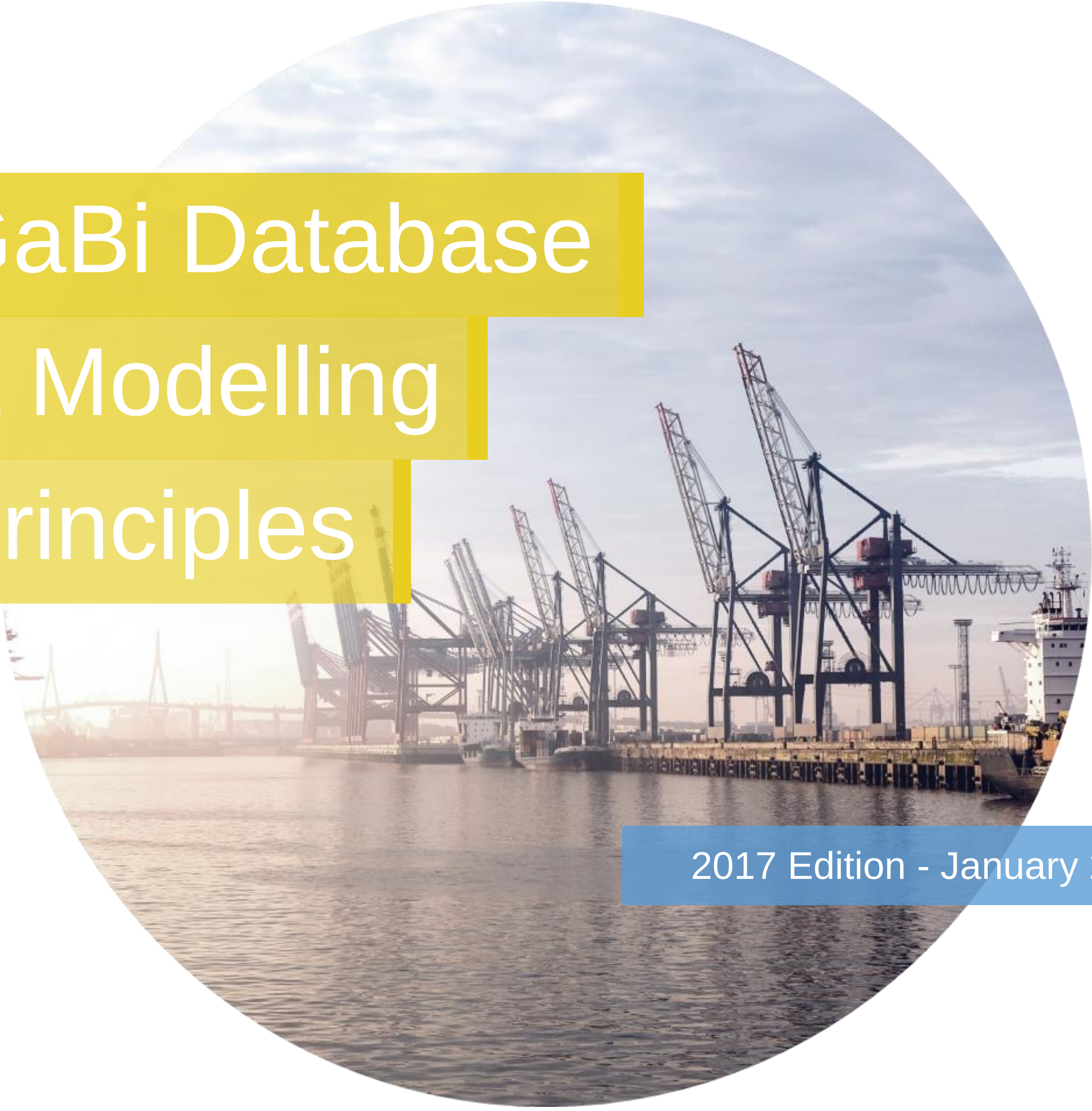
thinkstep
GaBi
Product Sustainability Performance

GaBi Database & Modelling Principles



2017 Edition - January 2017

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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 (German: Kumulierter Energieaufwand)
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LUC	Land Use Change
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	Terrestric 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 analysis. With over 1000 person years of experience thinkstep staff contribute 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.

This document does neither aim to guide / answer any possible (methodological or model) option /question nor to document any possible aspect; it rather aims to describe the import principles applied.

GaBi databases modelling orientates itself at major international standards and relevant professional initiatives, with quasi-standardisation effect. The modelling principles are only changed or adapted if the changes are justified and comprehendible.

GaBi databases modelling aims to mirror our existing global, regional and local economy and industry supply chains.

GaBi databases modelling principles are not used to test new methods at the end user. However GaBi databases modelling principles are open to be improved, if new methods or aspects have been sufficiently tested and proven to mirror the existing supply chains even more realistic.

The GaBi databases are basic data sources for multiple stakeholder groups: Academia and education, policy and regulation, research and development, consultancy and industry. Any of these stakeholders aiming for solid result needs solid, accurate and reliable data: Without data, there is no result. Without quality data, there is a high risk of inaccurate or misleading results. However, scientific and educational goals are often different to those in politics, development and industry. Widening of knowledge may be the focus of one group, framework setting the focus of another group and innovation and critical decision making the focus of a third group. These different interest require different interpretations of the same underlying data of our common supply chains.

This underpins that GaBi data has one overarching aim: Representing the technical reality of our dynamic and innovative economies as adequately as possible at the given point in time. To achieve this goal and to keep the quality continuously high, it requires technical adequateness, professional data set-up, database maintenance and governance, which are all important aspects of the daily work of thinkstep’s Content and Sector Expert Teams.

Professional database management is an important aspect, which helps ensure on-time delivery of databases, against an annual upgrade cycle. This not only ensures the accuracy and relevancy of results to help maintain competitive advantage, it also isolates clients from shocks caused by longer refresh cycles which introduce substantially different values which cannot be fully explained. This can cause too much uncertainty, lost time, money and reputational damage.

Important, general, methodological aspects and branch- or expert-specific methodological aspects are comprehensively documented.

This document provides the basis of all GaBi databases, which includes the professional database, extension databases, and 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

Embedded into the operational framework of thinkstep is the concept of a Master Database. The Master Database is one pillar of a three-pillar solution approach, the other pillars providing engineering consulting knowledge and professional software environment respectively. As illustrated in figure 2-1 below.

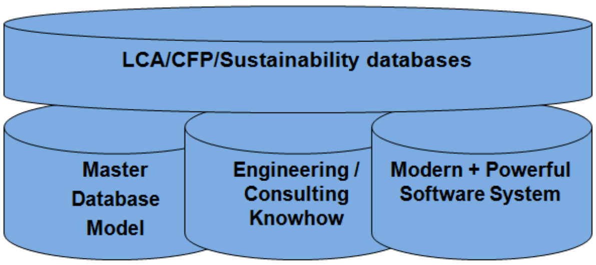

Figure 2-1: GaBi Database concept embedded in 3-pillar solution approach

Database development at thinkstep involves experts on LCA methodology, with technical expertise (see Chapter 2.6 for details on the different teams), and extensive knowledge of the relevant supply chain. Relevance checks and routine quality assurance checks are applied, methodically. 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 thinkstep, 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 round of validation by our cooperation partners LBP University of Stuttgart and Fraunhofer IBP or other independent organisations are undertaken, as necessary.

External resulting non-public quality checks: Data, which is generated in conjunction with industry or associations for distribution with GaBi databases to 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 thinkstep software and databases for public use, are constantly compared, benchmarked, screened and reviewed, and the results are published in various external, professional and third party LCA applications in industry, academia and policy bodies. User feedback happens publically via the online GaBi LinkedIn forum or directly from clients to individual contacts at thinkstep. The information fed back is incorporated into the standard maintenance and update process of the databases, where necessary and leads to consistent higher levels of quality and relevance. There is a process for continually I improving data, if there are knowledge or technology progresses, or industrial process chains develop and change.

Additional External review activities: The different elements of the GaBi databases were independently reviewed three times between 2012 and 2014, by three different organisations. The ILCD compatibility of selected GaBi processes across all branches was reviewed for the JRC in ISPRA, Italy by the Italian national Agency for new technologies, energy and Sustainable Economic Development (ENEA). In the light of the upcoming PEF Initiatives of the EU Commission, the Spanish Institution “Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT)” reviewed our data with focus on energy systems.

To complement our responsibility concerning external reviews thinkstep introduced a critical review process of its GaBi database with inspection and verification company DEKRA, the third external organisation to carry out a review. As LCA continues to be used more broadly in industry, companies require increased accuracy, transparency and credibility of their data sources in order to make the best-informed decisions. Recognising this and in order to ensure consistency and quality of its GaBi database, thinkstep finalized the first round of an “on-going critical review process with DEKRA”. The DEKRA critical review of the GaBi Database verifies:

- Credible independent sources underpinning each dataset
- Up to date engineering know-how used in composing the dataset
- Accurate meta information documenting the dataset

The review initially covers basic technologies, such as power plants, refineries and water treatment units underlying many other aggregated datasets and continues with dependent datasets derived from these core models. In addition to the datasets themselves, the quality assurance processes are also subject to an audit.

Quality Assurance processes and review procedures are an integrated part of the Database Management at thinkstep.

The Database Management at thinkstep protects private and project-related information of clients, (data providers and data consumers) while enabling all to benefit from the internal information, knowledge and expertise pool of thinkstep.

No information is allowed to leave the thinkstep internal database area without expressed release permissions.

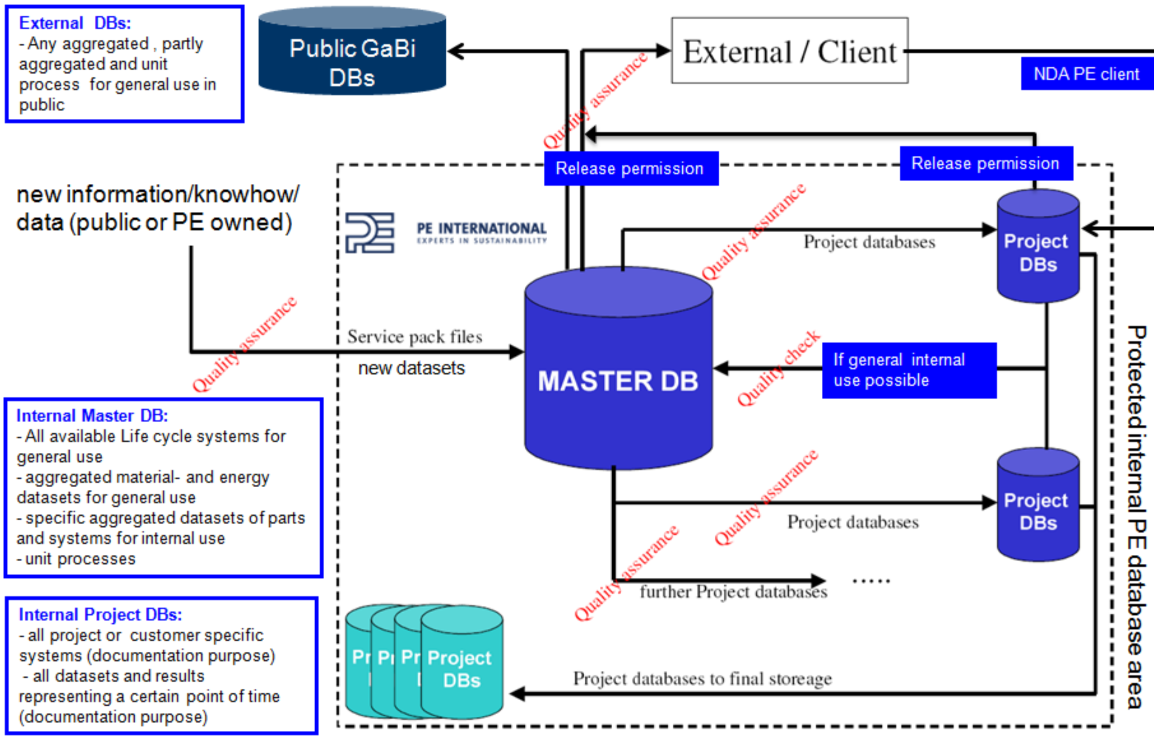

Figure 2-2: Database Management at thinkstep

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

2.2 GaBi Database development, maintenance and update

The development of LCA over the last 20 years has seen it mature into something that is industry-driven. Naturally, the best data for industry should ideally be born in industry, meaning the data is validated or sourced to ensure the proper representation of real circumstances. The need for sound methodological approaches within database and LCI modelling has attracted the academic world followed by standards bodies.

LCA databases began appearing in the early 1990s. GaBi was the early pioneer combining both database and software systems 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 both research and industry. Only professionally managed, maintained and updated databases continue to be relevant for industrial use.

Maintaining and updating databases is an important task, which is both time and management-intensive activity. Accuracy of data, new (practical, proven) methods and user requirements are just three examples requiring 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, new methods all require constant database development.
- Clients base decisions for development of new products based on LCA, optimisation or investment all of which depend on reliable results, applicability and continuity in daily practise.

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.”

thinkstep has an established management cycle concerning databases: Plan-Implement-Maintain-Review.

In **planning** innovations and demand are core drivers of the activities. This may be new technologies, new regulations, new standards or new knowledge. Stakeholder feedback is collected wherever possible to ensure relevance and value.

In **implementation,** relevancy and consistency are core drivers of the activities. This comprises LCI method and engineering knowledge combined to reflect the given economic and technical environment.

In **maintenance,** the frequency and temporal reliability of the delivery are core drivers to renew dynamic data and retire old data.

In **review,** actual user feedback and check of supply chains are core drivers to map the data from the previous year against possible relevant changes of technology, economy or society in the current year.

The GaBi database approach is done “for practice with information from practice” and so considers the “critical success factors” in professional LCA applications in industry. GaBi data is not any randomly available data, but rather best practise information, based on real world experience.

With access to raw data sources developed by thinkstep and in-house engineering expertise, enables the development and delivery within scope, on time, with high quality and guidance towards suitable data selection. A standard format for all LCI datasets is mandatory for all thinkstep-owned data.

thinkstep data is “Industry-born” based on extensive stakeholder involvement and validation, from industry and third part sources. thinkstep welcomes feedback, constructive review and as all are suggestions which drive improvement.

thinkstep models real supply chains for inter-sector use for all B2B and B2C relationships. The data reflects specific and up-to-date technology and 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 high levels of consistency and quality.

The ultimate goal is to attain flexibility in the application of data to address different topics allowing flexible assimilation between policy and industrial decision contexts. In other words, the same database can be used in making quick decisions or for more rigorous applications, for example to underpin an investment decision.

Regarding development, maintenance and update environments, a suitable group structure (see Chapter 2.6 for details) with different responsibilities at thinkstep is in place. There is a direct relationship between software and database development, which supports practical and relevant solution pathways, as many issues address 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 20,000 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.

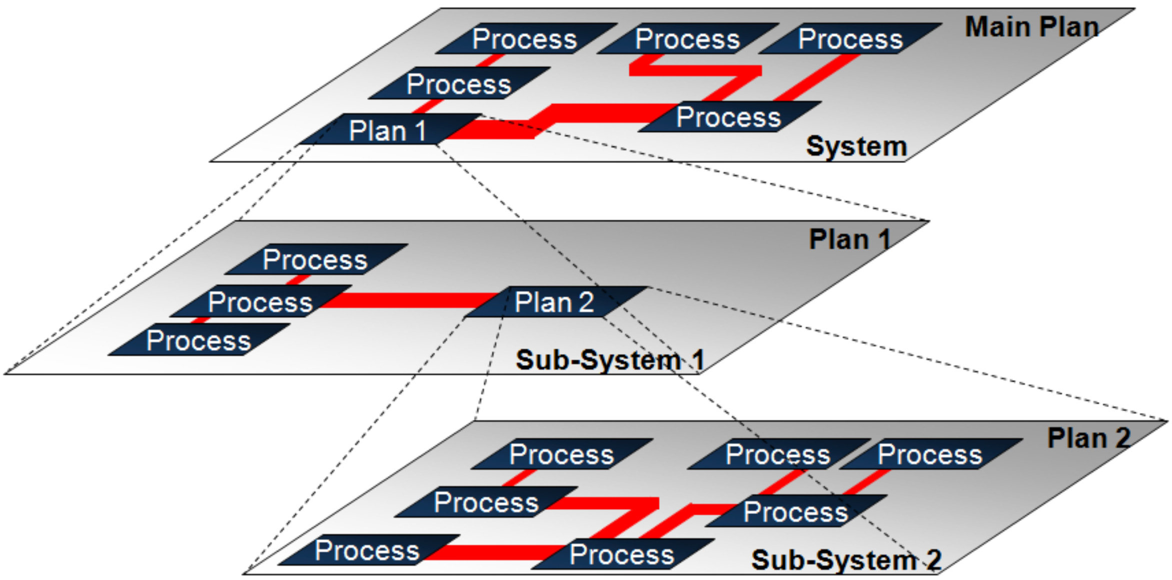

Figure 2-3: Hierarchical system in GaBi

Each thinkstep-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 pages[1]. 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.

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.

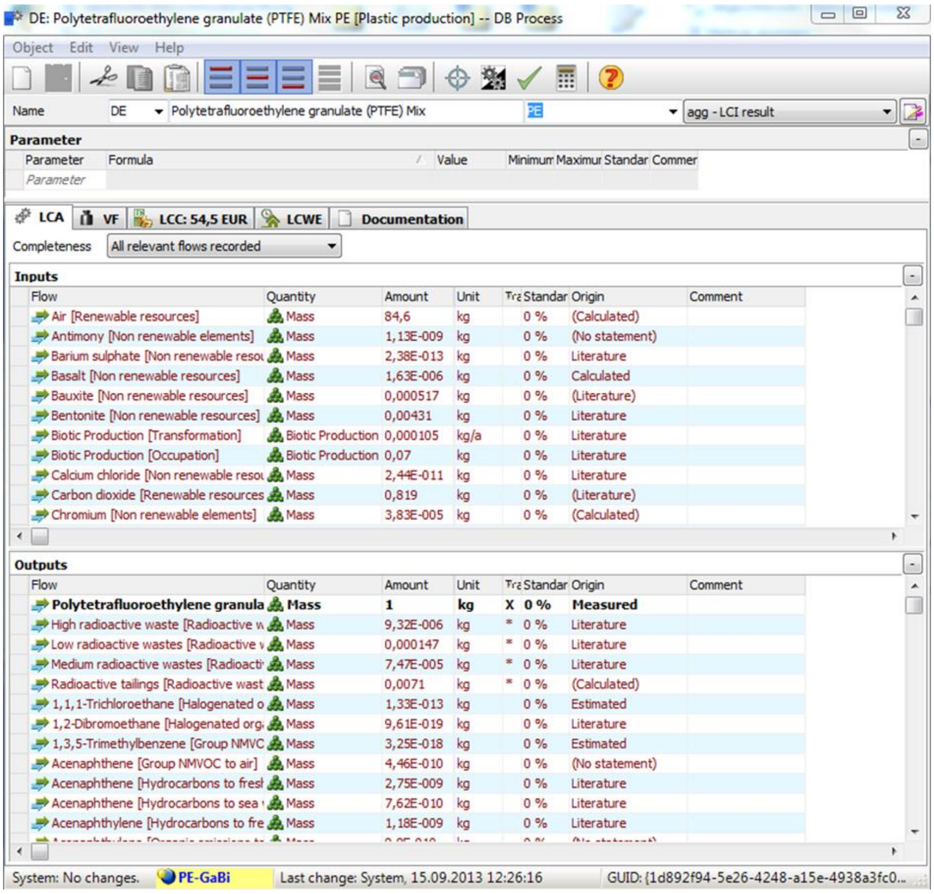

Figure 2-4: Aggregated dataset in GaBi

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.

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

[1] Rough estimate assuming two screenshots per page.

Opening the first level of the related polytetrafluoroethylene production in the Master database shows the polymerization step with the respective unit process in the centre. Upstream subsystems 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).

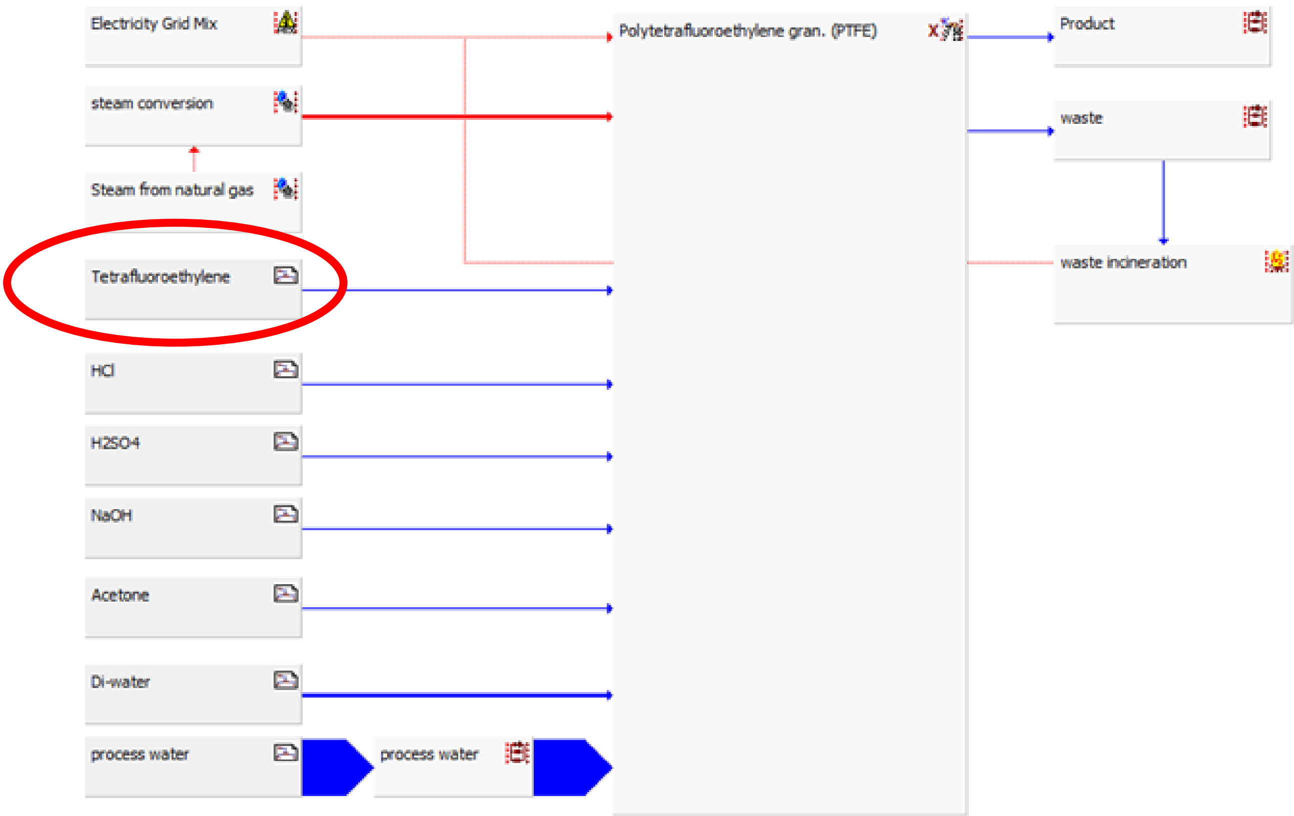

Figure 2-5: **Polymerisation subsystem in GaBi Master DB**

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

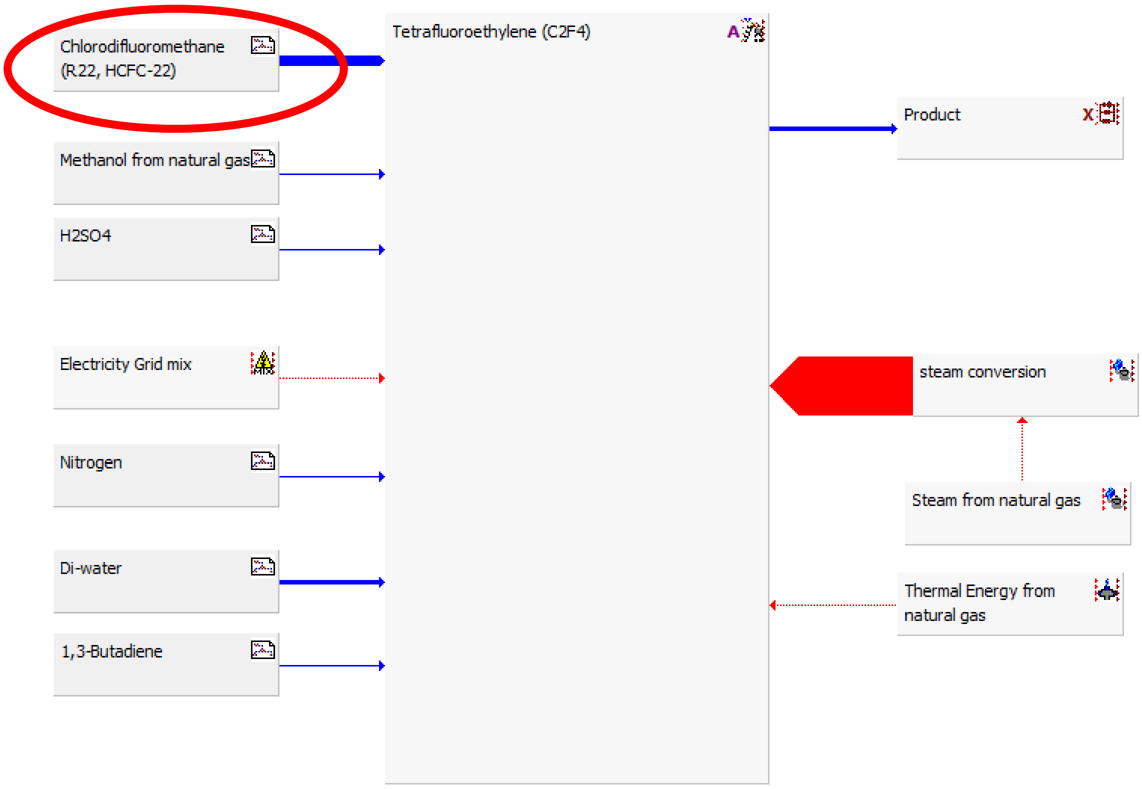

Figure 2-6: Tetrafluoroethylene subsystem in GaBi Master DB.

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

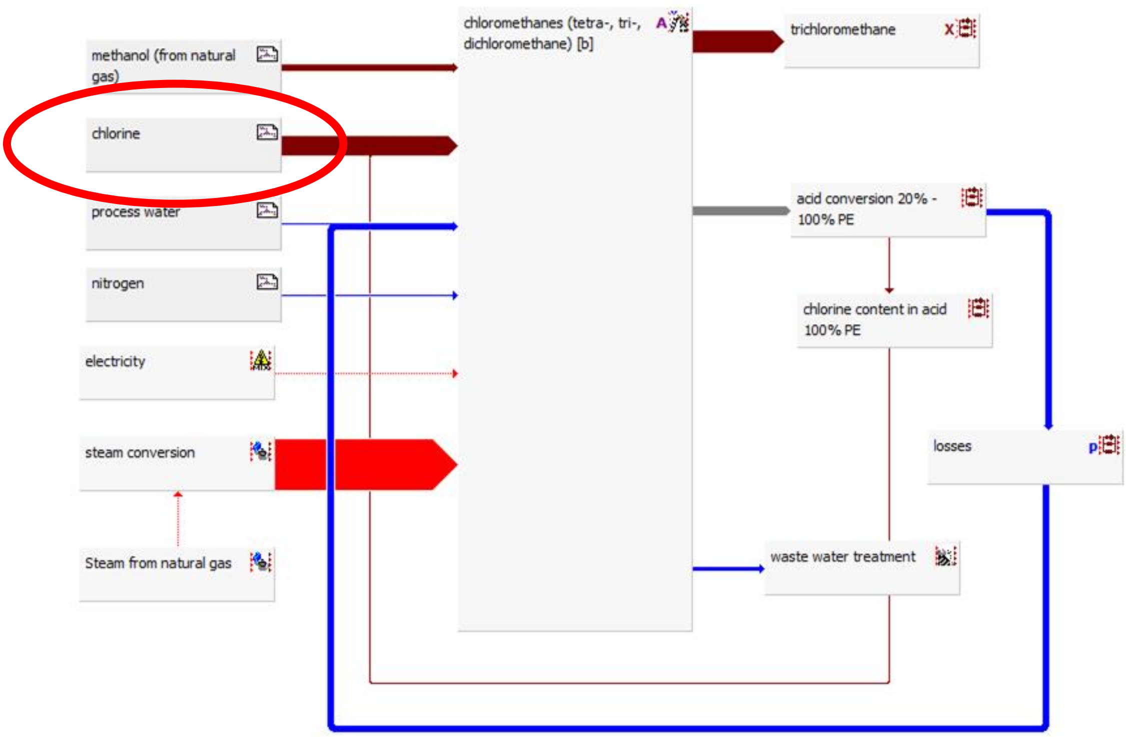

Figure 2-7: R22 subsystem in GaBi Master DB.

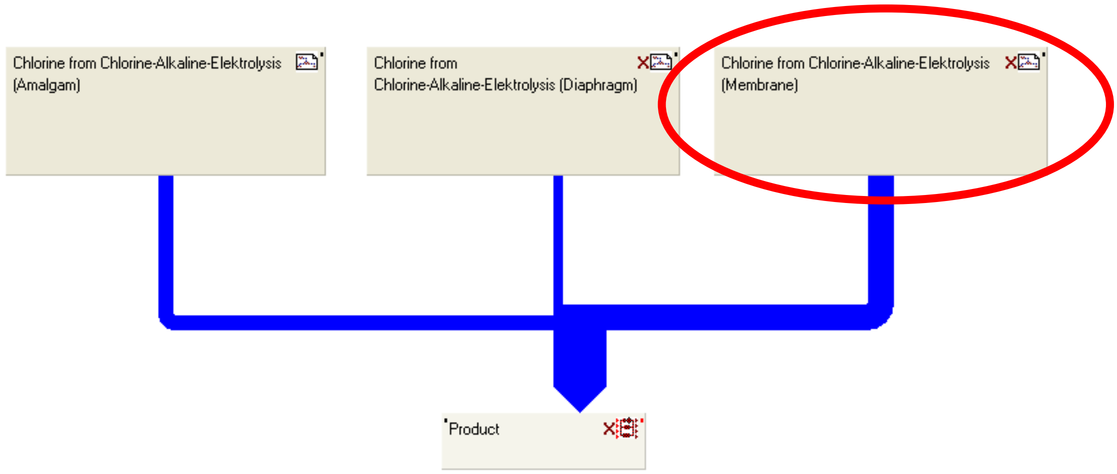

Figure 2-8: Chlorine production mix in GaBi Master DB.

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

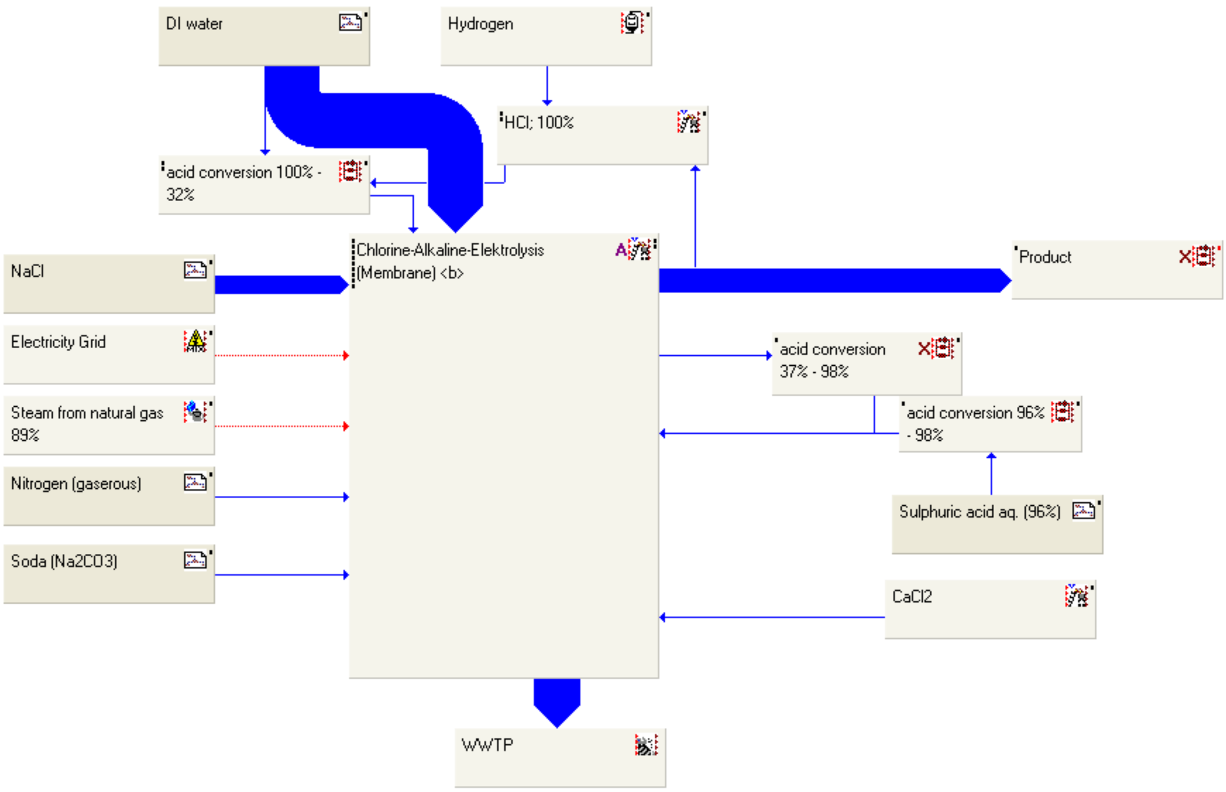

Figure 2-9: Chlorine membrane technology production in GaBi Master DB

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….

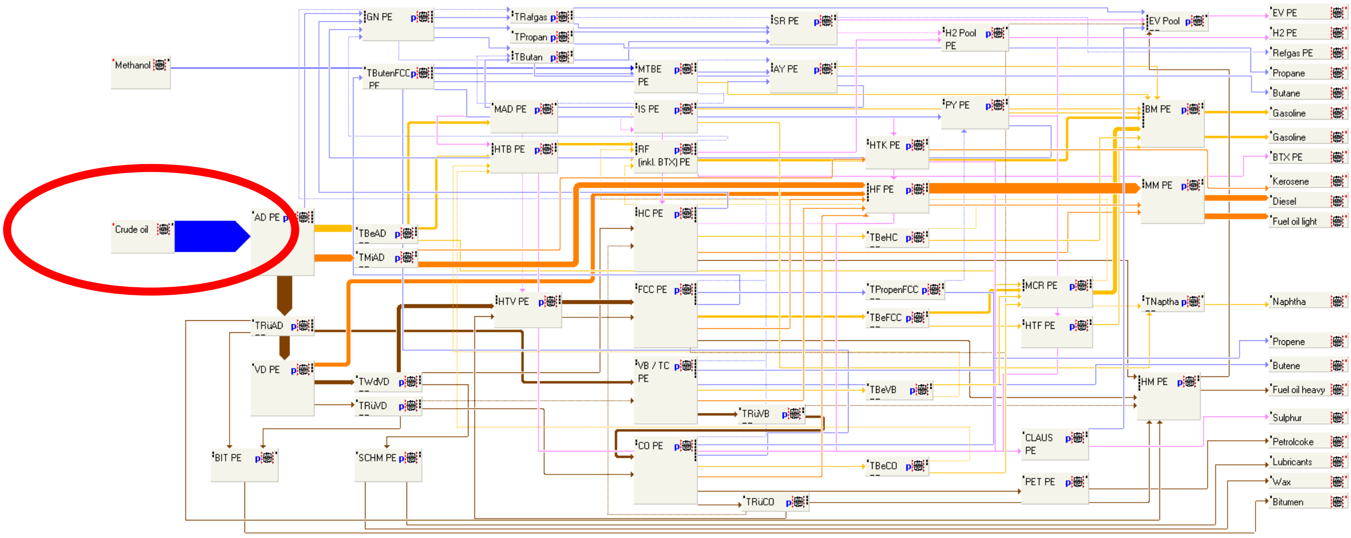

Figure 2-10: Refinery model in GaBi Master DB.

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

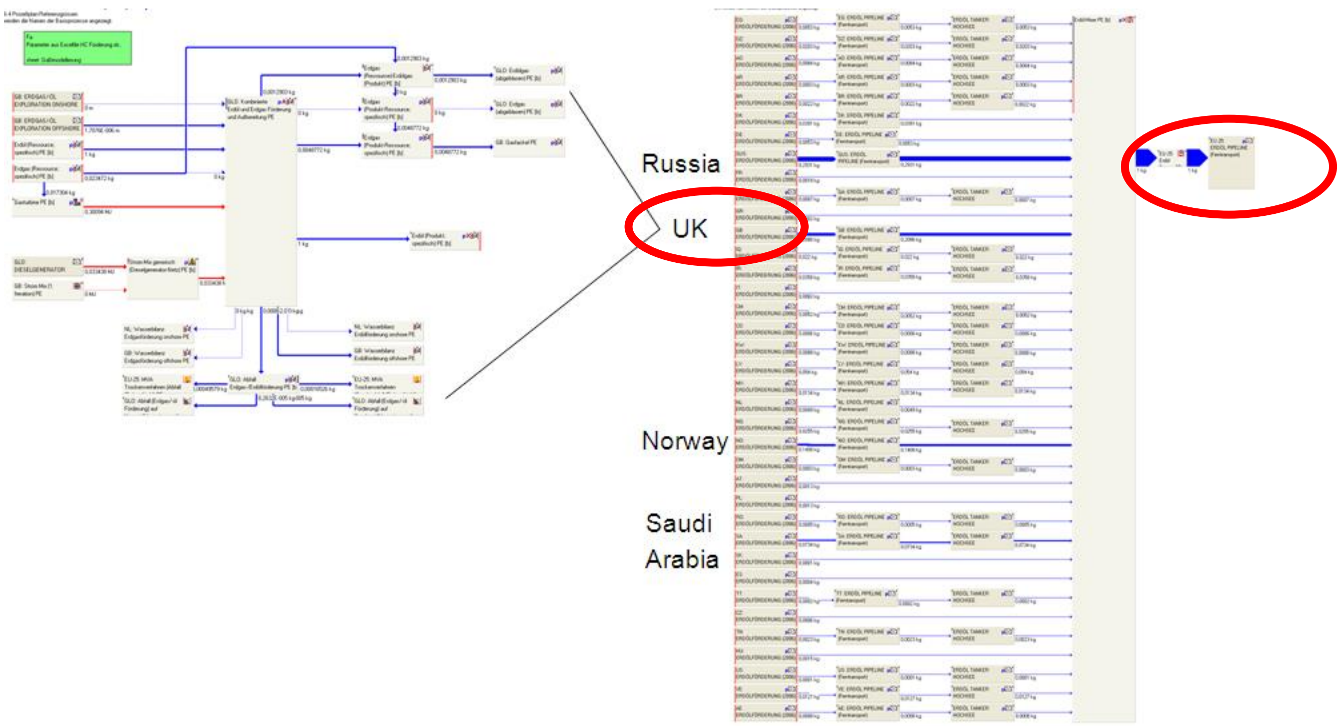

Figure 2-11: Crude oil import mix and country specific oil extraction in GaBi Master DB

…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.

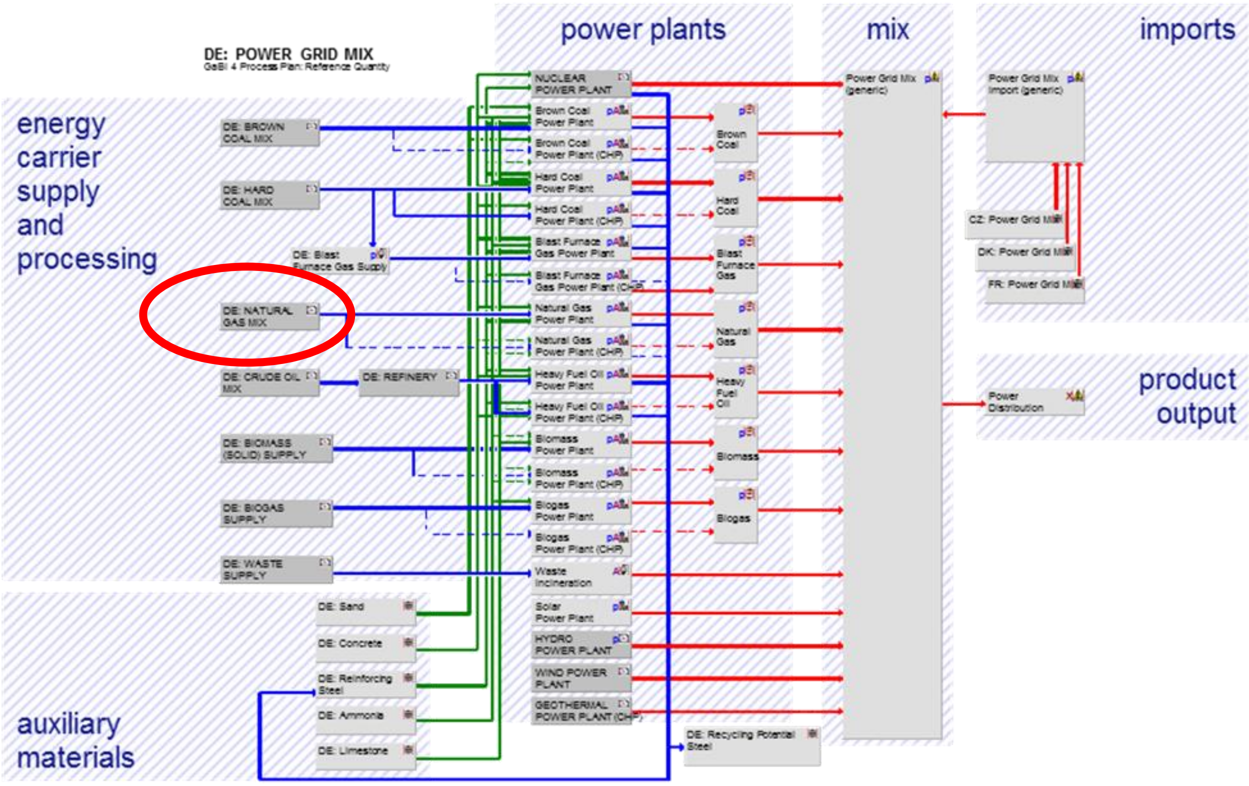

Figure 2-12: Power plant models of the Grid Mix modelling in GaBi Master DB.

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)….

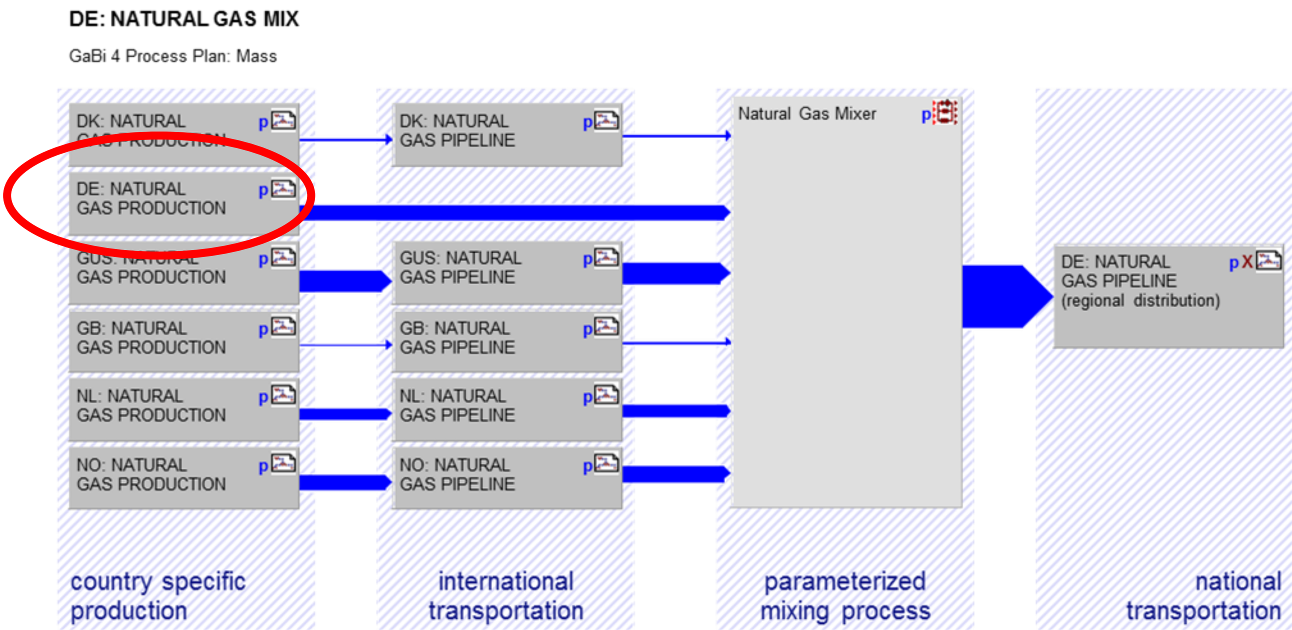

Figure 2-13: German Natural Gas Mix in GaBi Master DB.

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

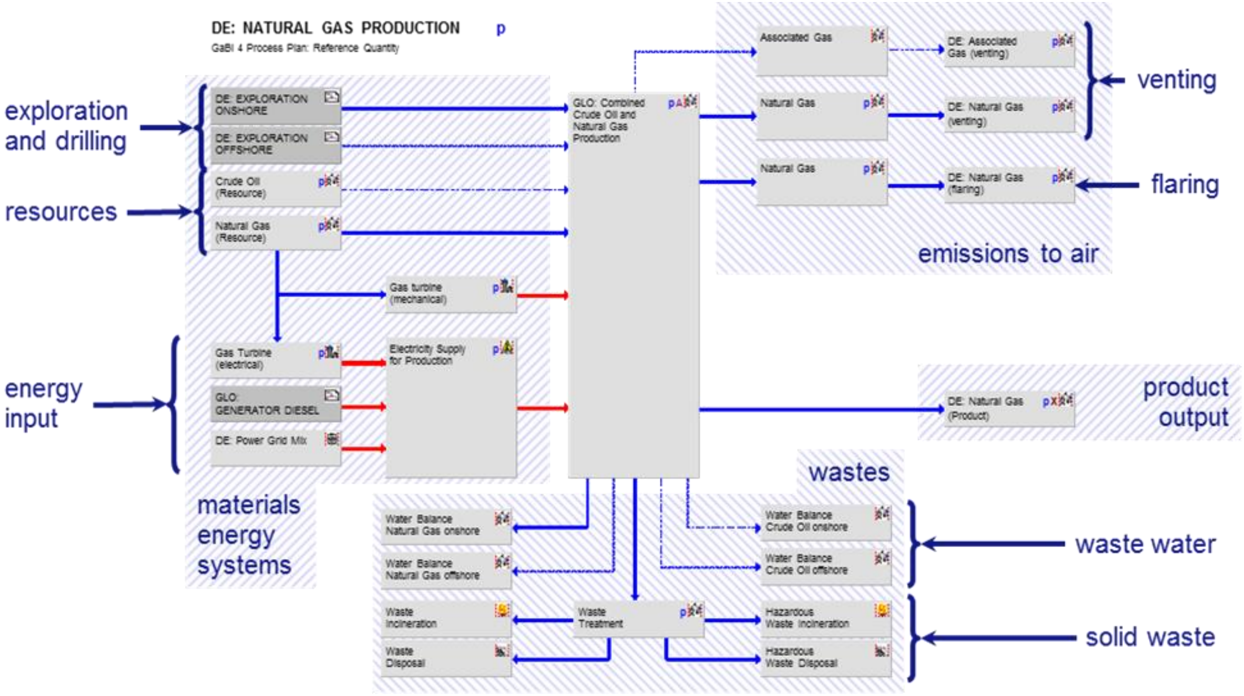

Figure 2-14: German Natural Gas production in GaBi Master DB.

…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, 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]
- Environmental labels [ISO 14020 : 2000] , Type II [ISO 14021:1999], Type 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/TS 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: Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF) [PEF GUIDE 2013], 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 frameworks (please visit also http://www.gabi-software.com/international/solutions/ for further details). It might be possible that some frameworks define in certain specific applications contrary requirements that one background dataset cannot match both by default. Therefore, the GaBi system supports and allows for specific addition/modification/adaptation of the dataset, if needed at all.

2.5 Databases in reference networks, standards and principles

GaBi databases are renowned for their practical relevance frequently used to support different initiatives, industry or national databases schemes. Conversely, initiatives, industry or national databases schemes influence GaBi databases. This symbiotic relationship enables practicability, applicability, compatibility and distribution of data within relevant professional frameworks. The following graph illustrates the dependencies within this coexisting symbiosis.

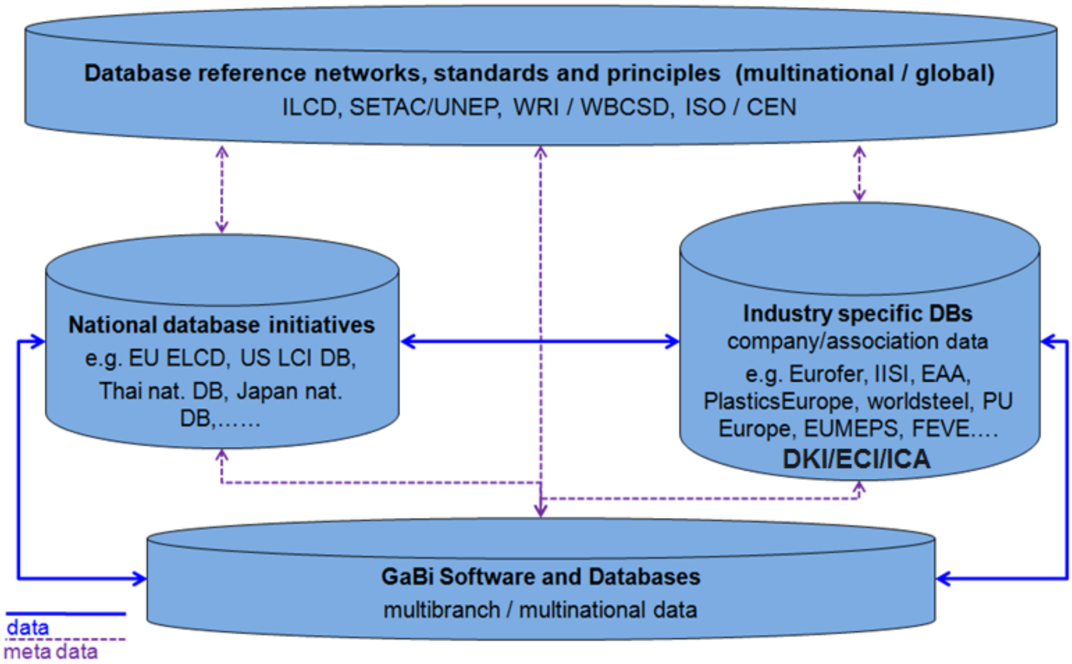

Figure 2-15: GaBi DB in the international context of databases and frameworks.

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

thinkstep data influences standards and standards influence thinkstep data. thinkstep data aims to be applicable in as many relevant standards as possible.

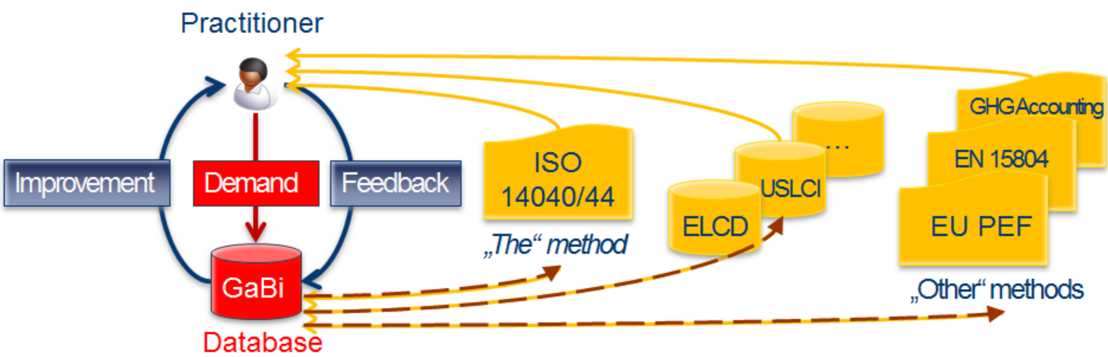

Figure 2-16: Improvement cycles of GaBi databases and of standards.

This calls for continuous adaption due to stakeholder feedback and the related implementation time needed to improve and evolve data and standards.

thinkstep databases turn theory into professional practice. Standards, guides and handbooks are an important basis of our supporting work.

Figure 2-17: Turning standards into technology solutions.

Turning paper (standards documentation) into technology is a core deliverable of thinkstep databases. This provides access to standardized information to a wide range of stakeholders in a form they can use in day-today operations, and improved upon through the continuous feedback loop outlined previously.

2.6 GaBi LCI Team

GaBi databases are the result of teamwork from 10 expert teams and one core content team, which orchestrate the process, ensuring the quality, and governance procedures are adhered to. Each expert team is responsible for modelling its specific system, as well as documenting the generated LCI. Each team requires experts that 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 to material production and/or power generation
- Sensitivity to the industry's current state 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 ultimately a consistent and synchronized database. It also serves as an interface to clients, the market and the scientific community to receive feedback on existing database, to make sure the GaBi databases are in line with the development of methodologies the demands of the market, and to constantly improve the internally used workflow and guidelines. In this way, consistency throughout all GaBi databases can be assured.

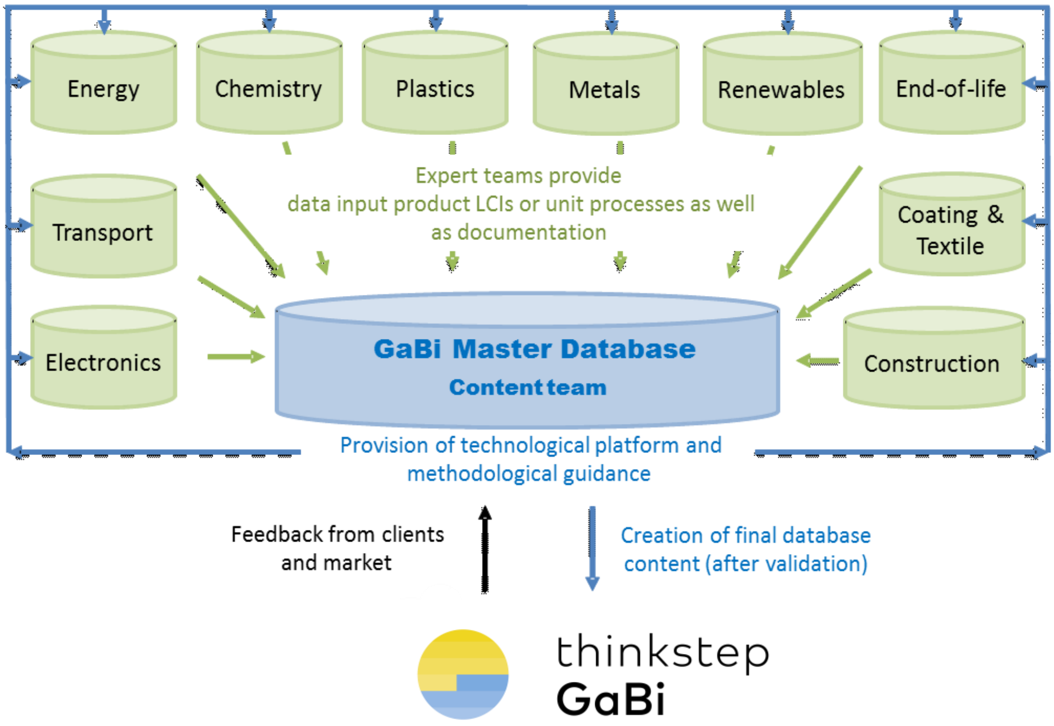

Figure 2-18: GaBi LCI Expert Teams and the core LCA content team

The thinkstep owned full LCA systems including unit processes, plan systems and aggregated data is the core of thinkstep data. However as we aim to host and provide all relevant data sources consistently, thinkstep are open for anybody that would like to publish technically sound and consistent data of any kind: This could be unit processes, plan systems or aggregated data.

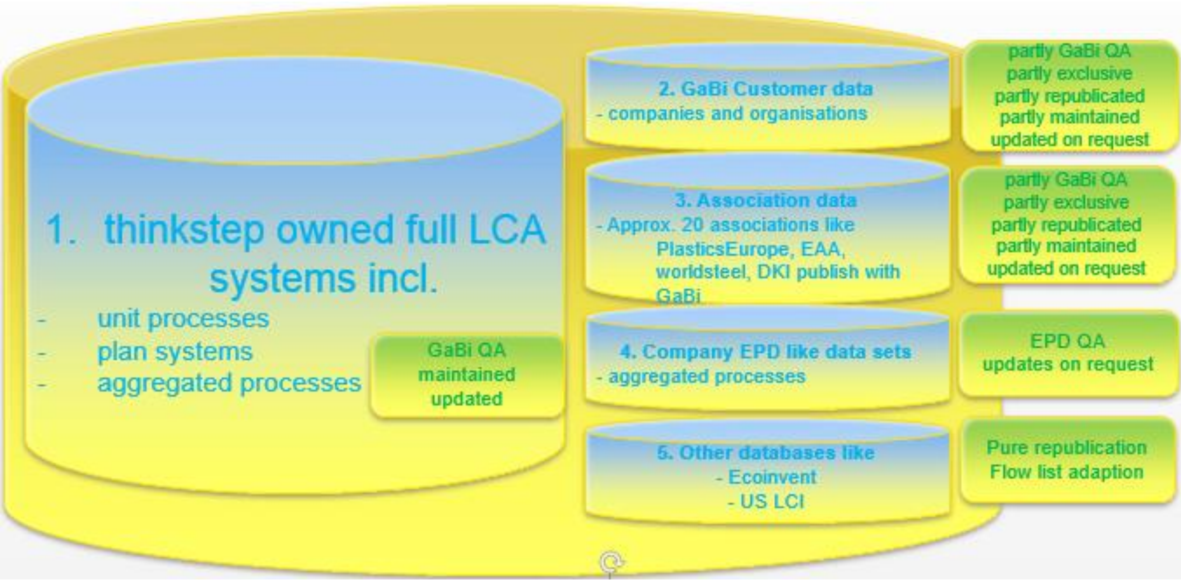

Figure 2-19: All relevant data sources consistently covered

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, the practitioner holds a degree of responsibility.

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 Grave[2]).

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 data that are more specific.

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.

[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 nutrition can be covered.

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.

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 2013] are essentially physical metric [SI]-units related to the amount of product, e.g. 1 kg, 1 MJ, 1000 kg, 1 m^3. The functional unit of each process is defined within the process. The choice of the SI-unit does not influence the results of a comparison, 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.

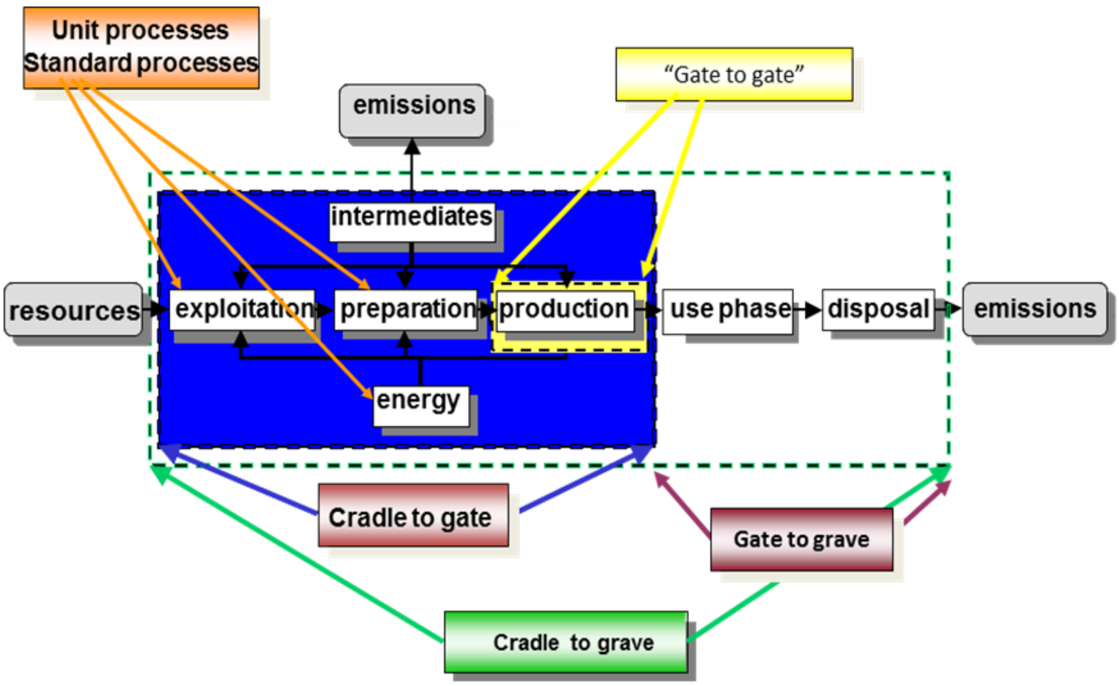

Figure 3-1: Graphic representation of different (sub-) system boundaries

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

is a 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, and 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.

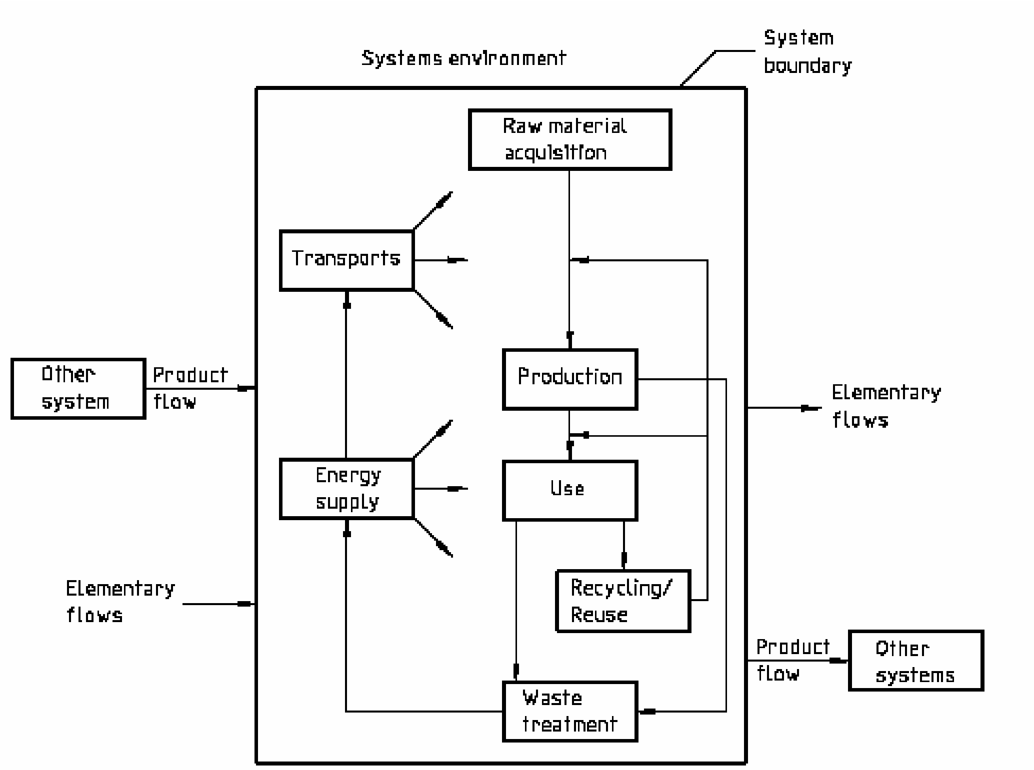

Figure 3-2: Generic example product system of a dataset development

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. thinkstep 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 boundary[3]	**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 boundary[3]	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, CO2, 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	
	DeNOx and DeSOx 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 boundary[3]	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 con-veyers 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 refining	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/	
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 boundary[3]	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 (ClO2, O3, ...)	
	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 (ClO2, O3, ...)	
	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, DeSOx	
	chemicals, water	
	Efficiency and energy recovery (electricity/heat)	
	Combustion calculation incl. all relevant emissions	
	see also http://www.gabi-	

	software.com/international/databases/	

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 thinkstep-owned datasets, the underlying plan systems are accessible in the Master database and thinkstep can grant access rights (e.g. for review purposes) under bilateral contracts. thinkstep Master database content is valuable, privately financed information, developed, collected and compiled with a tremendous amount of recourses 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 mathematical 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 and the knowhow of our engineers, 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 “precautionary principle” scenario (rather slightly over estimate than underestimating the impact) for the substance causing the gap. If the influence of the “precautionary principle” scenario on the overall result is smaller than 5%, the scenario can stay (gap closing insignificantly overestimates to the actual value). If the influence on the result is higher, more information is gathered or the sensitivity is 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 in parallel would only marginally improve the overall results.

All GaBi unit processes aim to reflect actual physical and thermodynamic laws. The mass balance of the key substances and fuels in the input must 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 not measured in practice, but 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 or benchmark 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 that 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, and 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_2H_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 crosschecked (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 CO_2 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 CO_2 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 CO_2, which amounts to about 0.09%-0.15% of the CO_2 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 CO_2 intensity of infrastructure would be further reduced and a distribution similar to GaBi model above could be expected.

Summary:

Consequently, 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 database[4].

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

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.

[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).

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 coastline). Freshwater consumption is therefore 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 seawater) is relevant from an impact assessment perspective because freshwater is a limited natural resource. Seawater is plentifully available and therefore not further assessed in 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 (water input) – total freshwater release from technosphere (water outputs) = water vapour (including water evaporated from input products and including evapotranspiration of rain water from plants) + water incorporated in product outputs + water (freshwater released to sea)

Furthermore, new and different water flows are being introduced for hydropower (e.g. “water (river water from technosphere, turbined)”) 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 cases where this differentiation is not possible. Fresh water is always classified as blue water.

- “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 (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.
- “Water (wastewater, untreated)”: This flow is generally treated in a Wastewater Treatment Plant, connected to a wastewater treatment plant module. It shall not be used as an elementary flow, since it has no Characterization factors in the LCIA methods for water assessment.
- 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 rainwater 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.

To increase the consistency with the ILCD flow naming, the water flows were renamed with SP32 (GaBi databases 2017). For further details regarding the names and structure of water flows in GaBi please refer to the Introduction to Water Assessment in GaBi Software [Thylmann 2017].

Original name (SP30, 2016)	New name (SP32, 2017)
Input	
Water (fresh water)	Fresh water
Water (ground water)	Ground water
Water (lake water)	Lake water
Water (rain water)	Rain water
Water (river water)	River water

[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.

[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.

Output

Water (lake water from technosphere, cooling water)	cooling water to lake
Water (river water from technosphere, cooling water)	cooling water to river
Water (groundwater from technosphere, waste water)	processed water to groundwater
Water (lake water from technosphere, waste water)	processed water to lake
Water (river water from technosphere, waste water)	processed water to river
Water (lake water from technosphere, turbined)	turbined water to lake
Water (river water from technosphere, turbined)	turbined water to river
Water (lake water from technosphere, rain water)	collected rainwater to lake
Water (river water from technosphere, rain water)	collected rainwater to river

Examples of how water was addressed in GaBi databases:

- Process using <u>process water</u> 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.

<u>1) General production process (in different industrial settings):</u>

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)").

- taken from a connected upstream water treatment process (e.g. water deionisation) → then apply the appropriate water technosphere flow/operating material (e.g. “water (deionised”).

- 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.

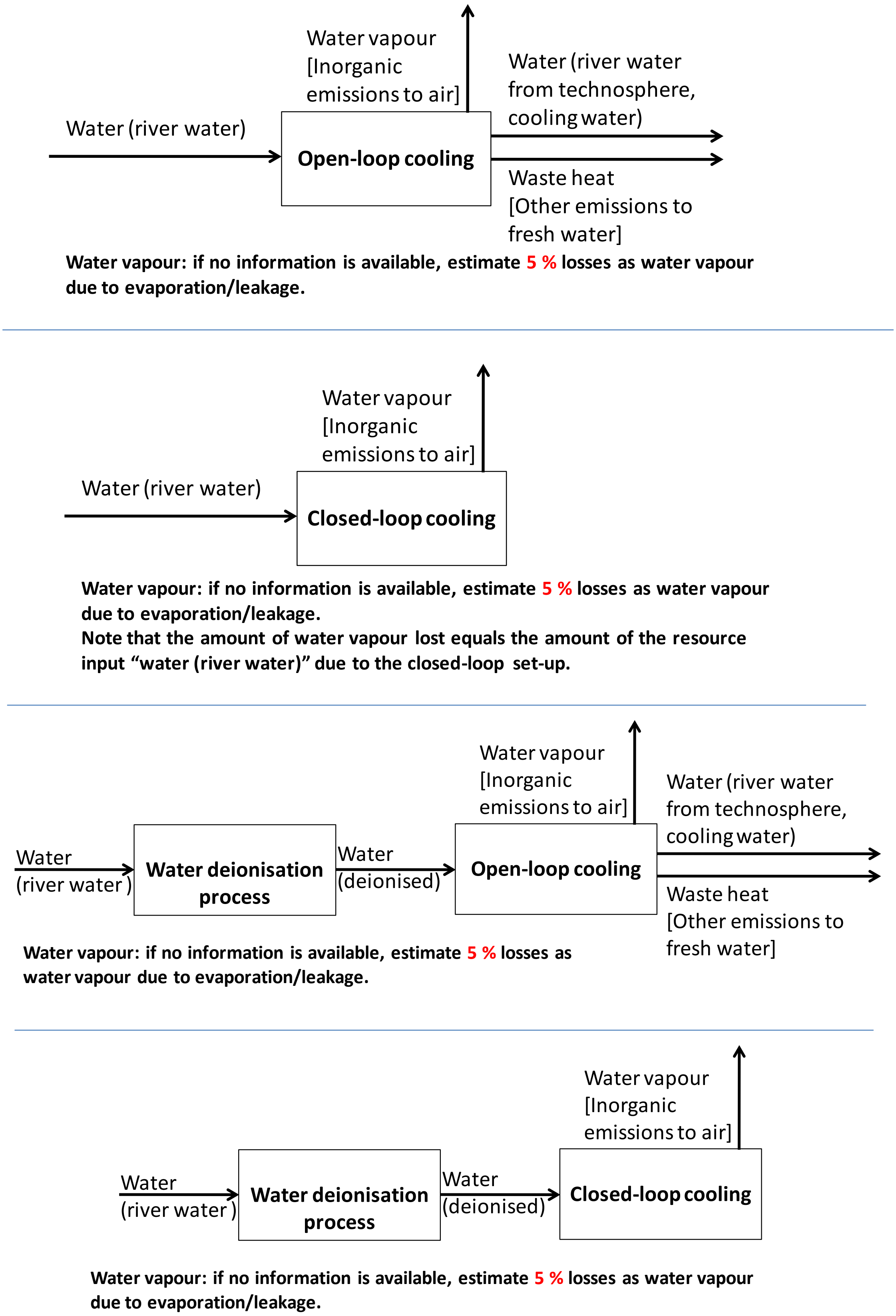

Figure 3-3: **Application water flows in open-loop and closed-loop cooling systems in various industrial settings**

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.

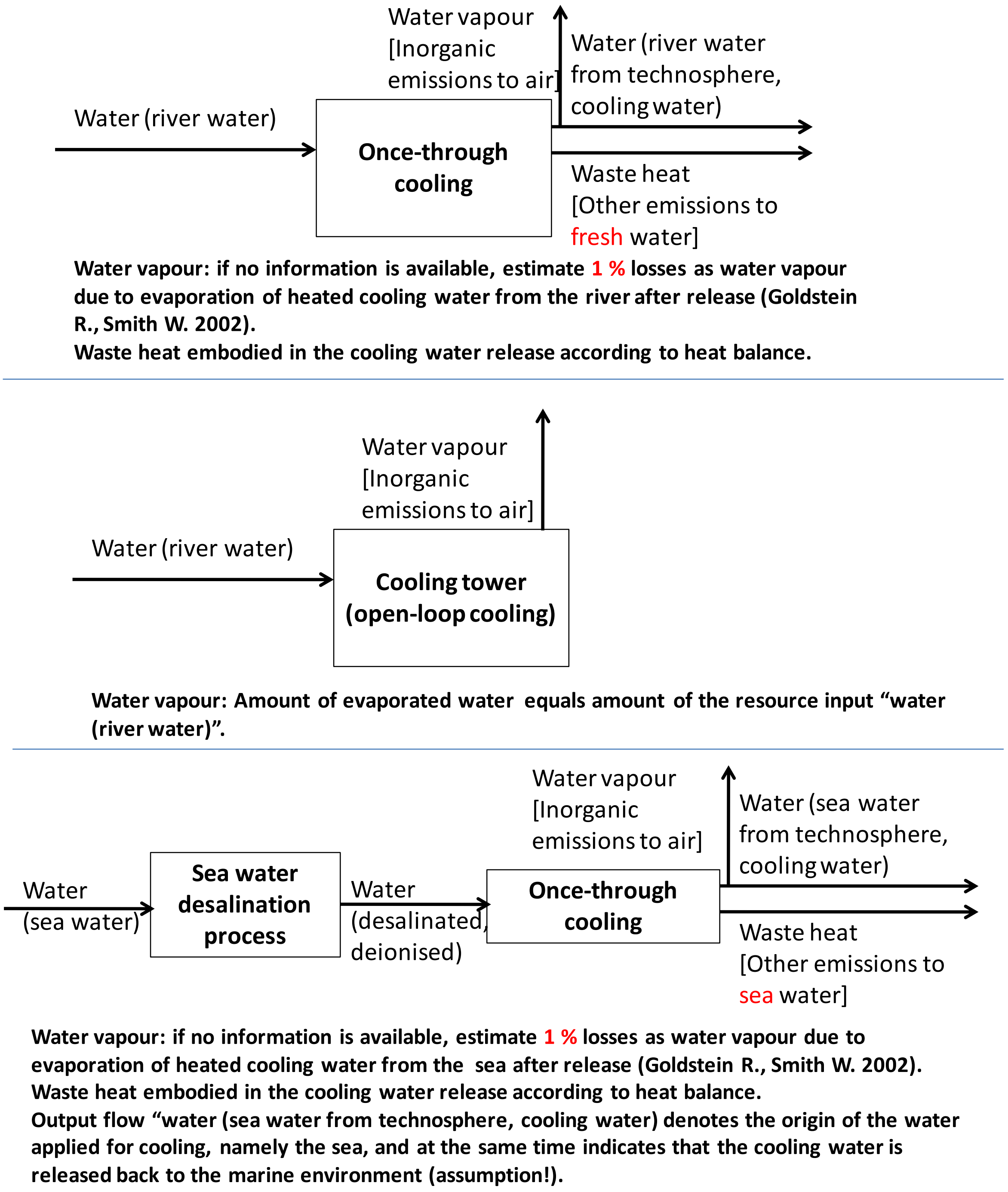

Figure 3-4: Application water flows in once-through cooling and cooling towers in energy/electricity generation

Use of water in hydropower generation:

For hydropower generation, the following 4 generation technologies are considered: run-of-river power station, pump-storage and storage power stations, and tidal/wave power plants. See the following graphs for instructions for inventorying the appropriate water flows.

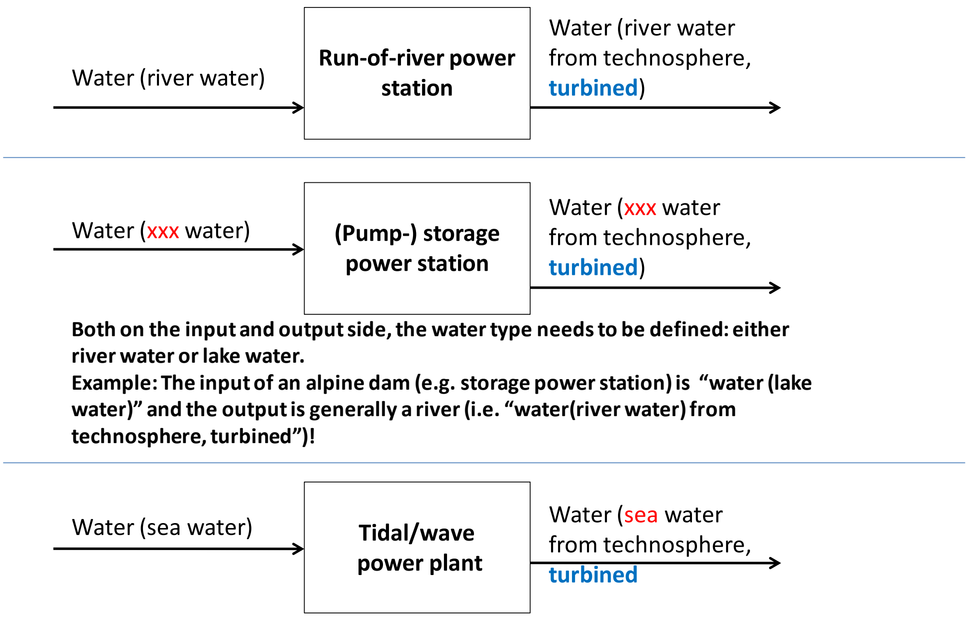

Figure 3-5: Application water flows in hydropower generation

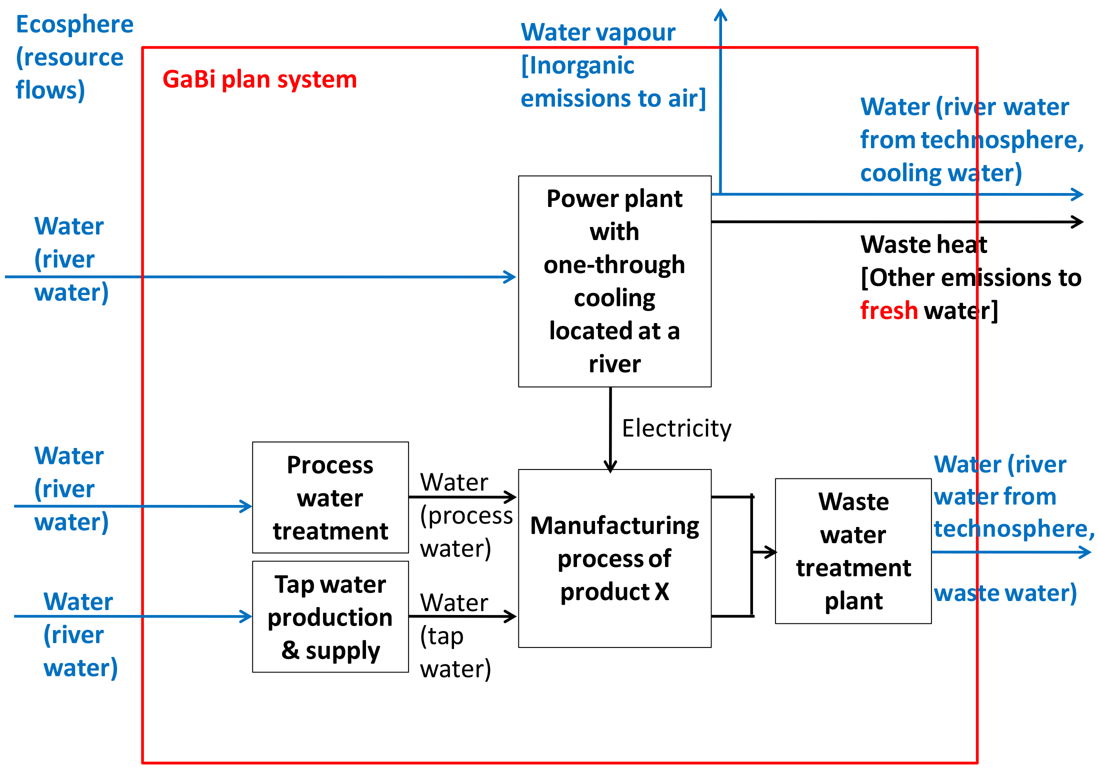

Figure 3-6: Ad hoc example of a simple plan system including different processes and water flows

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 occur[7]. 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.

3.3.10 Radioactive waste and stockpile goods

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. The radioactive flows belongs to this group and are therefore included in the output of every aggregated GaBi data set. The final disposal of radioactive waste is not yet implemented due to lacking political and technical definitions. Thus, the radioactive wastes as a special group of GaBi waste flows are defined in Table E.

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[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: Definitions of the radioactive waste flows in GaBi

Flow name	Flow type	Description
High radioactive waste [Radioactive waste]	Waste flow	Originates predominantly in the end of life processing of radioactive waste in the nuclear power plant. A modelling of the final disposal site for nuclear waste can yet not be implemented due to lacking political and technical definitions.
Medium radioactive wastes [Radioactive waste]	Waste flow	Originates predominantly in the end of life processing of radioactive waste in the nuclear power plant. A modelling of the final disposal site for nuclear waste can yet not be implemented due to lacking political and technical definitions.
Low radioactive wastes [Radioactive waste]	Waste flow	Originates in the upstream supply chain of the nuclear fuel from uranium mining, milling, conversion, enrichment and fuel assembly as well as to a significant amount from the end of life processing of radioactive waste in the nuclear power plant. A modelling of the final disposal site for nuclear waste can yet not be implemented due to lacking political and technical definitions.
Radioactive tailings [Radioactive waste]	Waste flow	Originates in the upstream supply chain of the nuclear fuel from uranium mining, milling, conversion, enrichment and fuel assembly. A modelling of the final disposal site for nuclear waste can yet not be implemented due to lacking political and technical definitions.
Radioactive waste in GaBi standard datasets is therefore predominantly due to nuclear energy production, use and EOL in the respective aggregated data sets.		

Table F summarizes the definition of the Stockpile goods, which can be classified as a special group of GaBi elementary flows.

Table F: Definitions of the Stockpile goods elementary flows in GaBi

Flow name	Flow type	Description
Hazardous waste (deposited) [Stockpile goods]	Elementary flow	Treatment of incineration residues (e.g. via vitrification), stored at underground waste disposals or specific landfill sites
Overburden (deposited) [Stockpile goods]	Elementary flow	Material like soil or rock which is removed by mining processes (e.g. Hard coal, lignite, ores/minerals), typically not contaminated. In specific branches maybe also called spoil (see below)
Spoil (deposited) [Stockpile goods]	Elementary flow	Material like soil or rock which is removed by mining processes (e.g. Hard coal, lignite, ores/minerals), typically not contaminated. In specific branches maybe also called overburden (see above)
Tailings (depos-	Elementary	Represents a processing/beneficiation of the mined

ited) [Stockpile goods]	flow	ore, e.g. copper, iron, titanium, chrome, lithium etc. Mechanical and chemical processes are used, results in a waste stream which is called tailings. Reagents and chemicals can remain in the tailing stream, as well the remaining part of metals/minerals and/or process water.
Waste (deposited) [Stockpile goods]	Elementary flow	Represents the remaining fraction of intern components (not converted into emissions, landfill gasses or leachate) which is stored in the body of waste disposal/landfill site.
Wastes (deposited) in GaBi standard datasets are therefore representing occupying available landfill body or available stockpile place of components considered to be not reactive anymore or inert respectively.		

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.

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
Polyolefin 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, encapsulation 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 that 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.

3.3.11 Aspects of biomass modelling

The carbon cycle in LCA can be defined as: CO_2 in atmosphere → CO_2 intake/H_2O/sunlight/surface → plant growth → harvested biomass → biomass use as fuel or matter → CO_2 combustion/decomposition → CO_2 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 2013]. 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 CO_2, which had been released previously.

The solar primary energy embedded or stored in the biomass is exactly the amount of solar energy that 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.

Biogenic carbon dioxide correction

Growing biomass absorbs CO_2 from the air; the carbon from the absorbed CO_2 is transformed into the plant tissue and is called biogenic carbon. The biogenic carbon comprises part of the product and eventually can be released into the air again as CO_2 (biogenic carbon dioxide) or as CH_4 (biogenic methane). For the sake of simplicity, this document speaks only of carbon dioxide, meaning both carbon dioxide and methane.

Figure 3-7: CO_2 Uptake

In the following diagram, it is shown what to do if you have a biomass in your product or system.

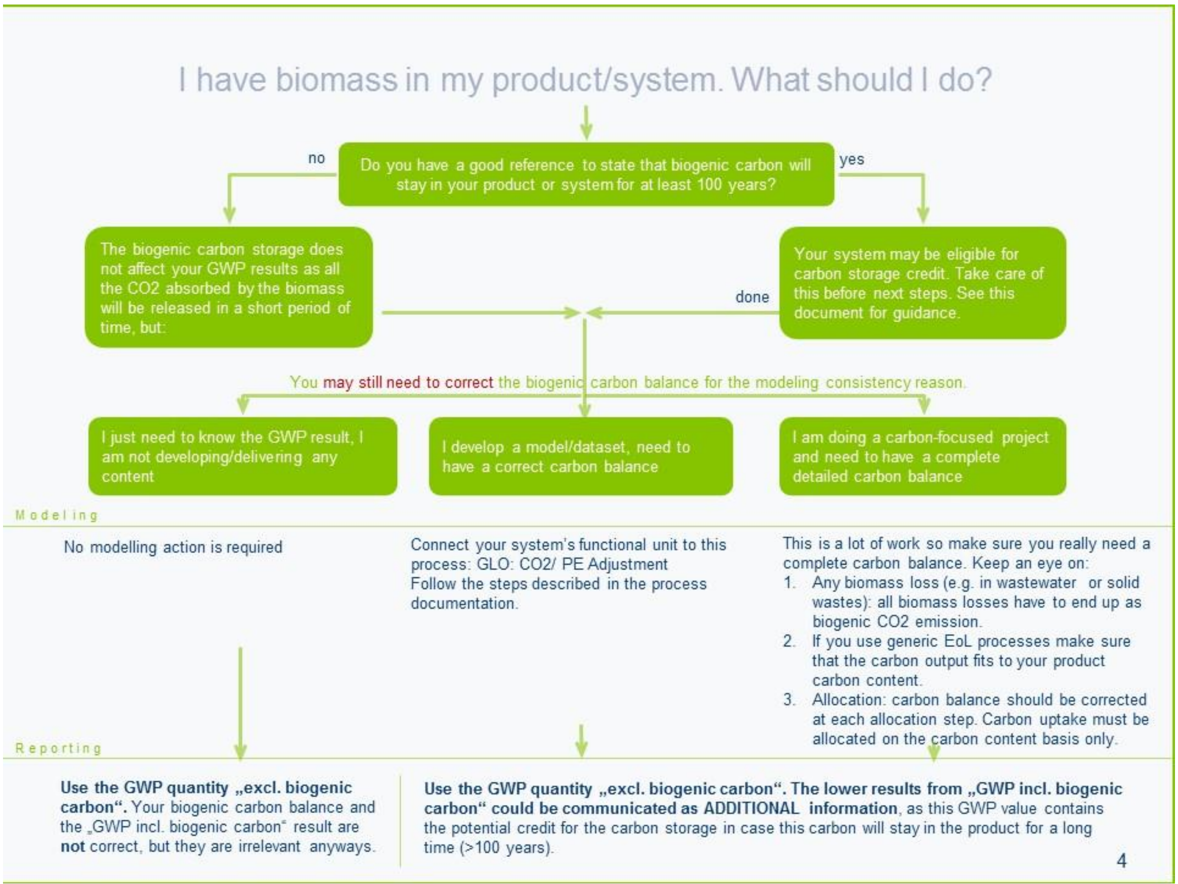


Figure 3-8: Carbon correction decision chart

Current biogenic carbon dioxide modelling approach

The biogenic carbon dioxide emissions are tracked separately from the fossil carbon dioxide emissions. For incomplete life cycles of products that contain biogenic carbon (e.g. cradle-to-gate LCA of wooden pallets), the biogenic and fossil carbon dioxide emissions as well as the resource uptake are reported in the LCI.

Reasons why the biogenic carbon dioxide should be corrected:

- Allocation is applied: In the current approach allocation results in distorted carbon credits assignment, as carbon uptake should be allocated based on physical basis – the biogenic carbon content - rather than economic value or any other allocation mean.
- Default approach is used: Certain systems do not have a right to claim the GWP credit from the carbon uptake (e.g. food products or fast-consumed products). In the current carbon modelling approach, this credit is given by default, creating an error-source and a deviation from a conservative principle.
- Carbon credit is overestimated: Biogenic carbon emissions are often left untracked if loss of the biomass is involved. E.g., there is carbon in the biomass that is leaving the system as sludge for disposal or as unidentified waste. This carbon however can end up as a credit for final product due to the biogenic carbon emissions left untracked.

<u>Biogenic carbon dioxide correction approach</u>

As mentioned before, the biogenic carbon is tracked in different flows in GaBi:

- The carbon dioxide uptake by growing biomass is modelled using: Carbon dioxide [Resources]
- Biogenic carbon emissions to air are modelled using: Carbon dioxide (biotic) [Inorganic emission to air]
- Biogenic methane emissions to air: Methane (biotic) [Organic emissions to air (group VOC)]

It is very important to have the information on the carbon and water content available. This information can either be found by looking at the flow (example see below) or through internet research. For documentation purposes, it is highly advised to enter the researched information into the flow properties:

Quantity	vari	1 kg = *	Unit	Standar	1 [Quantity]
C_biogen_wt		0.421	kg	0 %	2.38
C_wt		0.421	kg	0 %	2.38
Energy (gross calorific value)		14.8	MJ	0 %	0.0676
Energy (net calorific value)		14.3	MJ	0 %	0.0699
Modified organic natural materials (unspecified)		1	kg	0 %	1
N_wt		0.0163	kg	0 %	61.3
Price		0.1	EUR	0 %	10
Water_wt		0.14	kg	0 %	7.14
Quantity					

Figure 3-9: Carbon content flow properties

The following quantities are used:

C_Biogen_wt: amount of biogenic carbon (equivalent to total carbon if 100% biotic carbon)

C_wt: total amount of carbon in product (biotic and fossil)

Water_wt: water content of product

The biogenic carbon correction approach covers modelling and evaluation of biogenic carbon dioxide for products where biogenic carbon forms part of a product (e.g. wood fibre in a table). It does not cover systems where atmospheric carbon is taken up by a product over its life cycle (e.g. cement). The use phase of a product is also not considered.

The approach corrects the flow **Carbon dioxide [Resources]** on the input side, following the carbon dioxide balance equation shown below. The carbon correction process can be used on each single plan to keep the cause impact correlation close to each other.

The following diagram explains the basic concept of the carbon correction:

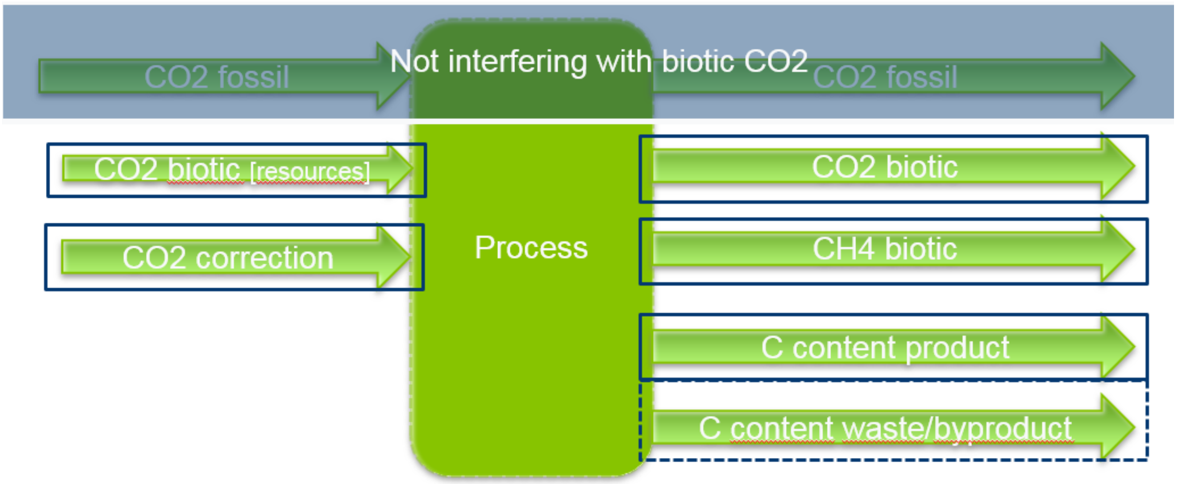


Figure 3-10: Basic concept carbon correction

The formula, which is used for the correction, is explained here. This formula should be entered in the carbon correction dummy (explanation see below):

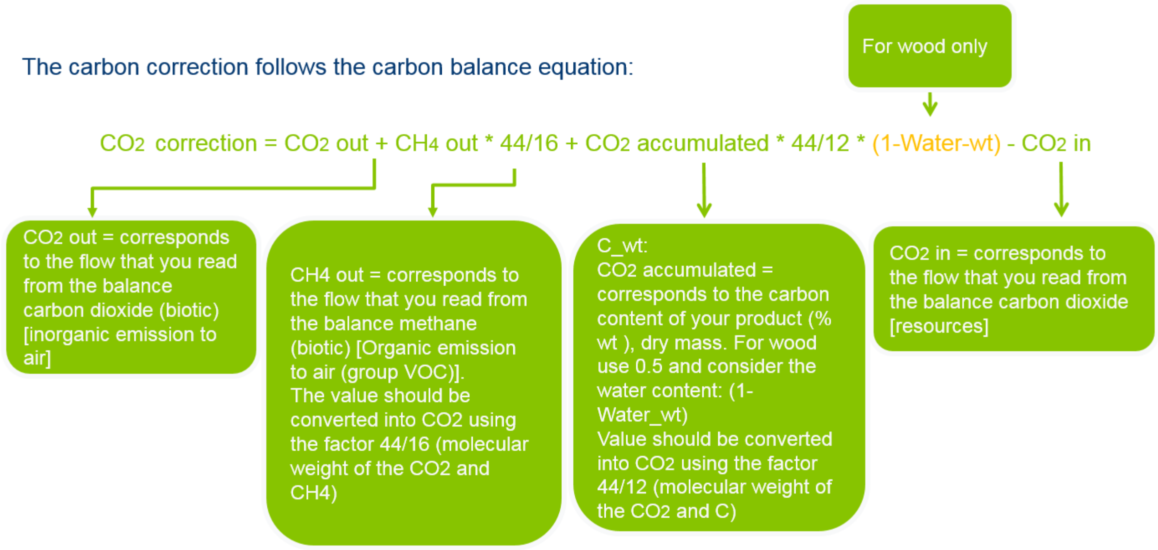


Figure 3-11: Carbon correction formula

How to correct the biogenic carbon in your model:

1. Check if the top plan level of your model is scaled to 1kg product. If the scaling is different, the values of carbon dioxide on the input side and carbon dioxide and methane on the output side need to be divided by the product weight in order to scale it to 1kg. The carbon content does not need to be adapted.
2. Copy and paste the process CO_2/ PE Adjustment GUID {F9B6537E-3A41-45CA-B04F-056C73F6B15B} to your plan
3. Connect the product flow to the process CO_2/ PE Adjustment
4. Identify the carbon content of the product. You can read this value from the product flow details (or through internet research). The carbon content refers to the fresh mass of the product. For wood, use 0.5 as C_wt. Only wood needs to be adjusted, since the models calculate with the dry mass, and the water content needs to be added.

C_biogen_wt	0.232	kg	0 %	4.31
C_wt	0.232	kg	0 %	4.31

5. Run a balance and copy values of the following flows:
   - Carbon dioxide (biotic) [inorganic emissions to air]
   - Carbon dioxide [resources]
   - If relevant; Methane (biotic) [Organic emissions to air (group VOC)]

Flows	**267**
Resources	**134**
Energy resources	**0.00602**
Land use	
Material resources	**134**
Non renewable elements	**0.000101**
Non renewable resources	**0.0315**
Renewable resources	**134**
Water	**133**
Air	0.779
Carbon dioxide	0.729
Nitrogen	2.47E-014
Oxygen	0.00898
Primary forest	1E-014
Others	
Deposited goods	**0.0145**
Emissions to air	**117**
Heavy metals to air	**2.17E-006**
Inorganic emissions to air	**116**
Ammonia	0.000122
Ammonium	3.36E-011
Ammonium nitrate	6.05E-019
Argon	1.28E-009
Barium	4.69E-007
Beryllium	2.23E-011
Boron	1.96E-015
Boron compounds (unspecified)	2.7E-009
Bromine	6.45E-010
Carbon dioxide	0.0186
Carbon dioxide (aviation)	1.33E-008
Carbon dioxide (biotic)	0.173
Carbon dioxide (land use change)	0.125
Carbon dioxide (peat oxidation)	2.11E-011
Carbon disulphide	5.02E-019

Figure 3-12: Balance view for carbon correction

Sulphur	3.12E-012
Sulphur dioxide	7.49E-005
Sulphur hexafluoride	7.93E-016
Sulphur trioxide	1.03E-009
Sulphuric acid	1.11E-011
Tin oxide	2.87E-023
Water (evapotranspiration)	116
Water vapour	0.344
Zinc chloride	2.02E-026
Zinc oxide	5.73E-023
Zinc sulphate	4.17E-012
Organic emissions to air (group VOC)	**0.000828**
Group NMVOC to air	**0.000379**
Hydrocarbons (unspecified)	1.51E-007
Methane	4.31E-005
Methane (biotic)	0.000406
Other emissions to air	**0.386**
Particles to air	**0.00102**
Pesticides to air	**7.7E-011**
Radioactive emissions to air	**1.71E-016**

Figure 3-13: Balance view for carbon correction

6. Open the process CO2 / PE Adjustment in “instance view” through a double-click and enter the values that you read from the balance and the carbon content of the product following the equation mentioned above.

Parameter	Formula	Value	Minimum	Maximur	Standar	Commen
CO2_corr	0.173040076+0.000406079*44/16+0.232*44/12-0.728546756503843	0.296				[kg] mar
PE_corr		0			0 %	[MJ] mai

Figure 3-14: CO_2 correction process - parameters

How you know that the biogenic carbon dioxide was corrected:

1. Once you entered the values in the CO_2 adjustment process run a mass balance again
2. Read the following values
   - Carbon dioxide [resources]
   - Carbon dioxide (biotic) [inorganic emission to air]
   - If relevant; Methane (biotic) [Organic emissions to air (group VOC)]
3. Calculate the difference between input and output flows
4. Check if the differences correspond to the carbon content of your product (use the conversion factor 44/12), if so the biogenic carbon was correctly corrected

From the quantities point of view GaBi has two GWP (CML) quantities: GWP including biogenic carbon and GWP excluding biogenic carbon. When the GWP quantity „excl. biogenic carbon“ is used, lower results from „GWP incl. biogenic carbon“ could be communicated as additional information, as this GWP value contains the potential credit for the carbon storage in case this carbon will stay in the product for a long time (>100 years).

Heavy metal uptake in biomass modelling

Renewables extract heavy metals from the ground when growing. The amount of this uptake is specific to the species as well as to the heavy metal content of the soil and can be measured as heavy metal content of the renewable material. Whether these heavy metals are in the soil for a long time or whether they are fresh immissions, e.g. from fossil energy generation or from fertilisers, is not known.

In Thinkstep datasets, this uptake is currently modelled as negative emission of heavy metal to ground. As a consequence the toxicity results of the renewables datasets are affected and in cradle to gate datasets the toxicity can also be overall negative. This is consistent with the modelling of carbon dioxide uptake into renewables that is described in this chapter. However in models that take into account the whole life cycle of the renewable material one would assume that all the heavy metals that are incorporated in the material are released again, as an emission to ground/water/air, and that the overall toxicity results in a cradle to grave model are always positive. This is however not always the case:

- If the heavy metals are incorporated in waste that is landfilled, then a large part of the heavy metals are not mobile and stay incorporated in the landfill body.
- If the heavy metals are incorporated in waste that is entering a new life cycle, then, according to the used method, the second life cycle is either cut off or after modelling the burdens of recycling a credit is given for the material that is substituted. In both cases the incorporated heavy metals are not released in the life cycle of the renewable itself, but are shifted to the life cycle where the waste is used.

As a consequence also cradle to grave models can have negative toxicity results. **The negative results are not wrong as long as the technical explanation for the negative results can be given. The negative results will lead however to difficulties in interpretation of the results, so practitioners would like to avoid these.**

Currently in the scientific LCA community, there are discussions on how to do this best. In the Guidance document 6.0 of the European Product Environmental Footprint [PEF Guidance 2016] (chapter 2.5.6) two possibilities are given:

1. Not to model the heavy metal uptake, when the final emissions are not accounted for
2. To model the heavy metal uptake, when the final emissions are accounted for (this is what thinkstep is currently doing)

Possibility 1 would solve the problem. This possibility however has a couple of drawbacks:

- The uptake of the heavy metals might be a feature of the system under study (e.g. when plants are used to clean contaminated soil). This could not be modelled at all.

- The final emissions of the heavy metals are an important distinction of different production routes and their ability to avoid or reduce heavy metal emissions to ground/water/air. Leaving these emissions out of the scope would certainly reduce the significance and technical correctness of the whole study.

Modelling the emissions but not modelling the uptake is also not a straightforward solution, since it is inconsistent with the current method for biogenic carbon, where both carbon dioxide uptake and emissions are modelled. And it also ignores the physical reality, since there is a heavy metal content in the renewable materials and the mass balance for the heavy metals is not closed.

Another idea is to not model the uptake as negative emissions, but to use resource flows for the heavy metals, which is consistent to carbon uptake. Then the heavy metal resources could have negative characterisation factors for toxicity. This does not solve the problem but simply shifts it from life cycle inventory to life cycle impact assessment. It would however add some transparency since the amount of uptake would be directly visible and the effect of the uptake could be assessed when interpreting the results. The negative side of this idea is that the results of the abiotic resource depletion for the renewables would dramatically change.

This shows that there at the moment is no solution available. Thinkstep is part of the scientific discussion around this topic and as soon as a consensus or a practicable solution is found, the solution will be implemented in the maintenance cycle of the databases.

3.3.12 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 efficiency[8], physical energy content method with virtual 100% efficiency for renewables[9], substitution approach to avoid renewable efficiencies with virtual thermal fossil efficiencies for renewables [10]) to define or compare the primary energy demand of a related usable energy form.

The IEA states[11]: “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

[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.

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 illustrate the situation adequately, comprehensively and transparently. This is especially important in countries with significant portions of renewables in the 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.

3.3.13 Land Use

Apart from the classical impact categories like Climate Change, Eutrophication, Acidification etc. land use as an environmental issue is widely considered important and constantly gains attention in the Life Cycle Assessment community.

In the software and database system GaBi, the ILCD elementary flows for land use are integrated and characterization factors (CF) for the LANCA® (Land Use Indicator Value Calculation in Life Cycle Assessment) indicators are provided. The methodology behind LANCA® 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) [Bos et al 2016] and [Beck, Bos, Wittstock et al. 2010]. A detailed description of the underlying methods as well as the characterization factors can be found in [Bos et al 2016] and [Beck, Bos, Wittstock et al. 2010]. The following set of indicators has been defined to model land use aspects in LCA:

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

On the inventory side country specific land use flows are used for "occupation" with the unit m^2*a and for "transformation from" and "transformation to" with the unit m^2 for all different land use types as for example "arable, irrigated, intensive" or "forest". The respective country specific characterization factors are integrated into the GaBi database and software in the impact assessment, and aggregated over the process chain to form environmental indicators that are representative for the entire life cycle. In the GaBi background processes land use information is addressed for all biomass and mining process. Through aggregation land use information is integrated in most of the processes. Therefore, land use can be considered as an additional aspect in LCA to extend its environmental impact evaluation.

LANCA® addresses at the moment the terrestrial biomes and not aquatic ones. However, this could be a further development process and therefore all water body/seabed flows are integrated characterized with the value "0".

All indicators are calculated for the transformation and occupation phase. One set of CFs is related to the "occupation" phase, one set to the "transformation from" phase and one to the "transformation to" phase. In order to explain the concept of transformation and occupation as well as the used data the relevant paragraphs of LANCA® are recommended:

httpLs://verlag.fraunhofer.de/BOOKSHOP/BUCH/LANCA/244600

LANCA is a regionalized method and uses regionalized flows in the GaBi processes that are marked as "ts" indicating thinkstep as the data source. 63 countries were selected based on their economic significance and coverage in the GaBi database. All EU28 countries are included in alignment with the PEF methodological guidelines. For other countries please use the un-regionalized flows and indicate your needs, so that thinkstep can expand the list of countries in the upcoming years accordingly.

Datasets from other data providers published in GaBi currently do not use regionalized flows. Land use assessment is possible for these datasets as well, but only using un-regionalized flows with global Characterization Factors. As a consequence, the interpretation of land use results comparing thinkstep datasets with datasets from other providers needs to be done with caution. Thinkstep believes that regionalization is a very important topic for land use assessment and will work towards a common use of regionalization in the future.

With the 2017 release of GaBi databases, the assessment of land use has made a big step forward. On the basis of the ILCD flow list, a mapping/conversion of all land use flows of different method developers and dataset providers into a common set of flows was possible. With this, in GaBi now the parallel assessment of land use is possible for the different LCIA methods LANCA, PEF/ILCD recommendation, ReCiPe, UBP, Impact 2002+ and EPS. The practitioners that have assessed land use before will recognise that the land use folders “hemeroby” and “hemeroby ecoinvent” are no longer there, since they have been merged with the other land use folders “Occupation” and “Transformation”

Land use is regarded as a resource category. Therefore, the flows for both occupation and transformation are located at the input side of processes and balance view. This is also true for the “transformation to” flows. As a consequence of this convention, the Characterization Factors of the “transformation from” and the “transformation to” have a different algebraic sign (one is positive, the other negative).

3.3.14 Land Use Change (LUC)

For a variety of reasons, there is an increasing demand of crops for the production of food, for bio fuels or for feedstock in materials. The replacement of natural land by agricultural systems or change from one to another agricultural system leads to land use change. Together with the change of the land use, system changes in the carbon stock, biodiversity and socio-economic effect might occur. These effects can be subdivided into:

- direct Land Use Change (dLUC):

  Change in human use or management of land within the boundaries of the product system being assessed

- indirect Land Use Change (iLUC):

  “Change in the use or management of land which is a consequence of direct land use change, but which occurs outside of the product system assessed” [OVID 2013]

3.3.14.1 Direct Land Use Change

Emissions from direct land use change are calculated with the "direct land use change assessment excel tool" for the approach “weighted average” (as required for compliance with the ENVIFOOD protocol; and can be applied for compliance with WRI GHG Protocol) based on the approach from PAS 2050-1:2012 and WRI GHG protocol.

The calculations for carbon stock changes are based on IPCC rules: The basic approach is to determine the total carbon stock change by assessing the difference between carbon stocks of the agricultural area - including both, soil and vegetation - of the previous and the changed situation. The assumptions for carbon stocks are dependent upon country, vegetation type, climate & soil type. The approach is crop-specific: The impacts from land use change in a specific country are allocated to all crops in this country, for which the value of 'area harvested' increased over time. This allocation is dependent on the crop's respective share of area increase in this country.

There are 3 different calculation approaches which can be applied (country known and previous land use is known, the country is known and the previous land use is not known, the country is not known and the previous land use in not known). For all GaBi datasets, the following situation is applied: The country is known (as defined by the respective dataset) but the previous land use is by default unknown. The emissions, which occur due to the land use change, are distributed over a time period of 20 years. The tool, which includes background information, documentation and calculations, can be downloaded at blonkconsultants.com. Underlying sources for the calculations are statistical data for crop yields, harvested area of crops from FAOSTAT, the area of forest and grassland from FAO's global forest resource assessment (Data from the Global Forest Resource Assessment of the FAO. See also http://www.fao.org/forestry/fra/fra2010/en/) [FAO 2012], the respective carbon stocks from EC JRC world map of climate types and world map of soil types (from EC JRC http://eusoils.jrc.ec.europa.eu/projects/RenewableEnergy), the above ground mass carbon stock, values of soil organic carbon stock and stock change factors from IPCC 2006. Changes in soil organic carbon stock are taken into account in this methodology. The emissions are calculated in a process and connected with the agrarian plant model per hectare and are scaled per reference unit respectively.

On LCI level, the emissions are reported separately with the flow "carbon dioxide from land use change" as required by certain standards. The emissions are per default directly released as carbon dioxide. In case different information is available, partly incineration is applied and is explicitly described in the respective dataset.

The analysis on LCIA level is described in chapter 3.3.14.3.

References

- Blonk (2014) Direct land use change assessment tool, version 2013.1 from Blonk Consultants, Gouda, 2013
- IPCC 2006: IPCC Guidelines for National Greenhouse Gas Inventories. 2006. Chapter 4.
- Global Forest Resource Assessment, 2010. FAO: http://www.fao.org/forestry/fra/fra2010/en/
- ISO/TS 14067 (2013) ISO 14067 Greenhouse gases – Carbon footprint of products – requirements and guidelines for quantification and communication, 2013.
- EC JRC (2013) Soil Projects; Support to Renewable Energy Directive http://eusoils.jrc.ec.europa.eu/projects/RenewableEnergy/. Accessed 15 July 2014.

3.3.14.2 Indirect Land Use Change

Indirect land use change is not considered in the LCI data of the GaBi Databases. This chapter will provide an outline why indirect LUC is not considered.

Finkbeiner [Finkbeiner 2014] analysed the scientific robustness of the indirect LUC concept and its consistency with international accounting standards for LCA: "The conclusion was that globally agreed accounting standards for LCA and carbon footprints do exist, while there are currently no accounting standards for indirect LUC at all". There is no need by standards to display indirect LUC results.

Finkbeiner further concluded: "There is just one thing which is commonly agreed: the uncertainty of indirect LUC quantification approaches and their results. There is full agreement in the scientific community that the uncertainty is way beyond a level that is usually aimed for in quantitative science." The scientific robustness is not sufficient for political and corporate decision-making [Finkbeiner 2014]

As there is no commonly agreed methodology the data basis is not sufficient for inclusion of indirect LUC data in the GaBi databases. Any data would rely on assumptions etc. indirect LUC calculations may be done on project basis.

3.3.14.3 GWP effects in agriculture, horticulture and silviculture

In agriculture, horticulture and silviculture additional GWP effects are to be considered, compared to fossil-based products.

Due to the renewable nature of the products, the biogenic carbon cycle is taking place much faster than the fossil carbon cycle. Besides the known standard emissions of fossil CO_2, CH_4 and alike, additionally CO_2 intake/uptake from atmosphere appears to build up the plants. Animals eat plants and grow. Anaerobic transformation from carbon into CH_4 happens in animals and in certain situations of rotting and decomposition. Carbon storage in the products and carbon losses influences the carbon balance. Biotic CO_2 emissions and biotic CH_4 emissions have to be differentiated from fossil emissions. Land use changes have an effect on the carbon balance, because different land use types release additional CO_2 amounts due to reduced carbon storage capabilities.

The following paragraphs describe the various aspects in more detail and summarize all GWP related aspects in an overview table.

Fossil GWP related emissions
Concerning fossil GWP emissions, the established standard approach is consistently applied to agriculture, horticulture and silviculture system as well.

Biotic CO_2
Concerning biotic CO_2, the uptake and emission have to be considered. Generally, in GaBi the carbon uptake from the atmosphere and the biotic emissions are modelled. This is done by using on the input the flow "carbon dioxide [renewable resource]" and on the output side the flow "carbon dioxide (biotic) [Inorganic emissions to air]" for all biotic CO_2 emissions. Carbon containing wastes and losses are modelled with the appropriate flows (and their respective carbon content) accordingly. An illustration is shown in Figure 3-15.

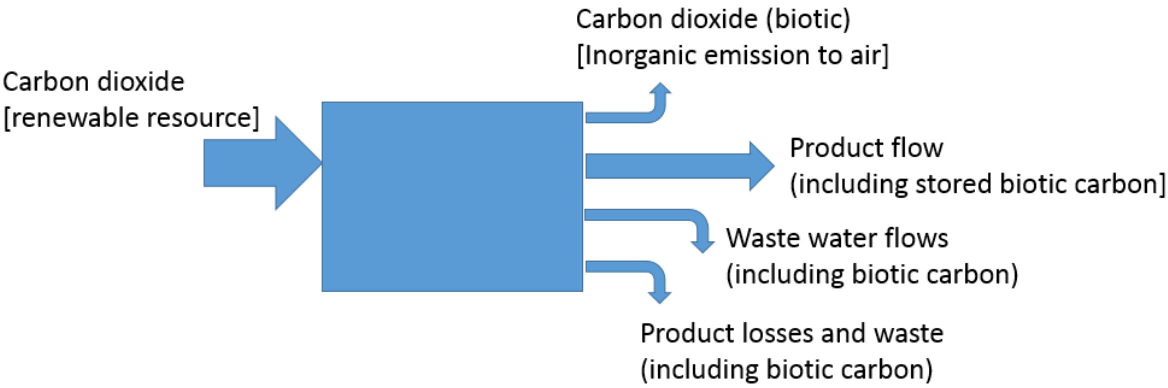


Figure 3-15: Example of different biotic carbon flows in GaBi.

Biogenic CH_4 emission

Concerning biotic CH_4, only emission have to be considered, as no CH_4 is taken up by nature. Biotic CH_4 may be created in anaerobic conditions turning carbon (which surely was initially taken up by the plant/fodder in form of CO_2 from the atmosphere) into CH_4 in certain decomposition processes, aqueous field techniques, landfill processes or in animal digestion. Generally, we model on the output side the biotic CH_4 emissions using the flow “Methane (biotic) [Organic emissions to air]” (as shown in Figure 3-16).

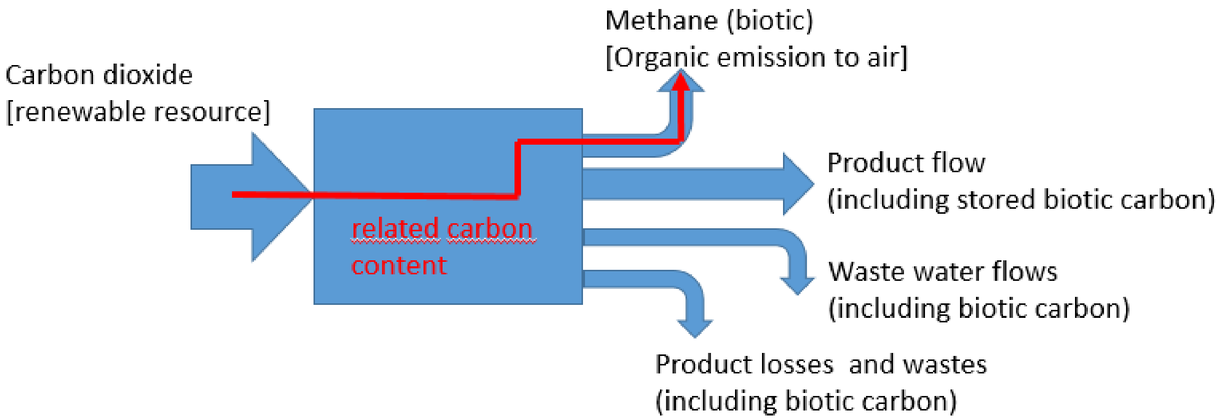


Figure 3-16: Example of methane biotic emissions to air.

Land use change related CO_2 emissions

Due to certain land use change activities, CO_2 releases of formally stored carbon in vegetation and soil might be unavoidable. Typical examples are the conversion from rain forest into plantations, or the conversion of deciduous forest into a quarry and the drying of a swap or peat bog. Those changes imply a change in the capability to uptake and store carbon in the vegetation or soil and to release the difference into the atmosphere respectively.

Underlying methodologies and databases for the calculation of these effects can be different. From result interpretation point of view, the main difference in the inventory in GaBi is the related accounting of land use change CO_2 either as:

a):

- Carbon dioxide (land use change) [Inorganic emissions to air] – this flow is used for all data based on the approach described in chapter 3.3.14.1. and

- Carbon dioxide (peat oxidation) [Inorganic emissions to air] – this flow is used if transformation occurred on peatland. Annual emissions occur over a longer period of time. This flow is only used in a very limited amount of datasets.

b)

- **Carbon dioxide [Inorganic emissions to air] –** for all datasets which are based on other methods or data (the respective approach is described in the documentation of the respective datasets)

Approach a) follows a more consistent approach but is built on more generic data. Approach b) is longer on the market, some data already existed and are used in practice. These datasets are based on detailed research and specific decisions on the modelling (see respective documentations). These datasets are clearly indicated by chosing a process name "incl. LUC as fossil CO2" in GaBi. Therefore we accept/respect datasets including information of method b), however new land use change data in GaBi is primarily produced by method a) (see GaBi Modelling Principles chapter 3.3.14) for details.

Accounting of impacts in Method a) by specific flows in Figure 3-17

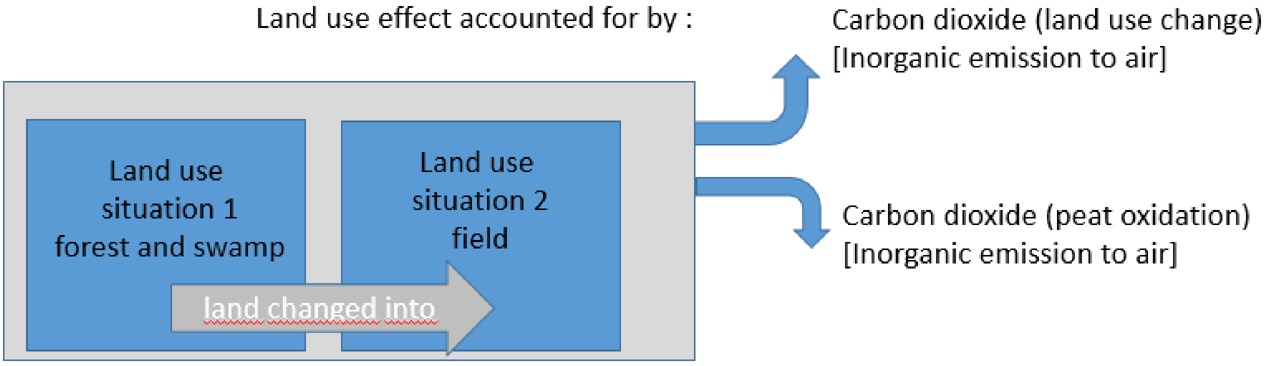


Figure 3-17: Example of LUC emissions occurring with additional LUC flows.

Accounting of impacts in Method b) by "fossil CO_2" in Figure 3-18.

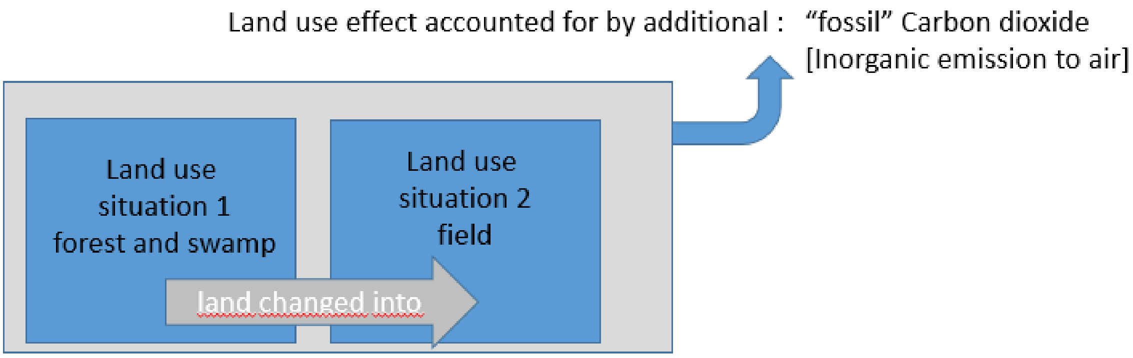


Figure 3-18: Example of LUC emissions occurring without an additional LUC flow as fossil CO2

A mix of both approaches in one dataset or supply chain is not used. So if land use change is a relevant impact in the related supply chain and data set the effects are either accounted for under fossil Carbon dioxide or alternatively under Carbon dioxide (land use change) and/or Carbon dioxide (peat oxidation).
Due to the fact that land use change is very important for one group of users and perceived as less relevant and potentially confusing for other users we added additional impact categories to enable the user to either include or exclude land use change effects and to still keep comparisons to former results consistent.

Below is an example for CML (but which is equally true for other GWP impact assessment methods:

Next to the existing standard Global Warming categories…
1. CML2001 - Apr. 2013, Global Warming Potential (GWP 100 years)
2. CML2001 - Apr. 2013, Global Warming Potential (GWP 100 years), excl. biogenic carbon

…three new Global Warming categories are consistently introduced:
3. CML2001 - Apr. 2013, Global Warming Potential (GWP 100), incl. biog. C, incl. LUC
4. CML2001 - Apr. 2013, Global Warming Potential (GWP 100), excl. biog. C, incl. LUC
5. CML2001 - Apr. 2013, Global Warming Potential (GWP 100), Land Use Change only

Example: If you do not like to look at land use change effects, you should use 1). If you like to include them you would use propose 3).
This solution serves to keep results of previous studies "comparable" without changing the impact assessment. Additionally, this approach enables compliance to your specific schemes or modelling approach used as well as full transparency over the related aspects and newest scientific findings in global warming effects in relation to the rising awareness of land use changes.

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 Labour statistics and Energy Information Administration data).

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

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

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

thinkstep'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, thinkstep 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. thinkstep 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 thinkstep 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 that 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.

Complete methodologies

- CML 2001, ver. 2013 [CML 2001], additionally ver. 2001-2010
- ReCiPe 1.08 Mid- and Endpoints (I+H+E) [RECIPE 2012], additionally ver.1.05 (H) and1.07 (H)
- TRACI 2.1 [THYLMANN 2017], additionally TRACI 1 and TRACI 2.0
- UBP 2013 [UBP 2013], additionally UBP 1998 and UBP 2006
- EDIP 2003 [HAUSCHILD 2003], additionally EDIP 1997
- Ecoindicator 99 [ECO-INDICATOR 99 : 2000] and 95 [ECO-INDICATOR 95 : 2000]
- Impact 2002+ [IMPACT 2002]
- ILCD/PEF: Combined using IPCC 2006, ReCiPe, USETox 2010, Soil Organic Matter (SOM), Accumulated Exceedance (AE), Riskpoll, ADP (reserve based), and UBP 2006.

Input-dependent methods

- Abiotic Depletion Potential (ADP), reserve base [CML 2001]
- Anthropogenic Abiotic Depletion Potential (AADP) [SCHNEIDER 2011])
- LANCA land use [BECK, BOS, WITTSTOCK ET AL. 2010]
- Primary energy non-renewable (entered as an additional quantity)
- Primary energy renewable (entered as an additional quantity)
- Demands on natural space (surface)
- Water use and water consumption

Output-dependent methods

- USETox 2010 [USETOX 2010]
- Soil Organic Matter (SOM) [MILA` I CANALS 2007]
- Accumulated Exceedance (AE) [SEPPÄLÄ ET AL. 2006]
- IPCC AR5 [IPCC 2013]
- Riskpoll [RABL AND SPADARO 2004]

3.4.5 Production and consumption mix

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

a. "**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.

b. "**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 3-19 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.

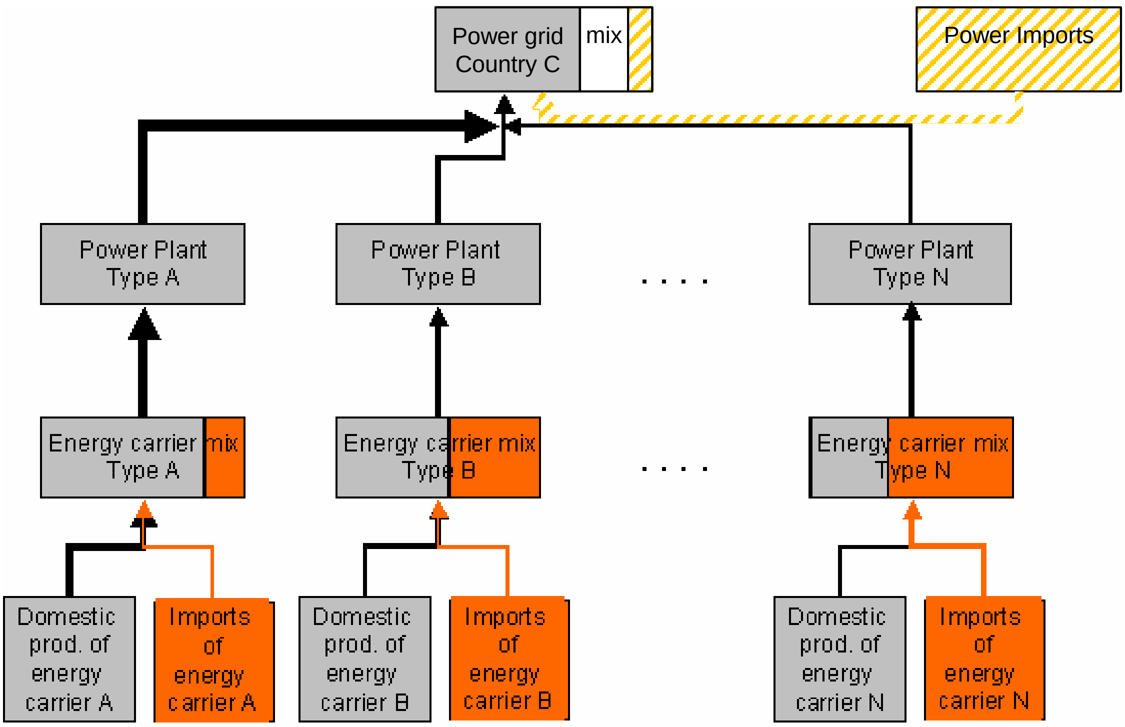


Figure 3-19: Difference between "production mix" and "consumption mix" (for power generation)

The part of the Figure 3-19 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 2013 database aims to provide consumption mixes wherever possible.

3.5 Data quality approach

Data quality is probably one of the most discussed issues of databases with the widest interpretation and application. Generally, data quality is discussed from two different standpoints:

- technical quality: how meaningful and representative is the given value for the defined use case
- methodological quality: how well are procedures of certain methods addressed

For the development of the current GaBi databases, the following method independent importance of “quality indicators” can be stated generally.

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

	indication of importance					
Indicator	**less**					**more**
credibility and source of data						
access to industry information						
relation of data to technology issues						
consitency						
representativeness of data						
age / validity of data						
transparency of documentation						
country/region specificness						
completness 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 has so far been established as the “best practice.” Either the methods are based on certain amount of expert judgements or a randomly chosen certain distribution probability to produce the results. This means no method or mathematical relation can objectively produce LCA DQIs, without certain engineering knowledge of an individual or group able to judge the quality or better consistency of the values relative to each other.

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 thinkstep approach is to use our experience and our relevant contacts to judge certain aspects , rather than trusting in figures that are calculated by a random procedure with little or no link to engineering reality.

As certain methodological DQI rules gain importance, these are combined with the GaBi DQI process ensuring technical and methodological quality in the most efficient and effective manner. The following paragraphs address the DQI approach in GaBi databases.

3.5.1 Decision context

The ILCD handbook ([ILCD 2011] „specific guide“) defines 4 decision contexts for LCA projects and required LCA methods to be followed. The decision context is also relevant in PEF [PEF GUIDE 2013], since the decision context of datasets used and results shall be stated. The definitions according to ILCD are:

Decision context A: Micro-level decision support

“Decision support, typically at the level of products, but also single process steps, sites/companies and other systems, with no or exclusively small-scale consequences in the background system or on other systems. I.e. the consequences of the analysed decision alone are too small to overcome thresholds and trigger structural changes of installed capacity elsewhere via market mechanisms.”

Decision context B: Meso/macro-level decision support

“Decision support for strategies with large-scale consequences in the background system or other systems. The analysed decision alone is large enough to result via market mechanisms in structural changes of installed capacity in at least one process outside the foreground system of the analysed system.”

Decision context C: Accounting

“From a decision-making point of view, a retrospective accounting / documentation of what has happened (or will happen based on extrapolating forecasting), with no interest in any additional consequences that the analysed system may have in the background system or on other systems. Situation C has two sub-types: C1 and C2. C1 describes an existing system but accounts for interactions it has with other systems (e.g. crediting existing avoided burdens from recycling). C2 describes an existing system in isolation without accounting for the interaction with other systems.”

Decision context C 1: Accounting, incl. interactions with other systems

“Note that any decision support that would be derived needs to employ the methods under Situation A or B, with Situation C having a preparatory role only. Note however that due to the simplified provisions of this document, the modelling of Situation A studies (micro-level decision support) is identical to that of Situation C1 studies, but not vice versa.”

Decision context C 2: Accounting, excl. interactions with other systems

The GaBi database is supporting decision context A, as it is designed for the following main applications:

- Product improvement
- Product comparisons
- Communication
- Accounting

All of these applications are listed under decision context A and C1, where A and C1 are identical (see above). This however does not mean that the use of GaBi databases is not possible in decision context B, since in these projects not all parts of the production system under supervision are affected by large-scale consequences. In these projects, the practitioner may use the attributional GaBi datasets, identify consequential parts of the system and change these consequential parts according to the needs of the project.

3.5.2 Data Quality Indicators (DQIs)

GaBi datasets aim to be technology specific. Various technologies may produce 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 that 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 delivered 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.

With the 2013 database upgrade, Data Quality Indicators (DQIs) are introduced for all thinkstep datasets (in total approx. 7200 datasets, professional DB, extension DBs, data on demand). The methodology is based on Product Environmental Footprint (PEF) requirements, further specifying the open framework set by the PEF guide [PEF GUIDE 2013]. Since the formal PEF review process for external independent reviews is not yet in place (status October 2013), thinkstep decided to introduce the DQIs as a part of the internal dependent review of the datasets. With this, the datasets are usable in PEF pilot projects.

Each dataset is reviewed by two thinkstep experts:

- One industry sector specific LCA expert
- One database expert ensuring overall consistency

The following chapters discuss the six quality indicators, the overall data quality indicator and the method for data quality assessment via expert judgement.

3.5.2.1 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 point of commission back to the resource extraction. Technology really does matter.

For the DQIs, the datasets are expert judged using the instance properties of the processes and plans of the system with an emphasis on unit processes and the main precursor materials/energies. The following settings are used:

- **Very good:** Completely representative - Technology mix or solely existing technology in the market regarding unit process and related main precursors (energy and materials)
- **Good:** Completely / partly - Main technology in the market AND precursors from the main technology of the market
- **Fair:** Partly representative - one of the relevant technologies in the market and precursors from the main technology of the market OR main technology of the market and precursors from one of the relevant technologies in the market
- **Poor:** Partly / not - one of the existing technologies and precursors from one of the existing technologies in the market
- **Very poor:** Not representative - one of the existing technologies that is known to be not representative

3.5.2.2 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 information of the technology mix 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, 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.

For the DQIs, the datasets are reviewed by expert judgement using the settings of the instance properties of the processes and plans of the system with an emphasis on the unit process and the main precursor materials/energies. Four criteria are used:

- Technology representative for the region/country stated?
- Precursor materials representative for the region/country stated?
- Precursor energies representative for the region/country stated?
- "Mix and location type" represents the one stated in the documentation?

The following settings are used:

- **Very good:** Completely representative - all 4 criteria met
- **Good:** Completely /partly representative - 3 out of 4 criteria met
- **Fair:** Partly representative - 2 out of 4 criteria met
- **Poor:** Partly / not representative - 1 out of 4 criteria met
- **Very poor:** Not representative - unit process and main precursors representing another geography than the area stated and are known to be not representative

3.5.2.3 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. 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 thinkstep engineers did not have any evidence that something changed or developed in process technology concerning this production step.

For the DQIs, the datasets are reviewed by expert judgement using the settings of the instance properties of the processes and plans of the system with an emphasis on the unit process and the main precursor materials/energies. The following settings are used:

- **Very good:** Completely representative - Check of representativeness or main data source not older than 3 years
- **Good:** Completely /partly representative
- **Fair:** Partly representative - Check of representativeness or main data source not older than 3 years, known changes but still partly representative
- **Poor:** Partly / not representative
- **Very poor:** Not representative - technology that is known to be not representative

3.5.2.4 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 by 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 not all flows can be recorded, this is the next option, which still enables good quality of results in terms of evaluation.
- **"individual relevant flows recorded "**: Only particular flows are recorded. It must be clear that in this case some important flows can have been omitted, 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 user-specific cases. This can be done on the plan-system level in GaBi, by indicating the technical, geographical and time-related representativeness.

For the DQIs, the datasets are reviewed by expert judgement using the settings described above:

- **Very good:** all flows recorded
- **Good:** all relevant flows recorded
- **Fair:** Individual relevant flows recorded

- **Poor:** some relevant flows not recorded
- **Very poor:** no statement about completeness available

3.5.2.5 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 thinkstep database content uses consistent data sources and background systems (e.g. transport, energy processes).

For the DQIs, the datasets are reviewed by expert judgement using the following settings:

- **Very good:** defined methodology or standard, certified compliance
- **Good:** GaBi modelling principles
- **Fair:** ISO 14.040 with additional method/consistency requirements mainly met
- **Poor:** ISO 14.040 with additional method/consistency requirements partly met
- **Very poor:** Methodology or consistency with known deficits

3.5.2.6 Uncertainty / Precision

Precision determines the probability distribution of data, and whether it has been measured, calculated or estimated. In the case of the GaBi database, the following procedure is adopted regarding the origin:

- **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 does not explicitly state, whether the value was measured or estimated.
- **Calculated:** The values were calculated, e.g. stoichiometric.
- **Estimated:** Expert judgement, e.g. referring to comparable products/processes or legislations.

Origin / reliability are not part of the 6 DQIs used by ILCD/PEF. But whether data is plausibility checked by an expert or not is an important fact concerning the precision and deserves to be part of the assessment process.

For this semi-DQI, the datasets are reviewed by expert judgement using the following settings:

- **Very good:** measured /calculated AND verified
- **Good:** measured / calculated / literature and plausibility checked by expert
- **Fair:** measured / calculated / literature and plausibility not checked by expert OR Qualified estimate based on calculations plausibility checked by expert
- **Poor:** Qualified estimate based on calculations, plausibility not checked by expert

* **Very poor:** Rough estimate with known deficits, not based on calculations

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 uncountable[12].

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, thinkstep chooses the following approach to minimise uncertainty:

1. Completing correct data collection (and close mass and energy balances).
2. Choosing representative LCA data for the upstream and background data, which represent the actual technology
3. Understanding the technical processes and defining 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 the LCA modeller and the reviewer have no indication how the identified technical parameters may perform or how the parameters are independent from each other, Monte Carlo Analysis is an alternative. It allows the examination of consequences of random uncertainties of known probability distribution 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 that is uncertain (all inputs, outputs, parameters, impact values). This analysis is not yet implemented for GaBi datasets. 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

[12] Not everything that can be counted counts and not everything that counts can be counted. Albert Einstein

- 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 background 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 diminish along the way. The next paragraph addresses thinkstep'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 example of 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

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 CO_2 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 number), 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 'chosen 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 H: 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:

3. 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.
4. 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.

Knowing about the difficulties of quantification of precision and also knowing that all of the other elements of data quality (technology, time, geography, completeness, methodological consistency, data origin) have an influence on precision, thinkstep decided to **calculate the arithmetic average out of the six criteria above (5 other DQIs plus Origin), but the result cannot be better than completeness.**

This follows the logic of PEF [PEF GUIDE 2013] (where the values given for precision are 100% minus the values for completeness) and also follows the logic of data that has a normal distribution, since for these the expected values and the standard deviations may simply be combined and form another normal distribution (addition theorem of normal distribution). thinkstep knows about the deficit this procedure has for low quality data (estimations), where one poor or very poor element of data quality (e.g. technological representativeness, see above) can spoil the precision regardless of the values of the other elements. But on the other hand the number of low quality datasets in the GaBi databases is very low and the experts reviewing the data quality in such cases are asked to be extremely critical regarding the other elements, which leads to the fact that datasets with known deficits ("poor" in any of the elements) do not have a precision better than "fair" in the GaBi database.

3.5.2.7 Overall Quality

The overall quality of the datasets depends on the values of the 6 DQIs described above. thinkstep has decided to calculate the average value from the 6 DQIs and use it for the overall quality. There are however other possibilities according to ILCD [ILCD 2011] and PEF [PEF GUIDE 2013]. The methods used in these two assessment schemes are illustrated in Figure 3-20 and Figure 3-21. In the documentation of the datasets, all three methods are used to give the practitioner an overview of the usability of the datasets in ILCD and PEF.

The outcome of the overall data quality of the GaBi databases is:

- 100% of the datasets are usable in ILCD/PEF related projects.
- **95% of the datasets achieved an overall GOOD data quality and are usable in PEF projects without any restrictions.**
- 4% of the datasets achieved an overall FAIR data quality and are usable in PEF projects, if these 4% do not account for more than 30% of the end results in each of the impact categories.
- 1% of the datasets achieved an overall POOR data quality and is usable in PEF projects, if this 1% do not account for more than 10% of the end results in each of the impact categories.

The overall data quality shall be calculated as detailed in Formula 3:

Formula 3 $$DQR = \frac{TeR + GR + TiR + C + P + M + X_w * 4}{i + 4}$$

- *DQR* : Data Quality Rating of the LCI data set; see Table 7
- *TeR, GR, TiR, C, P, M* : see Table 5
- *Xw* : weakest quality level obtained (i.e. highest numeric value) among the data quality indicators
- *i* : number of applicable (i.e. not equal "0") data quality indicators

Table 7 Overall quality level of a data set according to the achieved overall data quality rating

Overall data quality rating (DQR)	Overall data quality level
≤ 1.6[77]	"High quality"
>1.6 to ≤3	"Basic quality"
>3 to ≤4	"Data estimate"

Figure 3-20: Overall data quality according to ILCD assessment scheme [ILCD 2011]

Formula 1 $$DQR = \frac{TeR + GR + TiR + C + P + M}{6}$$

— *DQR: Data Quality Rating of the dataset*

— *TeR: Technological Representativeness*

— *GR: Geographical Representativeness*

— *TiR: Time-related Representativeness*

— *C: Completeness*

— *P: Precision/uncertainty*

— *M: Methodological Appropriateness and Consistency*

Table 6

Overall data quality level according to the achieved data quality rating

Overall data quality rating (DQR)	Overall data quality level
≤ 1,6	"Excellent quality"
1,6 to 2,0	"Very good quality"
2,0 to 3,0	"Good quality"
3 to 4,0	"Fair quality"
> 4	"Poor quality"

Figure 3-21: Overall data quality according to PEF assessment scheme [PEF GUIDE 2013]

3.5.2.8 Overview of the DQIs

	1	2	3	4	5	
	Very good	**Good**	**Fair**	**Poor**	**Very poor / not evaluated / unknown**	**Assistance to reviewer**
Technological representativeness	Completely representative - Technology mix or solely existing technology of the market regarding unit process and related main precursors (Energy and materials)	Completely / partly - Main technology of the market AND precursors from the main technology of the market	Partly representative - one of the relevant technologies of the market and precursors from the main technology of the market OR main technology of the market and precursors from one of the relevant technology of the market	Partly / not - one of the existing technologies and precursors from one of the existing technologies of the market	Not representative - one of the existing technologies that is known to be not representative	Settings of the instance properties of the processes and plans of the system. To be reviewed by expert judgement with an emphasis to the unit process and the main precursor materials/energies
Time representativeness	Completely representative - Check of representativeness or main data source not older than 3 a	Completely /partly representative	Partly representative - Check of representativeness or main data source not older than 3 a, known changes but still partly representative	Partly / not representative	Not representative - technology that is known to be not representative	Settings of the instance properties of the processes and plans of the system. To be reviewed by expert judgement with an emphasis to the unit process and the main precursor materials/energies
Geographical representativeness	Completely representative - all 4 criteria met	Completely /partly representative - 3 out of 4 criteria met	Partly representative - 2 out of 4 criteria met	Partly / not representative - 1 out of 4 criteria met	Not representative - unit process and main precursors representing another geography than the area stated and is known to be not representative	representative # precursor energies representative # "Mix and location type" represents the one stated in the documentation. Settings of the instance properties of the processes and plans of the system. To be reviewed by expert judgement with an emphasis to the unit process and the main precursor materials/energies
Completeness	All flows captured	All relevant flows recorded	Individual relevant flows recorded	Some relevant flows not recorded	No statement	Setting of the agg dataset as published
Methodological appropriateness and consistency	defined methodology or standard, certified compliance	GaBi modelling principles	ISO 14.040 with additional method/consistency requirements mainly met	ISO 14.040 with additional method/consistency requirements partly met	Methodology or consistency with known problems	
Origin / Reliability	measured /calculated AND verified	measured / calculated / literature and plausibility checked by expert	measured / calculated / literature and plausiblity not checked by expert OR Qualified estimate based on calculations plausibility checked by expert	Qualified estimate based on calculations, plausibility not checked by expert	Rough estimate with known deficits	
Precision (parameter uncertainty)						arithmetic average out of six (5 other DQIs plus Origin), but cannot be better than completeness. This follows the logic of PEF regarding (1-completeness) and also follows the logic of data that has a normal distribution, since for these the expected values and the standard deviations simply may be combined and form another normal distribution (Additionsteheorem Normalverteilung)
Overall quality						Arithmetic mean from the 6 DQIs above

Figure 3-22: Overview of the six DQIs and the criteria for the assessment

Figure 3-22 gives an overview of the criteria used when assessing the data quality via expert judgement. Figure 3-23 shows a screenshot of a dependent internal review that can be found in the documentation tab of thinkstep GaBi datasets in the category validation. The value of the DQIs can be seen and the other review details gives an overview of the achieved overall data quality according to the assessment schemes of GaBi, ILCD and PEF.

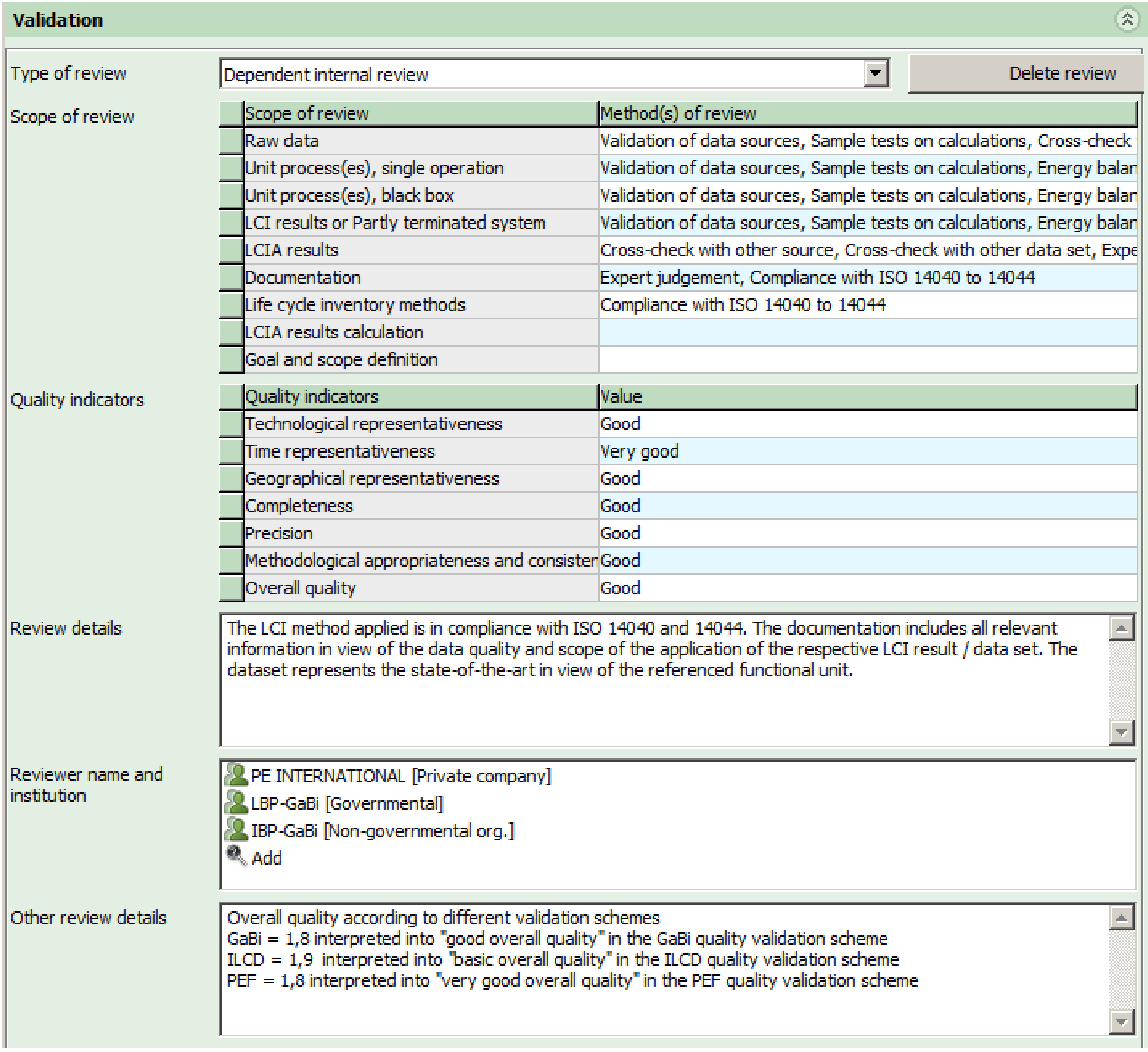


Figure 3-23: Screenshot of a dependent internal review including the DQIs

3.5.3 Reproducibility, Transparency, 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; furthermore, aggregation speeds up LCAs (lowering 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 (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 by 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 by a wider audience.

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 users[13].

Two types of aggregation exist:

- horizontal
- vertical

The following figure describes the difference.

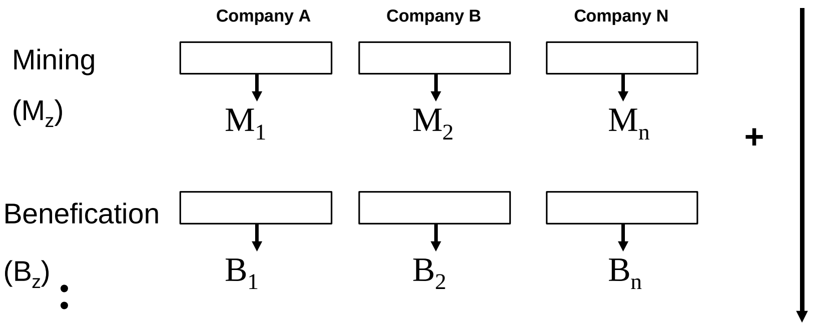


Figure 3-24: Principle graphical explanation of the relation of completeness, precision

The horizontal aggregation (M1+M2+M3+...) and (B1+B2+B3+...) 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

[13] 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.

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 can be subject to easy misinterpretations.

The vertical aggregation (M1+B1+...) and (M2+B2+...) 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.

4 System Modelling Features

The GaBi software system was developed to support the complete workflow 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 that 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 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 checklist 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 thinkstep. 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 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 is the object type flow. A GaBi 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 are the link between processes within a life cycle system.

Plans (or plan systems) are used in GaBi 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 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 system are proposes by academia and practise. 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 CO_2)
- Technical aspects like calorific value, element content or impact category
- Reference unit (e.g. kg, MJ, Bq, Nm^3)

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 2013] have already integrated elementary and product flows for more than 10000 datasets and the respective used flows are documented directly in the process headline.

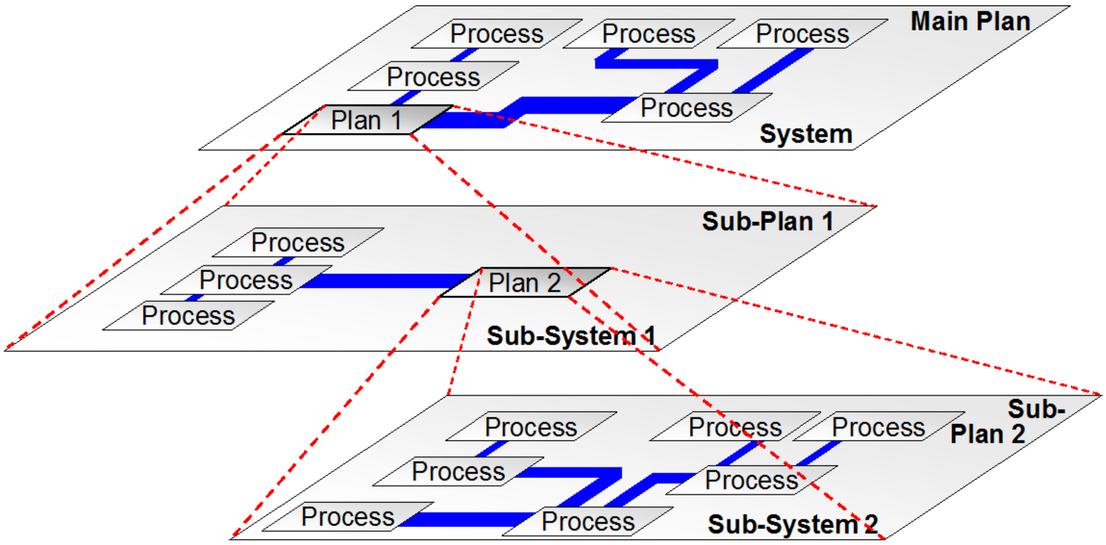


Figure 4-1: Hierarchical structure of the processes and plans

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 CO_2 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 boundaries) 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 2013 database [GaBi 2013]:

- 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.

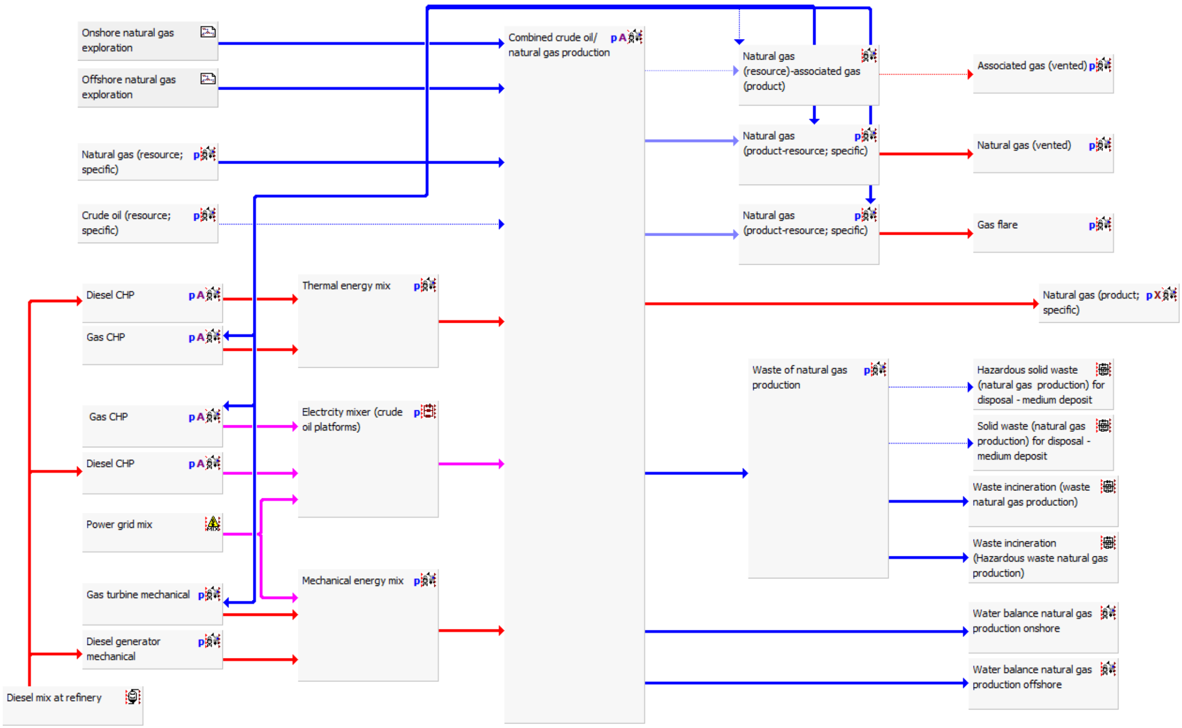


Figure 4-2: Conventional natural gas production in Germany

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.

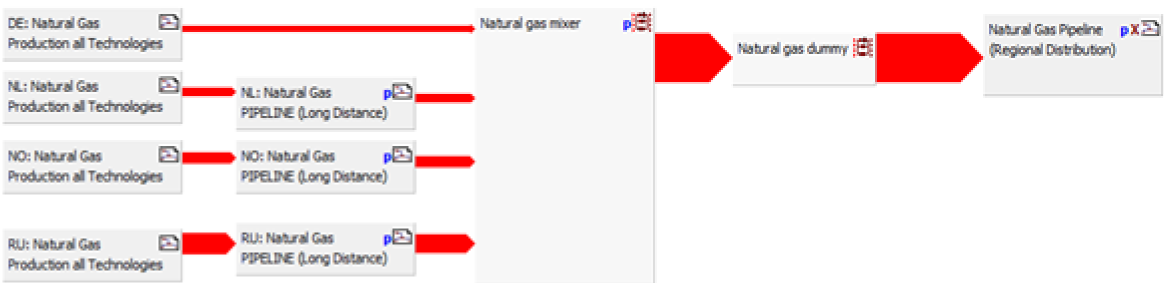


Figure 4-3: Natural gas supply for Germany

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. CO_2) 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.

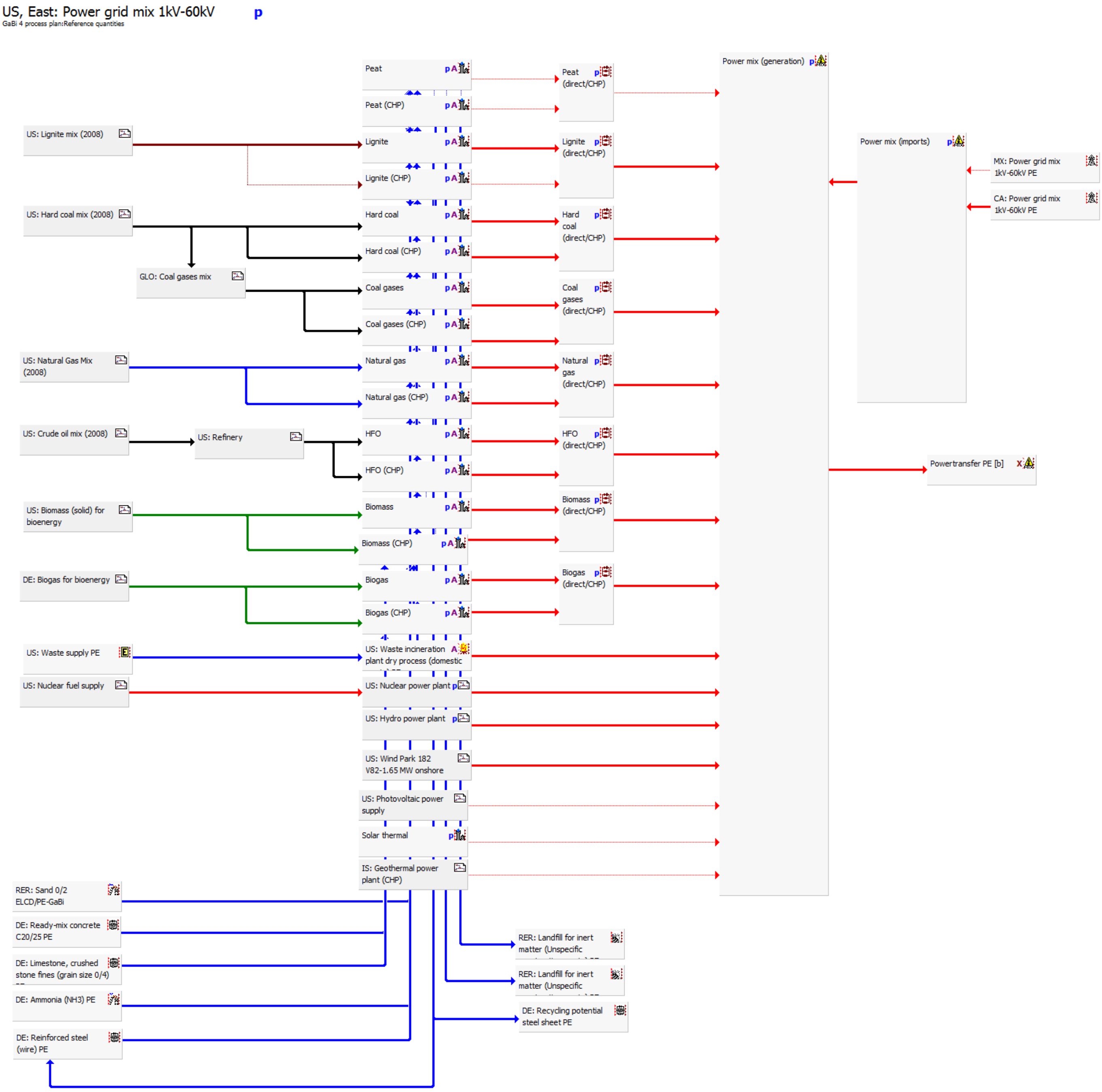


Figure 4-4: US, East electricity grid mix

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.

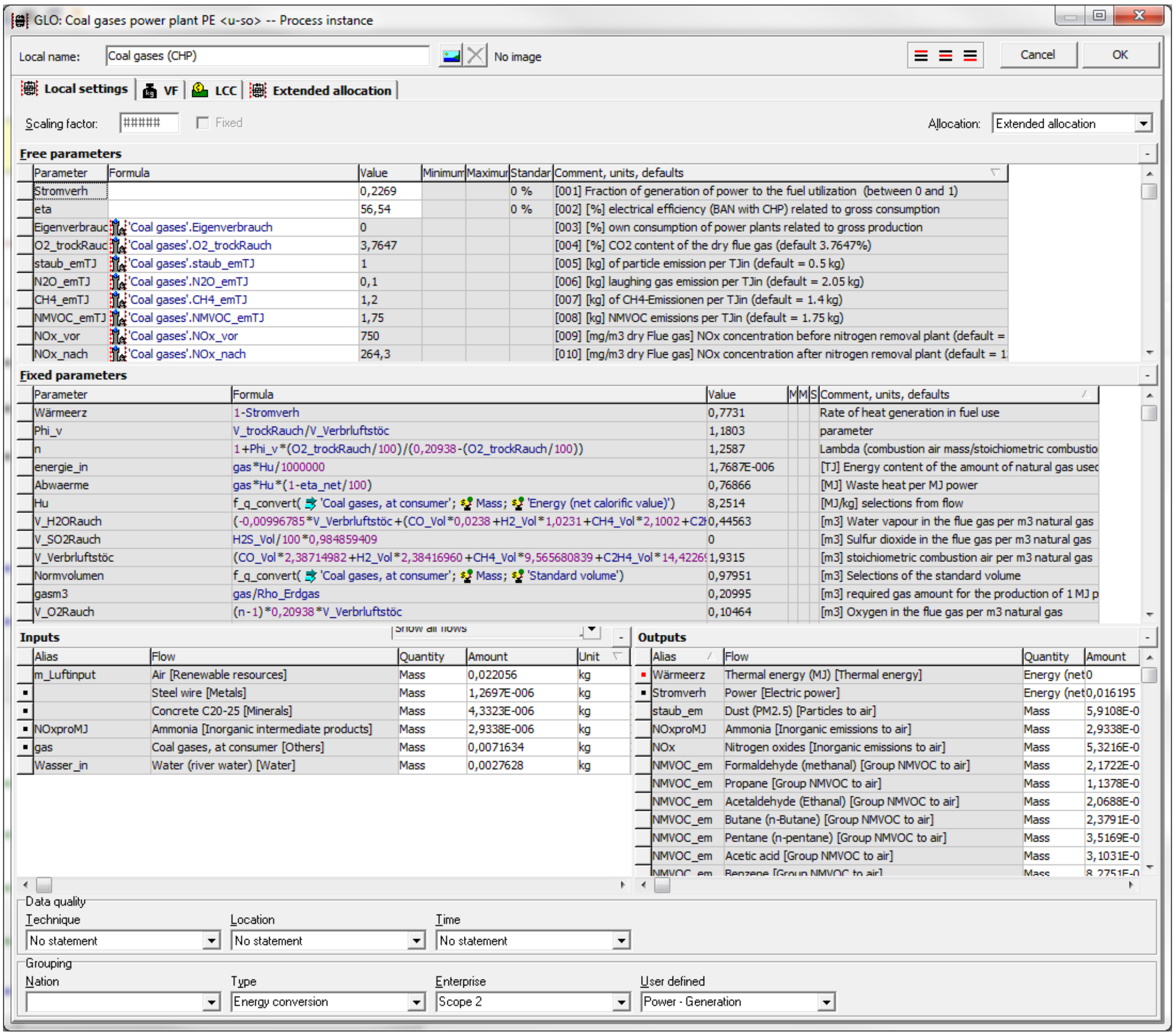


Figure 4-5: Parameterized US Coal gas CHP power plant

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.

GHG emissions in hydropower plants and geothermal power plants

Non-combustion emissions released in hydropower plants and geothermal power plants are significant, however not always commonly addressed. In GaBi databases these emissions are accounted for as it is important to gain adequate results, especially if renewable electricity generation is a significant part of a national grid mix and to be consistent regarding other options of electricity generation. From an LCA perspective there are relevant but still few sources concerning this emissions, which can be adequately used in LCA databases. The topic and regionally different effects is also still debated in science. However thinkstep collects and validates information on this topic and frequently checks it against new and updated information in our yearly upgrade process.

The case of **geothermal power plants** CO_2, CH_4 and H_2S emissions as well as SF_6 emissions (in electrical equipment use) play a significant role. Validation backbone of the emissions data applied in thinkstep's GaBis LCA models is the Report: "Emissions of greenhouse gases in Iceland from 1990 to 2010, National Inventory Report 2012". Facts and figures reported here are combined with the knowhow of our energy engineers into best available LCA data and frequently revisited and updated, if knowhow develops.

Concerning **hydro power plants** CO_2 and CH_4 emissions as a result of degradation of biomass in the dammed water play a significant role. Depending on the climatic boundary conditions different effects arise. In climatic cold and moderate regions : Increasing CO_2 emissions from aerobic degradation of biomass in the first years of operation, then temporary decreasing within the first 10 years of operation In climatic tropical regions: Increasing CH_4 emissions from anaerobic degradation of biomass in the first years then slower temporary decreasing, which can be longer than the first 10 years of operation. Vegetal boundary conditions (amount of inundated biomass) plays also a significant role. The used values of emissions are arithmetic mean values over 100 years of operation and are based on gross greenhouse gas emissions (problem of absorbed CO_2 from atmosphere), net emissions are estimated to be 30 – 50 % lower. Greenhouse gas emissions of run-of-river plants are minimal since the water is not stored for a long time. Validation backbone of the emissions data applied in thinkstep's GaBis LCA models is the Report: " Addressing Biogenic Greenhouse Gas Emissions from Hydropower in LCA; Edgar G. Hertwich; Industrial Ecology Programme and Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU)". Facts and figures reported here are combined with the knowhow of our energy engineers into best available LCA data and frequently revisited and updated, if knowhow develops.

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 CO_2 in fuel and total payload (total payload only applies to trucks).

Because 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:

$$Total\text{–}Emission_X = \left(\left(share\_mw \cdot mw_{Em}\right) + \left(share\_ru \cdot ru_{Em}\right) + \left(share\_ur \cdot ur_{Em}\right)\right) \cdot distance$$

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:

$$Total\text{–}Emission_X = \left(\left(share\_mw \cdot mw_{Em}\right) + \left(share\_ru \cdot ru_{Em}\right) + \left(share\_ur \cdot ur_{Em}\right)\right)$$

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 CO_2 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 CO_2 emissions of the total CO_2 emissions.

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

$S + O_2 \rightarrow SO_2$

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

EF_SO_2 Emission factor for SO_2

x_ppm_S Mass share in fuel

The emission factor for laughing gas (nitrous oxide, N_2O) is assumed to be constant for each emission class and each category of driving road. The emission factor for ammonia (NH_3) 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 6" 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.

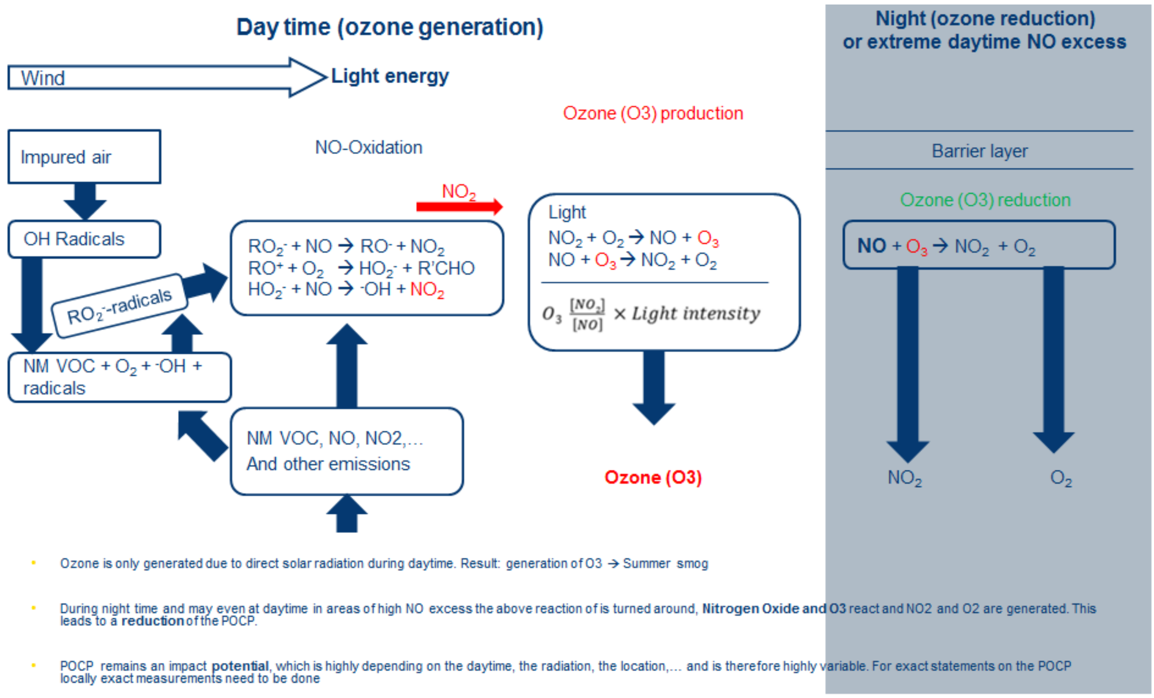
The reference year of the dataset is 2013, that data is representative for the period until 2017.

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 until 2017. 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 2017.

Negative photochemical oxidation figures due to NOx/NO/NO_2 figures

The photochemical oxidation, very often defined as summer smog, is the result of very complex still partly unknown reactions that take place between nitrogen oxides (NOx) and volatile organic compounds (VOC) exposed to UV radiation. The Photochemical Ozone Creation Potential, POCP, of some VOC's is related to a reference substance, in this case, the olefin ethylene (H2C=CH2) that relates the impact of the substances to the impact of the reference C2H4.

VOCs have different reactivity's with oxidants (Ozone, HO, NO2, NO,…) in the atmosphere and therefore they have different (positive and negative) effects on the Ozone formation in the troposphere, which are still under scientific research.



Source: http://www.umwelt.nrw.de/umwelt/luftqualitaet/ozon/bodennah.php

Figure 4-6: Principle known functions of tropospheric ozone creation and reduction

The emission spectrum of the truck transports within thinkstep databases are taken from the „Handbook emission factors for road transport (HBEFA)". It can be found under: http://www.hbefa.net/e/index.htm

In the course of the last upgrades of GaBi databases, NOx emissions have been separated in the NO2 and NO emissions as requested by users, handbooks and LCIA models to model more specifically.

Due to the split of NOx a potential negative value for the POCP may occur, according to the certain impact models chosen. Remind that during night NO and O_3 react to NO_2 and O_2 and a reduction of the POCP is taking place. NO is characterized in certain POCP methods in CML 2001 since several years with a factor of -2,34. An overview of all weighting factors can be found under: cml.leiden.edu/software/data-cmlia.html.

In earlier studies NOx (as sum of NO + NO_2 measured as and in NO_2 eq.) was modelled in off gases (impact factor NO2 > 0). Today NOx is requested to be spilt in NO + NO_2 (possible for LCI). However, the exact NOx chemistry is still hardly to define. LCIA gives factors for NO < 0 and NO_2 > 0 or only NO or NO_2 or NOx. In many off gases technically NO > NO_2 so resulting net negative impact may occur.

If this effect and the LCI emission as such is in core of your study or dominating the results it is recommended to do sensitivity analysis by taking NOx/NO and NO_2 factors and quantify the impact variation (ISO practise).

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 CO_2 (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 CO_2 (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 CO_2 (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], 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 (CO_2, SO_2, benzene, toluene and xylene) and others such as CH_4 and N_2O

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. In order to avoid influences from inflation, it is recommended to calculate the prices over the 10 years in relation to one specific year. This can be done using price deflators. 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 including 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 modelling 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 2007[14].

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

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.

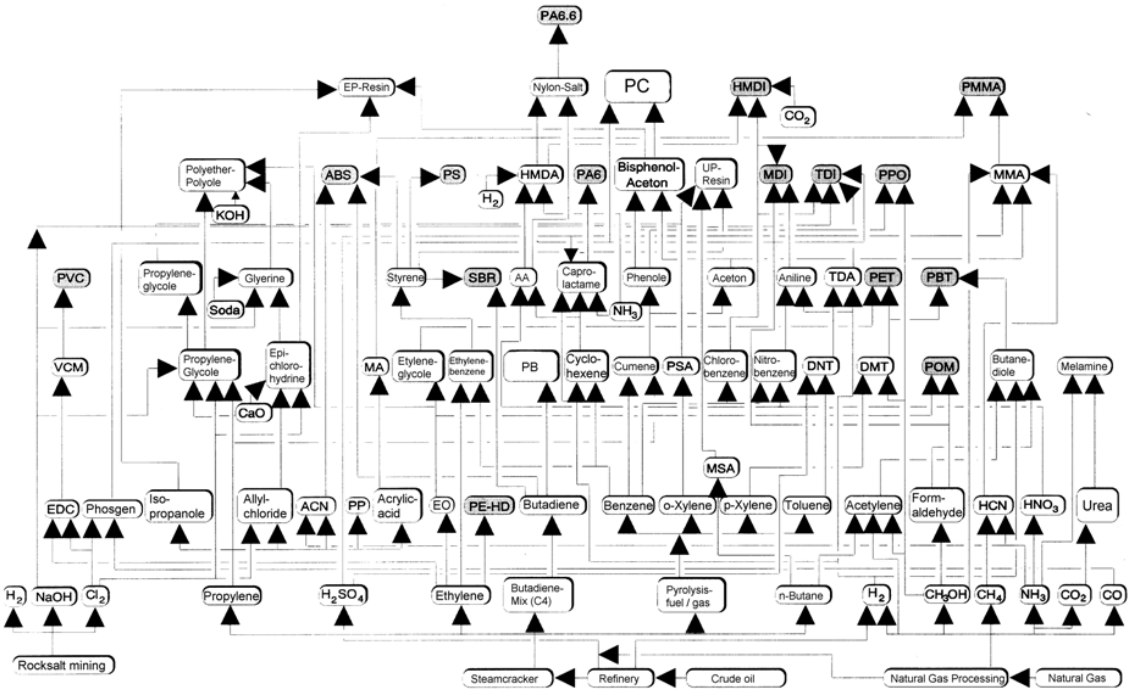


Figure 4-7: Excerpt of the organic network[15] considered in GaBi

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 Homepage[16].

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.

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[15] 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.

[16] http://www.plasticseurope.org/plastics-sustainability/eco-profiles/browse-by-flowchart.aspx (checked 03.11.2011)

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 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.

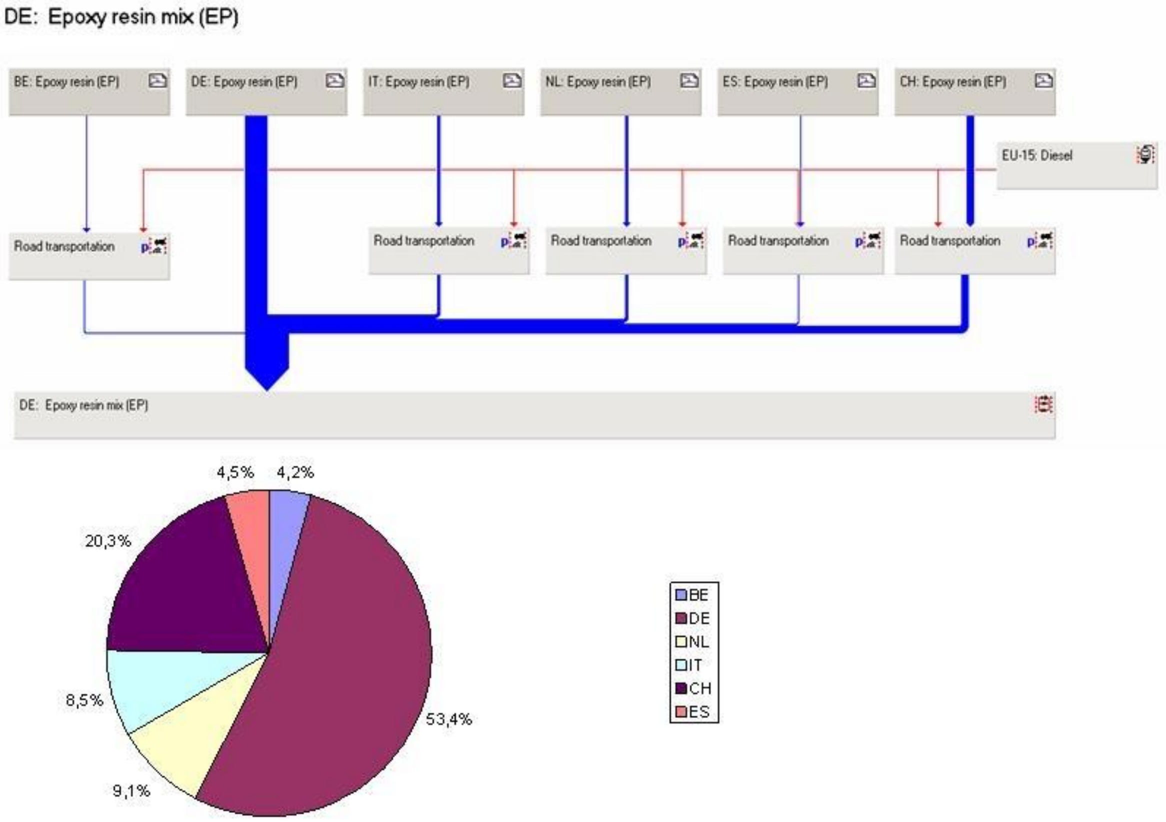

Figure 4-8: **Consumption mix of Epoxy resin in Germany**

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 Andrussow 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 allyl chloride synthesis, from methylene diisocyanate synthesis, from chlorobenzene synthesis)
- Benzene, toluene and xylene (from reformate or pyrolysis gas or dealkylation or by-product styrene)
- Acetone (via cumene or isopropanol)
- Hexamethylenediamine (via adipic acid or acrylonitrile)
- Titan dioxide (sulphate and chloride process)
- Caprolactam (via phenol or cyclohexane)
- Ethylene oxide (via O_2 or air)

The correct technology route for the right process chain can be decisive. thinkstep'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.

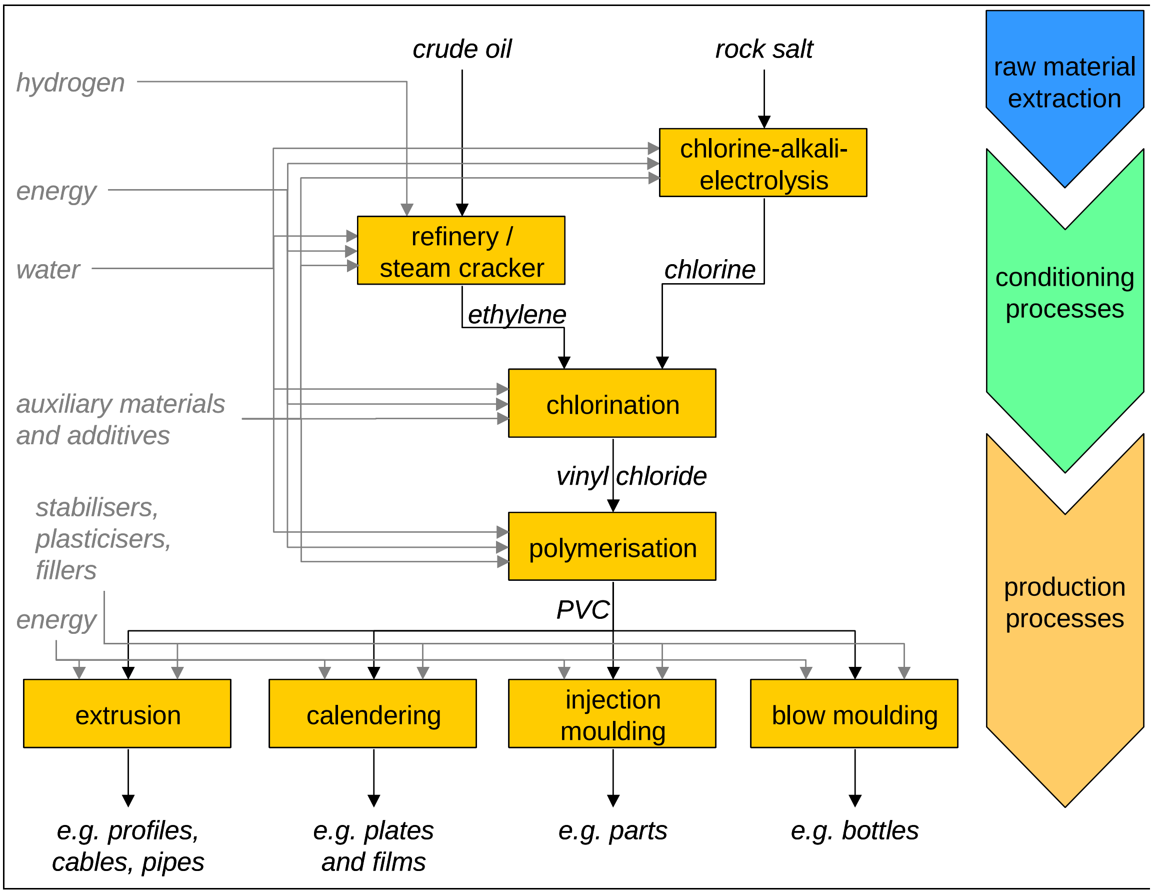

Figure 4-9: Example of PVC resin - compound- part

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

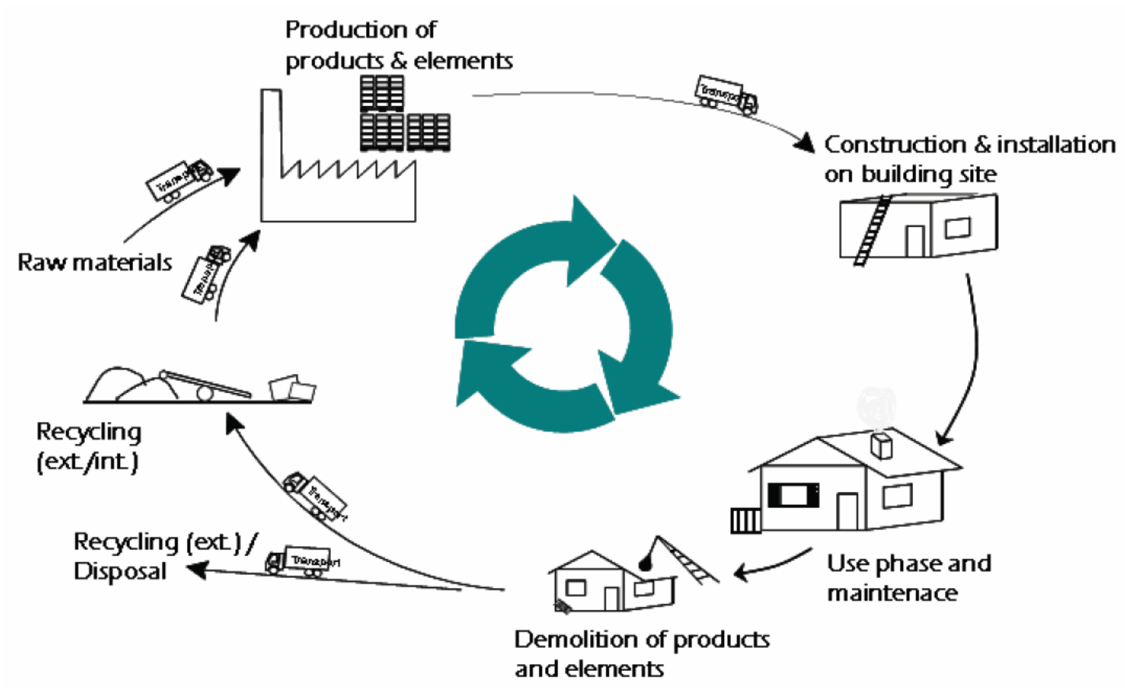

Figure 4-10: Schematic life cycle of a building

Every construction building product 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 2013 database [GaBi 2013] 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, sand lime, natural stones, as well as mineral insulation materials such as rock wool 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 thinkstep 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.

EN 15804

In the extension database for construction, new EN15804 ("Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products") compatible datasets have been added. Due to the partially specific scope of the standard, certain datasets show variations compared to previous datasets; others do not show differences, as the scope remained the same. To enable users to be conform to EN 15804 without forcing others to potentially change their scope we provide both versions. This even opens up the possibility for users to do a sensitivity analysis – as requested under ISO – if the user is unsure which data set might be the best one in his case. "This European standard provides core product category rules for all construction products and services. It provides a structure to ensure that all Environmental Product Declarations (EPD) of construction products, construction services and construction processes are derived, verified and presented in a harmonized way” [EN 15804: 2012]. The standard divides the life cycle of a building in life cycle stages and modules. Within the new database for construction, each dataset is modelled, grouped and marked in accordance with the EN 15804 methodology and modularity. The datasets can be used to model the whole life cycle of a building.

The EN 15804 methodology divides the life cycle of a building into the following stages:

1. Production
2. Installation
3. Use stage
4. End of life and
5. Benefits and loads derived from the life cycle process.

Each of those life cycle stages is further broken down into very detailed stages in the product life cycle, called modules (for example product stage in modules A1, A2, and A3). The modules are continuously numbered within the life cycle stages using a capital letter and a number.

The nomenclature system for the single life cycle modules is illustrated below.

Production			Installation		Use stage							End-of-Life				Next product system
Raw material supply (extraction, processing, recycled material)	Transport to manufacturer	Manufacturing	Transport to building site	Installation into building	Use / application	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction / demolition	Transport to EoL	Waste processing for reuse, recovery or recycling	Disposal	Reuse, recovery or recycling potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D

Figure 4-11: Life cycle stage modules according to EN 15804

The product stage is an information module that must be contained in each EPD and it includes:

- A1, raw material extraction and processing, processing of secondary material input (e.g. recycling processes),
- A2, transport to the manufacturer,
- A3, manufacturing,

including provision of all materials, products and energy, packaging processing and its transport, as well as waste processing up to the end-of waste state or disposal of final residues during the product stage.

Please note: in the GaBi Construction extension database, modules A1-A3 are aggregated.

The construction stage comprises:

- A4, transport to the construction site;
- A5, installation in the building;

including provision of all materials, products and energy, as well as waste processing up to the end-of-waste state or disposal of final residues during the construction stage. These information modules also include all impacts and aspects related to any losses during this construction stage (i.e. production, transport, and waste processing and disposal of the lost products and materials).

The use stage, related to the building fabric includes:

- B1, use or application of the installed product;
- B2, maintenance;
- B3, repair;
- B4, replacement;
- B5, refurbishment.

including provision and transport of all materials, products and related energy and water use, as well as waste processing up to the end-of-waste state or disposal of final residues during this part of the use stage. These information modules also include all impacts and aspects related to the losses during this part of the use stage (i.e. production, transport, and waste processing and disposal of the lost products and materials).

The use stage related to the operation of the building includes:

- B6, operational energy use (e.g. operation of heating system and other building related installed services);
- B7, operational water use;

These information modules include provision and transport of all materials, products, as well as energy and water provisions, waste processing up to the end-of-waste state or disposal of final residues during this part of the use stage.

The end-of-life stage starts when the construction product is replaced, dismantled or deconstructed from the building or construction works and does not provide any further function. It can also start at the end-of-life of the building, depending on the choice of the product's end-of-life scenario. This stage includes:

- C1, de-construction, demolition:
- C2, transport to waste processing;
- C3, waste processing for reuse, recovery and/or recycling;

- C4, disposal

including provision and all transports, provision of all materials, products and related energy and water use.

Module D includes any declared benefits and loads from net flows leaving the product system that have not been allocated as co-products and that have passed the end-of-waste state in the form of reuse, recovery and/or recycling potentials.

EN 15804 requires the declaration of the following impact categories:

The list below shows the 24 environmental indicators used in EN 15804 compliant EPD. There are seven environmental impact indicators, ten resource indicators, three waste indicators, and four output flow indicators.

Environmental Impact Indicators

- Global Warming Potential (GWP)
- Ozone Depletion Potential (ODP)
- Acidification potential (AP)
- Eutrophication potential (EP)
- Formation potential of tropospheric ozone (POCP)
- Abiotic depletion potential for non-fossil resources (ADP elements)
- Abiotic depletion potential for fossil resources (ADP fossil fuels)

Resource Use Indicators

- Use of renewable primary energy excluding renewable primary energy resources used as raw materials
- Use of renewable primary energy resources used as raw materials
- Total use of renewable primary energy resources (primary energy and primary energy resources used as raw materials)
- Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials
- Use of non-renewable primary energy resources used as raw materials
- Total use of non-renewable primary energy resources (primary energy and primary energy resources used as raw materials)
- Use of secondary material
- Use of renewable secondary fuels
- Use of non-renewable secondary fuels
- Use of net fresh water

Waste Category Indicators

- Hazardous waste deposited
- Non-hazardous waste disposed
- Radioactive waste disposed

Output Flow Indicators

- Components for re-use
- Materials for recycling
- Materials for energy recovery
- Exported energy

EN 15804 and CML impact list

The following chapter informs about the relation of Impact Categories required by EN 15804 to the frequently updated CML method collection of Impact categories (CML = Institute of Environmental Sciences Faculty of Science University of Leiden, Netherlands). Concerning the required impact categories the standard 15804 in its current version refers to the baseline versions of the CML collection of impact methods in the version Oct 2012.

The CML list is a dynamic list, which is frequently maintained, bug fixed, enlarged and updated. Only the most recent list is publically available for download at the CML website. The version available for download at the moment is version April 2015. This means the list of impact values given in the standard EN 15804 cannot be reproduced by the user with CML information given on the website of CML.

Further, the CML (baseline method) list is not to be understood as all encompassing. CML invites and inspires users to produce further characterisation factors for still “missing” emissions and interventions according to the methods documented and explained in background document downloadable from the CML homepage.

CML provides characterisation factors for emissions as far as it was possible to pre-calculate in the goal and scope of CML. It remains in the responsibility of the user to check, if emissions occur that are potentially impact relevant and are not pre-characterised. In this case, the user has the responsibility to

- either add a characterisation factor for the respective flow(s) by himself or
- to use another characterized flow representing the intervention adequately or
- To interpret the results in the light of this missing impact factor accordingly.

In the GaBi software we apply the characterisation factors of the CML baseline method and – to the comfort of GaBi users - already pre-characterise known important emission flows, which came across repeatedly in LCA work and which potentially have a known impact, but are not yet characterised according the respective CML method.

This chapter aims to transparently inform users and reviewers about the virtual differences between the cited versions of CML in the standard EN 15804 (standardisation document), the most up to date version publically available at CML (maintained method collection on webpage) and the respective GaBi implementation and additional pre-characterisation in the latest GaBi Version (maintained LCA solution).

Recommendation

We recommend generally – and not exclusively for EN 15804 - to use the latest versions of methods (like for CML the Apr. 2015 version). If a method (collection) like CML is maintained, the likelihood of errors is smaller and the amount of characterisation factors available is likely to be larger and relevant gaps in characterisation factors likely to be smaller in the newest version compared to predecessor versions.

Requirements in EN 15804

By using the CML Apr. 2015 version the user lives up with the requirements of EN 15804. The differences in CML versions are either nil, negligible or explainable.

If there are significant differences in a result using the EN 15804 standard list compared to a result using the GaBi/CML 2015 list - assuming of course that the user did model correct and consistent - the reason can be

a) a difference between CML 2012 and 2015 (CML added or modified characterisation factors) or

b) a difference between default CML 2015 list and thinkstep enlarged characterisation factor list 2015 (thinkstep added characterisation factors for flows that definitely need to be characterized to match consistency)

This might be the case due to

1) a mistake in any of the above implementation lists a) or b) or

2) due to an insufficient list of characterisation factors in EN 15804

Due to the constant maintenance of CML characterisation factors and GaBi characterisation factor implementation, the likelihood of 2) is higher.

Distinctions in the Characterisation factors

Background

To put the "difference" into perspective: The difference of the (older) CML version 2012 / (static) EN 15804 list and the (newer) CML 2013 / (adapted) GaBi list is small. Additional CML characterisation factors were only added to GaBi flows, if these are relevant in LCI as well as significant for a potentially consistent impact result (see above).

There are almost 5000 characterisation factors given in CML. These are 1:1 applied in GaBi. Additionally about 50 (significant) CF for (relevant) emission flows were added in GaBi to the CML 2013 list.

So per se GaBi and EN 15804 have a 99% fit, plus another 1% added valuable information.

If this 1% difference leads to a significant difference (>> 1%) in a result comparison EN 15804/CML 2012 vs. GaBi/CML 2013, the reason must be (according to ISO 14040/14044, were EN 15804 is tied to) evaluated anyway. The fact that a reviewer or user would not recognize (and virtually cut-off) the difference by using the (static) EN 15804 list 1:1 in GaBi, is no justification according to ISO (see chapter 4.2.3.3.3, ISO 14044). Environmental significance has to be taken into account and must be individually justified by the user/reviewer himself.

As a summary: The difference EN 15804/CML 2012 vs. GaBi/CML 2013 is per se small and if it gets significant, the reason is to be determined, and most likely the GaBi/CML 2013 result is the ISO conform one.

Details of added information EN 15804/CML 2012 → GaBi/CML 2013

The following table provides information about added emissions characterisation factors to CML 2012, to live up with the latest CML versions and the requirements in ISO 14044.

	Addional CML characerisation factors in comparison to list EN 15804 annex C			
	Acidification			
	Problem oriented approach: baseline (CML, 2001), acidification AP (incl. fate, average Europe total, A&B, Huijbregts, 1999)			
	Flow	**kg SO2-Equiv.**	**added by**	**Calculation remark**
1	Sulphur trioxide [Inorganic emissions to air]	0,960	CML	new factor
2	Sulphuric acid [Inorganic emissions to air]	0,784	CML	new factor
3	Sulphuric acid [Inorganic emissions to agricultural soil]	0,784	PE	AP, consistent for all compartments
4	Sulphuric acid [Inorganic emissions to fresh water]	0,784	PE	AP, consistent for all compartments
5	Sulphuric acid [Inorganic emissions to industrial soil]	0,784	PE	AP, consistent for all compartments
6	Sulphuric acid [Inorganic emissions to sea water]	0,784	PE	AP, consistent for all compartments
7	Ammonium [Inorganic emissions to air]	3,2	PE	AP, 2 x NH3 value due to 2 x H+ release potential
8	Ammonium nitrate [Inorganic emissions to air]	0,720	PE	AP, stoichometr. adaption of NH4+ value (x 18/80)
9	Sulphur oxides [Inorganic emissions to air]	1,2	PE	AP, characterised as SO2
10	Hydrogen chloride [Inorganic emissions to agricultural soil]	0,749	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
11	Hydrogen chloride [Inorganic emissions to air]	0,749	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
12	Hydrogen chloride [Inorganic emissions to fresh water]	0,749	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
13	Hydrogen chloride [Inorganic emissions to industrial soil]	0,749	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
14	Hydrogen chloride [Inorganic emissions to sea water]	0,749	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
15	Hydrogen bromine (hydrobromic acid) [Inorganic emissions to air]	0,328	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
16	Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to agricultural soil]	1,36	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
17	Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to fresh water]	1,36	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
18	Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to industrial soil]	1,36	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
19	Hydrogen fluoride (hydrofluoric acid) [Inorganic emissions to sea water]	1,36	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
20	Hydrogen fluoride [Inorganic emissions to air]	1,36	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
21	Hydrogen sulphide [Inorganic emissions to agricultural soil]	1,6	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
22	Hydrogen sulphide [Inorganic emissions to air]	1,6	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
23	Hydrogen sulphide [Inorganic emissions to fresh water]	1,6	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
24	Hydrogen sulphide [ecoinvent long-term to fresh water]	1,6	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
25	Hydrogen sulphide [Inorganic emissions to industrial soil]	1,6	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
26	Hydrogen sulphide [Inorganic emissions to sea water]	1,6	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
27	Nitric acid [Inorganic emissions to agricultural soil]	0,434	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
28	Nitric acid [Inorganic emissions to air]	0,434	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
29	Nitric acid [Inorganic emissions to fresh water]	0,434	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
30	Nitric acid [Inorganic emissions to industrial soil]	0,434	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
31	Nitric acid [Inorganic emissions to sea water]	0,434	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
32	Phosphoric acid [Inorganic emissions to agricultural soil]	0,834	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
33	Phosphoric acid [Inorganic emissions to air]	0,834	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
34	Phosphoric acid [Inorganic emissions to fresh water]	0,834	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
35	Phosphoric acid [Inorganic emissions to industrial soil]	0,834	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
36	Phosphoric acid [Inorganic emissions to sea water]	0,834	PE	AP, see CML (Hauschild & Wenzel (1998), excl. fate) *
	Eutrophication			
	Problem oriented approach: baseline (CML, 2001), eutrophication EP (fate not incl., Heijungs et al. 1992)			
	Flow	**kg PO4-Equiv.**	**added by**	**Calculation remark**
37	Octane [Hydrocarbons to sea water]	0,077	PE	Stoichiometric relation to COD impact
38	Octane [Hydrocarbons to fresh water]	0,077	PE	Stoichiometric relation to COD impact
39	Oil (unspecified) [Hydrocarbons to fresh water]	0,077	PE	Stoichiometric relation to COD impact, Oil = C10H22
40	Oil (unspecified) [Hydrocarbons to sea water]	0,077	PE	Stoichiometric relation to COD impact, Oil = C10H22
41	Organic compounds (dissolved) [Organic emissions to fresh water]	0,023	PE	Stoichiometric relation to COD impact, assum. CH2O
42	Organic compounds (unspecified) [Organic emissions to fresh water]	0,023	PE	Stoichiometric relation to COD impact, assum. CH2O
43	Organic compounds (dissolved) [Organic emissions to sea water]	0,023	PE	Stoichiometric relation to COD impact, assum. CH2O
44	Organic compounds (unspecified) [Organic emissions to sea water]	0,023	PE	Stoichiometric relation to COD impact, assum. CH2O
45	Sodium nitrate [Inorganic emissions to fresh water]	0,073	PE	as nitrate
46	Sodium nitrate (NaNO3) [Inorganic emissions to sea water]	0,073	PE	as nitrate
47	Total dissolved organic bounded carbon [Analytical measures to fresh water]	0,059	PE	Stoichiometric COD assuming C6H11O
48	Total dissolved organic bounded carbon [Analytical measures to sea water]	0,059	PE	Stoichiometric COD assuming C6H11O
49	Total organic bounded carbon [Analytical measures to sea water]	0,059	PE	Stoichiometric COD assuming C6H11O
50	Total organic bounded carbon [Analytical measures to fresh water]	0,059	PE	Stoichiometric COD assuming C6H11O
51	Xylene (isomers; dimethyl benzene) [Hydrocarbons to fresh water]	0,070	PE	Stoichiometric relation to COD impact
52	Xylene (isomers; dimethyl benzene) [Hydrocarbons to sea water]	0,070	PE	Stoichiometric relation to COD impact
53	Xylene (meta-Xylene; 1,3-Dimethylbenzene) [Hydrocarbons to fresh water]	0,070	PE	Stoichiometric relation to COD impact
54	Xylene (meta-Xylene; 1,3-Dimethylbenzene) [Hydrocarbons to sea water]	0,070	PE	Stoichiometric relation to COD impact
55	Xylene (ortho-Xylene; 1,2-Dimethylbenzene) [Hydrocarbons to sea water]	0,070	PE	Stoichiometric relation to COD impact
56	Xylene (ortho-Xylene; 1,2-Dimethylbenzene) [Hydrocarbons to fresh water]	0,070	PE	Stoichiometric relation to COD impact
57	Xylene (para-Xylene; 1,4-Dimethylbenzene) [Hydrocarbons to fresh water]	0,070	PE	Stoichiometric relation to COD impact
58	Xylene (para-Xylene; 1,4-Dimethylbenzene) [Hydrocarbons to sea water]	0,070	PE	Stoichiometric relation to COD impact
				** adatped by 0,85 to include fate consistently*

Application of existing (unspecific) characterisation factors to specific fossil resource flows

For ADP fossil CML only gives four value for the four main fossil resources in relation to a chosen mean calorific value. As the characteristics of fossil resources are strongly depending on the kind and location of the deposit, characteristics of fossil resources like the calorific value strongly varies.

Users and customers of GaBi ever since report or search for specific fossil resources with specific characteristics of specific deposits. Therefore, GaBi ever since has additionally many deposit and country specific fossil resources. The adoption of the Characterisation factor is straight forward, as the reference is the calorific value. So the following list is just the consequent and consistent application of existing (unspecific) characterisation factors to specific resource flows of the same nature.

ADP f		
Problem oriented approach: baseline (CML, 2001), ADPfossil fuels (Oers et al., 2001)		
Flow	**unit**	**according to calorific value**
Oil sand (10% bitumen) (in MJ) [Crude oil (resource)]	MJ	1
Oil sand (100% bitumen) (in MJ) [Crude oil (resource)]	MJ	1
Peat (in kg) [Peat (resource)]	kg	8,4
Peat (in MJ) [Peat (resource)]	MJ	1
Peat ecoinvent [Non renewable resources]	kg	8,74
Pit gas (in kg) [Natural gas (resource)]	kg	40,35
Pit gas ecoinvent [Natural gas (resource)]	Nm3	35,86
Pit Methane (in kg) [Natural gas (resource)]	kg	49,84
Pit Methane (in MJ) [Natural gas (resource)]	MJ	1
Raw hardcoal [Hard coal (resource)]	kg	18
Raw lignite [Lignite (resource)]	kg	7,999999983
Shale gas (in MJ) [Natural gas (resource)]	MJ	1
Tight gas (in MJ) [Natural gas (resource)]	MJ	1

ADP f		
Problem oriented approach: baseline (CML, 2001), ADPfossil fuels (Oers et al., 2001)		
Flow	**unit**	**according to calorific value**
Coalbed methane (in MJ) [Natural gas (resource)]	MJ	1
Crude oil (IISI) [Crude oil (resource)]	kg	41
Crude oil (in kg) [Crude oil (resource)]	kg	42,33
Crude oil (in MJ) [Crude oil (resource)]	MJ	1
Crude oil Algeria [Crude oil (resource)]	kg	43,52
Crude oil Angola [Crude oil (resource)]	kg	42,59
Crude oil Argentina [Crude oil (resource)]	kg	42,53
Crude oil Australia [Crude oil (resource)]	kg	43,53
Crude oil Austria [Crude oil (resource)]	kg	42,74
Crude oil Bolivia [Crude oil (resource)]	kg	43,31
Crude oil Brazil [Crude oil (resource)]	kg	42,5
Crude oil Brunei [Crude oil (resource)]	kg	42,45
Crude oil Bulgaria [Crude oil (resource)]	kg	42,05
Crude oil Cameroon [Crude oil (resource)]	kg	42,26
Crude oil Canada [Crude oil (resource)]	kg	41,89
Crude oil Chile [Crude oil (resource)]	kg	42,78
Crude oil China [Crude oil (resource)]	kg	42,84
Crude oil CIS [Crude oil (resource)]	kg	42,15
Crude oil Colombia [Crude oil (resource)]	kg	42,05
Crude oil Czech Republic [Crude oil (resource)]	kg	41,53
Crude oil Denmark [Crude oil (resource)]	kg	42,08
Crude oil ecoinvent [Crude oil (resource)]	kg	43,19
Crude oil Ecuador [Crude oil (resource)]	kg	42,09
Crude oil Egypt [Crude oil (resource)]	kg	42,39
Crude oil Equatorial Guinea [Crude oil (resource)]	kg	42,41
Crude oil France [Crude oil (resource)]	kg	42,43
Crude oil Gabon [Crude oil (resource)]	kg	42,41
Crude oil Germany [Crude oil (resource)]	kg	42,83
Crude oil Great Britain [Crude oil (resource)]	kg	42,33
Crude oil Greece [Crude oil (resource)]	kg	42,26
Crude oil Hungary [Crude oil (resource)]	kg	41,22
Crude oil India [Crude oil (resource)]	kg	41,41
Crude oil Indonesia [Crude oil (resource)]	kg	40,94
Crude oil Iran [Crude oil (resource)]	kg	42,29
Crude oil Iraq [Crude oil (resource)]	kg	42,54
Crude oil Ireland [Crude oil (resource)]	kg	42,33
Crude oil Italy [Crude oil (resource)]	kg	44,33
Crude oil Japan [Crude oil (resource)]	kg	42,8
Crude oil Kuwait [Crude oil (resource)]	kg	42,38
Crude oil Libya [Crude oil (resource)]	kg	43,74
Crude oil Malaysia [Crude oil (resource)]	kg	42,92
Crude oil Mexico [Crude oil (resource)]	kg	41,28
Crude oil Myanmar [Crude oil (resource)]	kg	42,05
Crude oil Netherlands [Crude oil (resource)]	kg	43,96
Crude oil New Zealand [Crude oil (resource)]	kg	39,28
Crude oil Nigeria [Crude oil (resource)]	kg	42,78
Crude oil Norway [Crude oil (resource)]	kg	42,83
Crude oil Oman [Crude oil (resource)]	kg	42,42
Crude oil Poland [Crude oil (resource)]	kg	42,57
Crude oil Qatar [Crude oil (resource)]	kg	43,4
Crude oil Romania [Crude oil (resource)]	kg	42,78
Crude oil Saudi Arabia [Crude oil (resource)]	kg	42,45
Crude oil Slovakia [Crude oil (resource)]	kg	41,53
Crude oil South Africa [Crude oil (resource)]	kg	43,06
Crude oil Spain [Crude oil (resource)]	kg	42,78
Crude oil Syria [Crude oil (resource)]	kg	44,27
Crude oil Taiwan [Crude oil (resource)]	kg	40,93
Crude oil Thailand [Crude oil (resource)]	kg	43,03
Crude oil Trinidad and Tobago [Crude oil (resource)]	kg	42,07
Crude oil Tunisia [Crude oil (resource)]	kg	43,04
Crude oil Turkey [Crude oil (resource)]	kg	42,43
Crude oil United Arab Emirates [Crude oil (resource)]	kg	43,11
Crude oil USA [Crude oil (resource)]	kg	41,94
Crude oil Venezuela [Crude oil (resource)]	kg	42,4

ADP f		
Problem oriented approach: baseline (CML, 2001), ADPfossil fuels (Oers et al., 2001)		
Flow	**unit**	**according to calorific value**
Hard coal (IISI) [Hard coal (resource)]	kg	30,5
Hard coal (in kg) [Hard coal (resource)]	kg	26,31
Hard coal (in MJ) [Hard coal (resource)]	MJ	1
Hard coal Australia [Hard coal (resource)]	kg	27,47
Hard coal Belgium [Hard coal (resource)]	kg	17,6
Hard coal Bosnia and Herzegovina [Hard coal (resource)]	kg	25,42
Hard coal Brazil [Hard coal (resource)]	kg	25,09
Hard coal Canada [Hard coal (resource)]	kg	27,36
Hard coal Chile [Hard coal (resource)]	kg	25,31
Hard coal China [Hard coal (resource)]	kg	25,4
Hard coal CIS [Hard coal (resource)]	kg	27,12
Hard coal Colombia [Hard coal (resource)]	kg	26,27
Hard coal Czech Republic [Hard coal (resource)]	kg	23,63
Hard coal ecoinvent [Hard coal (resource)]	kg	18,37
Hard coal France [Hard coal (resource)]	kg	26,81
Hard coal Germany [Hard coal (resource)]	kg	30,2
Hard coal Great Britain [Hard coal (resource)]	kg	24,75
Hard coal India [Hard coal (resource)]	kg	26,88
Hard coal Indonesia [Hard coal (resource)]	kg	23,69
Hard coal Italy [Hard coal (resource)]	kg	25,42
Hard coal Japan [Hard coal (resource)]	kg	22,31
Hard coal Malaysia [Hard coal (resource)]	kg	25,89
Hard coal Mexico [Hard coal (resource)]	kg	26,41
Hard coal New Zealand [Hard coal (resource)]	kg	27,47
Hard coal Poland [Hard coal (resource)]	kg	24
Hard coal Portugal [Hard coal (resource)]	kg	28,25
Hard coal South Africa [Hard coal (resource)]	kg	26
Hard coal South Korea [Hard coal (resource)]	kg	25,89
Hard coal Spain [Hard coal (resource)]	kg	30,62
Hard coal Turkey [Hard coal (resource)]	kg	27,42
Hard coal USA [Hard coal (resource)]	kg	27,7
Hard coal Venezuela [Hard coal (resource)]	kg	28,4
Hard coal Vietnam [Hard coal (resource)]	kg	25,89

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ADP f		
Problem oriented approach: baseline (CML, 2001), ADPfossil fuels (Oers et al., 2001)		
Flow	**unit**	**according to calorific value**
Lignite (in kg) [Lignite (resource)]	kg	11,88
Lignite (in MJ) [Lignite (resource)]	MJ	1
Lignite Australia [Lignite (resource)]	kg	9,29
Lignite Austria [Lignite (resource)]	kg	10
Lignite Bosnia and Herzegovina [Lignite (resource)]	kg	7,63
Lignite Bulgaria [Lignite (resource)]	kg	10,85
Lignite Canada [Lignite (resource)]	kg	14,25
Lignite CIS [Lignite (resource)]	kg	13,95
Lignite Czech Republic [Lignite (resource)]	kg	11,14
Lignite ecoinvent [Lignite (resource)]	kg	9,26
Lignite France [Lignite (resource)]	kg	7,8
Lignite Germany [Lignite (resource)]	kg	9,82
Lignite Germany (Central Germany) [Lignite (resource)]	kg	10,1
Lignite Germany (Lausitz) [Lignite (resource)]	kg	9,48
Lignite Germany (Rheinisch) [Lignite (resource)]	kg	9,97
Lignite Greece [Lignite (resource)]	kg	6,7
Lignite Hungary [Lignite (resource)]	kg	7,5
Lignite India [Lignite (resource)]	kg	11,63
Lignite Macedonia [Lignite (resource)]	kg	7,63
Lignite Poland [Lignite (resource)]	kg	8,85
Lignite Romania [Lignite (resource)]	kg	7,63
Lignite Serbia [Lignite (resource)]	kg	7,63
Lignite Slovakia [Lignite (resource)]	kg	11,15
Lignite Slovenia [Lignite (resource)]	kg	9,8
Lignite Spain [Lignite (resource)]	kg	7,84
Lignite Thailand [Lignite (resource)]	kg	11,63
Lignite Turkey [Lignite (resource)]	kg	10,98
Lignite USA [Lignite (resource)]	kg	14,02
Metallurgical coal [Non renewable resources]	kg	26,31

ADP f		
Problem oriented approach: baseline (CML, 2001), ADPfossil fuels (Oers et al., 2001)		
Flow	**unit**	**according to calorific value**
Natural gas (IISI) [Natural gas (resource)]	kg	46
Natural gas (in kg) [Natural gas (resource)]	kg	44,08
Natural gas (in MJ) [Natural gas (resource)]	MJ	1
Natural gas Algeria [Natural gas (resource)]	kg	44,54
Natural gas Angola [Natural gas (resource)]	kg	43,85
Natural gas Argentina [Natural gas (resource)]	kg	42,30
Natural gas Australia [Natural gas (resource)]	kg	40,37
Natural gas Austria [Natural gas (resource)]	kg	45,24
Natural gas Bolivia [Natural gas (resource)]	kg	42,30
Natural gas Brazil [Natural gas (resource)]	kg	41,32
Natural gas Brunei [Natural gas (resource)]	kg	46,01
Natural gas Bulgaria [Natural gas (resource)]	kg	42,76
Natural gas Cameroon [Natural gas (resource)]	kg	43,85
Natural gas Canada [Natural gas (resource)]	kg	45,35
Natural gas Chile [Natural gas (resource)]	kg	43,28
Natural gas China [Natural gas (resource)]	kg	46,22
Natural gas CIS [Natural gas (resource)]	kg	36,03
Natural gas Colombia [Natural gas (resource)]	kg	37,80
Natural gas Czech Republic [Natural gas (resource)]	kg	37,84
Natural gas Denmark [Natural gas (resource)]	kg	47,16
Natural gas ecoinvent [Natural gas (resource)]	Nm3	34,50
Natural gas Ecuador [Natural gas (resource)]	kg	48,29
Natural gas Egypt [Natural gas (resource)]	kg	43,85
Natural gas France [Natural gas (resource)]	kg	40,20
Natural gas Gabon [Natural gas (resource)]	kg	43,85
Natural gas Germany [Natural gas (resource)]	kg	43,32
Natural gas Great Britain [Natural gas (resource)]	kg	47,21
Natural gas Greece [Natural gas (resource)]	kg	47,64
Natural gas Hungary [Natural gas (resource)]	kg	38,85
Natural gas India [Natural gas (resource)]	kg	47,66
Natural gas Indonesia [Natural gas (resource)]	kg	44,83
Natural gas Iran [Natural gas (resource)]	kg	44,79
Natural gas Iraq [Natural gas (resource)]	kg	42,83
Natural gas Ireland [Natural gas (resource)]	kg	42,78
Natural gas Italy [Natural gas (resource)]	kg	41,02
Natural gas Japan [Natural gas (resource)]	kg	44,47
Natural gas Kuwait [Natural gas (resource)]	kg	42,83
Natural gas Libya [Natural gas (resource)]	kg	43,85
Natural gas Malaysia [Natural gas (resource)]	kg	39,22
Natural gas Mexico [Natural gas (resource)]	kg	46,36
Natural gas Myanmar [Natural gas (resource)]	kg	44,12
Natural gas Netherlands [Natural gas (resource)]	kg	38,13
Natural gas New Zealand [Natural gas (resource)]	kg	37,41
Natural gas Nigeria [Natural gas (resource)]	kg	43,85
Natural gas Norway [Natural gas (resource)]	kg	47,13
Natural gas Oman [Natural gas (resource)]	kg	42,83
Natural gas Poland [Natural gas (resource)]	kg	43,09999911
Natural gas Qatar [Natural gas (resource)]	kg	42,83
Natural gas Romania [Natural gas (resource)]	kg	43,33
Natural gas Saudi Arabia [Natural gas (resource)]	kg	42,83
Natural gas Slovakia [Natural gas (resource)]	kg	45,02
Natural gas South Africa [Natural gas (resource)]	kg	43,85
Natural gas Spain [Natural gas (resource)]	kg	44,85
Natural gas Syria [Natural gas (resource)]	kg	39,83
Natural gas Taiwan [Natural gas (resource)]	kg	40,51
Natural gas Thailand [Natural gas (resource)]	kg	39,56
Natural gas Trinidad and Tobago [Natural gas (resource)]	kg	42,32
Natural gas Tunisia [Natural gas (resource)]	kg	46,19
Natural gas Turkey [Natural gas (resource)]	kg	45,30
Natural gas United Arab Emirates [Natural gas (resource)]	kg	41,26
Natural gas USA [Natural gas (resource)]	kg	38,99
Natural gas Venezuela [Natural gas (resource)]	kg	46,48

Application of existing (unspecific) characterisation factors to specific mineral resource flows

For ADP elements, the same logic applies than for ADP fossil. CML only gives four value for the (unspecific) resources in relation to the element. As the characteristics of mineral resources are strongly depending on the kind and location of the deposit and the ore characteristics, the element value must be applied to the real ores existing in the earth crust as well.

Users and customers of GaBi ever since report or search for specific mineral ore resources with specific characteristics of specific deposits. Therefore, GaBi ever since has additionally many deposit specific ore resources. The adoption of the Characterisation factor is straight forward, as the reference is the element. So the following list is just the consequent and consistent application of existing (unspecific) characterisation factors to specific resource flows of the same nature.

ADP e		
Problem oriented approach: baseline (CML, 2001), ADPelements (Oers et al. 2001)		
Flow	**Unit**	**according to element content in Sb-Equivalent**
Aluminium [Non renewable elements]	kg	1,09E-09
Anhydrite (Rock) [Non renewable resources]	kg	0,00E+00
Antimonite [Non renewable resources]	kg	7,18E-01
Antimony [Non renewable elements]	kg	1,00E+00
Antimony - gold - ore (0.09%) [Non renewable resources]	kg	9,22E-03
Argon [Non renewable elements]	kg	0,00E+00
Arsenic [Non renewable elements]	kg	2,97E-03
Barium [Non renewable elements]	kg	6,04E-06
Barium sulphate [Non renewable resources]	kg	3,00E-05
Basalt [Non renewable resources]	kg	0,00E+00
Bauxite [Non renewable resources]	kg	3,79E-10
Bentonit clay [Non renewable resources]	kg	0,00E+00
Bentonite [Non renewable resources]	kg	0,00E+00
Beryllium [Non renewable elements]	kg	1,26E-05
Bismuth [Non renewable elements]	kg	4,11E-02
Borax [Non renewable resources]	kg	5,38E-04
Boron [Non renewable elements]	kg	4,27E-03
Bromine [Non renewable elements]	kg	4,39E-03
Cadmium [Non renewable elements]	kg	1,57E-01
Cadmium ore [Non renewable resources]	kg	1,57E-03
Calcium [Non renewable elements]	kg	0,00E+00
Calcium chloride [Non renewable resources]	kg	1,74E-05
Chalk (Calciumcarbonate) [Non renewable resources]	kg	0,00E+00
Chlorine [Non renewable elements]	kg	2,71E-05
Chromium [Non renewable elements]	kg	4,43E-04
Chromium ore (39%) [Non renewable resources]	kg	1,73E-04
Chromium ore (Cr2O3 30%) [Non renewable resources]	kg	8,85E-05
Chromium ore (Cr2O3 40%) [Non renewable resources]	kg	1,33E-04
Chrysotile [Non renewable resources]	kg	5,49E-10
Cinnabar [Non renewable resources]	kg	7,96E-02
Clay [Non renewable resources]	kg	0,00E+00
Coalbed methane (in MJ) [Natural gas (resource)]	MJ	0,00E+00
Cobalt [Non renewable elements]	kg	1,57E-05
Cobalt ore (0,04%) [Non renewable resources]	kg	6,26E-09
Cobalt ore (0.067%) [Non renewable resources]	kg	1,05E-08
Colemanite ore [Non renewable resources]	kg	6,84E-04

ADP e		
Problem oriented approach: baseline (CML, 2001), ADPelements (Oers et al. 2001)		
Flow	**Unit**	**according to element content in Sb-Equivalent**
Copper [Non renewable elements]	kg	1,37E-03
Copper - Gold - Ore (1,07% Cu; 0,54 g/t Au) [Non renewable	kg	4,27E-05
Copper - Gold - Silver - ore (0,51% Cu; 0,6 g/t Au; 1,5 g/t Ag	kg	4,00E-05
Copper - Gold - Silver - ore (1,0% Cu; 0,4 g/t Au; 66 g/t Ag) [	kg	1,13E-04
Copper - Gold - Silver - ore (1,1% Cu; 0,01 g/t Au; 2,86 g/t A	kg	1,89E-05
Copper - Gold - Silver - ore (1,13% Cu; 1,05 g/t Au; 3,72 g/t	kg	7,45E-05
Copper - Gold - Silver - ore (1,16% Cu; 0,002 g/t Au; 1,06 g/t	kg	1,72E-05
Copper - Gold - Silver - ore (1,7% Cu; 0,7 g/t Au; 3,5 g/t Ag)	kg	1,01E-04
Copper - Molybdenum - Gold - Silver - ore (1,13% Cu; 0,02%	kg	5,23E-03
Copper - Silver - ore (3,3% Cu; 5,5 g/t Ag) [Non renewable re	kg	5,16E-05
Copper ore (0.14%) [Non renewable resources]	kg	2,19E-06
Copper ore (0.2%) [Non renewable resources]	kg	2,73E-06
Copper ore (0.3%) [Non renewable resources]	kg	4,10E-06
Copper ore (1 %) [Non renewable resources]	kg	1,37E-05
Copper ore (1,13%) [Non renewable resources]	kg	1,78E-05
Copper ore (1.2%) [Non renewable resources]	kg	1,64E-05
Copper ore (1.28%) [Non renewable resources]	kg	1,75E-05
Copper ore (1.3 %) [Non renewable resources]	kg	1,75E-05
Copper ore (2%) [Non renewable resources]	kg	2,73E-05
Copper ore (4%) [Non renewable resources]	kg	5,46E-05
Copper ore (sulphidic, 1.1%) [Non renewable resources]	kg	1,54E-05
Copper, Cu 0.38%, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Pb	kg	1,37E-03
Cyanite [Non renewable resources]	kg	3,67E-10
Diatomite [Non renewable resources]	kg	6,54E-12
Dolomite [Non renewable resources]	kg	2,63E-10
Feldspar (aluminium silicates) [Non renewable resources]	kg	0,00E+00
Ferro manganese [Non renewable resources]	kg	1,30E-06
Fluorine [Non renewable elements]	kg	0,00E+00
Fluorspar (calcium fluoride; fluorite) [Non renewable resource	kg	0,00E+00
Gallium [Non renewable elements]	kg	1,46E-07
Germanium [Non renewable elements]	kg	6,52E-07
Gold [Non renewable elements]	kg	5,20E+01
Gold deposit (1ppm) [Non renewable resources]	kg	5,20E-05
Granite [Non renewable resources]	kg	0,00E+00
Graphite [Non renewable resources]	kg	0,00E+00
Gravel [Non renewable resources]	kg	0,00E+00
Gypsum (natural gypsum) [Non renewable resources]	kg	3,59E-05
Heavy spar (BaSO4) [Non renewable resources]	kg	3,55E-06
Helium [Non renewable elements]	kg	0,00E+00
Helium, 0.08% in natural gas [Non renewable resources]	kg	0,00E+00
Ilmenite (titanium ore) [Non renewable resources]	kg	8,86E-09
Indium [Non renewable elements]	kg	6,89E-03
Inert rock [Non renewable resources]	kg	0,00E+00
Iodine [Non renewable elements]	kg	2,50E-02
Iron [Non renewable elements]	kg	5,24E-08
Iron ore (56,86%) [Non renewable resources]	kg	2,98E-08
Iron ore (65%) [Non renewable resources]	kg	3,41E-08

ADP e		
Problem oriented approach: baseline (CML, 2001), ADPelements (Oers et al. 2001)		
Flow	Unit	according to element content in Sb-Equivalent
Kaolin ore [Non renewable resources]	kg	2,88E-10
Kaolinite (24% in ore as mined) [Non renewable resources]	kg	2,33E-10
Kieserite (25% in ore as mined) [Non renewable resources]	kg	0,00E+00
Krypton [Non renewable elements]	kg	0,00E+00
Lava [Non renewable resources]	kg	0,00E+00
Lead [Non renewable elements]	kg	6,34E-03
Lead - Zinc - Silver - ore (5,49% Pb; 12,15% Zn; 57,4 gpt Ag)	kg	4,81E-04
Lead - zinc ore (4.6%-0.6%) [Non renewable resources]	kg	2,95E-04
Lead ore (5%) [Non renewable resources]	kg	3,17E-04
Lead, Pb 0.014%, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu (	kg	6,34E-03
Limestone (calcium carbonate) [Non renewable resources]	kg	0,00E+00
Lithium [Non renewable elements]	kg	1,15E-05
Lithium ore (3%) [Non renewable resources]	kg	3,44E-07
Magnesit (Magnesium carbonate) [Non renewable resources]	kg	5,77E-10
Magnesium [Non renewable elements]	kg	2,02E-09
Magnesium chloride leach (40%) [Non renewable resources]	kg	8,08E-06
Manganese [Non renewable elements]	kg	2,54E-06
Manganese ore [Non renewable resources]	kg	1,14E-06
Manganese ore (43%) [Non renewable resources]	kg	1,09E-06
Manganese ore (45%) [Non renewable resources]	kg	1,14E-06
Manganese ore (R.O.M.) [Non renewable resources]	kg	1,14E-06
Mercury [Non renewable elements]	kg	9,22E-02
Metamorphic stone, containing graphite [Non renewable reso	kg	0,00E+00
Molybdenid disulfide (Mo 0.21%) [Non renewable resources]	kg	3,76E-05
Molybdenite (Mo 0,24%) [Non renewable resources]	kg	4,30E-05
Molybdenum [Non renewable elements]	kg	1,78E-02
Molybdenum ore (0,01%) [Non renewable resources]	kg	1,78E-06
Molybdenum ore (0.1%) [Non renewable resources]	kg	1,78E-05
Natural Aggregate [Non renewable resources]	kg	0,00E+00
Natural gas (in kg) [Natural gas (resource)]	kg	0,00E+00
Natural gas (in MJ) [Natural gas (resource)]	MJ	0,00E+00
Natural pumice [Non renewable resources]	kg	0,00E+00
Neon [Non renewable elements]	kg	0,00E+00
Nepheline [Non renewable resources]	kg	0,00E+00
Nickel [Non renewable elements]	kg	6,53E-05
Nickel ore (1,5%) [Non renewable resources]	kg	9,79E-07
Nickel ore (1.2%) [Non renewable resources]	kg	7,84E-07
Nickel ore (1.6%) [Non renewable resources]	kg	1,04E-06
Nickel ore (2.0%) [Non renewable resources]	kg	1,31E-06
Nickel ore (2.7%) [Non renewable resources]	kg	1,76E-06
Niobium [Non renewable elements]	kg	1,93E-05
Olivine [Non renewable resources]	kg	2,37E-08
Palladium [Non renewable elements]	kg	5,71E-01
Palladium deposit (7ppm) [Non renewable resources]	kg	3,99E-06
Perlite [Non renewable resources]	kg	1,69E-09
Perlite (Rhyolithe) [Non renewable resources]	kg	1,69E-09

ADP e		
Problem oriented approach: baseline (CML, 2001), ADPelements (Oers et al. 2001)		
Flow	**Unit**	**according to element content in Sb-Equivalent**
Phosphate ore [Non renewable resources]	kg	1,80E-06
Phosphorus [Non renewable elements]	kg	5,52E-06
Phosphorus minerals [Non renewable resources]	kg	5,52E-06
Phosphorus ore (29% P2O5) [Non renewable resources]	kg	6,98E-07
Platin deposit (3ppm) [Non renewable resources]	kg	6,65E-06
Platinum [Non renewable elements]	kg	2,22E+00
Potashsalt, crude (hard salt, 10% K2O) [Non renewable reso	kg	1,33E-09
Potassium [Non renewable elements]	kg	1,60E-08
Potassium chloride [Non renewable resources]	kg	1,28E-05
Precious metal ore (R.O.M) [Non renewable resources]	kg	5,21E-05
Pyrite [Non renewable resources]	kg	0,00E+00
Quartz sand (silica sand; silicon dioxide) [Non renewable res	kg	7,85E-12
Raw pumice [Non renewable resources]	kg	0,00E+00
Rhenium [Non renewable elements]	kg	6,03E-01
Rutile (titanium ore) [Non renewable resources]	kg	1,67E-08
Sand [Non renewable resources]	kg	0,00E+00
Sandy soil [Non renewable resources]	kg	0,00E+00
Selenium [Non renewable elements]	kg	1,94E-01
Selenium deposit (0.025) [Non renewable resources]	kg	4,85E-05
Shale [Non renewable resources]	kg	0,00E+00
Shale gas (in MJ) [Natural gas (resource)]	MJ	0,00E+00
Silicon [Non renewable elements]	kg	1,40E-11
Silt [Non renewable resources]	kg	0,00E+00
Silver [Non renewable elements]	kg	1,18E+00
Silver deposit (20ppm) [Non renewable resources]	kg	2,37E-05
Slate [Non renewable resources]	kg	0,00E+00
Sodium [Non renewable elements]	kg	5,50E-08
Sodium carbonate (soda) [Non renewable resources]	kg	2,39E-08
Sodium chloride (rock salt) [Non renewable resources]	kg	1,64E-05
Sodium nitrate [Non renewable resources]	kg	1,49E-08
Sodium sulphate [Non renewable resources]	kg	4,35E-05
Soil [Non renewable resources]	kg	0,00E+00
Specular stone [Non renewable resources]	kg	4,46E-09
Spodumen (LiAlSi2 O6) [Non renewable resources]	kg	4,32E-07
Stone and gravel from land [Non renewable resources]	kg	0,00E+00
Stone from mountains [Non renewable resources]	kg	0,00E+00
Stone, sand and gravel from sea [Non renewable resources]	kg	0,00E+00
Strontium [Non renewable elements]	kg	7,07E-07
Sulphur [Non renewable elements]	kg	1,93E-04
Sulphur (bonded) [Non renewable resources]	kg	1,93E-04
Sylvine [Non renewable resources]	kg	0,00E+00

thinkstep GaBi

ADP e		
Problem oriented approach: baseline (CML, 2001), ADPelements (Oers et al. 2001)		
Flow	**Unit**	**according to element content in Sb-Equivalent**
Talc [Non renewable resources]	kg	3,89E-10
Tantalum [Non renewable elements]	kg	4,06E-05
Tellurium [Non renewable elements]	kg	4,07E+01
Thallium [Non renewable elements]	kg	2,43E-05
Thorium [Non renewable elements]	kg	0,00E+00
Thulium [Non renewable elements]	kg	0,00E+00
Tin [Non renewable elements]	kg	1,62E-02
Tin ore [Non renewable resources]	kg	1,62E-06
Tin ore (0,01%) [Non renewable resources]	kg	1,62E-06
TiO2, 54% in ilmenite [Non renewable resources]	kg	1,67E-08
TiO2, 54% in ilmenite, 2.6% [Non renewable resources]	kg	1,67E-08
TiO2, 95% in rutile, 0.40% [Non renewable resources]	kg	1,67E-08
Titanium [Non renewable elements]	kg	2,79E-08
Titanium dioxide [Non renewable resources]	kg	1,67E-08
Titanium ore [Non renewable resources]	kg	1,67E-08
Tungsten [Non renewable elements]	kg	4,52E-03
Tungsten ore (1%) [Non renewable resources]	kg	4,52E-05
Ulexite [Non renewable resources]	kg	0,00E+00
Uranium ecoinvent [Uranium (resource)]	kg	1,40E-03
Uranium free ore [Uranium (resource)]	kg	1,13E-03
Uranium natural (in MJ) [Uranium (resource)]	MJ	2,50E-09
Uranium oxide (U3O8), 332 GJ per kg, in ore [Uranium (resou	kg	1,19E-03
Uranium, fuel grade, 2291 GJ per kg [Uranium products]	kg	1,40E-03
Uranium, in ground [Uranium (resource)]	kg	1,40E-03
Vanadium [Non renewable elements]	kg	7,70E-07
Vanadium ore (V2O5 0.94%) [Non renewable resources]	kg	4,06E-07
Vermiculite [Non renewable resources]	kg	0,00E+00
Wollastonite [Non renewable resources]	kg	3,37E-12
Xenon [Non renewable elements]	kg	0,00E+00
Yttrium [Non renewable elements]	kg	5,69E-07

ADP e		
Problem oriented approach: baseline (CML, 2001), ADPelements (Oers et al. 2001)		
Flow	Unit	according to element content in Sb-Equivalent
Zinc [Non renewable elements]	kg	5,38E-04
Zinc - Copper - Lead - Ore (2.11% Zn 0.51% Cu 0.86% Pb) [	kg	7,28E-05
Zinc - Copper - Lead - Ore (4% Zn 0.09% Cu 0.65% Pb) [No	kg	7,50E-05
Zinc - Copper - Lead - Ore (5.37% Zn 0.22% Cu 0.2% Pb) [N	kg	4,46E-05
Zinc - Copper - Lead - Ore (6.95% Zn 0.13% Cu 2.04% Pb) [	kg	1,68E-04
Zinc - copper ore (4.07%-2.59%) [Non renewable resources]	kg	5,73E-05
Zinc - lead - copper ore (12%-3%-2%) [Non renewable resour	kg	2,82E-04
Zinc - Lead - Silver - Ore (7,5% Zn; 4,0% Pb; 40,8 g/t Ag) [N	kg	3,42E-04
Zinc - Lead - Silver - ore (8,54% Zn; 5,48% Pb; 94 g/t Ag) [N	kg	5,05E-04
Zinc - Lead Ore (21.7%-5.6%) [Non renewable resources]	kg	4,72E-04
Zinc - lead ore (4.21%-4.96%) [Non renewable resources]	kg	3,37E-04
Zinc - lead ore (R.O.M) [Non renewable resources]	kg	3,37E-04
Zinc Ore (12.6% Zn) [Non renewable resources]	kg	6,78E-05
Zinc ore (3,98%) [Non renewable resources]	kg	2,14E-05
Zinc ore (4%) [Non renewable resources]	kg	2,15E-05
Zinc ore (8%) [Non renewable resources]	kg	4,30E-05
Zinc Ore (9.7-14% Zn 3.1-6.5% Pb) [Non renewable resource	kg	3,68E-04
Zinc ore (sulphide, zinc 3,98%) [Non renewable resources]	kg	2,14E-05
Zinc ore (sulphidic, 4%) [Non renewable resources]	kg	2,15E-05
Zinc, Zn 0.63%, Au 9.7E-4%, Ag 9.7E-4%, Cu 0.38%, Pb 0.(	kg	5,38E-04
Zirconium [Non renewable elements]	kg	5,44E-06

Remark: Any value given for the mineral resources as “0” is on purpose, as these resources are not considered scarce in human time frames.

4.6.6 Renewables

Please refer to the separate document Agricultural LCA model background documentation 2014, which is also available on the thinkstep home page.

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 thinkstep 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 significant 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.

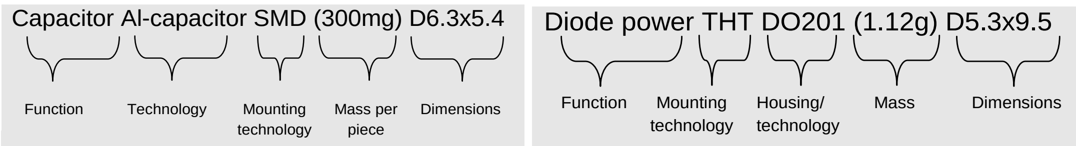
Even though not all electronic components can be judged according to their representativeness, the most relevant causes of environmental potentials from groups of similar electronic components can be identified, after the investigation of a certain amount of products. For example the difference in environmental 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 thinkstep 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 4-12.

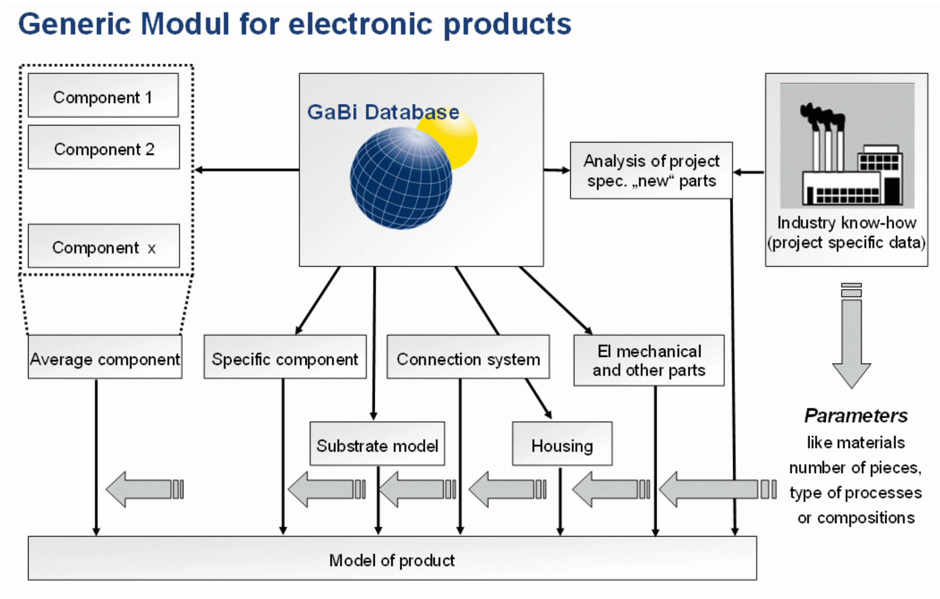


Figure 4-12: Creation of a model for an electronic product - modular structure via Generic Modules

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 analysing 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 modelled following methodological approaches such as cut-off approach, closed loop approach, open loop approach and value-corrected substitution approach.

Within the GaBi databases [GABI 2013] 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 steelworks), 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 analyse 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 2013].

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 modelling of secondary material inputs or outputs is completed, using the "value of scrap" approach, to avoid misinterpretation[17].

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., aluminium 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

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

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:

5. Waste incineration model
6. Landfill model
7. 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 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.

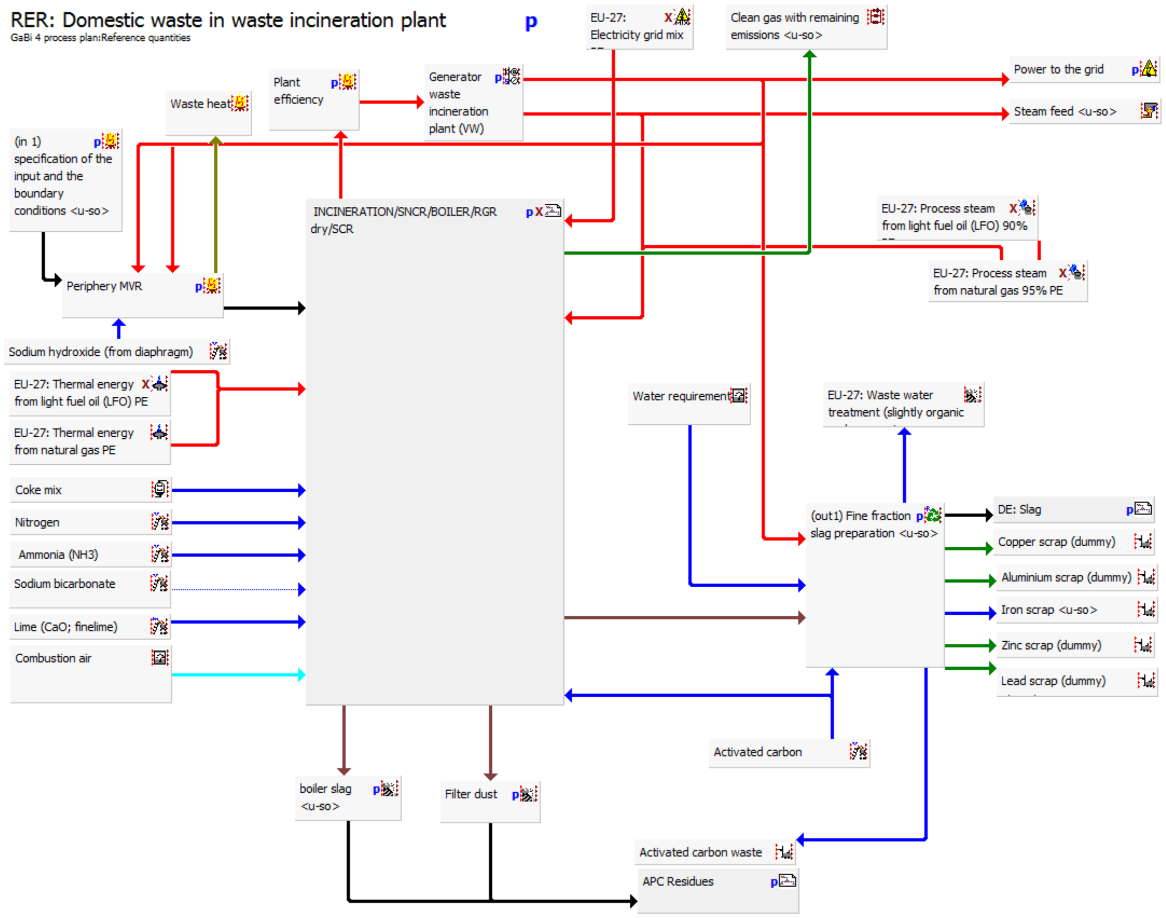


Figure 4-13: Exemplary incineration model with in GaBi (here average European domestic waste treatment with dry off-gas cleaning)

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.

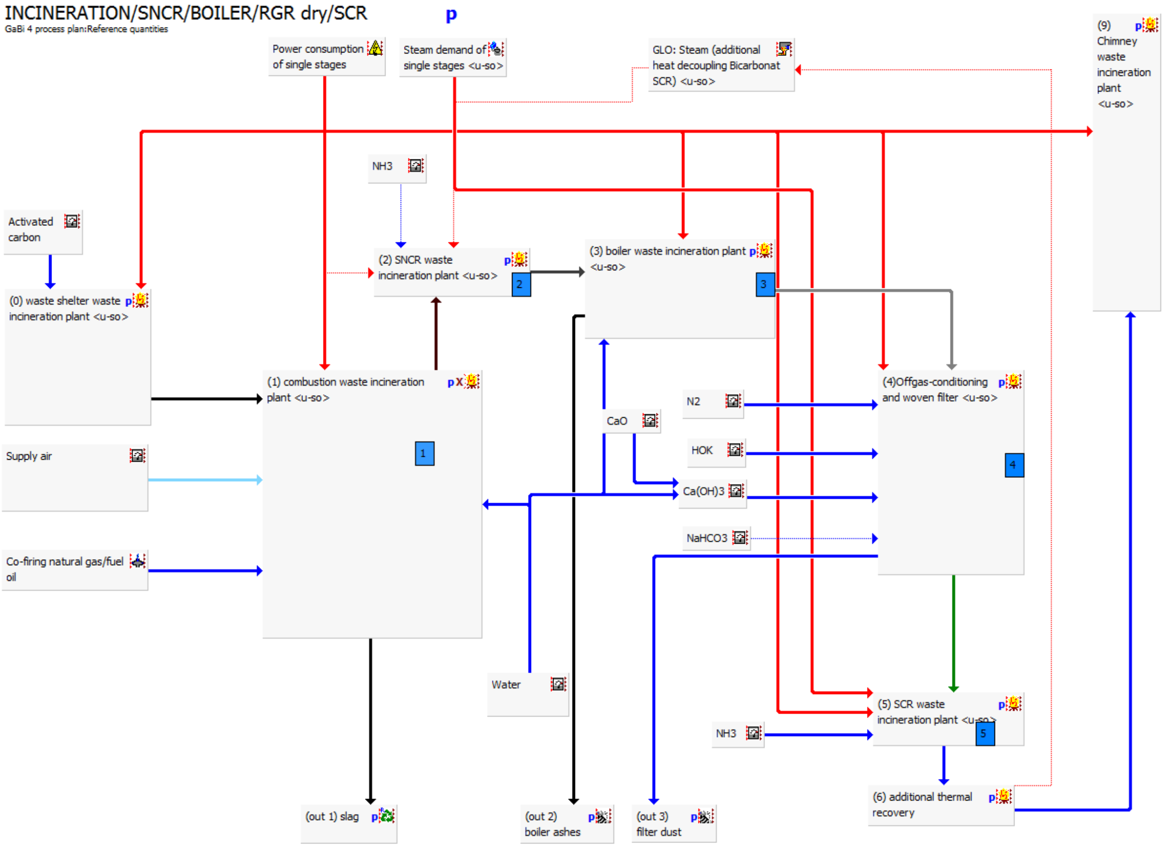


Figure 4-14: Details of incineration and dry off-gas cleaning in GaBi incineration model

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, AlOx, 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, H_2O, Hg, J, K, Mg, Mn, N, Na, NH4, Ni, O, P, Pb, S, Sb, SiO_2, Sn, SO4, Ti, Tl, V, Zn.

The modelled emissions to air in the flue gas of the incinerator are: As, Ba, Cd, Co, CO, CO_2 (fossil and biogenic), Cr, Cu, dioxins, HBr, HCl, HF, HJ, Hg, Mn, N_2O, NH_3, Ni, NMVOC, NO_x, particles, Pb, Sb, Sn, SO_2, Tl, V, Zn. Most of the emissions leaving the system are input-dependent. That means there is a stoichiometric 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 CO_2, HCl, HF, SO_2 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 that 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.

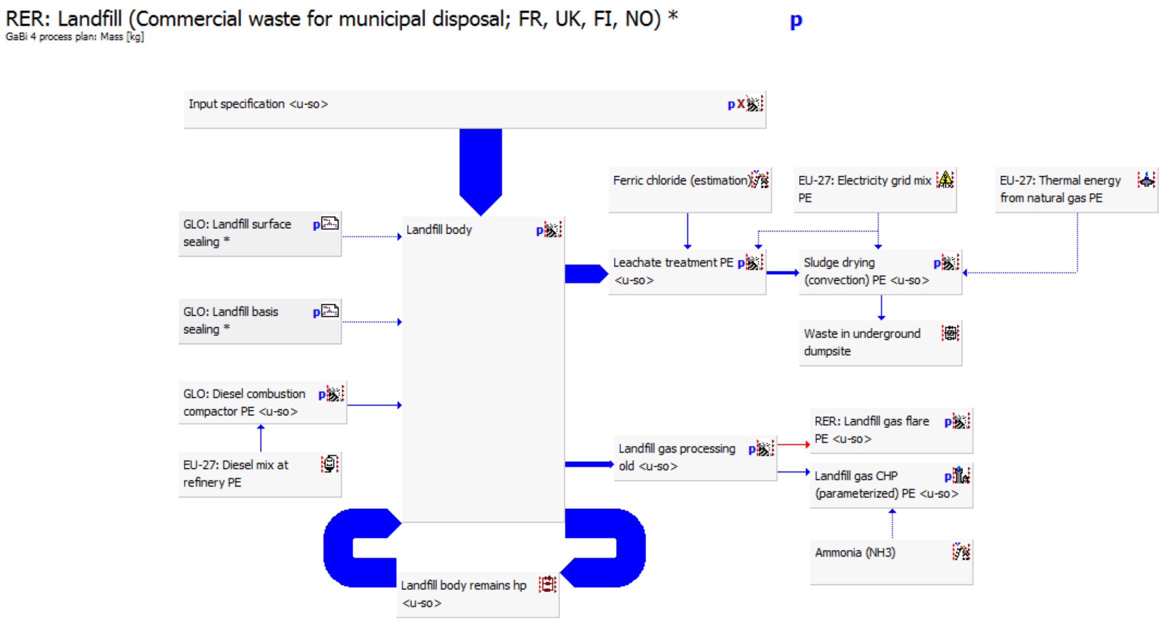


Figure 4-15: Exemplary landfill model in GaBi (here commercial waste composition for certain geographic example regions)

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 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).

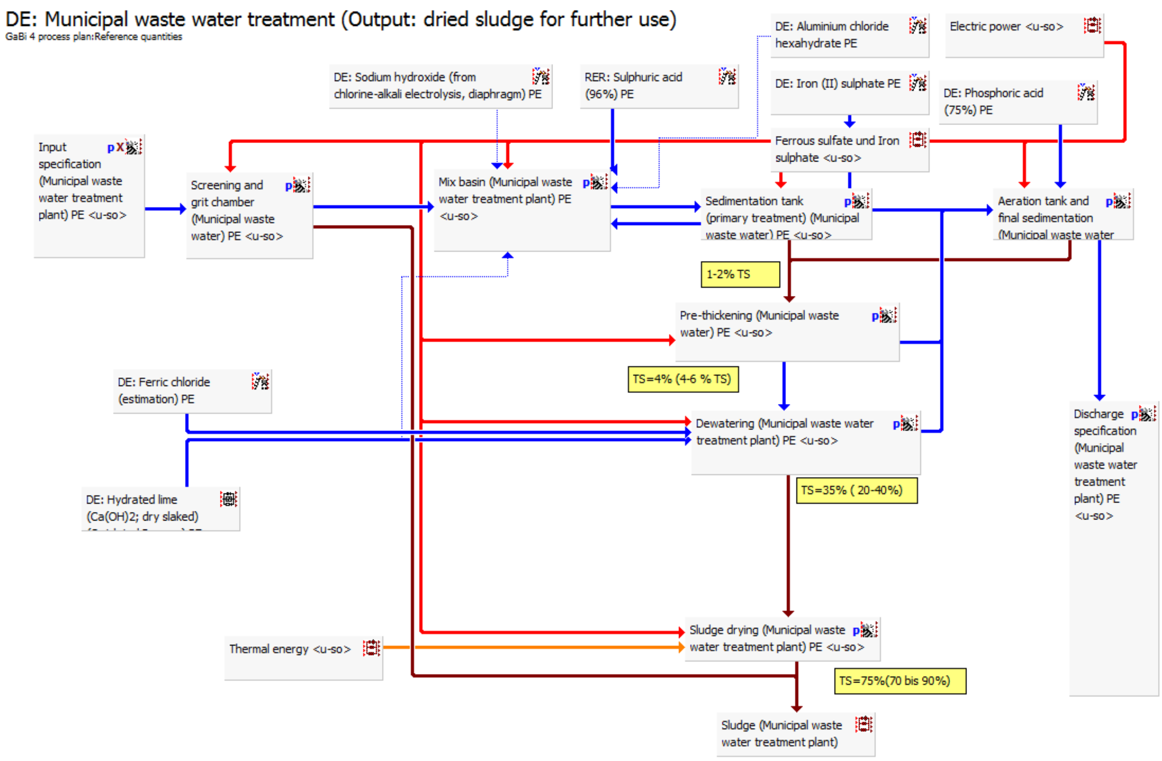


Figure 4-16: Exemplary wastewater treatment model in GaBi (here municipal wastewater for German circumstances)

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 and fats are removed. The settlement tank can remove the larger suspended solids. $FeSO_4$, and $Ca(OH)_2$ are used as precipitant agents in the mixing tank to remove metals. $Ca(OH)_2$ and H_2SO_4 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 thinkstep is to provide quality information. thinkstep 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
- Additional External review activities:

The different parts of the GaBi databases were in 2012/2013 three times reviewed by three different external organisations. The ILCD compatibility of selected GaBi processes across all branches was reviewed for the JRC in ISPRA, Italy by the Italian national Agency for new technologies, energy and Sustainable Economic Development (ENEA), Italy. In the light of the upcoming PEF Initiatives of the EU Commission, the Spanish Institution "Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT)" reviewed our data with focus on energy systems.

To complement our responsibility concerning external reviews thinkstep introduced a critical review process of its GaBi database with inspection and verification company DEKRA. As LCA continues to be used more broadly in industry, companies require increased accuracy, transparency and credibility of their data sources in order to make the best informed decisions. Recognising this and in order to ensure consistency and quality of its GaBi database, thinkstep finalized the first round of an "ongoing critical review process with DEKRA".

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 data[18] and process data handling are the main instruments to avoid, detect and reduce errors.

[18] Raw data is any data or metadata needed so set up an LCA dataset

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
- 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, NH_3)

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
- CO_2 balance not addressed (renewable), CO_2 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)
- CO_2 balance not addressed (renewable), CO_2 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 thinkstep 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 2013 database [GaBi 2013]" 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 2013] 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.

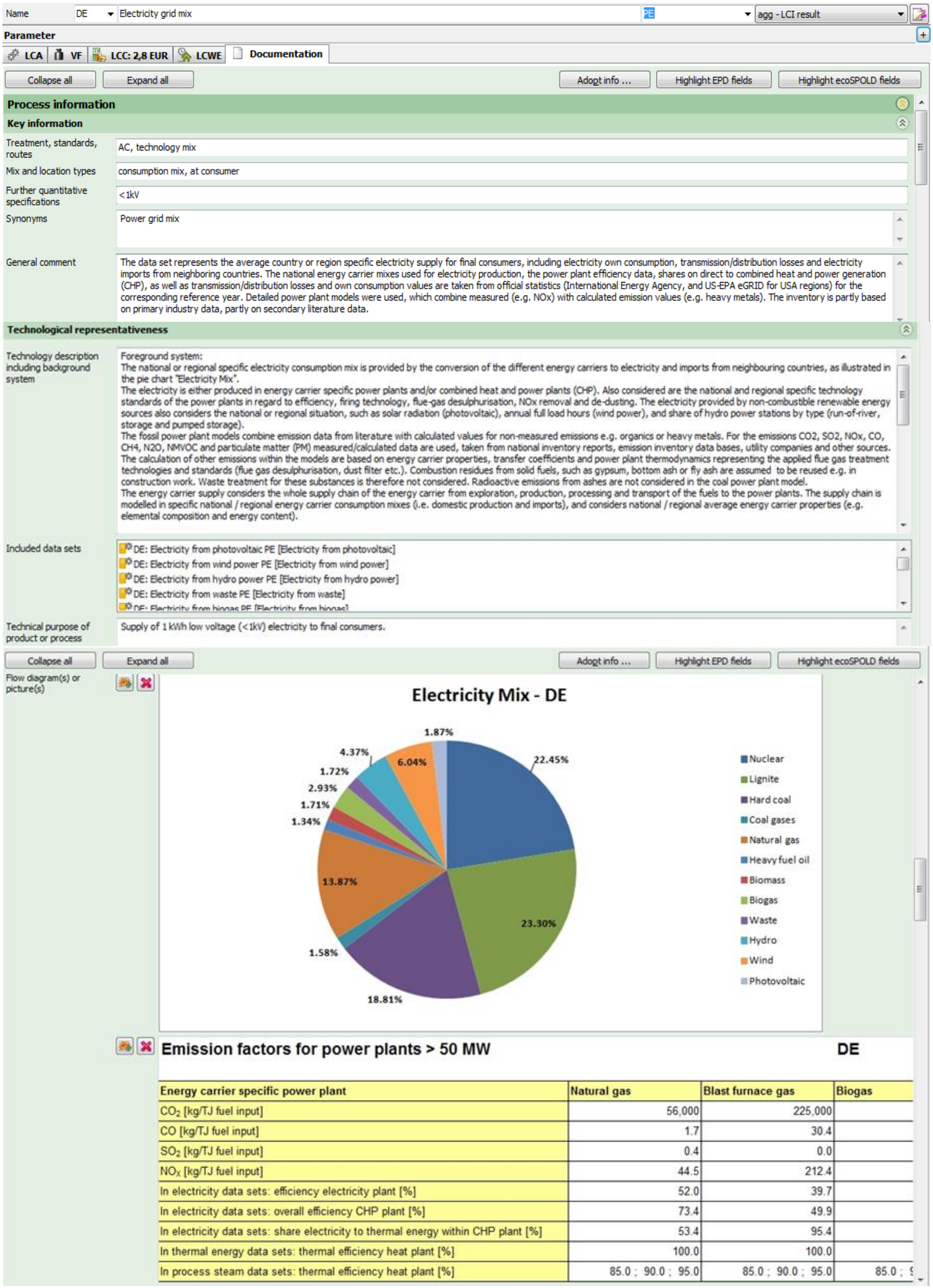
Flows in GaBi are (if suitable) documented by:

- 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 4-12).

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.



Energy carrier specific power plant	Natural gas	Blast furnace gas	Biogas
CO_2 [kg/TJ fuel input]	56,000	225,000	
CO [kg/TJ fuel input]	1.7	30.4	
SO_2 [kg/TJ fuel input]	0.4	0.0	
NO_X [kg/TJ fuel input]	44.5	212.4	
In electricity data sets: efficiency electricity plant [%]	52.0	39.7	
In electricity data sets: overall efficiency CHP plant [%]	73.4	49.9	
In electricity data sets: share electricity to thermal energy within CHP plant [%]	53.4	95.4	
In thermal energy data sets: thermal efficiency heat plant [%]	100.0	100.0	
In process steam data sets: thermal efficiency heat plant [%]	85.0 ; 90.0 ; 95.0	85.0 ; 90.0 ; 95.0	85.0 ; 9

Figure 5-1: Example documentation in GaBi (excerpt) [GaBi 2013]

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 thinkstep, following standard routine. thinkstep 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, thinkstep 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 thinkstep.

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. thinkstep 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.

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TRACI 2012	TRACI, TOOL FOR REDUCTION AND ASSESSMENT OF CHEMICAL AND OTHER ENVIRONMENTAL IMPACTS 2.1 (TRACI), U.S. ENVIRONMENTAL PROTECTION AGENCY, 2012; ONLINE: HTTP://WWW.EPA.GOV/NRMRL/STD/SAB/TRACI/
THYLMANN 2017	THYLMANN, D., KUPFER, T.: INTRODUCTION TO WATER ASSESSMENT IN GABI SOFTWARE, VERSION 2.0, 2017 HTTP://WWW.GABI-SOFTWARE.COM/DEUTSCH/SUPPORT/LATESTUPDATE
TRACI 1996	TRACI: THE TOOL FOR THE REDUCTION AND ASSESSMENT OF CHEMICALS AND OTHER ENVIRONMENTAL IMPACTS, US ENVIRONMENTAL PROTECTION AGENCY, U.S.A., 1996
UBA BERLIN 2004	UBA BERLIN; BUWAL / OFEFP BERN; UMWELTBUNDESAMT WIEN: HANDBUCH EMISSIONSFAKTOREN DES STRAßENVERKEHRS, VERSION 2.1, BERLIN, 2004
UBP 2013	SWISS ECO-FACTORS 2013 ACCORDING TO THE ECOLOGICAL SCARCITY METHOD.. FEDERAL OFFICE FOR THE ENVIRONMENT FOEN. BERN, 2013. HTTP://WWW.BAFU.ADMIN.CH/PUBLIKATIONEN/PUBLIKATION/01750
UNEP/SETAC 2011	UNEP/SETAC: GLOBAL GUIDANCE PRINCIPLES FOR LIFE CYCLE ASSESSMENT DATABASES – A BASIS FOR GREENER PROCESSES AND PRODUCTS, 2011
USETOX 2010	ROSENBAUM, RK *ET AL*: USETOX - THE UNEP/SETAC-CONSENSUS MODEL: RECOMMENDED CHARACTERISATION FACTORS FOR HUMAN TOXICITY AND FRESH-WATER ECOTOXICITY IN LIFE CYCLE IMPACT ASSESSMENT. INTERNATIONAL JOURNAL OF LIFE CYCLE ASSESSMENT 13(7): 532-546., 2008; USETOXTM MODEL 1.01 AND ORGANIC DATABASE 1.01, 2010
VBD 2003	PERSONAL INFORMATION: VERSUCHSANSTALT FÜR BINNENSCHIFFBAU E.V. (VBD), 2003 (RENAMED 2004 IN ENTWICKLUNGSZENTRUM FÜR SCHIFFSTECHNIK UND TRANSPORTSYSTEME E.V. (DST))
WORLD BANK 2012	HTTP://DATABANK.WORLDBANK.ORG/DATA/DATABASES.ASPX

Supplement A Description of result and impact categories

This chapter describes the impact assessment methodologies available in GaBi after the update 2013 (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, ReCiPe) 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 recommends 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 I. The approach of each methodology is described in the appropriate chapter.

Table I: 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 1.08 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 1.08 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 1.08 Midpoint (H) - Freshwater eutrophication + ReCiPe 1.08 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	Generic emission factor
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 feedstock energy content. It represents the still-usable energy content that can be recovered e.g. by incineration with energy recovery.

The primary energy consumption is available both as gross and net calorific value. The **"Goss calorific value"** represents the reaction where all the products of combustion are returned to the original pre-combustion temperature, and in particular condensing water vapour produced.

The **net calorific value** is the higher heating value minus the heat of vaporization of the water. The energy required to vaporize the water is not recovered as heat. This is the case for standard combustion processes where this re-condensation takes place in the surrounding environment. Table J below gives an overview of the primary energy categories present in GaBi.

Table J: Net and gross calorific value

	Non-renewable resources	**+**	**Renewable resources**	**=**	**Total**
Gross calorific value	Primary energy from non ren. resources (gross cal. value)	+	Primary energy from renewable raw materials (gross cal. value)	=	Primary energy demand from ren. and non ren. resources (gross cal. value)
Net calorific value	Primary energy from non ren. resources (net cal. value)	+	Primary energy from renewable raw materials (net cal. value)	=	Primary energy demand from ren. and non ren. resources (net cal. value)

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 (CO_2-Eq.), meaning that the greenhouse potential of an emission is given in relation to CO_2. 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.

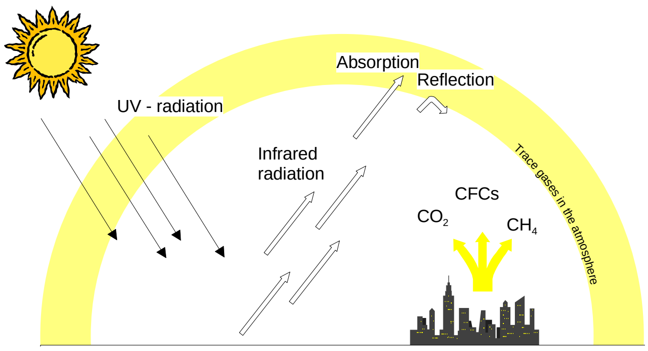


Figure A-1: Greenhouse effect (KREISSIG & KÜMMEL 1999)

Biogenic carbon

Global warming can be calculated including or excluding biogenic carbon. Including biogenic carbon means accounting for CO_2 taken up by plants with the factor 1 kg CO_2 eq./kg. If the carbon is released later as biogenic CO_2 or methane this is also accounted for; CO2 with the factor 1 and methane with a factor 25 kg CO_2 eq./kg. The carbon can also be stored e.g. in wood in buildings.

Excluding biogenic carbon means that CO_2 taken up by plants is excluded from the calculation; in practice by leaving it out of the calculation methods or giving it a factor 0. The same will be the case for biogenic CO2 emission; it is left out or with a factor 0.

If the carbon is released as biogenic methane this necessitates an adjustment of the emission factor. 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 CO_2 = 44 g : 1 mole CH_4 = 16 g

2.75 g CO_2 : 1 g CH_4

Consider a plant that sequesters 2.75 kg CO_2 and this carbon is eventually entirely released as 1 kg methane. If we model this system including the sequestered carbon, then the GWP calculation will be as follows:

- Sequestered CO_2 = 2.75 kg=> -2.75 kg CO_2e
- Emission of CH_4 = 1 kg => 25 kg CO_2e
- Net emission = 25 - 2.75 => 22.25 kg CO_2e

Therefore, if we set the sequestered CO_2 to zero, we need to give the biogenic CH_4 an emission factor of 22.25 kg CO_2 eq. to have the proper net emission factor.

An overview of the GWP methods including and excluding biogenic carbon is given in Table K below.

Table K: Global warming incl. and excl. carbon in GaBi

Method	Version	Incl. biogenic C	Excl. biogenic C
IPCC	2012	XX	X
ILCD	2007	XX	0
CML	1996 + 2001 + Dec. 2007 + Nov. 2009	XX	0
	Oct. 2010 + Apr. 2013	XX	X
ReCiPe	1.05 + 1.07, Midpoint (H) + Endpoint (H)	0	XX
	1.08 Midpoint (E)+(H)+(I) + Endpoint (E)+(H)+(I)	X	XX
TRACI	2.0	XX	0
	2.1	XX	X
EDIP	1997 + 2003	XX	0
I02+	2.1	XX	0

XX: Default version X: Additional method, adjusted by thinkstep 0: Not included

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.

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]

By default, CML includes biogenic carbon at the same level as fossil carbon, hence CO_2 uptake has a GWP of 1 kg CO_2 eq., and the subsequent release has the factor of 1 kg CO_2 eq. For the versions 2010 and 2013 an additional version excluding biogenic carbon is included.

ReCiPe 1.08

ReCiPe 2008 was updated to version 1.08, released in May 2013. This version is implemented in the update 2013. Furthermore, all three cultural perspectives of ReCiPe are included; Individual (I), hierarchical (H), and Egalitarian (E).

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

<u>Midpoint:</u>

The researchers are interested in the marginal effect of adding a relatively small amount of CO_2 or other greenhouse gas, and not the impact of all emissions. However, with no models readily available, the IPCC climate change equivalence factors from the 2007 report (including the 2012 errata) are used as the midpoint characterisation factors.

GWP impacts including biogenic carbon are added for each. This means setting CO2 uptake, biogenic CO2 emission, and biogenic methane emission with characterisation factors identical to the fossil versions.

<u>Endpoint</u>

ReCiPe have three damage-oriented categories: Human health, ecosystem quality and resources. Global warming has an impact on both human health and ecosystem quality; hence, there are two endpoint indicators for global warming in ReCiPe. Below is a short explanation of the steps involved:

- Step 1: Radiative forcing. A damage models developed for CO2. The other substances are taken into account using the IPCC equivalence factors.
- Step 2: Temperature effect. The residence time and the radiative forcing of CO2 link the emission of CO2 to a temperature increase based a wide range of climate models.
- Step 3a: Damage to human health. This is modelled using the work of WHO, WMO and UNEP. The health risk increases as a function of temperature increase for five different health effects in different world regions. This increase is combined with the current global burden of disease published by WHO to calculate DALY's.

- Step 3b: Damage to ecosystem diversity. This is modelled using the work of Thomas, C.D predicting the extinction of species on a global scale from various scenarios.

Figure A-2 depicts the impact pathway of the mid- and endpoint factor [RECIPE 2012]

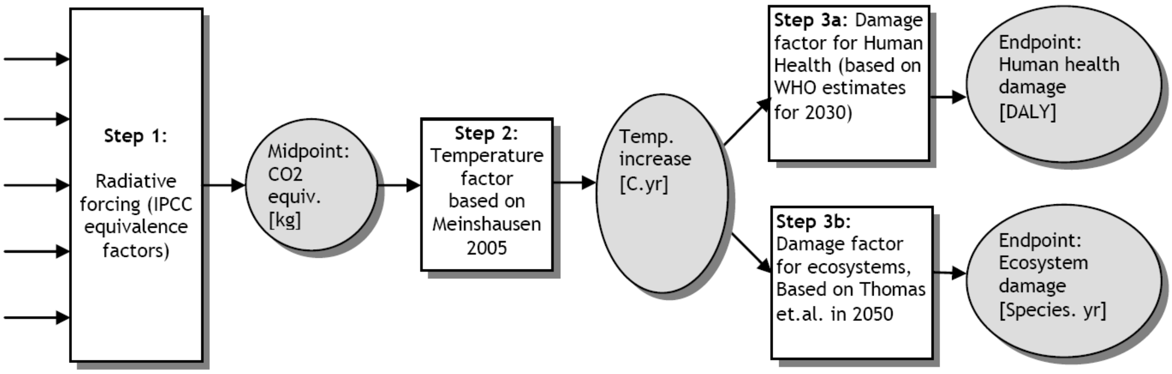


Figure A-2: Greenhouse effect impact pathway chain

Similarly to the midpoint method, an additional GWP method is implemented including biogenic carbon. The CO2 uptake and biogenic CO2 emission is given the same characterisation factor as fossil CO2 emission and the biogenic methane CF is changed to that of fossil methane.

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 CO_2, according to latest IPCC publications, almost identically to the CML methodology [THYLMANN 2017]. The default TRACI 2.1 method includes biogenic carbon emissions and uptakes. Similarly to CML and ReCiPe, the default version is supplied with the counterpart – here being TRACI GWP excluding biogenic carbon. CO2 uptakes and biogenic CO2 emissions are excluded, but based on correspondence with the authors of the TRACI 2.1 method the biogenic methane keeps the same CF as fossil methane emissions.

UBP 2013, 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 2013]

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 CO_2 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.

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. CO_2 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 CO_2-equivalents. The assumed time horizon is 500 years to account for both short and long-term effects. [IMPACT 2002]

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 (H_2SO_4 und HNO_3) 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-3 displays the primary impact pathways of acidification. [GUINÉE ET AL. 2001]

The acidification potential is given in sulphur dioxide equivalents (SO_2-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.

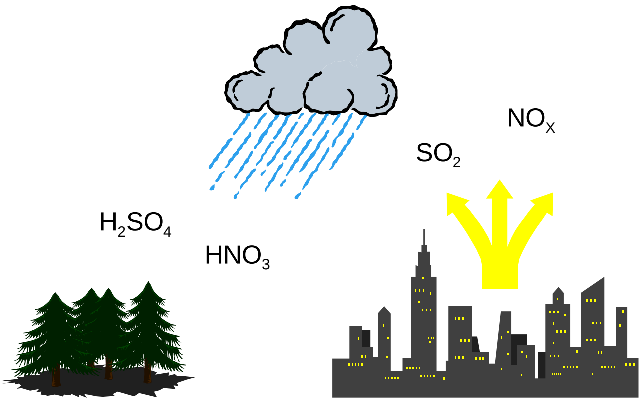


Figure A-3: Acidification Potential (KREISSIG & KÜMMEL 1999)

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 eutrophing 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].

ReCiPe 1.08

The ReCiPe methodology uses SO_2-Eq. as in the CML methodology for a midpoint indicator. The Potentially Disappeared Fraction (PDF) of species in forest ecosystems on a European scale is used as endpoint indicator, which is similar to the Ecoindicator approach. [RECIPE 2012]

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 SO_2 eq. [THYLMANN 2017]

UBP 2013, Ecological Scarcity Method

The method has adapted CML values as the approach for acidification [UBP 2013]

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 = m^2 UES).

In comparison, the EDIP97 acidification potential is expressed as the emission of SO_2 that would lead to the same potential release of protons in the environment (g SO_2-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 SO_2-equivalents and are adapted from the EDIP1997 methodology which also corresponds to the approach from CML. [IMPACT 2002]

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 nutrification 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-4. The eutrophication potential is calculated in phosphate equivalents (PO_4-Eq.). As with acidification potential, it is important to remember that the effects of eutrophication potential differ regionally.

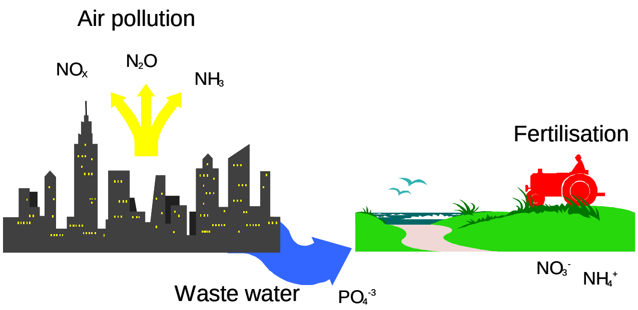


Figure A-4: Eutrophication Potential (KREISSIG & KÜMMEL 1999)

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 eutrophing 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]. The geographical extent of the model is so far limited to Europe.

As spatialisation is not yet integrated in GaBi, the method is only implemented with a generic factor calculated by ILCD [ILCD 2011].

ReCiPe 1.08

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 phosphorous 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 substances[19].

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. [THYLMANN 2017]

UBP 2013, 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 2013]

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

[19] The emissions to agricultural soil should be multiplied with the fertilizer factors in ReCiPe main report.

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 = m^2 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 PO_4^{3-}-equivalents) are given for emissions into air, water and soil with characterisation factors taken directly from CML. No aquatic eutrophication damage factors (in PDF·m^2·yr/kg emission) are given because no available studies support the assessment of damage factors for aquatic eutrophication. [IMPACT 2002]

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 NO_2, CO_2 and O_2. 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-5).

In Life Cycle Assessments photochemical ozone creation potential (POCP) is referred to in ethylene-equivalents (C_2H_4-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.

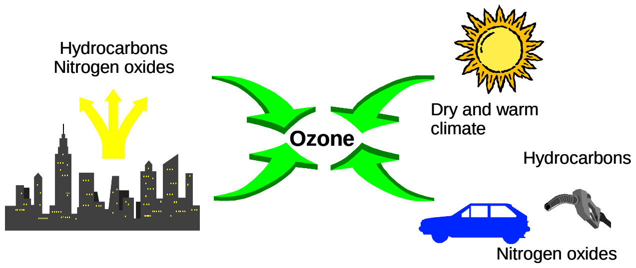


Figure A-5: **Photochemical Ozone Creation Potential (KREISSIG & KÜMMEL 1999)**

The most recent POCP factors are still the ones used for the original CML methodology with only a few adjustments. [GUINÉE ET AL. 2001]

ReCiPe 1.08

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/m^3) due to a marginal change in emission (in kg/year) expressed as NMVOC-equivalents.

The end-point indicator is human health expressed as DALYs. []

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). [THYLMANN 2017]

UBP 2013, 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 2013]:

- 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.

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]

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 that 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-6 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.

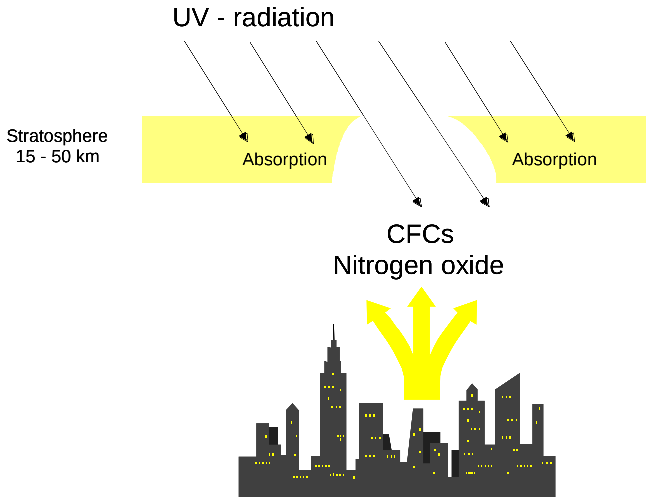


Figure A-6: **Ozone Depletion Potential (KREISSIG & KÜMMEL 1999)**

In CML, the ODPs published by the World Meteorological Organisation (WMO) from 2002 are used. [GUINÉE ET AL. 2001]

ReCiPe 1.08

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 2012]

TRACI 2.1

Within TRACI 2.1, the most recent sources of ODPs from WMO (World Meteorological Organization) are used for each substance. [THYLMANN 2017]

UBP 2013, 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 2013]

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]

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.

GaBi has a set of standard flows established through the LCA projects and models developed over the years. This flow list is expanded to include all the recommended characterisation factors from USETox, supplemented with a few factors from the interim group to allow for a consistent coverage of the GaBi standard flows. The remaining interim factors in USETox are available as an import file upon request to support@gabi-software.com.

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 m^3-day/ kg). [USETox 2010]

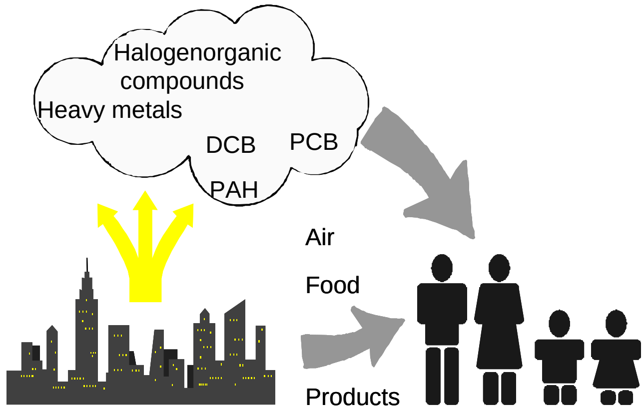


Figure A-7: **Human Toxicity Potential**

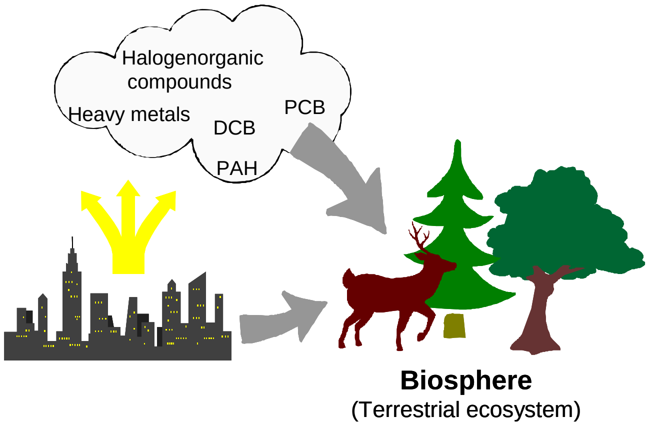


Figure A-8: **Terrestrial Eco-Toxicity Potential**

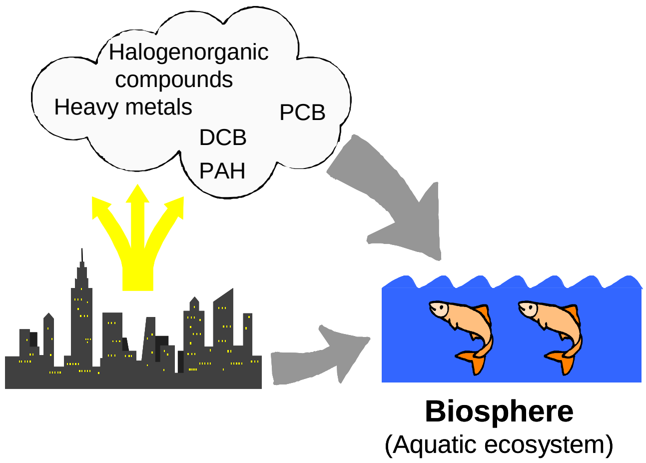


Figure A-9: Aquatic Eco-Toxicity Potential

ReCiPe 1.08

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 2012]

The upgrade to ReCiPe 1.08 has greatly increased the number of flows characterised. The substances in the GaBi standard flow list are implemented. The remaining factors are available as an import file upon request to support@gabi-software.com

TRACI 2.1

The TRACI 2.1 methodology has incorporated the USETox model to account for toxicity. [Thylmann 2017]

UBP 2013, Ecological Scarcity Method

The method has developed ecopoints per kg-emitted substance for only a limited amount of substances [UBP 2013].

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]

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 GaBi, one based on 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) all listed in MJ of lower calorific value. Uranium is accounted for in ADP (elements) and is not listed as a fossil fuel. [GUINÉE ET AL. 2001]

ReCiPe 1.08

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.). The endpoint indicator is the economic value in $. [ReCiPe 2012]

Anthropogenic Abiotic Depletion Potential (AADP)

Conventional ADP indicators excluded materials stored in the technosphere, the anthropogenic stock. Total anthropogenic stock is determined as the accumulated extraction rate since the beginning of records in ~1900 until 2008 based on data from the U.S. Geological Survey. It is assumed that the amount of materials mined before is negligible. This is split between employed and deposited stock.

Employed stock is the resource that is still in circulation. It is composed of resources in use and resources hibernating, which is resources in storage before eventually being discarded.

Expended stock is the total amount of resource that has been discarded. It is made up of deposited and dissipated stock. The deposited stock, e.g. in landfills, enables future recovery whereas the dissipated stock is emitted to the environment in a form that makes recovery almost impossible e.g. water emissions of metals.

The implemented AADP is the total anthropogenic stock (excluding the dissipated stock) added to the conventional ADP factors. It is indicated relative to antimony as has the unit kg Sb-eq. [Schneider 2011]

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. [Thylmann 2017]

UBP 2013, Ecological Scarcity Method

Eco-factors, expressed as eco-points per MJ of energy consumption are used for energy.

Minerals are not included. [UBP 2013]

Land Use, LANCA

Land use is considered a limited resource. It is integrated in GaBi via 5 indicators: Erosion resistance, mechanical filtration, physicochemical filtration, groundwater replenishment, and biotic production. The five indicators are available both as continuous land occupation and for land transformation. The land occupation and transformation is evaluated against the natural condition of the ecosystem. For European conditions, this is mostly forest.

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 [MILA` I CANALS 2007]. It is currently integrated via a set of generic factors for land occupation and transformation calculated by ILCD [ILCD 2011]. On a site-specific level, it can be calculated from LCI datasets as net CO_2 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 where implemented to reflect the latest status of best practise in water foot printing 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.

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]

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 1.08

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 PM_{10} 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 L.

Table L: **Normalization references**

Methodology	Impact calculated (year)	Area(s) covered
CML 2001	Total impact (2000)	World, Europe
ReCiPe 1.08, 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 2013	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 to each impact. This can be based on political reduction targets or on the opinions of experts and/or nonprofessionals, for example.

For the ReCiPe method, a weighting of the endpoint indicators is available from the authors based on one of the three cultural perspectives (E, H or I) or as an average. The midpoint indicators are not weighted.

In 2012 thinkstep 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-10 below gives an overview of the respondents with the area and colon of each rectangle representing the number of people within each category.

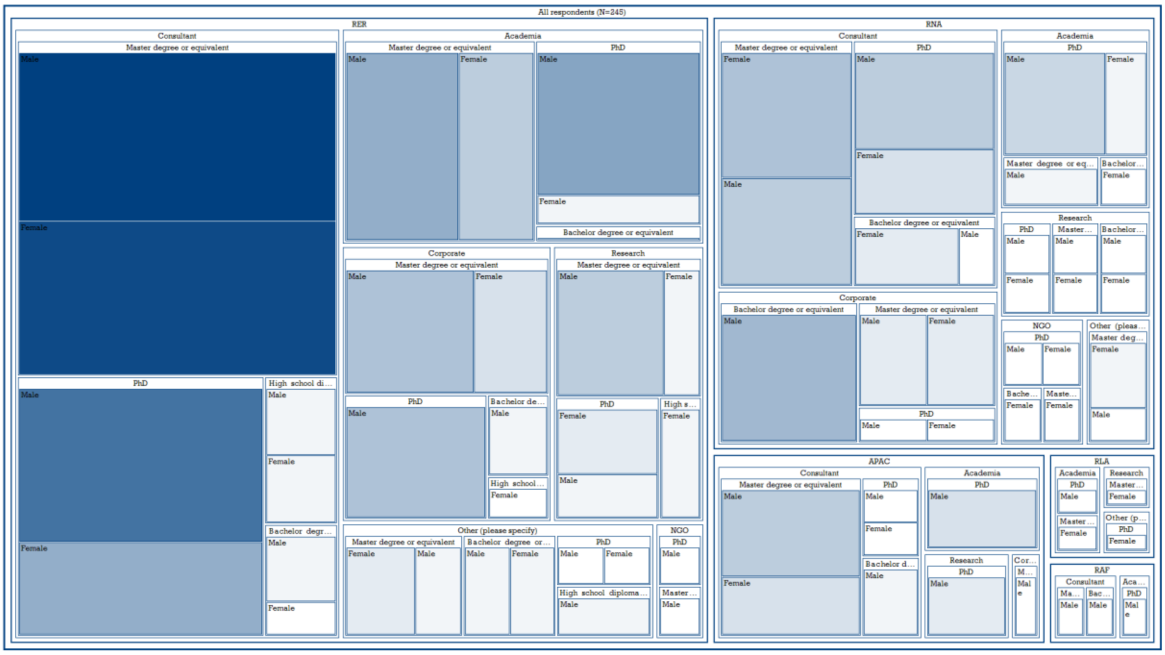


Figure A-10: Response to thinkstep Weighting 2012

The answers from the questionnaires led to the weighting factors in

Table **M**. 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 M: thinkstep 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 N: Chemical substance datasets available for various countries in GaBi

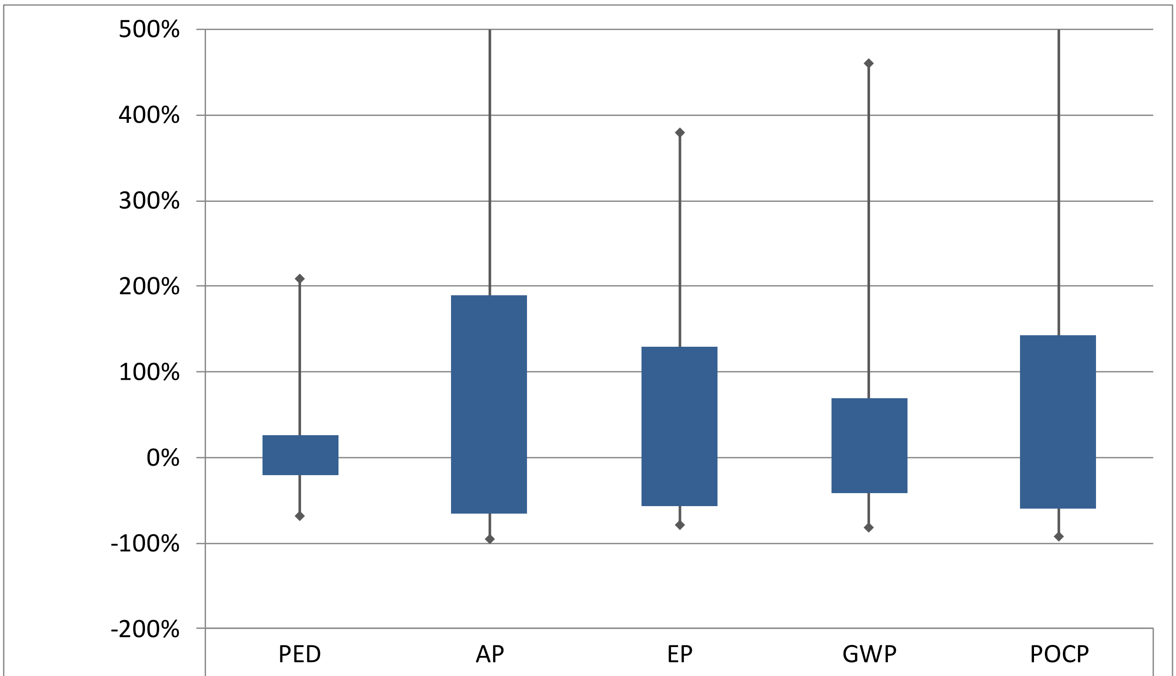
Acetic acid from methanol	Hydrogen (Steam reforming fuel oil s)
Acetone by-product phenol methyl styrene (from Cumol)	Hydrogen (Steam reforming natural gas)
Adipic acid from cyclohexane	Maleic anhydride (MA) by-product PSA (by oxidation of xylene)
AH-salt 63% (HMDA via adipic acid)	Maleic anhydride from 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, methanol
Benzene by-product BTX (from reformate)	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 sub-stances. 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.



	PED	AP	EP	GWP	POCP
10% percentile	-21%	-65%	-56%	-41%	-59%
choose min	-68%	-95%	-79%	-82%	-93%
choose max	209%	1870%	380%	461%	1288%
90% percentile	27%	189%	129%	70%	143%

Figure B-11: 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 Master DB 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

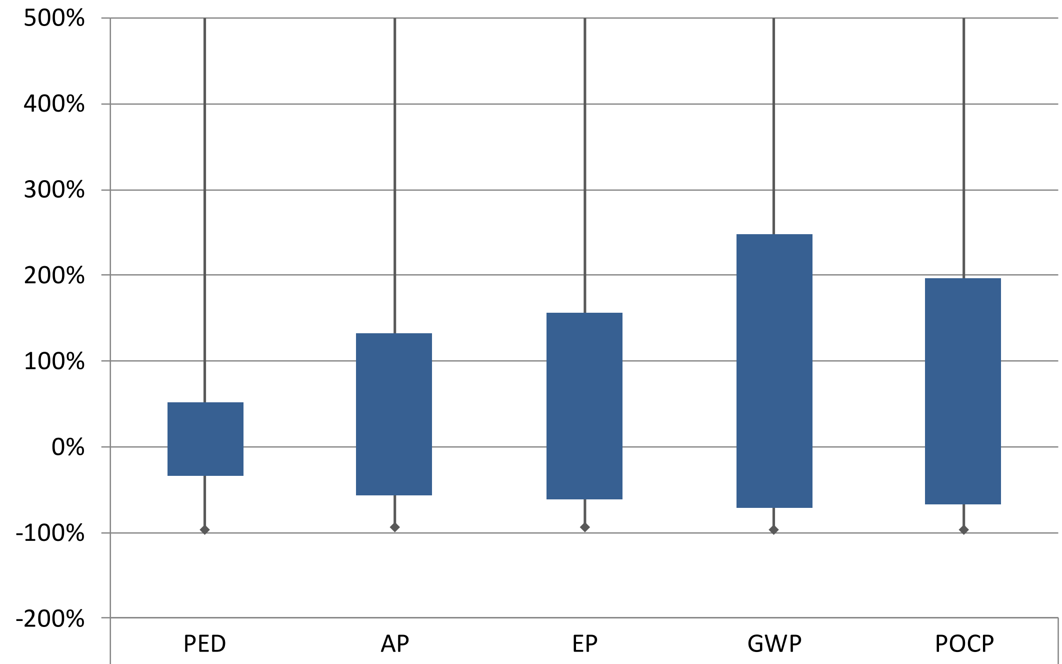
The following chemical substances were analysed regarding their variability with regard to their technology route in the same country.

Table O: 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 epichlorohydrine
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 Steam reforming fuel oil s
Ammonium sulphate by-product Caprolactam	Hydrogen Steam reforming 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
Dichlorpropane by-product epichlorohydrin	Phenol by-product acetone
Dichlorpropane by-product dichlorpropane	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 reformate

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.



	PED	AP	EP	GWP	POCP
10% percentile	-34%	-57%	-61%	-71%	-66%
choose min	-96%	-94%	-93%	-96%	-96%
choose max	2409%	1596%	1332%	2609%	2731%
90% percentile	52%	132%	156%	248%	197%

Figure B-12: 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.