{CO2}/kg_{fuel} for fuel consumption is assumed. A medium density of 0.832 kg/l (diesel), results in 2.642 kg_{CO2}/l_{diesel}, and a medium density of 0.742 kg/l (gasoline), results in 2.356 kg_{CO2}/l_{gasoline}. Due to biogenic shares in today's fuel, the possibility is given to select the share of biogenic CO₂ emissions of the total CO₂ emissions.

For sulphur dioxide, a complete stoichiometric conversion of the sulphur contained in the fuel and of oxygen into SO₂ is assumed. The sulphur content in the fuel is a variable parameter, which can be set individually by the user.



$$EF_{SO_2} = \frac{x_ppm_s}{1\,000\,000} \frac{kg_s}{kg_{fuel}} \cdot \frac{64g_{SO_2}}{32g_s} \cdot fuel_consumption \frac{kg_{Diesel}}{kg_{Cargo}} \left[\frac{kg_{SO_2}}{kg_{Cargo}} \right]$$

EF_{SO₂} Emission factor for SO₂

x_ppm_s Mass share in fuel

The emission factor for laughing gas (nitrous oxide, N₂O) is assumed to be constant for each emission class and each category of driving road. The emission factor for ammonia (NH₃) is set as constant throughout all categories.

The following systems and emissions are excluded:

- Vehicle production (for passenger car integration is possible due to existing valuable flow)
- Vehicle disposal (for passenger car 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 [SCHWARZ ET AL 1999])
- Tire and brake abrasion

Representativeness

Concerning representativeness, the emission classes from “Pre-Euro” to “Euro 5” are covered. The technologies are representative throughout Europe and can be adapted for worldwide locations with a few restrictions. There is a need to identify the corresponding emission classes.

The referring locations are Germany, Austria and Switzerland. Due to the similarity of the vehicle structure and the same emissions limit values, the models are representative for the entire EU. With a few restrictions the model can be assigned to other countries worldwide. Attention should be paid to the fact that the imprecision increases with the increase of the deviation of the vehicle structure as the basis. The road categories and the utilisation behaviour also affect imprecision. An adaptation can be carried out by setting the driving share (mw/ru/ur), as well as the utilisation ratio and sulphur content in the fuel, for individual conditions.

The reference year of the dataset is 2011, that data is representative for the period of 2010 to 2016.

Modification of the age structure of vehicles for each emission class leads to changes of the emission profile. The validity of the dataset is given for about five years (until 2016). Prognoses in [HBEFA 2010] based on comprehensive time series report that there is no change of emission profiles within a certain size class, emissions class or road category. Only the different composition of the total vehicle fleet results in some changes between 2010 and 2016.

Air Transport

The functional unit of air transportation processes is the transportation of 1 kg cargo over a distance of 2500 km. Adaptable variable parameters in the parameterised datasets (with default setting) are: distance (2500 km), utilisation ratio (66%), sulphur content of fuel (400 ppm) and share of biogenic CO₂ (0%). Three payload capacity categories (22 t / 65 t / 113 t) are addressed based on technical parameters and properties of A320 / A330 / B747 aircraft.

Inputs: Kerosene and cargo.

Outputs: Cargo and combustion emissions (carbon dioxide, carbon monoxide, methane, nitrogen oxides, NMVOC, sulphur dioxide, dust)

Not included in the datasets are plane production, end-of-life treatment of the plane and the fuel supply chain (emissions of exploration, refinery and transportation).

The fuel supply dataset (kerosene) must be linked with the dataset.

The foundation of the data is specifications for A320 / A330 / B747 aircraft, as well as the Third Edition of the Atmospheric Emission Inventory Guidebook [EMEP/CORINAIR 2002].

Rail Transport

Rail transport processes cover transportation of bulk commodities or packaged goods via light, average and extra-large diesel and/or electric cargo train. The functional unit is the transportation of 1 kg cargo over a distance of 100 km. Variable parameters (with default setting) are: distance (100 km), utilisation (40 %) and for diesel trains the sulphur content of fuel (10 ppm) and share of biogenic CO₂ (5 %).

Inputs: Diesel/electricity and cargo

Outputs: Cargo and for the diesel train also combustion emissions

Train production, end-of-life treatment of the train and upstream processes for fuel/electricity production are not included in the dataset.

The fuel/electricity supply dataset must be linked with the dataset.

The datasets are mainly based on literature data. [ECOTRANSIT2010], [IFEU 2010A]

Ship Transport

Ship transport processes cover transportation of various goods via several inland, coastal and ocean-going vessels. The functional unit is the transportation of 1 kg of cargo over a distance of 100 km. Variable parameters (with the default setting) are: distance (100 km), utilisation (65% for inland vessels and 48% for ocean-going vessels), sulphur content of fuel (50 ppm for inland vessels up to 2.7% for ocean-going vessels) and share of biogenic CO₂ (5% for inland vessels and 0% for ocean-going vessels).

Inputs: Fuel and cargo

Outputs: Cargo and combustion emissions (carbon dioxide, carbon monoxide, methane, nitrogen oxides, NMVOC, particulate matter PM 2.5, sulphur dioxide)

Vessel production, end-of-life treatment of the vessel and the fuel supply chain (emissions of exploration, refinery and transportation) are not included in the dataset.

The datasets are mainly based on literature data from the International Maritime Organization [IMO 2009], technical information [VBD 2003] **Fehler! Verweisquelle konnte nicht gefunden werden.**, emission data from the European Energy Agency [EMEP/CORINAIR 2006] and the Intergovernmental Panel on Climate Change [IPCC 2006].

Transport of fluids in pipelines

The LCI dataset should be used for LCI/LCA studies where fluids must be transported via pipeline over a longer distance. The dataset allows individual settings of the variable parameters. The following parameters are variable (default settings): utilisation ratio (28%) and distance (100 km). Default values of the variable parameters must be checked and adjusted for individual use. The dataset does not include the energy supply route. Therefore the energy supply dataset (electricity) must be linked with this dataset.

The pipeline transport processes can be used to model transportation of fluids in continuous working pipelines. Some representative diameters (0.4 to 1 m) and gradients of pipelines are analysed, because many variations are possible. The specific energy consumptions as a function of the utilisation ratio are determined from four basis formulas. The different energy consumption of different diameters over the utilisation ratio can therefore be calculated. The average utilisation ratio is approximately 28%. Two ranges of diameters and two different gradients are shown. Additionally, an average pipeline was calculated. The transported kilometres and the mass of the cargo are known, so the energy consumption in MJ of electricity can be calculated. The distance and the mass of the transported cargo must be entered by the user. Different pipelines can be chosen (varying the gradient and diameter). The energy consumption is calculated per ton cargo.

Inputs: Cargo and electric power

Outputs: Cargo

Not included in the datasets are pipeline production, end-of-life treatment of the pipeline and the electricity supply chain.

The main source of data is the energy consumption study for transportation systems of the RWTH Aachen [RWTH 1990].

Other Transport

Other transport consists of excavators for construction works and mining activities, as well as mining trucks. The functional unit is the handling of 1 t of excavated material. Vehicle performance, load factor, fuel consumption, emission factors, sulphur content of fuel and other technical boundary conditions can be individually adapted via variable parameters. The predefined parameter settings represent an average performance of the vehicle.

Inputs: Diesel and excavated material

Outputs: Excavated material and combustion emissions due to engine operation, including regulated emissions (NO_x, CO, Hydrocarbons and Particles), fuel-dependent emissions (CO₂, SO₂, benzene, toluene and xylene) and others such as CH₄ and N₂O

Not included in the datasets are vehicle production, end-of-life treatment of the vehicle and the fuel supply chain.

The datasets are mainly based on vehicle-specific technical data, as well as averaged literature data for emission profiles from the European Energy Agency [EMEP/CORINAIR 2006B].

4.6.3 Mining, metals and metallurgy

Primary metals are sourced from metal ores containing several different metal components. The production of a certain metal is therefore typically accompanied by the production of metallic and non-metallic co-products, e.g. nickel production with cobalt, other platinum group metals and sulphuric acid.

To calculate the Life Cycle Inventory of a single metal, the multifunctionality between product and co-products must be addressed. Allocation is often the only suitable way to deal with these highly complex co-production issues in a way that the technical circumstances are properly reflected. The choice of an appropriate allocation key is important because the metals and other valuable substances contained in ores are very different concerning their physical properties and value.

For metals with different economic values (e.g. copper production with gold as a co-product), the market price of the metals is a suitable allocation factor. In order to maintain consistency in environmental impacts as market values vary, average market prices over several years (e.g. 10-year market averages) are used. Usually the market price for concentrate or metal ore cannot be easily determined and in this case the market price is “derived” based on the metal content.

For other non-metallic co-products, such as the co-products sulphur, benzene, tar of coke for integrated steelwork creation, other allocation factors are applied, such as the net calorific value.

The metal datasets represent cradle-to-gate datasets of the actual technology mix, e.g. a region-specific mix of pyro-metallurgical and hydrometallurgical processes for the production of non-ferrous metals, covering all relevant technical process steps along the value chain, including mining, beneficiation (ore processing includ-

ing jaw crushing, milling, Dense Media Separation, Heavy Media Separation (HMS)), smelting (e.g. rotary kiln, flash furnace, blast furnace, TSL furnace, electric arc furnace), magnetic separation or leaching and refining (chemical or electro).

The LCI modelling of the process steps mining and beneficiation considers the composition of the mined ore bodies and the related metal-, process- and site-specific recovery rate, e.g. mill recovery rates within copper production could be Cu (90%), Mo (75%), Ag (70%) and Au (70%).

Under the assumption that tailing dams include a lining system where water is captured and put back in settling dams or water treatment facilities for reuse, the tailing dam emissions are considered as water losses through evaporation of the tailing dam.

Metal Recycling

Considering and evaluating the potential and benefit of metal recycling in LCA depends on the specific characteristic of the data system (e.g. field of application, question to be answered, goal & scope). The following principles are to be taken into account in setting up the life cycle system as the basis for a suitable and representative database for metals:

1. **Market situation:** According to the specific market situation, the metal production of the system under study can be characterised as primary metal production, secondary metal production or the market mix from possible primary and secondary production routes.
2. **Upstream burden and downstream credit:** For metals recovery, the end of life consideration covering the recycling of metal (downstream credit) turns into an upstream consideration (upstream burden) from the viewpoint of the product system consuming the recovery metal. Chapter 4.3.4.2 Allocation procedure in ISO 14044 [ISO 14044 : 2006] requires that allocation procedures must be uniformly applied to similar inputs and outputs of the product system under study, i.e. the use of recovered metal within a product system (=input) is to be treated equally from a methodological point of view to metal recovery from a product system (=output). Often this requirement is met by considering only the net amount of recovered metal to credit for metal recovery. The net amount of recovered metal is specified by the difference in the amount of metal recovery at the end of life of a product, as well as the use of recovered metal for production of the product system considered. This procedure is justified as only the metal loss over the complete product life cycle that is to be taken into account. Nevertheless, in doing so, the differences between the single life cycle phases (production, use and end of life) will be obliterated.
3. **100% primary / 100% secondary production routes:** It should be noted for Life Cycle Inventory modeling that in actual metal production a 100% primary or a 100% secondary route is not always given.
4. **Definition of key parameters:** A mutual understanding of the definitions and terms, e.g. Recycling rate in LCA = "Ratio of amount of material recycled compared to material introduced in the system initially" is highly important.
5. **End of Life scenario/situation "versus" End of Life methodology/approach:** It is necessary to distinguish between the End of Life scenario describing the recycling situation at products' End of Life, e.g. recycling into the same product system, no change in inherent material properties, and the (modelling) approaches/methodologies applied to consider and describe the resulting effects within LCA.

In LCA practice various methodological approaches to consider the recycling of products at their End of Life phase within LCA are applied. Aspects to be considered in selecting the appropriate End of Life approach are: ISO-conformity, mass and energy balance, reflection of optimization and reality, data availability, transparency, easy communication and understanding, field of application and fairness (to any material or product application).

A harmonised and consistent description and discussion of these approaches can be found in PFLIEGER/ILG 2007¹⁵.

4.6.4 Chemistry and plastics

Chemical and plastic products are key players toward environmental performance for two reasons: Chemical and plastic production uses substantial amounts of energy and resources but the resulting products help to save substantial amounts of energy or reduce environmental burden in suitable applications. Chemical and plastic products therefore provide an important foundation for many other industrial fields and products. In electronics, automotive and construction chemicals and plastics are used in various systems as input materials. It is therefore important to achieve a level of high engineering quality in the modelling of the processes in these fields.

Primary data collection and/or industrial feedback or validation of the information used, are the best choice. With specific engineering knowledge, data for chemical plants and operations can be developed with secondary information, thus making industry/expert feedback and validation even more important.

Data development of chemical processes follows a defined route in GaBi database work.

1. Information about current technologies is collected
2. Checking relevancy for the given geographical representation
3. Defining the name of the reaction route(s). There is often more than one, even with the same reactants.
4. Defining related stoichiometric equations
5. Defining suitable yields
6. Drawing a process flow sheet
7. Setting up the unit process network and the system

A validation or benchmark of the secondary data with existing data or is done.

Modelling

For each material several different processing technologies are often available. For example, for the production of polypropylene, “polymerisation in fluidised bed reactor” and “vertical stirred reactor” is both technologies that are applied. For each relevant technology an individual process model is created.

Chemical and plastics production sites are often highly integrated. Modelling a single substance product chain is possible by isolating integrated production lines. The following figure gives a simplified overview for important organic networks.

¹⁵ http://www.netzwerk-lebenszyklusdaten.de/cms/webdav/site/lca/groups/allPersonsActive/public/Projektberichte/NetLZD-Metalle_S01_v02_2007.pdf

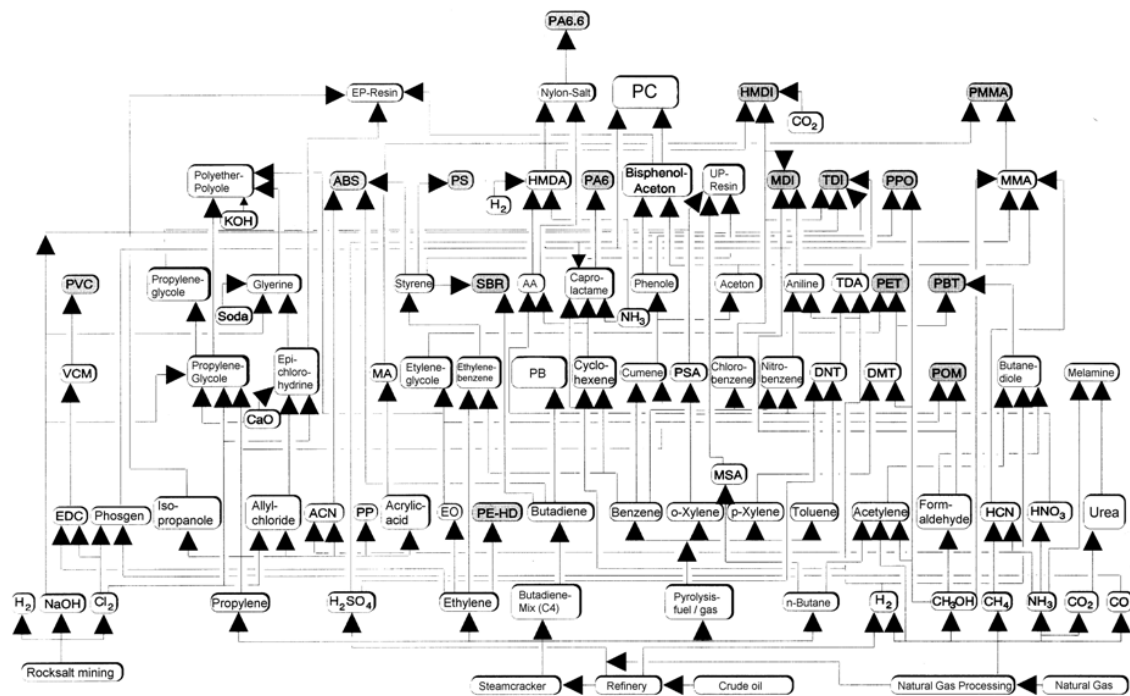


Figure 4-6: Excerpt of the organic network¹⁶ considered in GaBi

To avoid inappropriate isolation measures it is essential to have engineering and technical information to accurately model those systems.

A well-arranged online overview of important parts of the chemical network is given on the Plastics Europe Homepage¹⁷.

In case of chemical and plastics, it is not meaningful to apply generic modules because the technology specifications differ significantly. Country-specific consumption mixes are useful, because chemical and plastic products are traded worldwide, meaning 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, see Chapter 4.2.

Chemical processes often have a co-product system. Unit process isolation (subdivision) is preferable in this case. If it is not possible, energy products (e.g. fuel gases or steam) are substituted. For remaining by-products, allocation is applied. If all products and by-products have a calorific value, the allocation key energy is often used, because it is a good representation of value and upstream demand.

Waste and/or wastewater are always treated (landfill, incineration and/or wastewater treatment) if treatment pathways are obvious. The treatment technology (landfill or incineration or wastewater treatment) is selected according to the country-specific situation or individual information.

Production and consumption mix

As the users of the dataset are not always able or willing to determine the exact technology for the production of their upstream materials, a representative production mix or consumption mix is also provided. The share of

¹⁶ Acknowledgements to Dr. Manfred Schuckert for introducing the organic network thinking in the early 90s into GaBi. Still not broadly considered in the complete LCA community.

¹⁷ <http://www.plasticseurope.org/plastics-sustainability/eco-profiles/browse-by-flowchart.aspx> (checked 03.11.2011)

production or consumption was determined, separately from the dataset for each relevant technology. For chemicals with different possible production routes, the technology mix represents the distribution of the production mix of each technology inside the reference area.

For example, the production of standard polypropylene in the different regions is based on different polymerisation technologies, including the fluidised bed reactor and the vertical stirred reactor. For standard polypropylene the main process models are mixed according to their share in industrial applications with an average polypropylene dataset.

The consumption mix considers the material trade. Figure 10 shows an example of a mix for the consumption of epoxy resin in Germany for the reference year 2011. The epoxy resin, which is consumed in Germany, is produced in Germany (53.4%), Switzerland (20.3%), the Netherlands (9.1%), Italy (8.5%), Spain (4.5%) and Belgium (4.2%), as seen in the following example.

DE: Epoxy resin mix (EP)

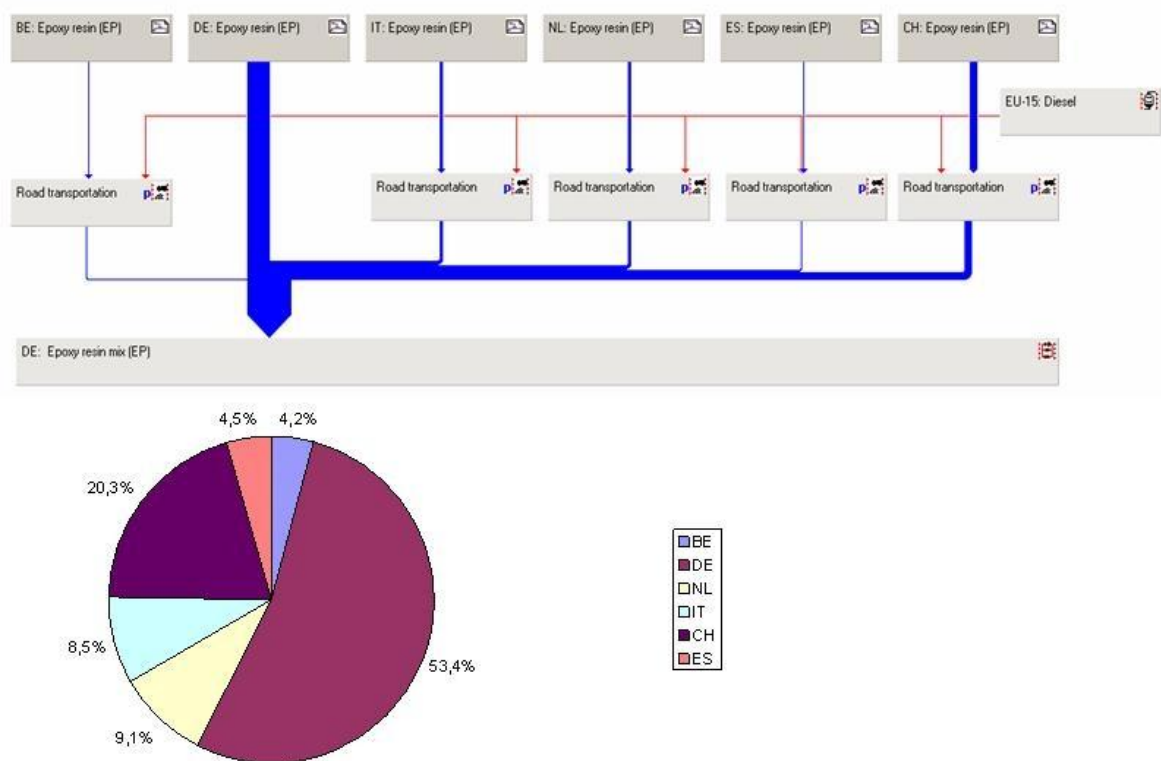


Figure 4-7: Consumption mix of Epoxy resin in Germany

Technology aspects

A suitable technology route is important for the proper modelling of chemical data. Technological differentiations in GaBi chemical process modelling are considered for different technology routes such as:

- Chlorine and NaOH (amalgam, diaphragm, membrane technology)
- Methanol (combined reforming stand alone and integrated)
- Steam Cracking (gas to naphtha input shares and related product spectrum)

- Hydrogen peroxide (SMA and Andrussov process)
- Hydrogen (steam reforming natural gas/fuel oil via synthesis gas, cracking/refinery by-product)
- Oxygen/nitrogen/argon (liquid or gaseous)
- Sulphuric acid (refining desulphurisation, fertiliser production, secondary metallurgy)
- Hydrochloric acid (primary, from epichlorohydrin synthesis, from allylchloride synthesis, from methylene diisocyanate synthesis, from chlorobenzene synthesis)
- Benzene, toluene and xylene (from reformat or pyrolysis gas or dealkylation or by-product styrene)
- Acetone (via cumene or isopropanol)
- Hexamethylemediamine (via adipic acid or acrylonitrile)
- Titan dioxide (sulphate and chloride process)
- Caprolactam (via phenol or cyclohexane)
- Ethylene oxide (via O₂ or air)

The correct technology route for the right process chain can be decisive. PE INTERNATIONAL's knowledge is constantly updated according to the latest developments in the chemical industry, including from being open to feedback and constructive comments while keeping the chemical networks up-to-date.

By-product handling

Methodological tools such as allocation or substitution open up ways to cope with any by-products. Technical reality guides GaBi modelling, first and foremost, before methodological choices are made. Prominent by-products are:

- steam (often not at a level of pressure that is directly compatible to the necessary input level)
- fuel gases
- various inorganic or organic acids
- purge or impure side streams
- unreacted monomers
- various salts

In GaBi chemical modelling the use or fate of by-products is investigated. Often chemical sites have a steam system with various feeds and withdrawing points with different temperature and pressure levels, which makes substitution of proper temperature and pressure level a suitable approach to handle the overall benefit of the by-product steam for the entire plant.

Fuel gases can often be used in firing or pre-heating the reaction within the plant, to reduce the use of primary sources. Related emissions are taken into account.

Acids are often sold. Allocation takes into account that those extracted acids must be cleaned, purified, diluted or concentrated.

Purge and impure side streams or unreacted monomers are often cycled back into the process after cleaning, distillation or purification.

Proper methodological handling and technical modelling based in fact are important..

Polymer modelling

Aside from the aforementioned topics of consistent mass and energy balances and the correct technology route, another aspect of polymer modelling should be mentioned: There is a difference between polymer granulate/resin, polymer compound and polymer part.

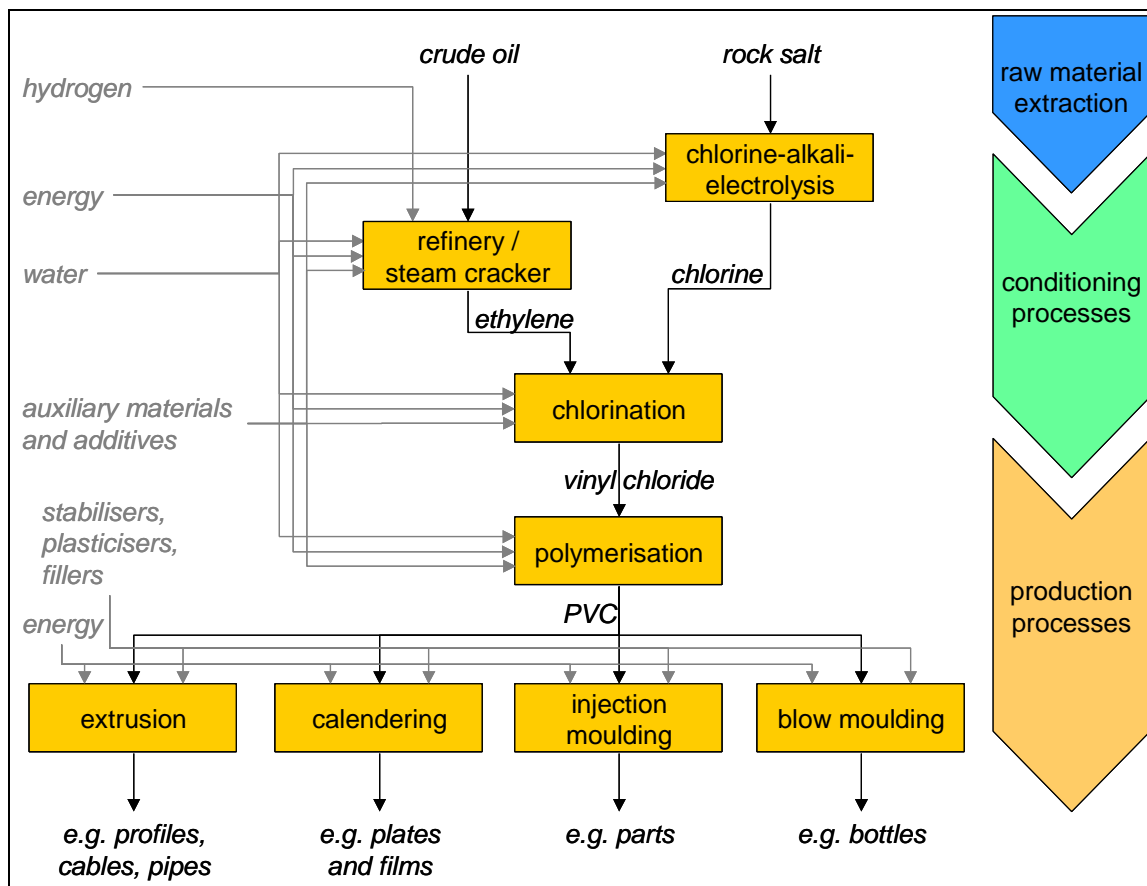


Figure 4-8: Example of PVC resin - compound- part

As compounds can be produced and used in thousands of specific recipes, GaBi primarily provides granulate data, which can be used individually to add additives to produce individual compounds and to set up individual polymer part data.

4.6.5 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 con-

struction products are responsible for the consumption of approximately 40% of the total European energy consumption, as well as for the consumption of approximately 40-50% of natural resources.

The anthropogenic material flows caused by the life-cycle of buildings contribute through many environmental categories to the impact potentials. In order to describe a building during the entire life-cycle, various information 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 utilisation of the building), land use (a quarry and surface sealing by the building) and waste treatment (construction, use, renovation, demolition) is required.

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

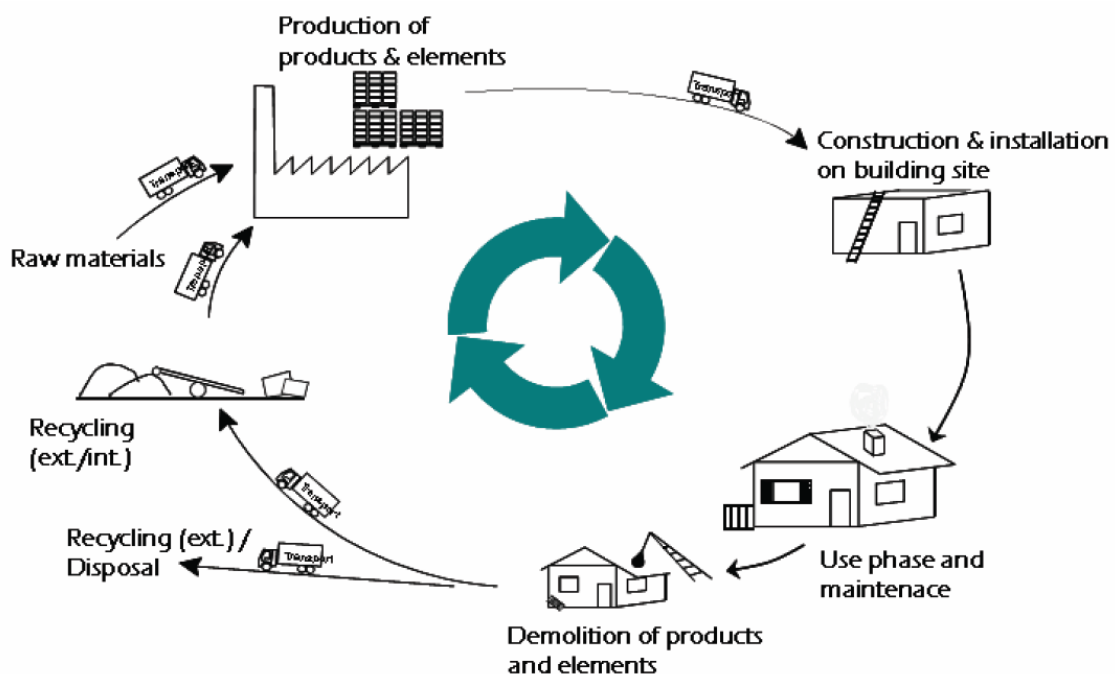


Figure 4-9: Schematic life cycle of a building

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

The background data (e.g. transport, energy supply) used to model the production of construction materials must be comparable. It will be true for system boundaries and methodological key points (such as cut-off-criteria and allocation rules), and may influence the result considerably. For construction materials the consistent GaBi background system is used.

The GABI 2012 database [GABI 2012] 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 is divided into mineral products (including concrete and concrete products, bricks, sandlime, natural stones, as well as mineral insulation materials such as rockwool and glass wool), metals (construction), polymers (for construction, including insulation materials such as PUR, EPS or XPS), wood for construction, cement and gypsum/mortar products and coatings and paints. The database also contains several ready-to-use building components such as windows with different dimensions and 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 stated above, the life cycle inventories of construction materials are – similar to 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 must consider the intended function. At the LBP-GaBi and PE 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 undergoing further development in order to meet the needs 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 can 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, they are used as example to explain this concept below.

4.6.6 Renewables

Basic approach of the model

Due to the determinant influence of environmental conditions being variable in time and space at a high spatial heterogeneity of site conditions, agrarian systems belong to the most complex production systems.

Due to the inherent complications characterising an agricultural system, a nonlinear complex agrarian model was used for plant production (developed by PE and the University of Stuttgart, Germany), this model covers a multitude of input data, emission factors and parameters.

One significant advantage of the model is its worldwide usability. With affordable operating efforts the model provides consistent and very accurate results for various agricultural and plantation products and differentiated adjustable farming practises.

General information on the foreground system

Agrarian systems belong to the most complex production systems within LCA due to their dependence on environmental conditions that are variable in time (e.g. within a year, from year to year) and in space (e.g. by country, region, site conditions). The following factors contribute to the complexity of agricultural modelling:

- The variety of different locations

- Small scale soil variability within locations
- The large number of farms
- The variety of agricultural practises
- Technically, no determined border to the environment
- Complex and indirect dependence of the output (harvest, emissions) from the input (fertilizers, location conditions)
- Variable weather conditions within and between different years
- Variable pest populations (insects, weeds, disease pathogens)
- Different crop rotations

System boundary for renewable model

The model includes cradle-to-gate burdens of all relevant input materials for the cultivation process itself (commercial fertilizer including lime, organic fertilizer, pesticides, seeds, including their production and transport). The model includes the cradle-to-gate emissions of fuel consumed, as well as the direct emissions to air from combustions, in the field for operations fuel. The model includes irrigation where it is relevant and excludes agricultural infrastructure and farm buildings. All relevant processes taking place in the area under cultivation including emissions into air and ground water (lower limit of rooted soil zone) are considered. Heavy metals remaining in soil are considered as emissions in soil. Integration of erosive loss of N_{org} (organic nitrogen) and C_{org} (organic carbon) as well as of nutrients (e.g. phosphorus) in water is considered.

Time reference

For annual crops a cultivation period is considered beginning immediately after the harvest of the preceding crop and ending after harvest of the respective cultivar. In the case of perennial cultivars (i.e. plantations), the process starts with plantation preparation (ground clearing) and lasts until the respective cultivar must be cleared for further uses.

Nitrogen cycle

Nitrogen plays a fundamental role for agricultural productivity and is also a major driver for the environmental performance of an agricultural production system. For these reasons it is essential to evaluate all relevant nitrogen flows within, to and from the agricultural system. PE's agriculture model accounted for the nitrogen cycle that occurs in agricultural systems.

The agriculture and plantation model consists of several sub-models. These are more or less interconnected, and therefore, modelled together in just one process.

In principle the model considers two themes:

- Allocation of fertilizer on crop rotations (allowable external fertilizer needs or profit of the main crop)
- The N losses as NO_3 into the groundwater and NH_3 , N_2O and N_2 into the air and on soil erosion as NO_3^- and N_{org} ¹⁸ in surface waters during the cultivation of the main crop

¹⁸ Organic Nitrogen

The model ensures that nitrogen emissions are consistent for the cultivated species. Specifically the model includes emissions of nitrate (NO_3^-) in water and nitrous oxide (N_2O), nitrogen oxide (NO) and ammonia (NH_3) into air. The model ensures that emissions from erosion and nutrient transfers within crop rotations are modelled consistently. The figure below shows the most important nitrogen flows illustrated by an intensive cultivation system of an example grain.

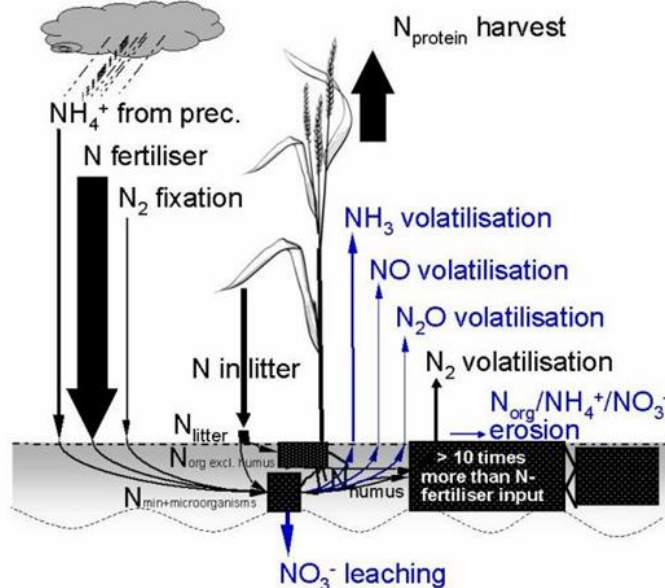


Figure 4-10: Nitrogen in the agrarian system

The different N-based emissions were calculated as follows:

- NH_3 emissions to air from organic fertilizers were adapted from the model of (BRENTROP, F. ET. AL. 2000.) and modelled specifically for the cropping system dependent on the fertilizer- NH_4 content, the soil-pH, rainfall and temperature. NH_3 emissions to air from mineral fertilizers were also adapted from (BRENTROP, F. ET. AL. 2000) and modelled specifically for the cropping system dependent on the kind of fertilizer and the soil pH.
- N_2 emissions to air occur from complete denitrification. N_2 emissions were also taken into consideration to determine the nitrate leaching potential.
- NO emissions to air occur from partial denitrification.
- N_2O emissions to air occur from partial denitrification. Indirect N_2O emissions are calculated from the shares of N leached/runoff and volatilised by using emission factors.
- N_{org} , NO_3^- and NH_4 emissions to water occur due to erosive surface run-off.
- NO_3^- emission to groundwater is calculated based on the rest of the incoming N not occurring as gaseous losses or in harvests, litter, unused extractions from the site, storage in soil. Depending on the leakage water quantity during the time period evaluated, an increasing part of this remaining N was calculated as leached nitrate.

Besides nitrogen-based emissions to water and air, phosphorus emissions are taken into consideration. Phosphorus is a stable compound which is not leached to groundwater significantly but can be washed out

with surface runoff of soil to surface water. The reason for this is that the washed out amount of soil contains a portion of phosphorus which causes an eutrophication effect in the water bodies.

Carbon modelling

Carbon-based emissions such as CH₄, CO and CO₂ are considered in foreground and background datasets. Background datasets include emissions resulting from the production of fertilizer, pesticides, electricity and diesel, while foreground datasets contain emissions such as CO₂ due to combustion of fossil fuels by the tractor or irrigation engines and application and decomposition of urea fertilizer in the soil.

Soil carbon is another potential source or sink of carbon dioxide. Soil carbon balances are used to describe any increase or decrease in soil organic carbon (SOC) content caused by a change in land management, with the implication that increased/decreased soil carbon (C) storage mitigates or increases climate change. Limitations of C sequestration for climate change mitigation include the following constraints: (i) the quantity of C stored in soil is finite, (ii) the process is reversible and (iii) even if SOC is increased there may be changes in the fluxes of other greenhouse gases, especially nitrous oxide (N₂O) and methane. Due to the strong scepticism present in current literature, the large amount of variables included in soil carbon sequestration is not considered within the scope of this study.

Aside from emissions, positive effects (sinks) due to natural conversion of gases in the soil were considered. Gaseous sinks are related predominantly to the methane depression function of natural soils due to their oxidising and microbial transformation of methane.

The biogenic CO₂ sequestered in the cotton plant and its fibre is directly accounted for in the inventory as an input or uptake of carbon dioxide, which is treated as a negative emission of carbon dioxide to air.

The complete bio-carbon modelling across the entire GaBi database content was checked and wherever divides into bio-carbon and fossil carbon could be identified, it was updated.

Water in the renewable modelling

Water use is modelled based on the calculations of Pfister (PFISTER2011). A generic water model allows the selection of different plant water requirements and irrigation regimes depending on the specific regional conditions (e.g. precipitation, irrigation demand and irrigation technique). For details please see the reference "Environmental Impact of Water Use in Global Crop Production".

Land use in the renewable modelling

Based on site-specific soil and climate parameters such as soil type, humus content, summer precipitation or evapotranspiration, implications of different land use types have been modelled for both transformation and occupation.

A set of indicators related to ecosystem functions has been defined to model land use aspects in LCA and incorporate them into the software: Erosion Resistance, capability of soil to prevent soil loss; Physicochemical Filtration, ability of soil to absorb dissolved substances from the soil solution to prevent pollutants from entering the soil matrix (characteristic value: cation exchange capacity); Mechanical Filtration, mechanical ability of soils to clean a suspension through the binding of pollutants on soil particles; Groundwater Replenishment, capacity to regenerate groundwater; Biotic Production: ability of the ecosystem to produce biomass.

Electricity and thermal energy in the renewable modelling

The electricity (and thermal energy as by-product) used is modelled according to the individual country-specific situation. The country-specific modelling is achieved on multiple levels. First, the individual power plants in service are modelled according to the current national grid. This modelling includes net losses and imported electricity. Second, the national emission and efficiency standards of the power plants are modelled. Third, the country-specific fuel supply (share of resources used, by import and/or domestic supply) including the country-specific properties (e.g. element and energy contents) are accounted for. Fourth, the import, transport, mining and exploration processes for the energy carrier supply chain are modelled according to the specific situation of each power-producing country. The different mining and exploration techniques (emissions and efficiencies) in the different exploration countries are accounted for according to current engineering knowledge and information.

Transport in the renewable modelling

If transportation is present, all relevant and known transport processes are included. Overseas transport, including rail and truck transport to and from major ports for imported bulk resources are included, if relevant. Furthermore, all relevant and known pipeline and/or tanker transport of gases and oil imports are included.

Fuels in the renewable modelling

Coal, crude oil, natural gas and uranium are modelled according to the specific import situation (see electricity). Refinery products: Diesel, gasoline, technical gases, fuel oils, basic oils and residues such as bitumen are modelled via a country-specific, refinery parameterised model. The refinery model represents the current national standard in refinery techniques (e.g. emission level, internal energy consumption) as well as the individual country-specific product output spectrum, which can be quite different from country to country. The refinery products used show the individual country-specific use of resources. The supply of crude oil is modelled, again, according to the country-specific crude oil situation with the respective properties of each resource.

4.6.7 Electronics

The distinct characteristics of electronic and electro-mechanic components are complexity, sizeable 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.

The demand exists to make datasets for electronic components available, since electronics are applied in various fields such as automotive, houses, consumer products, and information and communication systems. It is currently not possible from a timeframe and resource perspective to create an individual dataset for each of the 10 million electronic components. The challenge here is selection, which datasets to utilise, how to deal with the vast amount of parts and how to reduce the numbers of datasets by providing the representativeness of those datasets.

In order to make a statement about the representativeness of an electronic component, the whole scene must be understood. The extensive experience of the electronics team at PE INTERNATIONAL facilitates representative component determination, after having analysed hundreds of electronic boards and always/often/rarely-used components and their applications. Knowledge of often-used materials and most sig-

nificant steps of component manufacture are also important. The identification of significant manufacturing steps is supported by other technical fields. If data are not directly acquired from the electronics supply chain, either similar technical processes or comparable technical fields in which the identified manufacturing processes have been applied, supporting the determination of the relevant environmental impact. Only the interaction of all three conditions: experience, knowledge about similar processes and knowledge concerning the market situation, make the identification of relevant and representative components with their technologies and materials possible.

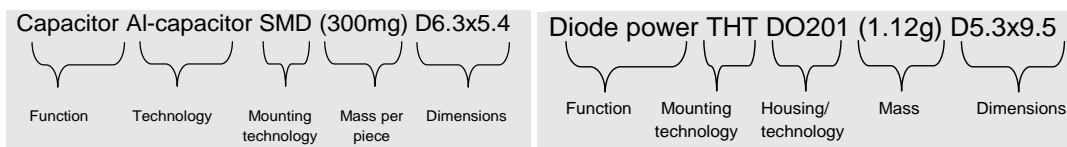
Even though not all electronic components can be judged according to their representativeness, the most relevant causes of environmental potentials from groups of similar electronic components can be identified, after the investigation of a certain amount of products. For example the difference in environmental impacts is possible to identify between semiconductors and resistors, or between active components (e.g. semiconductors, diodes and discrete transistors) and passive components (e.g. capacitors, resistors, inductions), 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.

In order to model representative electronic products, subsystems or components, environmental knowledge and availability of huge numbers of materials are necessary, such as metals, plastics and ceramics, since electronic products can consist of most elements in the periodic table. Additionally, 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.

As a result a list of electronic components covers this vast milieu. Its representatively is distinguished by various specifications related to their function, size, housing types, material content and composition, as well as mounting technology.

Clearly-structured nomenclature including all required information for component specification ensures the intended use of available datasets:

Examples for dataset nomenclature:



For representative LCI models of electronic assemblies and systems, like populated printed wiring boards, the following modelling principles are applied:

- Electronic components are modelled according to component-specific properties, e.g. function, case type, size, number of pins, die size, SMD/THT.
- Electronic components are modelled according to a functional unit “Number of pieces.”
- In the event that a dataset representing a component to be modelled is not available in the GaBi database, informed assumptions are made by choosing electronic components that are most similar, and related to housing types, function and production processes. A component scaling tool is available to support such a selection process.

Printed wiring boards (PWB) are mainly modelled by area (functional unit) due to fact that PWB dimensions and number of layers are the most sensitive parameters for PWB-related environmental impacts and primary energy use.

Modelling

Based on the necessity to model and assess electronic systems with justifiable effort, the electronics team of PE INTERNATIONAL developed the modular system called Generic Modules system. The target is to establish a Generic Module for each group of electronic components, e.g. resistors, ceramic capacitors or substrates.

The model based on Generic Modules of a typical electronic system follows a hierarchical structure. The system is divided into several subsystems. The subsystems themselves are modelled on the basis of the Generic Modules, as presented in Figure 4-11.

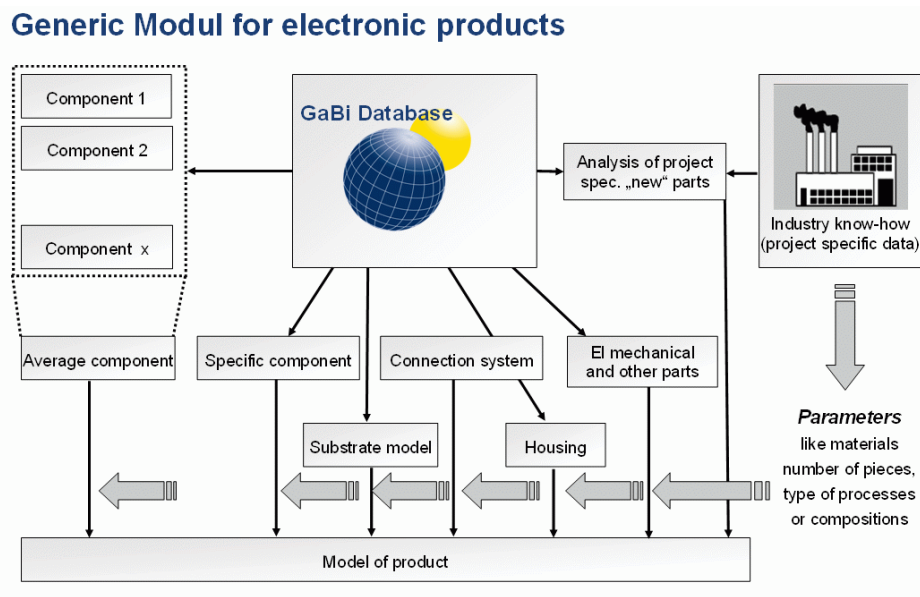


Figure 4-11: Creation of a model for an electronic product - modular structure via Generic Modules

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 adapted to a specific product or system under consideration.

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

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 or the connection system. PWBs are modelled according to the number of layers, size, weight and composition (e.g. content of copper, glass fibres, TBBA or Au/Ni finishing). If this information is not available, pre-defined average compositions may be used as described above.

Connection system: Usually solder pastes, formerly mainly SnPbAg and now typically lead-free solders, are used based on a number of varying metal solder elements.

Electronic components: An extensive database containing the material contents of the main groups of components such as resistors, capacitors, coils, filters, transistors, diodes and semiconductors are available. Seeing as millions of different components may be contained in electronic products, they are reduced to several representative components and are constantly updated and extended.

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

The Generic Modules are adapted via variable parameters. The significant functional units used depend on the subsystem, e.g. piece for components, area for boards and assembly lines, kilograms for solders and electro-mechanics.

The GaBi database contains aggregated datasets for components, which are based on the above-described Generic Modules. Further datasets can be set up easily using the Generic Modules.

4.6.8 Recycling or End-of-Life measures

Resource conservation and keeping valuable materials in the technical life-cycles are relevant aspects in analyzing the environmental performance of many materials.

After the life cycle phases of production and use/maintenance several options exist concerning the further application of used materials and products (like recycling, recovery and disposal or any share of each) or offsetting their secondary value.

According to ISO only elementary flows (plus the product flows) describe a Life Cycle Inventory. Secondary materials such as scrap (like metal scrap or glass cullet) represent non-elementary flows and are linked to previous or subsequent product life cycles. Within a LCA study these flows are typically modeled following methodological approaches such as cut-off approach, closed loop approach, open loop approach and value-corrected substitution approach.

Within the GaBi databases [GABI 2012] the cradle-to-gate data for metals (or container/float glass) still list the externally supplied secondary material inputs (e.g. carbon steel scrap sourced from merchants or other steel-works), if given and of significance regarding the overall environmental performance. This allows the user of the dataset to apply the methodological approach of choice to analyze in detail the potential/benefit of recycling along the life cycle of a product. Example life cycle models are provided within the GaBi databases for user guidance [GABI 2012].

In cases where an input or output of a secondary material is of no or very low relevance regarding the environmental life cycle performance of a material or product, the modeling of secondary material inputs or outputs is completed, using the “value of scrap” approach, to avoid misinterpretation¹⁹.

¹⁹ The possible (small) error made introduces much less uncertainty than the potential (large) error to be made, if left untreated.

The “value of scrap” approach addresses the question of how to deal with the recycling of metal scrap in LCA/LCI. The principle idea behind the approach is to define the Life Cycle Inventory of metal scrap, describing the “value of scrap.”

The “value of scrap” is defined as the difference in LCI of the (theoretical) 100% primary and 100% scrap production routes in metal production, considering the process yield of the recycling step.

Datasets provided with GaBi with the “value of scrap” are carbon steel scrap by World Steel Association (worldsteel) and stainless steel scrap by the European Steel Association (EUROFER).

Furthermore, we provide datasets on “value corrected substitution”. The intent is to apply a value-corrected credit for the substitution of metals in open-loop recycling situations where the inherent properties of the material have been changed in the sense of down cycling. To apply the dataset, connect the EoL scrap flow (after collection and separation, but before remelting) to the input of this process flow of the type [Waste for recovery]. Then connect the primary metal dataset to be substituted, to the negative input flow of the type [Metals]. The negative input applies the appropriate credit for the scrap class stated in the process name (e.g., aluminum auto fragments, baled used beverage can, etc.). The parameter for the price ratio represents the ratio between the scrap class and the LME primary metal price, which may be changed by the user, if necessary, using the referenced sources.

Recycling

Two general different recycling cases can be found in LCA discussion: Closed loop recycling and open loop recycling.

Closed loop recycling involves the recycling, recovery or reuse of material in a quasi-identical second use, including the respective demand to do so.

Open loop recycling corresponds to the conversion of material from one or more products into a new product or other application, involving a change in the inherent properties of the material itself (often with quality degradation).

Recycling can be understood as allocation between different life cycles. Time must be taken into account for durable products and the current situation of production must be separated from that of future recycling options and possibilities. For production, the current market situation must be assessed (ratio of primary material to recycled material in current production). In parallel, the recycling potential reflects the gross “value” of the product that principally exists in EOL. The net recycling potential reflects the current secondary material use in the market situation (deducted from the theoretical “value”).

In the GaBi databases current secondary material use and recycling rates are modelled according to the individual commodity or material and the respective market situation. Please see the specific data and chapters below for details. GaBi focuses on consistency of recycling and end-of-life processes like incineration, landfill and wastewater treatment with all other life-cycle stages. Three generic models were therefore generated:

3. Waste incineration model
4. Landfill model
5. Wastewater treatment model

These models follow the general rules of the modelling principles. All models represent standard technologies and are based on parameterised unit processes. For the generation of datasets (e.g. DE: Landfill for inert

matter), the models are specified according to the conditions as outlined in the dataset documentation. Included are country or region-specific background datasets, country or region-specific process efficiencies and specific input information about the characteristics of waste and wastewater.

Incineration model

The incineration model is defined based on the treatment of average municipal solid waste (MSW). The thermal treatment of a single waste fraction like paper or plastic or even specific wastes like Polyamide 6 is not actually done in a waste-to-energy (WtE) plant. The model and settings for the average MSW allow the environmental burden (emissions and also resource consumption of auxiliaries), energy production, as well as the credits (metal scrap recovery) to be attributed to a single fraction or specific incinerated waste within a standard MSW. The following figure gives an overview of the first level of the GaBi incineration model.

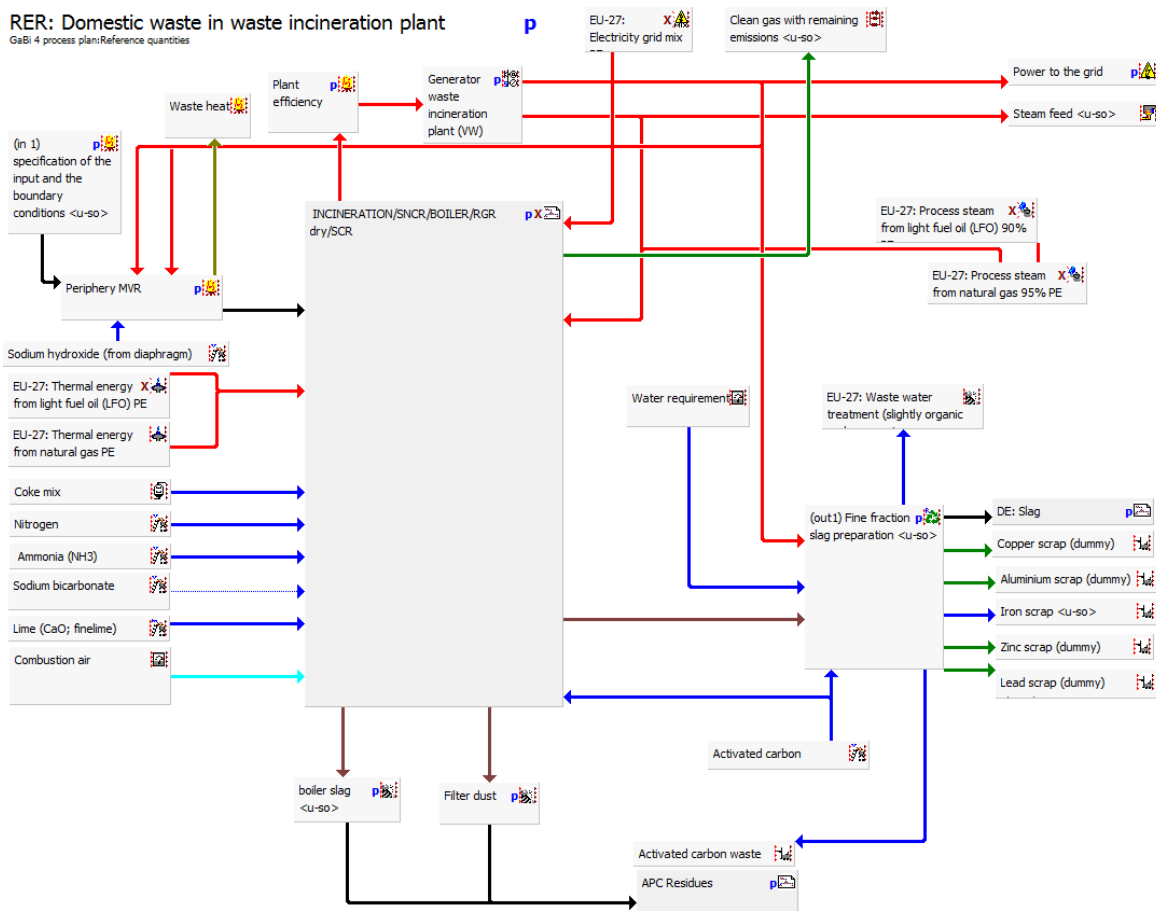


Figure 4-12: Exemplary incineration model with in GaBi (here average European domestic waste treatment with dry offgas cleaning)

The output of energy products (electricity and steam) leaving the product system is dependent on the heating value of the specific input and the internal consumption of energy necessary to treat the specific waste. The internal energy consumption is calculated based on the elementary composition of the specific input (e.g. energy demand for flue gas treatment) and standard values (e.g. handling of waste before incineration). The gross energy efficiency and the share of produced electricity and steam is taken from the country-/region-specific average WtE plant for municipal solid waste (MSW) in Germany or Europe.

Opening up the core plan “incineration/SNCR/Boiler/Off-gas treatment” of the previous figure will show further detail of the GaBi incineration model.

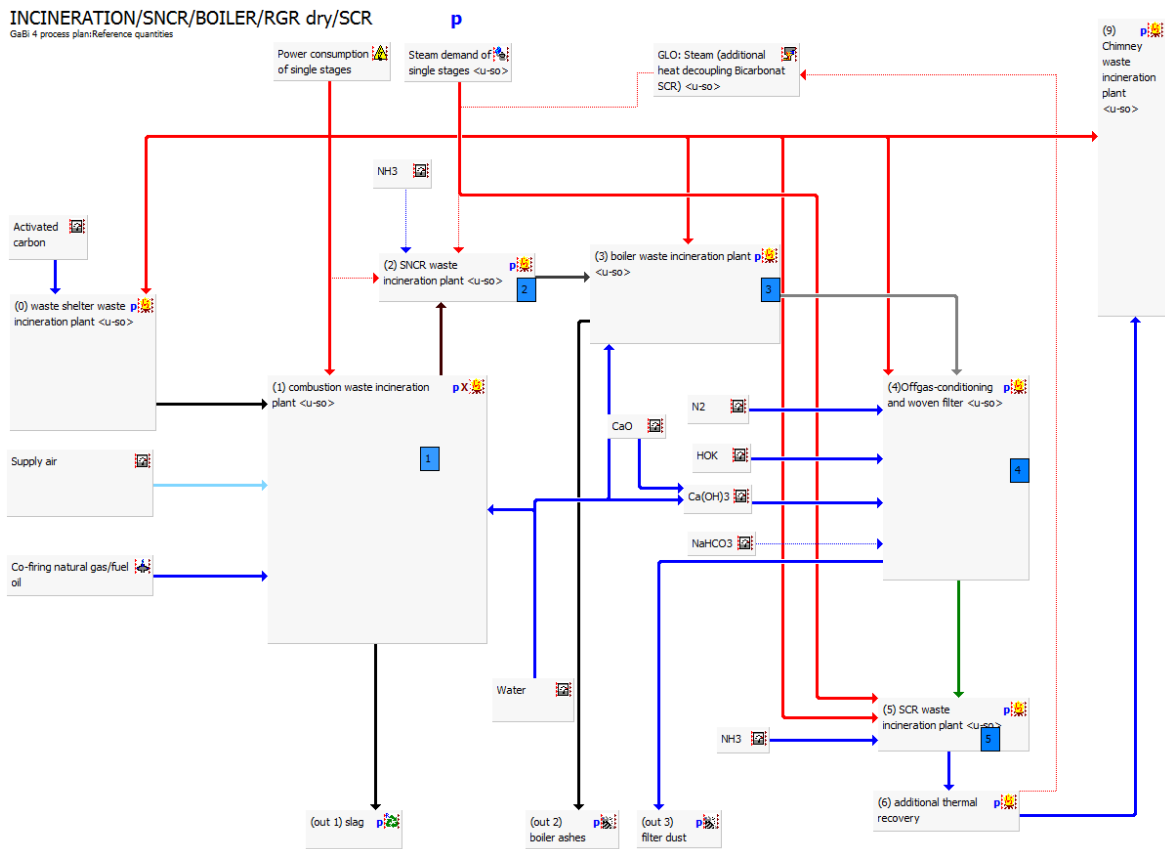


Figure 4-13: Details of incineration and dry offgas cleaning in GaBi incineration model

The incineration model was set-up to account for two technologies (wet and dry off-gas treatment) and verified with measured data from a number of German and European incinerators, as well as data from literature. The heating value of the input can be specified or calculated based on the elementary composition of the input. The material flow in the plant is calculated using individual transfer coefficients for every element and stage of the incinerator. The transfer coefficients for the final release of the flue gas to the atmosphere is verified and adapted with literature data and real plant data of European and WtE plants.

For input specification in the model, the following elements and compounds can be used: Ag, Al, AlO_x, As, ash, Ba, Br, C_Carbonate (inorganic carbon), C_HC (fossil carbon), C_HB_Bio (biogenic carbon) Ca, Cd, Cl, CN, Co, Cr, Cu, F, Fe, H, H₂O, Hg, J, K, Mg, Mn, N, Na, NH₄, Ni, O, P, Pb, S, Sb, SiO₂, Sn, SO₄, Ti, Tl, V, Zn.

The modelled emissions to air in the flue gas of the incinerator are: As, Ba, Cd, Co, CO, CO₂ (fossil and biogenic), Cr, Cu, dioxins, HBr, HCl, HF, HJ, Hg, Mn, N₂O, NH₃, Ni, NMVOC, NO_x, particles, Pb, Sb, Sn, SO₂, Tl, V, Zn. Most of the emissions leaving the system are input-dependent. That means there is a stoichiometrical correlation between input and output. Other emissions are a function of the technology utilised and therefore independent of the specific input. The input-dependent emissions are linear to the elementary composition of the waste. The technology dependent emissions are constant in a specific range. Input-dependent parameters

are the emissions CO₂, HCl, HF, SO₂ caused by the relevant input of these elements. The amounts of slag, boiler and filter ash produced, as well as recovered ferrous metal scrap, are also input-dependent. Technology dependent parameters are CO, VOC and dioxin emissions.

Ashes and filter residues which are dumped in specific hazardous waste underground dumps – as in the 2011 version – but are accounted for as “hazardous waste (deposited)” are to acknowledge EPD best practise.

The datasets already include the credits given for the recovery of ferrous metal scrap.

Landfill model

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

The input of auxiliaries for the landfilling of one kilogram of waste is partially constant for all types of wastes (e.g. energy for compacting, materials for the landfill construction) and partially dependent on the elementary composition of the waste (e.g. ferric chloride for the treatment of leachate). The inert landfill sites do not generate landfill gas, nor is the leakage technically treated before going to the receiving water.

Landfill gas losses/flare and recovery ratios were checked and adapted to reflect the latest information.

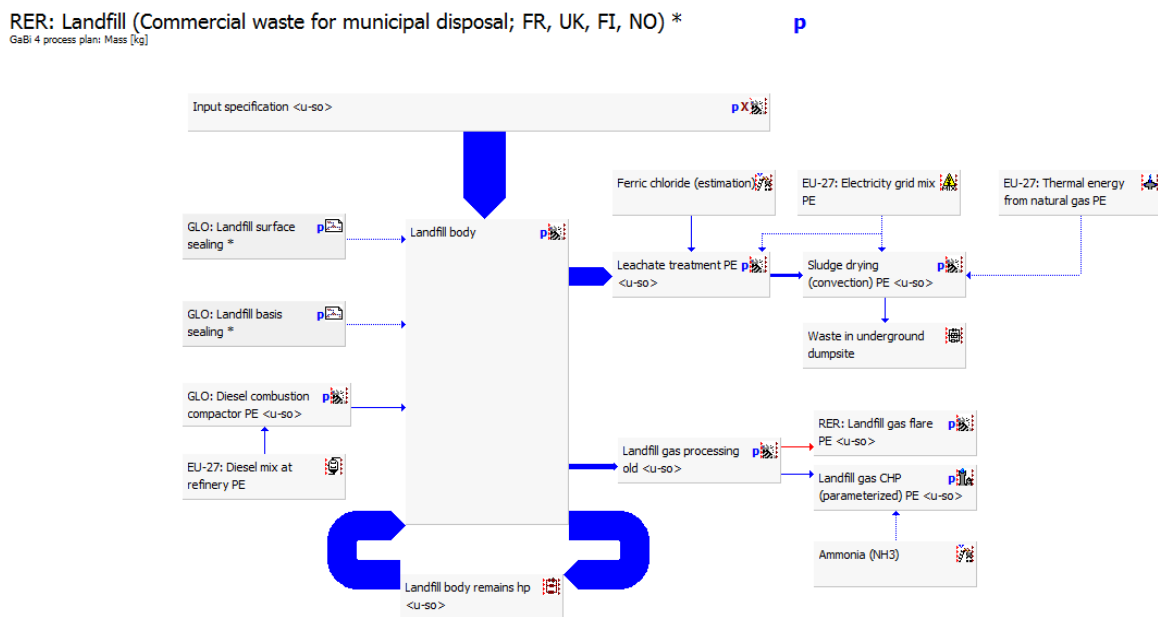


Figure 4-14: Exemplary landfill model in GaBi (here commercial waste composition for certain geographic example regions)

The landfill model is parameterised to allow the generation of different datasets according to the waste input and region/country specific details. Important parameters and parameter sets:

- elementary composition of the disposed waste
- different technologies for the sealing and cap (layers)
- differing PE 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 to describe the fate of elements over a period of 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 model of the landfill body calculates, based on the element specific transfer coefficients, the input dependent amount of substances and elements going to leakage collection, landfill gas and soil.

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 wastewater) 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.

Part of the landfill gas is collected and either flared or used to produce electricity or both electricity and heat. The uncollected landfill gas is directly released to the atmosphere. The share of the different treatment route of landfill gas can be adjusted to the country or region-specific situation. For simplification reasons, the landfill gas composition only represents the average useable landfill gas. The amount depends on the organic carbon content in the waste composition and the assumed degradation over 100 years.

Wastewater treatment model

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

The wastewater treatment represents an average/typical wastewater treatment from industrial processes. It contains mechanical, biological and chemical treatment steps for the wastewater (including precipitation and neutralisation), and treatment steps for the sludge (thickening, dewatering). The outflow goes directly to the receiving water (natural surface water).

DE: Municipal waste water treatment (Output: dried sludge for further use)

GaBi 4 process plan/Reference quantities

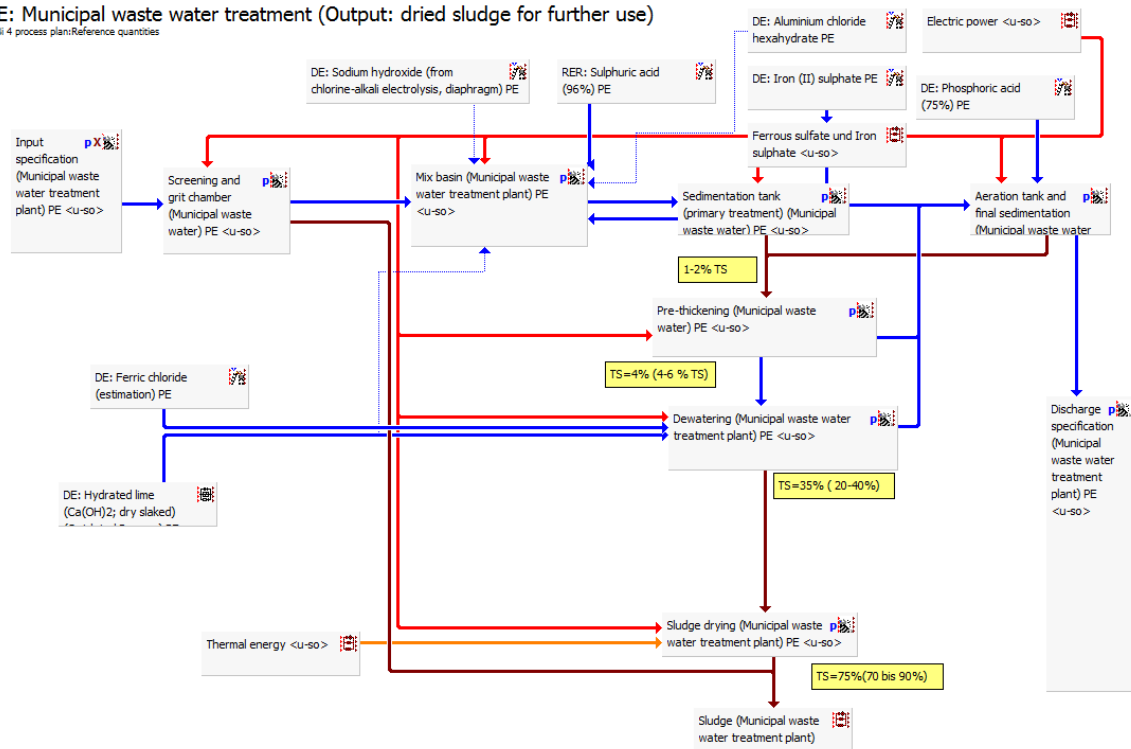


Figure 4-15: Exemplary wastewater treatment model in GaBi (here municipal wastewater for German circumstances)

The process steps take 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) from the raw sewage. Next, the sewage is transported to the grit tanks. These tanks reduce the velocity of the sewage so 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 $\text{Ca}(\text{OH})_2$ are used as precipitant agents in the mixing tank to remove metals. $\text{Ca}(\text{OH})_2$ and H_2SO_4 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 are 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 of the thickened sludge is 96%). The sludge is pumped to filter presses for dewatering, which use chemical flocculants to separate the water from the solids (water content of the dewatered sludge is 65%). In this dataset sludge for agricultural application is produced. For this reason the sludge is not dried and supplied after dewatering. The output is wet sludge (dry content is 35%) containing N, P_2O_5 and K_2O according to statistics and calculations which is included in the plan for the given fertilizer credit.

5 Review, documentation and validation

Data that is officially published in publications or a web page is not sufficient proof of its quality. Even if professional review processes are in place for journal publications, the scientific quality of the article or paper can be proven, and the “correctness” of the underlying data cannot be validated in most cases. Even if it is easier for the user to simply “cite” a data source, a validation or verification routine for the data is essential.

There is presently no specific ISO standard in existence for data quality reviews. The existing ISO standards ensure quality and consistency of LCA reporting.

5.1 Review procedures and check routines

The core principle of PE is to provide quality information. PE has therefore set up a review and validation procedure within its GaBi Database concept and management scheme based on the four quality check layers:

- Internal entry quality checks
- Internal resulting quality checks
- External resulting non-public quality checks
- External resulting public quality checks

See Chapter 2.1 for more details. It is important to base the review of data and databases on ISO principles accompanied by practical experiences in data collection, data set-up, database maintenance and updates in industrial practises. Plausibility and technical routines in GaBi raw data²⁰ and process data handling are the main instruments to avoid, detect and reduce errors.

These routines support data collection and systematic error identification in inventories by understanding the underlying technical process and being able to identify potentially incorrect or missing values and flows (conspicuous values, type faults, conversion/unit errors).

5.1.1 Technical information and documentation routines in GaBi

The checklist for the collected data and resulting unit process information, which is documented either on plan system level, in the unit process or in the resulting aggregated process:

- Data source (reproducibility), reliability of the sources, representativeness of the sources
- Technical conditions (state of the art, conventional process, established process, pilot plant, laboratory operation)
- Process integration: Stand-alone process or integrated into a large facility
- Calculation method (average, specific)
- Technically relevant process steps are represented on plan system level
- Types and quantity reactant/product
- Efficiency/stoichiometry of chemical reactions; monitoring of the rate of yield
- Types and quantity of by-products, wastes or remaining and its fate

²⁰ Raw data is any data or metadata needed so set up an LCA dataset

- Emissions spectrum (relation between in- and outputs, comparison to similar processes)
- Types and quantity of circulating flows (purge, monomers, production recycling material)
- Auxiliary material and utilities
- Input chemicals and substances for end of pipe measures (lime, NH₃)

These technical information points help to identify gaps and enable balance checks and plausibility checks.

5.1.2 Important material and energy balances

The following balance checks are done with any unit process and plan system, to trace and eliminate gaps and errors.

- Energy balance: net or gross calorific value (sum of renewable and non-renewable)
- Mass balance (what goes in must come out)
- Element balance: often C or metal content (also check for raw material recovery)
- Reaction equations

5.1.3 Plausibility of emission profiles and avoiding errors

The basic principle is to avoid too high and too low values and/or missing emissions. The plausibility and error checking must therefore not only take place on the process level but also on the plan and supply chain level.

There are typical emissions for typical industrial operations for each type of process. These indications are used to monitor and compare similar processes. Knowing the frequent error sources is the best way to manage and avoid them.

Data entry with the wrong comma/point setting (factor 10, 100, 1000) results in figures that are too high or too low. New or updated data in GaBi is double checked, individually by the data developer with existing or comparable datasets, and in the case of bigger data volumes, automatically ("GaBi process comparison tool") by routine checks of the relevant impacts with the predecessor.

Another error source is data entry with wrong units:

- mg – µg or kg – t leads towards factor 1000 / 0.001 error
- MJ – kWh leads towards factor 3.6 / 0.28 error
- BTU – kWh leads towards factor 1000 / 0.001 error
- BTU – MJ leads towards factor 3000 / 0.0003 error

GaBi supports the avoidance of this error by offering automatic unit conversion.

If the emissions or impacts appear to be surprisingly low, the following checks are undertaken in GaBi database work:

- connection of significant processes back to the resource (aggregated dataset or plan system of upstream processes)
- modelling of fuels only, omitting combustion emissions in the unit process (thermal energy or emission modelling)

- transports are modelled but not adjusted to the correct distances
- unsuitable substitution used
- wastewater impacts not modelled (wastewater leaves untreated)
- burden free entry of secondary materials into the life cycle phase
- CO₂ balance not addressed (renewable), CO₂ intake or emission not/wrongly considered

If the emissions or impacts appear to be surprisingly high, the following checks are undertaken in GaBi database work:

- by-products not substituted or allocated
- system expansion not suitable (loss of focus or function added in unsuitable way)
- useful energy output (e.g. steam) not considered correctly
- waste treatment or wastewater treatment overestimated, scrap input modelled as pure primary route (sector-specific)
- CO₂ balance not addressed (renewable), CO₂ intake or emission not/wrongly considered

Plausibility and error checks are critically discussed and optimised in data-related projects with industrial customers and respective critical reviewers of our work, with our academic cooperation partners, LBP- University of Stuttgart and Fraunhofer IBP, as well as with independent testing and certification partners.

5.2 Documentation

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

In GaBi documentation, recommendations to mandatory and optional information, which are either based on international standards such as ISO 14040, ISO 14044 and ELCD or on the experience of PE INTERNATIONAL and LBP- University of Stuttgart. The requirements of ISO 14040 [ISO 14040 : 2006] and 14044 [ISO 14044 : 2006] are considered.

The metadata documentation of the datasets in "GABI 2012 database [GABI 2012]" is based on the documentation recommendations of the "International Reference Life Cycle Data System" [ILCD 2010] Handbook of the European Commission's European Platform on Life Cycle Assessment, while – due to the dynamic nature of the topic database harmonisation [see UNEP/SETAC 2011] – not strictly meeting them in each and every case.

Please see the individual GaBi documentation [GABI 2012] in the respective LCI processes of the GaBi database (example of documentation is shown in Chapter 5.2.3) or on the GaBi Webpage <http://www.gabi-software.com>.

5.2.1 Nomenclature

Consistent nomenclature is an essential aspect of the database quality. Any database object including impact characterisation factors or flow characteristics like calorific values, flows, processes and plan systems must be properly named.

Flow and process names are especially important. The flows and processes in GaBi are arranged in a hierarchy for storage.

The flow hierarchy is structured according to technical aspects (for non-elementary flows and resources) and according to emission compartments air, water and soil.

In general all relevant LCI elementary flows (resources and emissions) in GaBi are pre-defined. Therefore the number of elementary flows that must be newly-defined by the user is few to none.

If a new process or new flow is created because it is not available in the database, consistency with existing processes or flows is kept.

In the GaBi database flows and processes are biunique, which is an important basis of consistency and a prerequisite for data exchange.

5.2.2 Documentation of Flows

The documentation of flows is an important component of the inherent documentation of processes and LCI results. Flow documentation is an integral part due to the direct influence of the flow properties to the results of LCI and LCIA.

Flows in GaBi are (if suitable) documented by:

- Reference quantity
- Synonyms of the main flow name
- CAS number
- Sum formula
- Region or location of the flow, e.g. region Western Europe
- Field for general comments to add further information

Information for the flow such as synonyms and CAS number are documented in GaBi according to ILCD (see Figure 4-11).

5.2.3 Documentation of LCI process data

The documentation of the LCI datasets in GaBi covers relevant technical and supply chain information that is necessary to understand the technological basis and background of the modelled system. Further multiple metadata are given to enable the further use within important documentation schemes like ILCD, EPDs and EcoSpold. For further details see the documentation tab in each dataset.

Name: DE Electricity grid mix PE-GaBi agg - LCI result

Parameter: LCA VF LCC: -0,0084595 € LCWE Documentation

Collapse all Expand all Adopt info ... Highlight EPD fields Highlight ecoSPOLD fields

Process information

Key information

Treatment, standards, routes: AC

Mix and location types: consumption mix, at consumer

Further quantitative specifications: 230V

General comment: Data sets represents the average country or region specific electricity supply for final consumers, including own consumption, net losses and imports from neighbouring countries. The national energy carrier mixes used for electricity production as well as data about efficiencies, net losses and own consumption are taken from official statistics (mainly International Energy Agency) for the relevant reference year. Detailed power plant models were used, which combine measured emissions plus calculated values for not measured emissions of e.g. organics or heavy metals. Inventory is partly based on primary industry data, partly on secondary literature data.

Technological representativeness

Technology description including background system: The national or region specific electricity consumption mix is provided by different energy carriers, as illustrated in the pie chart "Electricity Grid Mix". The electricity is either produced in energy carrier specific power plants and / or energy carrier specific heat and power plants (CHP). The national or regional specific fuel supply (share of resources used, by import and / or domestic supply), including the national specific energy carrier properties (e.g. element and energy contents) are considered, as well as the national and regional specific technology standards of power plants regarding efficiency, firing technology, flue-gas desulphurisation, NOx removal and dedusting.

For the included electricity from renewable energies the average national situation is reflected for the following parameters: solar radiation, annual full load hours for wind power plants, solid biomass supply, share of hydro power station type (storage, run-of-river and pumped storage).

The power grid includes imported electricity from neighbouring countries, distribution losses and the own use by energy producers (own consumption of power plants, pumped storage hydro power station etc.). The logic for the modeling of the electricity consumption mix is represented in the flow diagram "Modelling of Power Consumption Mix". The data set considers the whole supply chain of the fuels from exploration, with the extraction and preparation to the transport of the fuels to the power plants.

Included data sets: DE: Electricity from photovoltaic PE [Power from photovoltaics]
DE: Electricity from wind power ELCD/PE-GaBi [Power from wind power]
DE: Electricity from hydro power PE [Power from hydro power]
DE: Electricity from waste PE [Power from waste]
DE: Electricity from biomass PE [Power from biomass]

Technical purpose of product or process: Provision of low voltage (<1kV) electricity for final consumers.

Flow diagram(s) or picture(s):

Energy specific power plant	natural gas	blast furnace gas	biogas	heavy fuel oil	hard coal	brown coal	biomass
CO2 [kg/TJ fuel input]	58	225	101	89	94	112	101
CO [kg/TJ fuel input]	1,7	30,4	100,0	6,5	8,7	58,5	99,0
SO2 [kg/TJ fuel input]	0,4	0,0	75,6	153,6	69,9	75,6	43,6
NOx [kg/TJ fuel input]	44,5	212,4	100,0	68,1	64,0	77,0	58,0
efficiency [%] *	47,7	40,5	26,2	42,3	37,7	38,8	23,3

* the efficiency rate includes CHP

Figure 5-1: Example documentation in GaBi (excerpt) [GABI 2012]

5.3 Validation

The validation procedures of GaBi databases are implemented on different levels.

1. Consistency and Completeness of database objects

Consistency of flows and completeness of the necessary flow characteristics are validated internally at PE, following standard routine. PE provides several different databases consistent to our own databases. Routines and technical tools exist therefore to trace and identify possible errors and ensure consistency, completeness and biunique database entries.

2. Content on technical process level

The technical content is constantly validated in LCA work with GaBi data by related industry experts, branch experts or process operators. Validating technical content of datasets needs technical understanding. If companies provide data, PE validates the data (because it must fit in detail and consistency to the surrounding system) and, depending on the type and purpose of the data, LBP University of Stuttgart or a third-party validator or reviewer is involved.

3. Methodological LCI approach

Methodological LCI approaches in GaBi databases are based on relevant standards and reference works, and are presented and discussed in and benchmarked against different academic, political and professional frameworks (like e.g. ILCD 2010, NETZWERK2011, PLASTICSEU 2011, UNEP/SETAC 2011, ISO 21930:2007) to ensure acceptance and applicability. A validation of methodological approaches is constantly conducted in the context of the use of GaBi data and process chain details within the given framework and the respective critical reviews of studies which utilise the databases.

4. Methodological approach LCIA

New impact methods in GaBi are implemented preferably by involving the respective LCIA method developers, to implement the given method in the most suitable way. This implementation includes proactive critical discourse between scientific detail and practical applicability. The validation of the method is preferably conducted jointly by the developers and PE.

5. Content on LCI and LCIA level

In many LCA projects reviews are undertaken and the background data (chains) are reviewed and discussed with the project group and with the reviewer. We grant reviewers access to the background systems under bilateral agreements. PE INTERNATIONAL studies, GaBi results and dataset benchmarks are often publicly discussed in external field tests or in comparisons. A broad user community is constantly using, comparing, benchmarking, screening and reviewing GaBi data and data results, which are published in various channels. User feedback is collected and incorporated into the database management routine.

6 Literature

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Supplement A Description of result and impact categories

This chapter describes the impact assessment methodologies available in GaBi 6 (called quantities in the GaBi tool). The description is divided into overall impact categories (e.g. global warming, acidification.) and the approach of each of the available impact methodologies (e.g. CML, Ecoindicator) is described.

Methodologies covering only specific impact categories, e.g. USEtox for toxicity and IPCC for global warming, are described under each impact category.

The International Reference Life Cycle Data System (ILCD) has published 'Recommendations for Life Cycle Impact Assessment in the European context' which chooses the methodology which has been evaluated as the best within the impact category [ILCD 2011]. This leads to the set of impact categories in Table J. The approach of each methodology is described in the appropriate chapter.

Table J: ILCD set of recommended impacts

Impact category	Recommended midpoint LCIA method	Indicator	GaBi implementation
Climate change	Baseline model of 100 years of the IPCC	Radiative forcing as Global Warming Potential (GWP100)	Specific IPCC category (incl biogenic carbon)
Ozone depletion	Steady-state ODPs 1999 as in WMO assessment	Ozone Depletion Potential (ODP)	TRACI 2.1, Ozone Depletion Air
Human toxicity, cancer effects	USEtox model (Rosenbaum et al, 2008)	Comparative Toxic Unit for humans (CTU _h)	USEtox, Human toxicity, cancer (recommended)
Human toxicity, non-cancer effects	USEtox model (Rosenbaum et al, 2008)	Comparative Toxic Unit for humans (CTU _h)	USEtox, Human toxicity, non-canc. (recommended)
Particulate matter/Respiratory inorganics	RiskPoll model (Rabl and Spadaro, 2004) and Greco et al 2007	Intake fraction for fine particles (kg PM2.5-eq/kg)	Particulate matter/Respiratory inorganics, RiskPoll
Ionising radiation, human health	Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al, 2000)	Human exposure efficiency relative to U ₂₃₅	ReCiPe 1.07 Midpoint (H) - Ionising radiation
Ionising radiation, ecosystems	No methods recommended		Not shown
Photochemical ozone formation	LOTOS-EUROS (Van Zelm et al, 2008) as applied in ReCiPe	Tropospheric ozone concentration increase	ReCiPe 1.07 Midpoint (H) - Photochemical oxidant formation
Acidification	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)	Accumulated Exceedance (AE)	Generic emission factor
Eutrophication, terrestrial	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)	Accumulated Exceedance (AE)	
Eutrophication, aquatic	EUTREND model (Struijs et al, 2009b) as implemented in ReCiPe	Fraction of nutrients reaching freshwater end compartment (P) or marine end compartment (N)	ReCiPe 1.07 Midpoint (H) - Freshwater eutrophication + ReCiPe 1.07 Midpoint (H) - Marine eutrophication
Ecotoxicity (freshwater)	USEtox model, (Rosenbaum et al, 2008)	Comparative Toxic Unit for ecosystems (CTU _e)	USEtox, Ecotoxicity (recommended)
Ecotoxicity (terrestrial and marine)	No methods recommended		Not shown
Land use	Model based on Soil Organic Matter (SOM) (Milà i Canals et al, 2007b)	Soil Organic Matter	Can be calculated from LCI dataset: CO ₂ extracted from atmosphere minus carbon flows to water, and carbon uptake in products.
Resource depletion, water	Model for water consumption as in Swiss Ecoscarcity (Frischknecht et al, 2008)	Water use related to local scarcity of water	Total Freshwater consumption. Average value for OECD
Resource depletion, mineral, fossil and renewable	CML 2002 (Guinée et al., 2002)	Scarcity	CML2002 Resource Depletion, fossil and mineral, reserve Based

Supplement A 1 Primary energy consumption

Primary energy demand (PED) is often difficult to determine due to the various types of energy sources. Primary energy demand is the quantity of energy directly withdrawn from the hydrosphere, atmosphere or geosphere or energy source without any anthropogenic changes. For fossil fuels and uranium, PED would be the amount of resources withdrawn expressed in their energy equivalents (i.e. the energy content of the raw material). For renewable resources, the energy characterised by the amount of biomass consumed would be described. PED for hydropower would be based on the amount of energy that is gained from the change in the potential energy of the water (i.e. from the height difference). The following primary energies are designated as aggregated values:

The total “**Primary energy consumption non-renewable,**” given in MJ, essentially characterises the gain from the energy sources: natural gas, crude oil, lignite, coal and uranium. Natural gas and crude oil will be used both for energy production and as material constituents, such as in plastics. Coal will primarily be used for energy production. Uranium will only be used for electricity production in nuclear power stations.

The total “**Primary energy consumption renewable,**” given in MJ, is generally accounted for separately and comprises hydropower, wind power, solar energy and biomass.

It is important that end use energy (e.g. 1 kWh of electricity) and primary energy are not confused with each other; otherwise, the efficiency loss in production and supply of the end energy will not be accounted for.

The energy content of the manufactured products will be considered to be feedstock energy content. It will be characterised by the net calorific value of the product. It represents the still-usable energy content that results, such as incineration with energy recovery.

Supplement A 2 Waste categories

In GaBi background databases waste is further treated for known waste pathways towards final emissions in incinerators or landfill bodies, if suitable indications exist (e.g. according to waste directives).

If specific wastes are deposited without further treatment, they are indicated with the addition “deposited.”

If waste treatment routes are unknown, unspecific or not definable, GaBi documents the related specific waste flow and the specific waste amount with a waste star “*” meaning it can be further treated if the user knows the specific waste treatment pathway. Categories such as stockpile goods, consumer waste, hazardous waste and radioactive waste, group those specific waste flows together.

Supplement A 3 Global Warming Potential (GWP)

The mechanism of the greenhouse effect can be observed on a small scale, as the name suggests, in a greenhouse. These effects also occur on a global scale. The occurring short-wave radiation from the sun comes into contact with the earth’s surface and is partially absorbed (leading to direct warming) and partially reflected as infrared radiation. The reflected part is absorbed by greenhouse gases in the troposphere and is re-radiated in all directions, including back to earth. This results in a warming effect at the earth’s surface.

In addition to the natural mechanism, the greenhouse effect is enhanced by human activities. Greenhouse gases, believed to be anthropogenically caused or increased, include carbon dioxide, methane and CFCs. Figure A-1 shows the main processes of the anthropogenic greenhouse effect. An analysis of the greenhouse effect should consider the possible long term global effects.

The global warming potential is calculated in carbon dioxide equivalents (CO₂-Eq.), meaning that the greenhouse potential of an emission is given in relation to CO₂. Since the residence time of gases in the atmosphere is incorporated into the calculation, a time range for the assessment must also be specified. A usual period is 100 years.

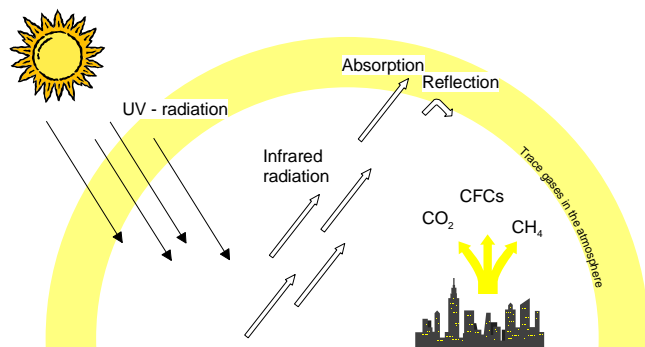


Figure A-1: Greenhouse effect
(KREISSIG & KÜMMEL 1999)

IPCC

All LCIA methodologies have GWP factors which have been determined from the International Panel on Climate Change (IPCC) as the basis of the GWP factors. However, because update schedules are different, two specific IPCC lists of GWP factors are available in GaBi, as updated in the summer 2012. One includes biogenic carbon and one excludes it – see further description of this under ReCiPe 1.07.

CML

CML uses the indices published by the IPCC. Because of the uncertainties in net GWPs for ozone-depleting gases, these indices have not been included in the baseline method. If these uncertainties can be narrowed down in further research, net GWPs should be used for ozone-depleting gases. [CML 2001]

The GWPs for 100 years are recommended as the baseline characterisation method for climate change. The IPCC also provides GWPs for 20 and 500 years. Although 500 years is closer to eternity, CML does not recommend using the GWPs for 500 years as the baseline, due to growing uncertainties in GWP with increasing time span. [CML 2001]

CML includes biogenic carbon at the same level as fossil carbon, hence CO₂ uptake has a GWP of -1 kg CO₂ eq., and the subsequent release has the factor of 1 kg CO₂ eq.

EDIP 2003

The criteria applied in the EDIP methodology to determine if a substance contributes to global warming follow the IPCC's recommendation. At one point the EDIP method goes further than the IPCC's recommendation by including contribution from organic compounds and carbon monoxide of petrochemical origin, which is degraded to CO₂ in the atmosphere. CO₂ emissions are evaluated for whether they constitute a net addition of CO₂ to the atmosphere, and not what they derive from fossil carbon sources, but rather from biomass, and simply represent a manipulation of part of the natural carbon cycle. [HAUSCHILD 2003]

Ecoindicator 99

Ecoindicator 99 works with three damage-oriented categories: Human health, ecosystem quality and resources. These categories are subdivided into mid-point indicators falling under human health impact from climate change which here is considered equivalent to global warming. [GUINÉE ET AL. 2001]

The health-indicator is expressed as the number of Disability-Adjusted Life Years (DALYs), measuring the total amount of ill health, due to disability and premature death, attributable to specific diseases and injuries.

The methodology document mentions several possible effects from climate change of which three are included in the impact classification:

- Exposure to thermal extremes with the outcome of altered rates of heat- and cold-related illnesses and death
- Effects on range and activity of vectors and infective parasites with subsequent disease incidences
- Sea-level rise, with population displacement and damage to infrastructure, and with the outcome of an increased risk of infectious disease and psychological disorders

These effects appear in one calculation factor of a number of DALYs per kg of substance emission.

Impact 2002+

The Impact 2002+ methodology operates with the same three damage-oriented impact categories as Ecoindicator 99: Human health, ecosystem quality and resources. However, from the authors' point of view, the modelling up to the damage of the impact of climate change on ecosystem quality and human health is not accurate enough to derive reliable damage characterisation factors. The interpretation, therefore, directly takes place at midpoint level, making global warming a stand-alone endpoint category with units of kg of CO₂-equivalents. The assumed time horizon is 500 years to account for both short and long term effects. [IMPACT 2002]

ReCiPe 1.07

The ReCiPe methodology operates with both mid-point and end-point indicators:

- End-point: The same three damage-oriented impact categories as Ecoindicator 99 and Impact 2002+; Human health, ecosystem quality, and resources
- Mid-point: 18 mid-point indicators; one of which is global warming.

ReCiPe 2008 was updated to version 1.07, released in July 2012. The researchers are interested in the marginal effect of adding a relatively small amount of CO₂ or other greenhouse gas, and not the impact of all emissions. With no models readily available, the IPCC climate change equivalence factors from the 2007 report are used as the midpoint characterisation factors.

Furthermore, data was found in literature linking the mid-point indicator to a temperature increase and afterwards, to effects on ecosystem quality and human health. [RECIPE 201]

ReCiPe excludes biogenic carbon from the calculations, therefore CO₂ uptake has the factor 0, as does the subsequent release of biogenic carbon.

This necessitates an adjustment of the emission factor for biogenic methane release. The argument is that if we model carbon dioxide uptake which is later released as methane, then we need to have a 1:1 molar carbon balance.

We therefore need:

1 mole CO₂ = 44 g : 1 mole CH₄ = 16 g

44 g CO₂ : 16 g CH₄

2.75 g CO₂ : 1 g CH₄

Consider a plant that sequesters 2.75 kg CO₂ and this carbon is eventually entirely re-released as 1 kg methane. If we model this system including the sequestered carbon, then the GWP calculation will be as follows:

- Sequestered CO₂ = 2.75 kg => -2.75 kg CO₂e
- Emission of CH₄ = 1 kg => 25 kg CO₂e
- Net emission = 25 - 2.75 => 22.25 kg CO₂e

Therefore, if we set the sequestered CO₂ to zero, we need to give the biogenic CH₄ an emission factor of 22.25 kg CO₂ eq to have the proper net emission factor.

TRACI 2.1

TRACI was updated to version 2.1 in the summer of 2012. The methodology utilises global warming potentials (GWPs) to calculate the potency of greenhouse gases relative to CO₂, according to latest IPCC publications, almost identically to the CML methodology. [TRACI 2012]

UBP 2006, Ecological Scarcity Method

The “ecological scarcity” method permits impact assessment of life cycle inventories according to the “distance to target” principle.

Eco-factors, expressed as eco-points per unit of pollutant emission or resource extraction, are normalised and weighted according to Swiss national policy targets, as well as international targets supported by Switzerland. For global warming the Kyoto protocol governs the reduction target, and the IPCC factors translate into the other greenhouse gases. [UBP 2006]

For the comfort of the user, we applied some frequently used impact methods of “Global Warming Potential” (like CML and IPCC) with both approaches, including and excluding biogenic carbon flows. If biogenic carbon as an emission is accounted for, the respective CO₂ uptake from air (modelled as resources) is consistently modelled as well. Before interpreting and communicating results, the user should check for the specific goal, scope and modelling approach in his application case and choose an appropriate Global Warming Impact method, including or excluding biogenic carbon flows.

Global Warming Impact methods excluding biogenic carbon

IPCC global warming, excluding biogenic carbon [kg CO₂-Equiv.]

CML2001 - Nov. 2010, Global Warming Potential, excl biogenic carbon (GWP 100 years) [kg CO₂-Equiv.]

ReCiPe Midpoint (H) - Climate change [kg CO₂-Equiv.]

ReCiPe 1.07 Midpoint (H) - Climate change [kg CO₂-Equiv.]

TRACI 2.0, Global Warming Air, excluding biogenic carbon [kg CO₂-Equiv.]

TRACI 2.1, Global Warming Air [kg CO₂-Equiv.]

Global Warming Impact methods including biogenic carbon

IPCC global warming, including biogenic carbon [kg CO₂-Equiv.]

CML2001 - Nov. 2010, Global Warming Potential (GWP 100 years) [kg CO₂-Equiv.]

CML96, Global warming potential (GWP 100 years) [kg CO₂-Equiv.]

CML96, Global warming potential (GWP 20 years) [kg CO₂-Equiv.]

CML96, Global warming potential (GWP 500 years) [kg CO₂-Equiv.]

I02+ v2.1 - Global warming 500yr - Midpoint [kg CO₂-Eq. to air]

TRACI 2.0, Global Warming Air [kg CO₂-Equiv.]

EDIP 2003, Global warming [kg CO₂-Equiv.]

EDIP 1997, Global warming potential (GWP 100 years) [kg CO₂-Equiv.]

Supplement A 4 Acidification Potential (AP)

CML

The acidification of soils and waters occurs predominantly through the transformation of air pollutants into acids. This leads to a decrease in the pH-value of rainwater and fog from 5.6 to 4 and below. Sulphur dioxide and nitrogen oxide and their respective acids (H₂SO₄ und HNO₃) produce relevant contributions. Ecosystems are damaged, so forest dieback is the most well-known impact.

Acidification has direct and indirect damaging effects (such as nutrients being washed out of soils or an increased solubility of metals into soils). But even buildings and building materials can be damaged. Examples include metals and natural stones which are corroded or disintegrated at an increased rate.

When analysing acidification, it should be considered that although it is a global problem, the regional effects of acidification can vary. Figure A-2 displays the primary impact pathways of acidification. [GUINÉE ET AL. 2001]

The acidification potential is given in sulphur dioxide equivalents (SO₂-Eq.). The acidification potential is described as the ability of certain substances to build and release H⁺ ions. Certain emissions can also have an acidification potential, if the given S-, N- and halogen atoms are set in proportion to the molecular mass of the emission. The reference substance is sulphur dioxide.

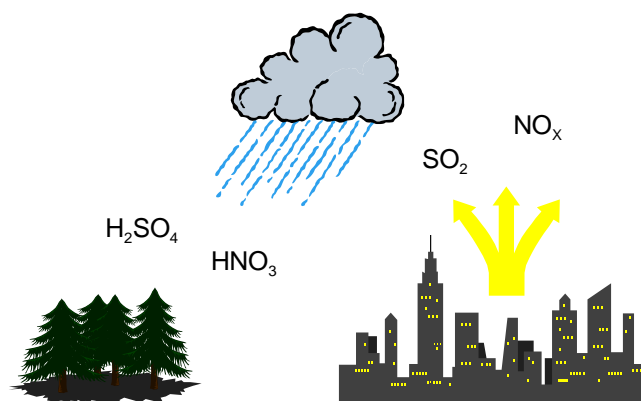


Figure A-2: Acidification Potential
(KREISSIG & KÜMMELE 1999)

The average European characterisation factors of [CML 2001] are currently recommended as the best available practise. Regional factors have not been adopted as the baseline, because it is not always possible, nor desirable, to consider differences between emission sites in LCA.

It is therefore important that emission site-independent characterisation factors become available, even for those impact categories for which local sensitivity is important. [GUINÉE ET AL. 2001]

Accumulated exceedance (AE)

This study uses atmospheric models to calculate the deposition of released acidifying and eutrophying substance per release country and relates this value to the capacity of the receiving soil to neutralize the effects. The method integrates both the exceeded area and amount of exceedance per kg of released substance [SEPPÄLÄ ET AL. 2006].

EDIP 2003

Site-generic factors have been established as well as site-dependent factors for 44 European countries or regions. The acidification factors relate an emission by its region of release to the acidifying impact on its deposition areas.

The application of the EDIP2003 site-*generic* acidification factors is similar to the application of EDIP97 factors which are also site-generic.

The site-generic as well as the site-dependent EDIP2003 acidification potentials of an emission are expressed as the area of ecosystem which is brought to exceed the critical load of acidification as a consequence of the emission (area of unprotected ecosystem = m² UES).

In comparison the EDIP97 acidification potential is expressed as the emission of SO₂ that would lead to the same potential release of protons in the environment (g SO₂-Eq.) similar to the CML methodology. [HAUSCHILD 2003]

Ecoindicator 99

For acidification, eutrophication and land-use the impacts are calculated using the Potentially Disappeared Fraction (PDF) of species. The PDF is used to express the effects on vascular plant populations in an area. The PDF can be interpreted as the fraction of species that has a high probability of no occurrence in a region due to unfavourable conditions. The fate and damage of emitted substances are calculated via computer models of the Netherlands.

Impact 2002+

The characterisation factors for aquatic acidification are expressed in SO₂-equivalents and are adapted from the EDIP1997 methodology which also corresponds to the approach from CML. [IMPACT 2002]

ReCiPe 1.07

The ReCiPe methodology calculates acidification as the Potentially Disappeared Fraction (PDF) of species in forest ecosystems on a European scale, which is similar to the Ecoindicator approach. [RECIPE 201]

TRACI 2.1

TRACI 2.1 utilises the existing TRACI methodology for acidification plus some additional substances. The calculations are performed for US conditions and the reference substance is kg SO₂ eq. [TRACI 201]

UBP 2006, Ecological Scarcity Method

The method has adapted CML values as the approach for acidification.

Supplement A 5 Eutrophication Potential (EP)

CML

Eutrophication is the enrichment of nutrients in a certain place. Eutrophication can be aquatic or terrestrial. Air pollutants, wastewater and fertilisation in agriculture all contribute to eutrophication.

The result in water is an accelerated algae growth, which in turn, prevents sunlight from reaching the lower depths. This leads to a decrease in photosynthesis and less oxygen production. Oxygen is also needed for the decomposition of dead algae. Both effects cause a decreased oxygen concentration in the water, which can eventually lead to fish dying and to anaerobic decomposition (decomposition without the presence of oxygen). Hydrogen sulphide and methane are produced. This can lead to the destruction of the eco-system, among other consequences.

On eutrophicated soils an increased susceptibility of plants to diseases and pests is often observed, as is degradation of plant stability. If the nitrification level exceeds the amounts of nitrogen necessary for a maximum harvest, it can lead to an enrichment of nitrate. This can cause, by means of leaching, increased nitrate content in groundwater. Nitrate also ends up in drinking water.

Nitrate at low levels is harmless from a toxicological point of view. Nitrite, however, is a reaction product of nitrate and toxic to humans. The causes of eutrophication are displayed in Figure A-3. The eutrophication potential is calculated in phosphate equivalents ($\text{PO}_4\text{-Eq.}$). As with acidification potential, it is important to remember that the effects of eutrophication potential differ regionally.

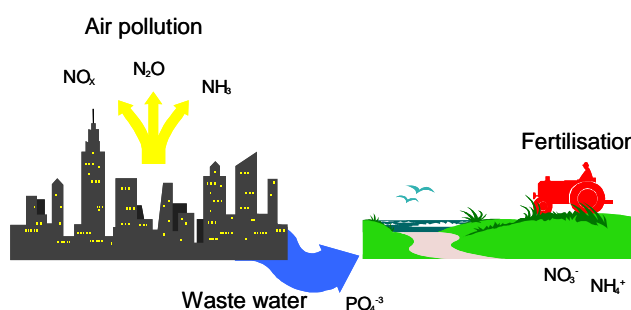


Figure A-3: Eutrophication Potential (KREISSIG & KÜMMELE 1999)

All emissions of N and P to air, water and soil and of organic matter to water are aggregated into a single measure, as this allows both terrestrial and aquatic eutrophication to be assessed. The characterisation factors in PO_4 -equivalents, NO_3 -equivalents and O_2 -equivalents are all interchangeable, and PO_4 -equivalents are used. [GUINÉE ET AL. 2001]

Accumulated exceedance (AE)

This study uses atmospheric models to calculate the deposition of released acidifying and eutrophying substance per releasing country and relates this to the capacity of the receiving soil to neutralize the effects. The

method integrates both the exceeded area and amount of exceedance per kg of released substance [SEPPÄLÄ ET AL. 2006].

EDIP 2003

The EDIP 2003 methodology distinguishes between aquatic and terrestrial eutrophication.

Aquatic eutrophication

The aquatic inputs are atmospheric deposition of nitrogen on soil and coastal seas, phosphorus and nitrogen supply to agricultural soils, phosphorus and nitrogen discharged with municipal wastewater. A computer model (CARMEN) calculates transport of the inlet nutrients to surface water.

The nitrogen and phosphorus sources have been allocated to each grid-element on the basis of the distribution of land uses in the given grid-element (arable land, grassland, permanent crops, forest, urban area, inland waters).

The transport of nutrient by rivers to sea is modelled assuming fixed removal rates of N and P in freshwater systems. [HAUSCHILD 2003]

Terrestrial eutrophication

Site-dependent factors have been established for 44 European countries or regions. The eutrophication factors relate an emission by its region of release to the acidifying impact on its deposition areas.

The site-generic terrestrial eutrophication factors are established as the European average over the 15 EU member countries in the EU15 plus Switzerland and Norway, weighted by the national emissions. The site-generic as well as the site-dependent EDIP2003 acidification potentials of an emission are expressed as the area of ecosystem whose inclusion exceeds the critical load of eutrophication as a consequence of the emission (area of unprotected ecosystem = m² UES). [HAUSCHILD 2003]

Ecoindicator 99

For acidification, eutrophication and land-use the impacts are calculated using the Potentially Disappeared Fraction (PDF) of species. The PDF is used to express the effects on vascular plant populations in an area. The PDF can be interpreted as the fraction of species that has a high probability of no occurrence in a region due to unfavourable conditions. The fate and damage of emitted substances are calculated via computer models of the Netherlands. [ECO-INDICATOR 99 : 2000]

Impact 2002+

Midpoint characterisation factors (in kg PO₄³⁻-equivalents) are given for emissions into air, water and soil with characterisation factors taken directly from CML.

No aquatic eutrophication damage factors (in PDF·m²·yr/kg emission) are given because no available studies support the assessment of damage factors for aquatic eutrophication. [IMPACT 2002]

ReCiPe 1.07

ReCiPe operates with both mid-point and end-point indicators.

Mid-point indicators are divided into freshwater and marine eutrophication. At the freshwater level, only phosphorus is included and at the marine level, only nitrogen is included. It can be written as the marginal concentration increment in tn/km^3 in exposed aquatic system per marginal increase of emission rate in tn/yr , hence with the unit yr/km^3 . This is the amount supplied per kg of pure nitrogen or phosphorus emitted. When included in GaBi this value is then converted into phosphorus and nitrogen equivalents for the emitted substances²¹.

As an endpoint, ReCiPe operates with species loss in freshwater on a European scale. [RECIPE 2012]

TRACI 2.1

The characterisation factors of TRACI 2.1 estimate the eutrophication potential of a release of chemical containing N or P to air or water relative to 1 kg N discharged directly to surface freshwater, therefore with the unit kg N eq. [TRACI 201]

UBP 2006, Ecological Scarcity Method

The “ecological scarcity” method permits impact assessment of life cycle inventories according to the “distance to target” principle.

Eco-factors, expressed as eco-points per unit of pollutant emission or resource extraction, are normalised and weighted according to Swiss national policy targets, as well as international targets supported by Switzerland. For acidification this is a 50% reduction target in Rhine catchment according to the OSPAR Commission. [UBP 2006]

Supplement A 6 Photochemical Ozone Creation Potential (POCP)

CML

Despite playing a protective role in the stratosphere, ozone at ground level is classified as a damaging trace gas. Photochemical ozone production in the troposphere, also known as summer smog, is suspected to damage vegetation and material. High concentrations of ozone are toxic to humans.

Radiation from the sun and the presence of nitrogen oxides and hydrocarbons incur complex chemical reactions, producing aggressive reaction products, one of which is ozone. Nitrogen oxides alone do not cause high ozone concentration levels.

Hydrocarbon emissions occur from incomplete combustion, in conjunction with petrol (storage, turnover, refuelling) or from solvents. High concentrations of ozone arise when temperature is high, humidity is low, air is relatively static and there are high concentrations of hydrocarbons. Today it is assumed that the existence of NO and CO reduces the accumulated ozone to NO₂, CO₂ and O₂. This means that high concentrations of ozone do not often occur near hydrocarbon emission sources. Higher ozone concentrations more commonly arise in areas of clean air, such as forests, where there is less NO and CO (Figure A-4).

²¹ The emissions to agricultural soil should be multiplied with the fertilizer factors in ReCiPe main report.

In Life Cycle Assessments photochemical ozone creation potential (POCP) is referred to in ethylene-equivalents (C₂H₄-Eq.). During analysis it is important to note that the actual ozone concentration is strongly influenced by the weather and by the characteristics of local conditions.

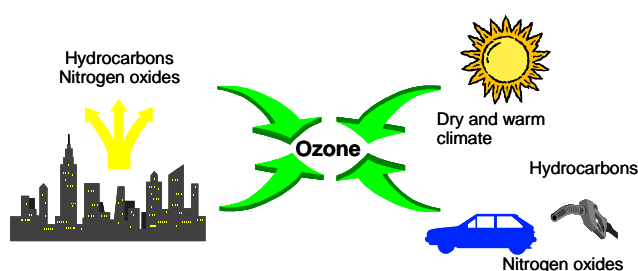


Figure A-4: Photochemical Ozone Creation Potential (KREISSIG & KÜMMEL 1999)

The most recent POCP factors are still the ones used for the original CML methodology with only a few adjustments. [GUINÉE ET AL. 2001]

EDIP 2003

The EDIP2003 characterisation factors for photochemical ozone formation have been developed using the RAINS model which was also used for development of characterisation factors for acidification and terrestrial eutrophication. Site-generic factors have been established, in addition to site-dependent factors for 41 European countries or regions. The photochemical ozone formation factors relate an emission by its region of release to the ozone exposure and impact on vegetation or human beings within its deposition areas. [HAUSCHILD 2003]

Ecoindicator 99

In Ecoindicator 99 the POCP expresses the incremental ozone concentration per incremental emission for specific VOC species normalised by the ratio for ethylene, equivalent to the CML approach. This is then calculated further via epidemiological studies to yield the end-point indicator of Disability Adjusted Life Years (DALYs). [ECO-INDICATOR 99 : 2000]

Impact 2002+

Photochemical oxidation (damage in DALY/kg emissions) is taken directly from Eco-indicator 99. Midpoints are given relative to air emissions of ethylene equivalent to CML. [IMPACT 2002]

ReCiPe 1.07

The dynamic model LOTOS-EUROS was applied to calculate intake fractions for ozone due to emissions of NO_x.

The mid-point characterisation factor for ozone formation of a substance is defined as the marginal change in the 24h-average European concentration of ozone (in kg/m³) due to a marginal change in emission (in kg/year) expressed as NMVOC-equivalents.

The end-point indicator is human health expressed as DALYs. [RECIPE 201]

TRACI 2.1

Impacts of photochemical ozone creation are quantified using the Maximum Incremental Reactivity (MIR) scale. This scale is based on model calculations of effects of additions of the VOCs on ozone formation in one-day box model scenarios representing conditions where ambient ozone is most sensitive to changes in VOC emissions. The emissions are normalised relative to ozone (O_3 -equivalents). [TRACI 201]

UBP 2006, Ecological Scarcity Method

Eco-factors, expressed as eco-points per unit of pollutant emission, are normalised against the entirety of Switzerland and weighted according to Swiss national policy targets. For POCP the target value is the average of three values [UBP 2006];

- Swiss Federal Air Pollution Control Ordinance's ambient limit values for ozone
- The Swiss air pollution control strategy stipulates a reduction to the level of 1960 as a minimum target for NMVOCs
- The environment ministers of Germany, Liechtenstein, Switzerland and Austria adopted a declaration setting the target of reducing NMVOC emissions by 70-80% from the level of the 1980s.

Supplement A 7 Ozone Depletion Potential (ODP)

Ozone is created in the stratosphere by the disassociation of oxygen atoms that are exposed to short-wave UV-light. This leads to the formation of the so-called ozone layer in the stratosphere (15-50 km high). About 10% of this ozone reaches the troposphere through mixing processes. In spite of its minimal concentration, the ozone layer is essential for life on earth. Ozone absorbs the short-wave UV-radiation and releases it in longer wavelengths. As a result, only a small part of the UV-radiation reaches the earth.

Anthropogenic emissions deplete ozone. This is well-known from reports on the hole in the ozone layer. The hole is currently confined to the region above Antarctica; however further ozone depletion can be identified, albeit not to the same extent, over the mid-latitudes (e.g. Europe). The substances which have a depleting effect on the ozone can essentially be divided into two groups; the chlorofluorocarbons (CFCs) and the nitrogen oxides (NO_x). Figure A-5 depicts the procedure of ozone depletion.

One effect of ozone depletion is the warming of the earth's surface. The sensitivity of humans, animals and plants to UV-B and UV-A radiation is of particular importance. Possible effects are changes in growth or a decrease in harvest crops (disruption of photosynthesis), indications of tumours (skin cancer and eye diseases) and a decrease of sea plankton, which would strongly affect the food chain. In calculating the ozone depletion potential, the anthropogenically-released halogenated hydrocarbons, which can destroy many ozone molecules, are recorded first. The Ozone Depletion Potential (ODP) results from the calculation of the potential of different ozone relevant substances.

A scenario for a fixed quantity of emissions of a CFC reference (CFC 11) is calculated, resulting in an equilibrium state of total ozone reduction. The same scenario is considered for each substance under study where CFC 11 is replaced by the quantity of the substance. This leads to the ozone depletion potential for each respective substance, which is given in CFC 11-equivalents. An evaluation of the ozone depletion potential should take into consideration the long term, global and partly irreversible effects.

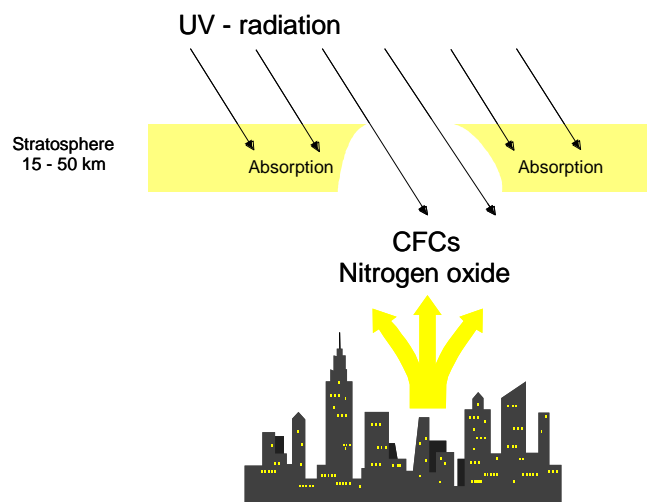


Figure A-5: Ozone Depletion Potential
(KREISSIG & KÜMMEL 1999)

In CML the ODPs published by the World Meteorological Organisation (WMO) from 2002 are used. [GUINÉE ET AL. 2001]

EDIP 2003

The EDIP factors are calculated via the same principle as CML. [HAUSCHILD 2003]

Ecoindicator 99

The fate of CFC11 was modelled and used to estimate the fate of other substances. Standard ODPs are used to relate this to reduction in ozone. The increase in UV radiation was then used to estimate the increase in eye cataract and skin cancer which is finally expressed as Disability Adjusted Life Years (DALYs). [ECO-INDICATOR 99 : 2000]

Impact 2002+

Midpoints (kg CFC-11-Eq. into air/kg emission) have been obtained from the US Environmental Protection Agency Ozone Depletion Potential List. The damage factor (in DALY/kg emission) for the midpoint reference substance (CFC-11) was taken directly from Eco-indicator 99. Damage (in DALY/kg emission) for other substances has been obtained by the multiplication of the midpoints (in kg CFC-11- Eq. into air/kg emission) and the CFC-11 damage factor (in DALY/kg CFC-11 emission). [IMPACT 2002]

ReCiPe 1.07

The ODPs from Ecoindicator are used as equivalency factors, characterising substances at the midpoint level. As an end-point indicator, only damage to human health (skin cancer and cataracts) is addressed because uncertainty regarding other areas of protection was considered too large. In a new approach the fate of a marginal increase of emission of ozone depleting substances and the resulting worldwide increase of UVB exposure is evaluated, taking into account population density, latitude and altitude. For characterisation of

damage, protective factors are accounted for, such as skin colour and culturally-determined habits such as clothing. [RECIPE 201]

TRACI 2.1

Within TRACI 2.1, the most recent sources of ODPs from WMO (World Meteorological Organization) are used for each substance. [TRACI 201]

UBP 2006, Ecological Scarcity Method

The Swiss Chemicals Risk Reduction Ordinance prohibits the production, importation and use of ozone-depleting substances. Exemptions regarding importation and use are presently only in place for the maintenance of existing HCFC refrigeration equipment and for the recycling of HCFC refrigerants with a transitional period lasting until 2015.

The primary stocks formed in building insulation materials will continue releasing considerable amounts. No critical flow can therefore be derived directly from the wide-ranging ban on the consumption of ozone-depleting substances.

The tolerated emissions are taken as the basis for determining the critical flow. As the exemptions for HCFC use in existing refrigeration equipment terminate in 2015, the anticipated emissions in 2015 are used as the critical flow (the target). The current emissions are estimated to calculate the ecofactor.

Standard ODPs are used to convert this ecofactor to other ozone-depleting substances. [UBP 2006]

Supplement A 8 Human and eco-toxicity, USEtox

USEtox is a scientific consensus model developed by those behind the CalTOX, IMPACT 2002, USES-LCA, BETR, EDIP, WATSON and EcoSense.

In 2005, a comprehensive comparison of life cycle impact assessment toxicity characterisation models was initiated by the United Nations Environment Program (UNEP)–Society for Environmental Toxicology and Chemistry (SETAC) Life Cycle Initiative, directly involving the model developers of CalTOX, IMPACT 2002, USES-LCA, BETR, EDIP, WATSON and EcoSense.

The main objectives of this effort were (1) to identify specific sources of differences between the models' results and structure, (2) to detect the indispensable model components and (3) to build a scientific consensus model from them, which represent the recommended practise.

Based on a referenced database, it has now been used to calculate CFs for several thousand substances, and forms the basis of the recommendations from UNEP-SETAC's Life Cycle Initiative regarding characterisation of toxic impacts in life cycle assessment.

The model provides both recommended and interim (not recommended and to be used with caution) characterisation factors for human health and freshwater ecotoxicity impacts.

USEtox calculates characterisation factors for human toxicity and freshwater ecotoxicity via three steps: environmental fate, exposure and effects.

The continental scale of the model consists of six compartments: urban air, rural air, agricultural soil, industrial soil, freshwater and coastal marine water. The global scale has the same structure, but without the urban air.

The human exposure model quantifies the increase in amount of a compound transferred into the human population based on the concentration increase in the different media.

Human effect factors relate the quantity taken in to the potential risk of adverse effects in humans. It is based on cancerous and non-cancerous effects derived from laboratory studies.

Effect factors for freshwater ecosystems are based on species-specific data of concentration at which 50% of a population displays an effect.

The final characterisation factor for human toxicity and aquatic ecotoxicity is calculated by summation of the continental- and the global-scale assessments.

The characterisation factor for human toxicity is expressed in comparative toxic units (CTUh), providing the estimated increase in morbidity per unit mass of a chemical emitted (cases per kilogram).

The characterisation factor for aquatic ecotoxicity is expressed in comparative toxic units (CTUe) and provides an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of a chemical emitted (PAF m³-day/ kg). [USEtox 2010]

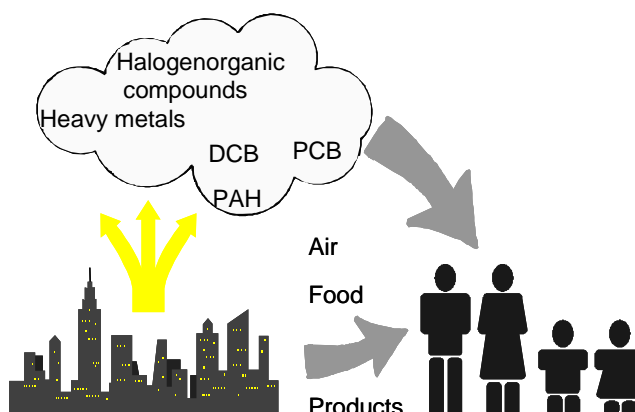


Figure A-6: Human Toxicity Potential

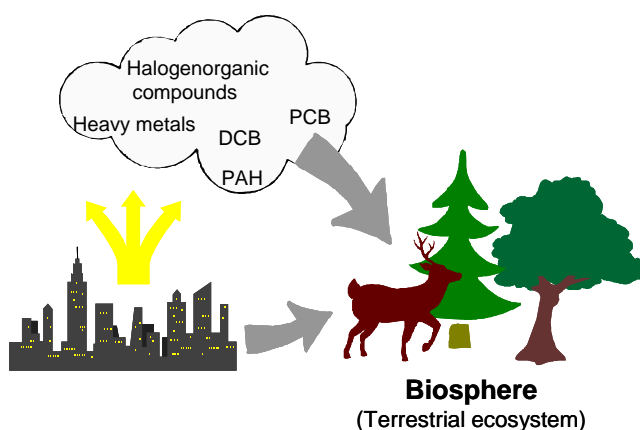


Figure A-7: Terrestrial Eco-Toxicity Potential

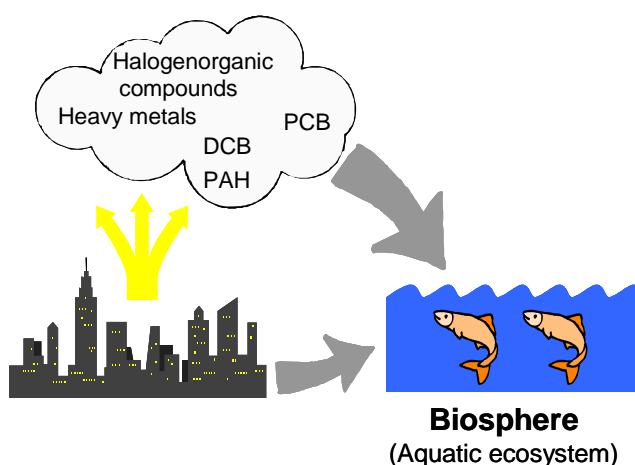


Figure A-8: Aquatic Eco-Toxicity Potential

CML

The CML toxicity calculations are based on fate modelling with USES-LCA. This multimedia fate is divided into 3% surface water, 60% natural soil, 27% agricultural soil and 10% industrial soil. 25% of the rainwater is infiltrated into the soil.

The potential toxicities (human, aquatic and terrestrial ecosystems) are generated from a proportion based on the reference substance 1,4-Dichlorbenzol ($C_6H_4Cl_2$) in the air reference section. The unit is kg 1,4-Dichlorbenzol-Equiv. (kg DCB-Eq.) per kg emission [GUINÉE ET AL. 2002].

The identification of the toxicity potential is rife with uncertainties because the impacts of the individual substances are extremely dependent on exposure times and various potential effects are aggregated. The model is therefore based on a comparison of effects and exposure assessment. It calculates the concentration in the environment via the amount of emissions, a distribution model and the risk characterisation via an input-sensitive module. Degradation and transport in other environmental compartments are not represented. [GUINÉE ET AL. 2001]

EDIP 2003

Toxicity impacts from EDIP 2003 are no longer included in GaBi, as the EDIP methodology has shifted to using the USEtox methodology to assess toxicity impacts.

Ecoindicator 99

For the fate analysis of carcinogenic substances causing damage to Human Health and ecotoxic substances causing damage to Ecosystem Quality, the European Uniform System for the Evaluation of Substances (EUSES) is used. Different environmental media (air, water, sediment, and soil) are modelled as homogeneous, well-mixed compartments or boxes.

Substances that cause respiratory effects are modelled with atmospheric deposition models and empirical observations.

The damage, expressed as the number of Disability-Adjusted Life Years (DALYs), measures the total amount of ill health, due to disability and premature death, attributable to specific diseases and injuries. [ECO-INDICATOR 99 : 2000]

Impact 2002+

Impact 2002+ expresses toxicity in a total of four mid-point impact categories; human toxicity (carcinogen and non-carcinogen effects), respiratory effects (caused by inorganics), aquatic ecotoxicity, and terrestrial ecotoxicity.

Damages are expressed in Disability-Adjusted Life Years for human effects and Potentially Disappeared Fraction (PDF) of species for ecotoxic effects. [IMPACT 2002]

ReCiPe 1.07

The characterisation factor of human toxicity and ecotoxicity is composed of the environmental persistence (fate) and accumulation in the human food chain (exposure), and toxicity (effect) of a chemical. The ReCiPe method uses an update of the model used in the CML methodology referred to as USES-LCA 2.0.

The potential human toxicity and three categories of eco-toxicity (freshwater, marine and terrestrial) are expressed as mid-point indicators relative to 1,4-Dichlorbenzol (kg DCB-Eq.).

The end-point indicators are expressed in DALYs for human toxicity and species loss for ecotoxicity. [RECIPE 201]

TRACI 2.1

The TRACI 2.1 methodology has adopted the approach of the USEtox model combined with some additions from the original TRACI methodology. [TRACI 201]

UBP 2006, Ecological Scarcity Method

The method has developed ecopoints per kg-emitted substance for only a limited amount of substances. [UBP]

Supplement A 9 Resource depletion**CML**

The abiotic depletion potential (ADP) covers some selected natural resources as metal-containing ores, crude oil and mineral raw materials. Abiotic resources include raw materials from non-living resources that are non-renewable. This impact category describes the reduction of the global amount of non-renewable raw materials. Non-renewable means a time frame of at least 500 years. The abiotic depletion potential is split into two sub-categories, elements and fossil.

Abiotic depletion potential (elements) covers an evaluation of the availability of natural elements like minerals and ores, including uranium ore. The reference substance for the characterisation factors is antimony. Two calculations of ADP (elements) from CML are integrated in GaBi5, one based on ultimate ultimate resources (i.e. the total mineral content in the earth crust) and one based on what is evaluated as being economically feasible to extract. The latter version is recommended by ILCD.

The second sub-category is abiotic depletion potential (fossil), which includes the fossil energy carriers (crude oil, natural gas, coal resources). MJ is the respective unit. [GUINÉE ET AL. 2001]

EDIP 2003

The former EDIP methodology, EDIP 1997, contained a resource category consisting of 87 resource quantities (minerals and fossil resources) without any classification or characterisation. This category is omitted in the EDIP 2003 update. [HAUSCHILD 2003]

Ecoindicator 99

The primary assumption in this method is that if the resource quality is reduced, the effort to extract the remaining resource increases. Plain market forces will ensure that mankind always exploits the resources with the highest quality. This means each time a kg of a resource is used, the quality of the remaining resources is slightly decreased and thus the effort to extract the remaining resources is increased. The damage to resources is measured in MJ of surplus energy which is defined as the difference between the energy needed to extract a resource now and at some specific point in the future. [ECO-INDICATOR 99 : 2000]

Impact 2002+

Characterisation factors for non-renewable energy consumption, in terms of the total primary energy extracted, are calculated with the upper heating value. It is taken from ecoinvent (Frischknecht et al. 2003).

Mineral extractions in MJ surplus energy are taken directly from Eco-indicator. [IMPACT 2002]

ReCiPe 1.07

The marginal cost increase on the deposit level can be defined as the marginal average cost increase (\$/\$) due to extracting a dollar value of deposit (1/\$).

From the marginal cost increase factor on the deposit level, the cost increase factor on commercial metal level is calculated. The mid-point is then related to iron as iron equivalents (Fe-Eq.).

TRACI 2.1

The abiotic resource depletion in TRACI 2.1 focuses on fossil fuels with an approach taken from Ecoindicator. Extraction and production of fossil fuels consume the most economically recoverable reserves first, making continued extraction more energy intensive, hence the unit of MJ surplus energy. [TRACI 201]

UBP 2006, Ecological Scarcity Method

Eco-factors, expressed as eco-points per MJ of energy consumption are used for energy.

Minerals are not included. [UBP 2006]

Land Use, LANCA

Land use is also considered a limited resource. It is integrated in GaBi 6 via 5 indicators: Erosion resistance, mechanical filtration, physicochemical filtration, groundwater replenishment, and biotic production. The background is the LANCA tool (Land Use Indicator Calculation Tool) based on country-specific input data and the respective land use types. A detailed description of the underlying methods can be found in BECK, BOS, WITTSTOCK ET AL. 2010.

Land Use, Soil Organic Matter (SOM)

SOM (closely related to soil organic carbon, SOC) is basically a balance of the organic matter in soil related to the anthropogenic use of land for human activity. Initial organic content, as well as an annual balance of the organic matter in the soil, is necessary to calculate this [MILÁ I CANALS 2007]. It is currently not integrated in

GaBi5 as an impact category but can be calculated from LCI datasets as CO₂ extracted from atmosphere minus carbon flows to water, and carbon uptake in products.

Water

Standardisation for the creation of an approach for water footprinting and water use as an impact assessment category is underway.

All water-related flows of GaBi LCI data are updated to enable consistent, high quality water modelling for water use assessments and water footprinting according to the upcoming ISO Water Footprint standard, the Water Footprint Network Manual and other emerging guidelines.

Four new water quantities were implemented to reflect the latest status of best practise in water footprinting and water assessments.

Total freshwater consumption (including rainwater)

Blue water consumption

Blue water use

Total freshwater use

Furthermore, we added a “Total freshwater consumption (including rainwater)” quantity in the light of the recommended ILCD methods carrying a characterised value according to the UBP method.

Supplement A 10 Particulate matter formation (PM)

Riskpoll

The Riskpoll model evaluates human health impacts from primary particles emitted directly and from secondary particles formed in the air by emitted substances [RABL AND SPADARO 2004]. The reference unit is kg PM_{2.5} eq.

ReCiPe 1.07

The atmospheric fate was calculated using a combination of the models EUTREND and LOTOS-EUROS including effects of both primary and secondary particles. The reference unit is kg PM₁₀ eq.

TRACI 2.1

These intake fractions are calculated as a function of the amount of substance emitted into the environment, the resulting increase in air concentration, and the breathing rate of the exposed population. The increasing air concentrations are a function of the location of the release and the accompanying meteorology and the background concentrations of substances, which may influence secondary particle formation. Substances were characterised using PM_{2.5} as the reference substance.

Supplement A 11 Normalization

Normalization relates each impact to a reference of a per capita or a total impact for a given area for a given year. An overview is given in Table K.

Table K: Normalization references

Methodology	Impact calculated (year)	Area(s) covered
CML 2001	Total impact (2000)	World, Europe
ReCiPe 1.07, Ecoindicator	Per capita impact (2000)	World, Europe
TRACI 2.1	Per capita impact (2006)	USA, USA+Canada
EDIP 2003	Per capita impact (1994)	Europe
UBP 2006	Per capita impact (various)	Switzerland
USEtox	Per capita impact (2004 Europe) (2002/2008 North America)	Europe, North America

Conversion between CML and ReCiPe is possible using a global population of 6,118,131,162 and a EU25+3 population of 464,621,109 in year 2000 [EUROSTAT 2012][WORLD BANK 2012]. Notably the '+3' countries in EU25+3 are Iceland, Norway, and Switzerland.

Supplement A 12 Weighting

The weighting attaches a value to each of the normalized values giving a value based importance of each impact. This can be based on political reduction targets or on the opinions of experts and/or laymen, for example.

In 2012 PE INTERNATIONAL sent out a questionnaire worldwide asking experts to value the main environmental impact categories on a 1-10 scale. The total number of respondents were 245 mainly consultants and academia and mainly from Europe and North America. Figure A-9 below gives an overview of the respondents with the area and colon of each rectangle representing the number of people within each category.

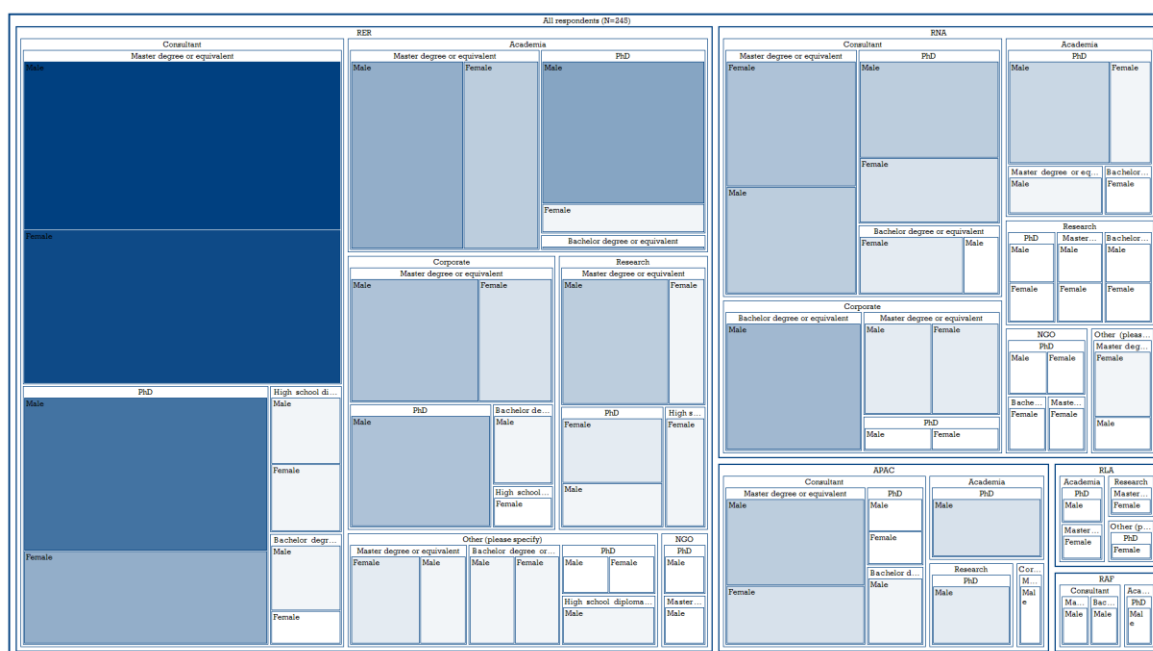


Figure A-9: Response to PE Weighting 2012

The answers from the questionnaires led to the weighting factors in Table L. The weighting factors are linked to the impact categories of CML and ReCiPe (Global + Europe), and for TRACI 2.1 (Global + North America). Additionally, the IPCC category for global warming is also included (Global + Europe + North America).

Table L: PE Weighting 2012

Impact	Europe	North America	Global
Acidification	6.2	5.9	6.1
Eco-Toxicity	6.6	7.0	6.8
Eutrophication	6.6	6.6	6.6
Global Warming	9.3	9.5	9.3
Human Toxicity	6.9	7.5	7.1
Ionising Radiation	5.8	5.0	5.7
Ozone Depletion	6.2	6.1	6.2
Particulate Matter Formation	6.5	6.9	6.7
Photochemical Ozone	6.5	6.7	6.5
Resources, ADP elements	6.3	6.1	6.4
Resources, ADP fossil	6.9	6.7	7.0
Resources, Land Use	7.2	7.1	7.2
Water Footprint	7.9	8.4	8.0

Supplement B Background information on uncertainty

The following chapter provides background information on uncertainty issues in LCA.

Aspects of data uncertainty due to variability in supply chains

While Chapter 1 addressed data and model uncertainty assuming that the practitioner has been able to select the most appropriate or 'representative' datasets for the product system under study, this chapter will attempt to quantify relevant aspects of uncertainty in background data due to its variability concerning technological and geographical representativeness.

As mentioned in the previous chapter, +/-10% uncertainty appears to be the minimum overall uncertainty, even if the model is set up with data of high quality containing few errors.

The model's degree of representativeness regarding supply chains and technology routes depends on the specific situation under consideration. It varies due to factors including specific supplier companies and geographical/national import situations.

The correlation between the background data and the specific situation at hand can only be answered by performing a primary data collection for each specific supply situation and comparing it with the average situation represented by the background data.

The background data as such may be very precise and of extremely high representativeness within the situation where it was set up. The goal of this chapter is to estimate possible variations in background data due to the mismatch between the average and actual supply chain in a specific situation. To achieve this goal two types of possible misrepresentation introduced by the user of the data are assessed:

- the influence of varying the import/production country
- the influence of varying the technology route in the same country to supply the same material or substance

The analysis focuses on chemical products and intermediate products.

Disclaimer:

The following analyses are specific to the products and datasets available in the GaBi databases. The results cannot be generalised to other products or data sources.

Influence of varying import/production country for same technology

The following chemical substances were analysed for their variability with regard to their geography.

Table M: Chemical substance datasets available for various countries in GaBi

Acetic acid from methanol	Hydrogen (Steamreforming fuel oil s)
Acetone by-product phenol methyl styrene (from Cumol)	Hydrogen (Steamreforming natural gas)
Adipic acid from cyclohexane	Maleic anhydride (MA) by-product PSA (by oxidation of xylene)
AH-salt 63% (HMDA via adipic acid)	Maleic anhydride from n-butane
Ammonium sulphate by-product caprolactam	Methyl methacrylate (MMA) spent acid recycling
Benzene (from pyrolysis gasoline)	Methyl methacrylate (MMA) from acetone and hydrogen cyanide
Benzene (from toluene dealkylation)	Methylene diisocyanate (MDI) by-product hydrochloric acid, methano
Benzene by-product BTX (from reformatee)	Phenol (toluene oxidation)
Caprolactam from cyclohexane	Phenol from cumene
Caprolactam from phenol	Phosphoric acid (wet process)
Chlorine from chlorine-alkali electrolysis (amalgam)	Phthalic anhydride (PAA) (by oxidation of xylene)
Chlorine from chlorine-alkali electrolysis (diaphragm)	Propylene glycol over PO-hydrogenation
Chlorine from chlorine-alkali electrolysis (membrane)	Propylene oxide (Cell Liquor)
Ethanol (96%) (hydrogenation with nitric acid)	Propylene oxide (Chlorohydrin process)
Ethene (ethylene) from steam cracking	Propylene oxide by-product t-butanol (Oxirane process)
Ethylbenzene (liquid phase alkylation)	p-Xylene (from reformate)
Ethylene glycol from ethene and oxygen via EO	Toluene (from pyrolysis gasoline)
Ethylene oxide (EO) by-product carbon dioxide from air	Toluene by-product BTX (from reformate)
Ethylene oxide (EO) by-product ethylene glycol	Toluene by-product styrene
Hexamethylene diamine (HMDA) via adipic acid	Toluene diisocyanate (TDI) by-product toluene diamine, hydrochloric acid (phosgenation)
Hydrochloric acid by-product methylene diisocyanate (MDI)	Xylene mix by-product benzene (from pyrolysis gasoline)

These routes were analysed (as available) concerning process boundary conditions in various countries including:

Australia (AU), Belgium (BE), China (CN), Germany (DE), Spain (ES), France (FR), Great Britain (GB), Italy (IT), Japan (JP), Netherlands (NL), Norway (NO), Thailand (TH), United States (US)

The following figure shows the resulting maximum variations of all analysed materials and substances. The respective technologies are kept constant and only the country of origin is varied. The figure shows the maximum variability across the various chemicals that have been analysed, as well as the 90% and 10% percentiles.

Two cases were calculated for each route, assuming that the actual location of the supplier is unknown in a given LCA project. Choosing the dataset with the lowest burden while the one with the highest burden would have been appropriate ('choose min'; uncertainty = (min-max)/max) and vice versa ('choose max'; uncertainty = (max-min)/min). The resulting values are therefore the relative '**worst-case errors**' possible based on the datasets considered.

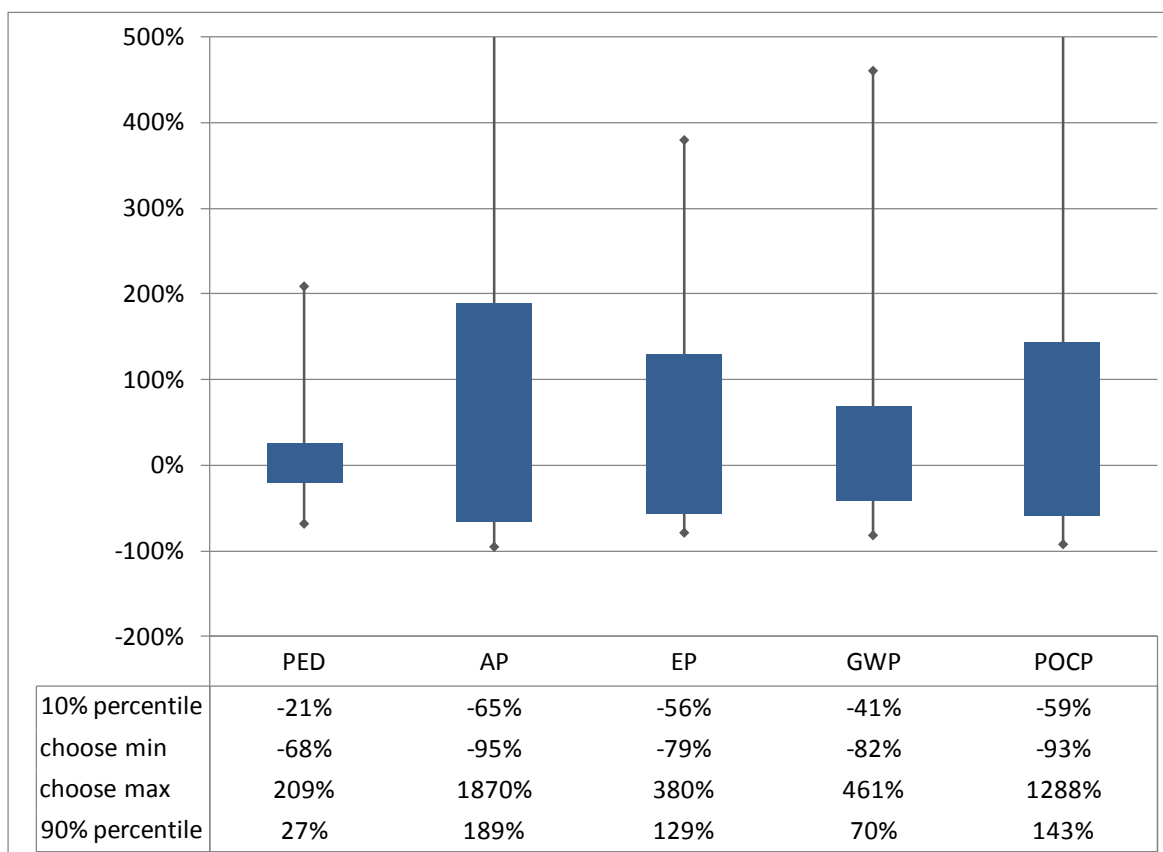


Figure B-10: Maximum errors regarding randomly chosen geography

Figure B-10 shows that when assuming that the technology route for a certain substance is known and the specific country of origin route is not, the maximum uncertainty of the related impacts is **between -65% and +189% for 80% of all chemical substances** for which different country-specific datasets are available in the GaBi Database.

When taking the background information of the GaBi MasterDB in to account, the sensitivity concerning the country of origin appears to be more relevant for process chains where energy and the respective emissions from energy supply dominate the impacts. In selected cases country-specific emissions or synthesis efficiencies and differences in country-specific upstream supply are also relevant.

Influence of varying technology in the same country

The following chemical substances were analysed regarding their variability with regard to their technology route in the same country.

Table N: Chemical substance datasets available for various technology routes in GaBi

Chlorine from chlorine-alkali electrolysis diaphragm	Ethylene-t-Butylether from C4 and bio ethanol
Chlorine from chlorine-alkali electrolysis membrane	Hexamethylene diamine via Adiponitrile
Chlorine from chlorine-alkali electrolysis amalgam	Hexamethylene diamine via adipic acid
Acetic acid from vinyl acetate	Hydrochloric acid primary from chlorine
Acetic acid from methanol	Hydrochloric acid by-product allyl chloride
Acrylamide catalytic hydrolysis	Hydrochloric acid by-product chlorobenzene
Acrylamide enzymatic hydration	Hydrochloric acid by-product epichlorohydrin
AH salt 63% HMDA from adipic acid	Hydrochloric acid by-product Methylene diisocyanate
AH salt 63% HMDA from acrylonitrile	Hydrogen Cracker
Ammonium sulphate by-product acetone cyanhydrin	Hydrogen Steamreforming fuel oil s
Ammonium sulphate by-product Caprolactam	Hydrogen Steamreforming natural gas
Benzene from pyrolysis gasoline	Maleic anhydride from n-butane
Benzene from toluene dealkylation	Maleic anhydride by-product phthalic anhydride
Benzene by-product BTX	Maleic anhydride from benzene
Benzene by-product ethine	Methyl methacrylate from acetone and hydrogen cyanide
Butanediol from ethine, H2 Cracker, allotherm	Methyl methacrylate spent acid recycling
Butanediol from ethine H2 Steam ref. natural gas, autotherm	Oleic acid from palm oil
Chlorodifluoroethane from 1,1,1-Trichloroethane	Oleic acid from rape oil
Chlorodifluoroethane by-product Dichloro-1-fluoroethane	Phenol by toluene oxidation
Dichloropropane by-product epichlorohydrin	Phenol by-product acetone
Dichloropropane by-product dichloropropane	Phosphoric acid (54%)
Ethanol catalytic hydrogenation with phosphoric acid	Phosphoric acid (100%)
Ethanol hydrogenation with nitric acid	Propylene oxide Cell Liquor
Ethylene glycol by-product Ethylene oxide	Propylene oxide Chlorohydrin process
Ethylene glycol of Ethene + oxygen via EO	Propylene oxide Oxirane process
Ethylene glycol from Ethyleneoxide	Toluene from pyrolysis gasoline
Ethylene oxide by-product carbon dioxide	Toluene by-product BTX
Ethylene oxide by-product ethylene glycol via CO2/methane	Toluene by-product styrene
Ethylene oxide by-product ethylene glycol via CO2/methane with CO2 use	Xylene from pyrolysis gasoline
Ethylene-t-Butylether from C4	Xylene from reformat

The following figure shows the resulting maximum errors across all analysed materials and substances. Here, the respective countries of origin are kept constant and only the technology route is varied. The figure shows the maximum errors across the various chemicals analysed, as well as the 90% and 10% percentiles.

Again, two cases were calculated for each country, assuming that the actual technology route of the supplier is unknown in a given LCA project: choosing the technology-specific dataset with the lowest burden while the one with the highest burden would have been appropriate ('choose min'; uncertainty = (min-max)/max) and vice versa ('choose max'; uncertainty = (max-min)/min). The resulting values are therefore again the relative 'worst-case errors' possible based on the available datasets.

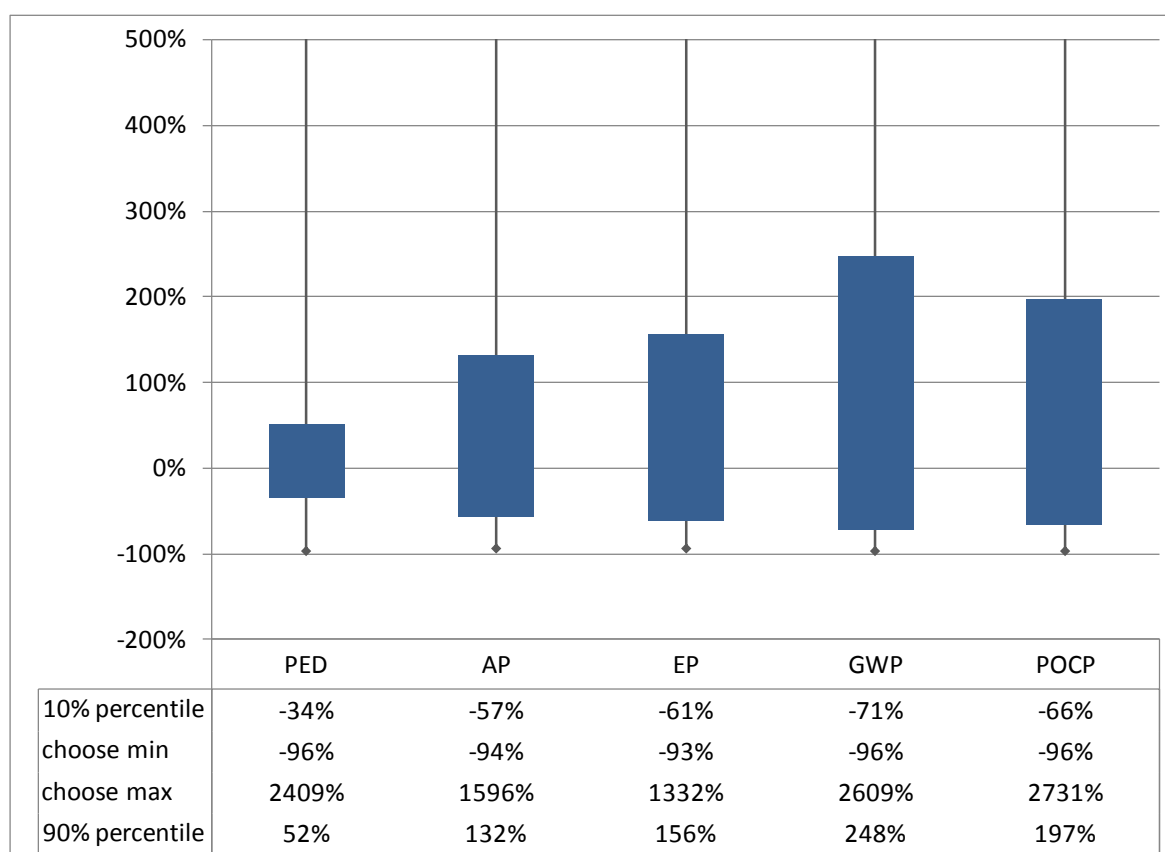


Figure B-11: Maximum errors regarding randomly chosen technology

Figure B-11 shows that when assuming that the country of origin for a certain substance is known and the specific technology route is not, the errors of the related impacts falls **between -71% and +248% for 80% of all chemical substances** for which different technologies are available in the GaBi Database. Comparing the values to the ones in the previous part concerning geography, it is fair to state that it is worse to have an undefined specific technology route than an undefined country of origin, since all values are higher for the latter.