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Overview and Methodology

Data v2.0 (2007)

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Project "ecoinvent data v2.0"

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Project "ecoinvent 2000" (ecoinvent data v1.0-1.3)

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Overview and Methodology

Subproject "Methodology"

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Acknowledgement v2.0

After four years of intensive work version 2.0 of the ecoinvent data is released. In the mean time, the ecoinvent database became the most widespread and acknowledged life cycle inventory database worldwide.

This success was only possible because of the on-going support by Swiss Federal Offices and European Organisations. In particular we wish to express our thanks to the Swiss Federal Office for the Environment (FOEN - BAFU), the Swiss Federal Office for Energy (BFE) and the Swiss Federal Office for Agriculture (BLW). We received further support from several associations, namely Alcosuisse, Biogas Forum Schweiz, Entsorgung und Recycling Zürich, Amt für Hochbauten Stadt Zürich, Erdöl-Vereinigung, the European Photovoltaics Industry Association (EPIA) and others. We wish to express our thanks for their valuable support.

We wish to thank the ecoinvent member institutes for their in kind contributions in maintaining and extending the ecoinvent database and by that keeping it up-to-date and the relevant source for environmental life cycle information.

Acknowledgement v1.01 to v1.3

The first steps for the ecoinvent project have been taken during the late 1990ties. In the first phase of the project financing and its positioning in existing institutions were negotiated. We thank all the persons involved in this phase who helped to start up this project.

We thank the institutions which supported the development of the ecoinvent database and the investigation of the ecoinvent data v1.01 to v1.3.

The individual projects for data harmonisation and compilation have been funded by the Swiss Federal Roads Authority (ASTRA), the Swiss Federal Office for Construction and Logistics (BBL), the Swiss Federal Office for Energy (BFE), the Swiss Federal Office for Agriculture (BLW), and the Swiss Agency for the Environment, Forests and Landscape (BUWAL).

The database software development was funded by the Swiss Centre for Life Cycle Inventories and the salary for the project management by Empa and the Swiss Centre for Life Cycle Inventories.

Summary

This report describes the general structure of the ecoinvent database developed by the Swiss Centre for Life Cycle Inventories. The database accommodates about 4’000 datasets for products, services and processes often used in LCA case studies.

First the background of this project and the objectives for the investigation of datasets for this background database are described.

Then, the quality guidelines, established in order to ensure a coherent data acquisition and reporting across the various economic sectors and the institutes involved, are described. They include aspects like the reporting of pollutants (e.g., heavy metals), or the naming of processes and elementary flows. Further on modelling issues like allocation have been harmonized within the project.

Finally, the data (exchange) format EcoSpold is described. The data exchange format complies with the ISO/TS 14048 data documentation format. Data exchange between the ecoinvent database and its cutomers is based on XML technology. The report describes the matrix inversion used to calculate the cumulative LCA data.

In some sections we also give an outlook on shortcomings of the approaches developed for and used in the ecoinvent datasets and suggestions are made for the further development of large LCI databases.

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1 Introduction and overview

1.1 The motivation and problem setting

Up to the late nineties, several public Life Cycle Assessment (LCA) databases existed in Switzerland, partly covering the same economic sectors (Frischknecht et al. 1996; Frischknecht et al. 1994; Gaillard et al. 1997; Habersatter et al. 1996; Habersatter et al. 1998; Künniger & Richter 1995). These databases have been developed by different institutes and organisations. Life cycle inventory data for a particular material or process available from these databases often do not coincide and therefore the outcome of an LCA is (also) dependent on the institute working on it. Furthermore the efforts required to maintain and update comprehensive and high quality LCA-databases are beyond the capacity of any individual institute.

At the same time, LCA gets more and more attention by industry and authorities as one important tool for e.g., Integrated Product Policy (IPP), Technology Assessment (TA) or Design for the Environment (DfE). In parallel with this increasing trend in LCA applications, the demand for high quality, reliable, transparent, independent and consistent LCA data increased as well. Only a few publicly available life cycle inventory (LCI) databases fulfil these criteria and most of them were published in the nineties.

After the successful launch of ecoinvent data v1.01 in 2003, the work concentrated on an extension and revision of the contents in view of a new release in 2007.

1.2 The project partners of ecoinvent data v2.0

Under the lead of PSI, LCA-institutes in the ETH domain (Swiss Federal Institutes of Technology (ETH) Zürich and Lausanne, Paul Scherrer Institute (PSI) Villigen, and Swiss Federal Laboratories for Materials Testing and Research (Empa) in St. Gallen and Dübendorf) as well as the LCA-group of the Agroscope Reckenholz-Tänikon Research Station (ART) in Zürich continued their co-operation in the Swiss Centre for Life Cycle Inventories, the ecoinvent Centre.

Besides the institutions mentioned above the following consultants contributed with LCI data compilation: Basler & Hofmann, Zürich, Bau- und Umweltchemie, Zürich, Carbotech AG, Basel, Chudacoff Oekoscience, Zürich, Doka Life Cycle Assessments, Zürich, Dr. Werner Environment & Development, Zürich, Ecointesys - Life Cycle Systems Sarl., Lausanne, ENERS Energy Concept, Lausanne, ESU-services Ltd., Uster, Infras AG, Bern and Umwelt- und Kompostberatung, Grenchen. Rolf Frischknecht lead the ecoinvent management, Annette Köhler was in charge with Marketing and sales and ifu Hamburg GmbH with software development and support.

1.3 Database content, ecoinvent data v2.0

The ecoinvent data v2.0 comprise LCI data covering energy (including oil, natural gas, hard coal, lignite, nuclear energy, hydro power, photovoltaics, solar heat, wind power, electricity mixes, biofuels), transport, building materials, wood (European and tropical wood), renewable fibres, metals (including precious metals), chemicals (including petrochemical solvents and detergents), electronics, mechanical engineering (metals treatment and compressed air), paper and pulp, plastics, waste treatment and agricultural products. The tasks are distributed according to the expert knowledge of the partners (see Tab. 1.1). The complete list of datasets is available via the Internet and on this CD-ROM (filename "ecoinventData/ecoinventnames.xls").

Tab. 1.1 ecoinvent data v2.0 contents and data generators

Sector	Database content	Data generator
Energy	Hard coal	Paul Scherrer Institute
	Oil	ESU-services Ltd.
	Natural gas	ESU-services Ltd., Paul Scherrer Institute
	Nuclear power	Paul Scherrer Institute
	Hydroelectric power	Paul Scherrer Institute
	Wood energy	Paul Scherrer Institute
	Wind power	Paul Scherrer Institute
	Photovoltaics	ESU-services Ltd.
	Solar heat	ESU-services Ltd.
	Electricity supply and mixes	ESU-services Ltd., Paul Scherrer Institute
	Small scale CHP systems	Basler & Hofmann
	Biofuels	ESU-services Ltd., Carbotech, ENERS, ETHZ-UNS[1], Infras, LASEN/EPFL, Paul Scherrer Institute, Umwelt- und Kompostberatung
materials	Building materials	Empa[2], Bau- und Umweltchemie, ESU-services Ltd.
	Metals	Empa[2], ESU-services Ltd.
	Plastics	Empa[2]
	Paper and Board	Empa[2]
renewable materials	Wood	Empa[2]
	Tropical wood	Dr. Frank Werner Environment and Development
	Renewable fibres	Carbotech
Chemicals	Basic Chemicals	ETHZ-ICB[3], Empa[2], Chudacoff Ökoscience, ESU-services Ltd.
	Petrochemical solvents	ETHZ-ICB[3]
	Detergents	Empa[2]
Transport	Transport services	Paul Scherrer Institute, ESU-services Ltd.
Waste management	Waste treatment services	Doka Life Cycle Assessments
Agriculture	Agricultural products and processes	ART[4], Carbotech, ETHZ-ICB[3]
Electronics	Electronics	Empa[2]
Mechanical engineering	Metals processing and compressed air	ESU-services Ltd.

[1] Institute for Environmental Decisions, Natural and Social Science Interface, Swiss Federal Institute of Technology, Zurich (ETHZ)

[2] Swiss Federal Laboratories for Materials Testing and Research

[3] Institute for Chemical and Bioengineering, Safety and Environmental Technology Group, Swiss Fed-eral Institute of Technology Zurich (ETHZ)

[4] Agroscope Reckenholz-Tänikon Research Station, Life Cycle Assessment group

1.4 The basic structure of the ecoinvent database system

A large, network-based database and efficient calculation routines are required for handling, storage, calculation and presentation of data and are developed in the course of the project. These components partly take pattern from preceding work performed at ETH Zurich (Frischknecht & Kolm 1995).

The ecoinvent database system consists of the following components (see also Fig. 1.1):

1) The central database,
2) Calculation routines,
3) The editor (EcoEditor) and an add-in for MS-EXCEL (EcoSpold Access) for translation between MS-EXCEL and XML,
4) The administration tool (EcoAdmin),
5) The query tool (EcoQuery, www.ecoinvent.org),

6) The data (exchange) format EcoSpold,
7) Local databases.

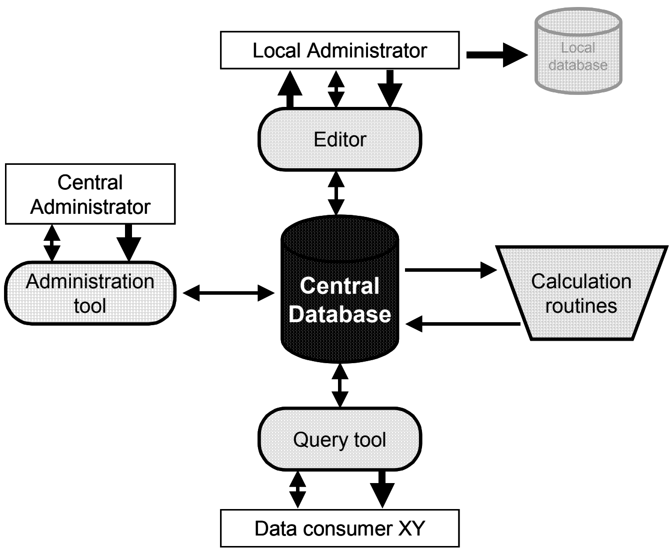

Fig. 1.1 The basic structure of ecoinvent database system

Ad 1. The central database contains Life Cycle Inventory data on energy systems, transport systems, waste treatment systems, chemicals, building materials, et cetera, and Life Cycle Impact Assessment methods such as the Swiss Ecological Scarcity 1997, the ecological footprint, Eco-indicator 99 or the CML characterisation scheme 2001. The database is located on a server and accessible via the Internet.

Ad 2. Data are supplied by the partner institutes as non-terminated unit processes. The computation of cumulative inventory results is performed with powerful calculation routines related to the central database. Unit process raw data as well as LCI results include (cumulative) uncertainty ranges.

Ad 3. The local administrators use MS-EXCEL with an add-in for the translation to XML (EcoSpold Access) and the editor (EcoEditor) to create new datasets and to change, complete or delete existing datasets. The editor administrates the dataset names (via a direct link to the central database, where the index of dataset names is placed), ensures the use of the actual list of names when compiling new inventories and includes a unit converter. The editor acts as the interface between the local administrator and the central database and generates files in the ecoinvent data format (named EcoSpold, see below).

Ad 4. The administration tool supports the integration of datasets delivered by the co-operating institutes into the central database. It helps to verify the completeness of datasets, calculates inventories and (normalised and weighted) category indicator results and ensures the accessibility for clients respecting the users' rights.

Ad 5. The Query tool on www.ecoinvent.org is used to interrogate the database and to download datasets from the central database. It enables the search for individual processes, for processes of a certain economic sector (e.g., transport or energy sector) or for data from a certain institute. General information (so-called meta information) about the processes (technology, age of data, geographic coverage, *et cetera*) is accessible to everybody whereas the quantitative LCI data is only accessible for registered ecoinvent members (clients).

Ad 6. The data exchange format lists all data fields that need to be completed when data is imported into the central database. It has evolved from the international SPOLD data exchange format (Weidema 1999) and has been adapted to the ISO technical specification ISO/TS 14048 (International Organization for Standardization (ISO) 2002). Some of the data fields are mandatory, i.e. information must be provided. Among other features, the data exchange format allows for specifying the data uncertainty by upper and lower estimates (or the 95% standard deviation) as well as the probability distribution (e.g., lognormal).

Ad 7. Commercially available LCA-software tools such as SimaPro, Umberto Emis, Regis, and others may be used as local databases. These local databases are suited for an implementation and use of ecoinvent data v2.0. The EcoSpold data (exchange) format is recommended for that purpose.

1.5 Final reports of the ecoinvent projects

The results of the ecoinvent projects are described in several separate reports. Tab. 1.2 shows the complete list of reports.

Tab. 1.2 List of final reports for the ecoinvent project

Themes	No	Citation
Methodology		
Overview and Methodology	1	Frischknecht et al. 2007c
Code of Practice	2	Frischknecht et al. 2007d
Implementation of Life Cycle Impact Assessment Methods	3	Frischknecht et al. 2007b
Technical Documentation of the ecoinvent Database	4	Hedemann & König 2003
Life Cycle Inventories of ...		
Energy Systems: Results for Current Systems in Switzerland and other UCTE Countries	5	Dones et al. 2004
Energiesysteme (energy systems, reports in German):	6	Dones et al. 2007
Erdöl (crude oil)	6-IV	Jungbluth 2007a
Erdgas (natural gas)	6-V	Faist Emmenegger et al. 2007
Kohle (coal)	6-VI	Röder et al. 2007
Kernenergie (nuclear energy)	6-VII	Dones 2007
Wasserkraft (hydro power)	6-VIII	Bolliger & Bauer 2007
Holzenergie (wood energy)	6-IX	Bauer 2007
Wärmepumpen (heat pumps)	6-X	Heck 2007b
Sonnenkollektor-Anlagen (solar collectors systems)	6-XI	Jungbluth 2007b
Photovoltaics (Photovoltaik)	6-XII	Jungbluth & Tuchschmid 2007
Windkraft (wind power)	6-XIII	Burger & Bauer 2007
Wärme-Kraft-Kopplung (combined heat and power plants)	6-XIV	Heck 2007a
Strommix und Stromnetz (electricity mixes and distribution)	6-XVI	Frischknecht et al. 2007e
Building Products	7	Kellenberger et al. 2007
Chemicals	8	Althaus et al. 2007a
Wood as Fuel and Construction Material	9	Werner et al. 2007
Metals	10	Classen et al. 2007
Packaging and Graphical Paper	11	Hischier 2007
Detergents	12	Zah & Hischier 2007
Waste Treatment Services	13	Doka 2007
Transport Services	14	Spielmann et al. 2007
Agricultural Production Systems	15	Nemecek et al. 2007
Changes[1]	16	-
Biofuels	17	Jungbluth et al. 2007
Electric and Electronic Equipment	18	Hischier et al. 2007
Highly Pure Chemicals	19	Sutter 2007a
New CHP systems	20	Primas 2007
Renewable materials	21	Althaus et al. 2007b
Petrochemical solvents	22	Sutter 2007b
Metals processing and compressed air supply	23	Steiner & Frischknecht 2007
Komfortlüftungen im Wohnbereich	25	Hässig & Primas 2007

[1] In case of changes in intermediate updates (e.g. ecoinvent data v2.1)

1.6 Quality control during the course of the project

In order to achieve the intended harmonization of about 4'000 datasets in the database the quality control plays an important role. One of the first tasks of the experts group was to set up quality guidelines valid during the investigation of life cycle inventories by the institutes and analysts involved in the project. The first versions of these guidelines have been developed in advance of the data collection phase. During the course of the project unsolved issues were discussed in monthly meetings of the experts group. Decisions taken during these meetings form an additional basis for the harmonization of the data collection. The aim of this report is to structure and describe these quality guidelines.

During the ecoinvent v2.0 projects only a few additional aspects were discussed and added to the guidelines.

1.7 Structure of this report

The creation of one central life cycle assessment database requires a high degree of co-ordination and harmonisation. In this report several harmonisation issues are listed and described. Besides structural aspects and naming conventions, content-related aspects have been discussed and unified. This guarantees a maximum degree of consistency of process data available in the database.

The goals of the ecoinvent projects are described in Chapter 2, followed by a short description of the LCA methodology in Chapter 3. The temporal, geographic and technical scope and modelling principles as well as naming rules for processes and services are described in Chapter 4.

The emission of pollutants and the extraction of resources are not always reported in the desired level of detail. For certain pollutants several reporting possibilities exist (e.g., the mass of metal in a compound or the total mass of the metal containing compound). The rules applied in the ecoinvent projects are documented in Chapter 5. One special focus was set on land use as the impact assessment of land use has been further developed in the last few years. Based on the most recent knowledge, we developed inventory indicators for land transformation and land occupation. The methodology applied is described in Section 5.7.3.

The treatment of multifunction processes, co- and by-products as well as recycling in the ecoinvent database is described in Chapter 6.

The uncertainty of all inputs and outputs of each unit process in the database is quantified. In case the data sources did not contain such information we applied a standard data quality assessment scheme to estimate the uncertainty range. Uncertainty quantification and data quality scheme are described in Chapter 7.

Data administration, documentation, and computation are made within the ecoinvent database system. Data format and calculation principles are described in Chapter 8. A more extensive description can be found in Hedemann & König (2003).

An extensive documentation and an internal review of all datasets are two prerequisites of a high quality LCA database. Recommendations made for reporting, for reviewing and for database version management are described in Chapter 9. The database contains data of more than one thousand pollutants and resources. The result discussion in the reports however is made based on a small selection of indicators from this long list of elementary flows. The selection of these indicators is described in Subchapter 9.6.

Not all methodological issues are described in this report. There are certain aspects which are only relevant for one particular economic sector. Methodological issues concerning the estimation and calculation of emissions from arable land, for instance, are relevant for the agricultural inventories only. Such sector-specific issues are described in the respective reports of the project.

2 Goals of the ecoinvent projects

The goal of the Swiss Centre for Life Cycle Inventories is to offer a set of unified and generic LCI data of high quality, including the areas of energy and bioenergy, transportation, waste management, construction, chemicals, detergents, papers, agriculture, electronics and mechanical engineering.

Consistent and coherent LCA datasets of basic processes make it easier to perform life cycle assessment studies, and increase the credibility and acceptance of the life cycle assessment results. The assured quality of the life cycle data and the user-friendly access to the database are prerequisites to establish LCA as a reliable tool for environmental assessment that will support an Integrated Product Policy (IPP).

Since a few years a distinction between attributional (descriptive) and consequential (change-oriented or decision-oriented) life cycle inventory analysis is made (see Ekvall 1999; Frischknecht 1997; Frischknecht 1998; Frischknecht 2006; Guinée et al. 2001). The ecoinvent database with its modular structure supplying unit process raw data is suited to support descriptive as well as decision-oriented life cycle assessments.

Most of the ecoinvent datasets may serve as background data in specific LCA studies. LCI datasets such as the supply of light fuel oil to a European consumer or the supply of primary aluminium for the European market are often required in LCA case studies which have their focus on a particular consumer good or a particular service. The LCI and LCIA results of ecoinvent datasets should not directly be compared with the aim to identify environmentally preferable products or services. For comparative assessments, problem- and case-specific particularities need to be taken into account, if relevant.

3 Life cycle assessment methodology

The ecoinvent studies follows the method of life cycle assessment (LCA). LCA studies systematically and adequately address the environmental aspects of product systems, from raw material acquisition to final disposal (from "cradle to grave"). The International Organisation for Standardisation published international standards on LCA (International Organization for Standardization (ISO) 2006a; International Organization for Standardization (ISO) 2006b). The method distinguishes four main steps, namely (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation (see Fig. 3.1).

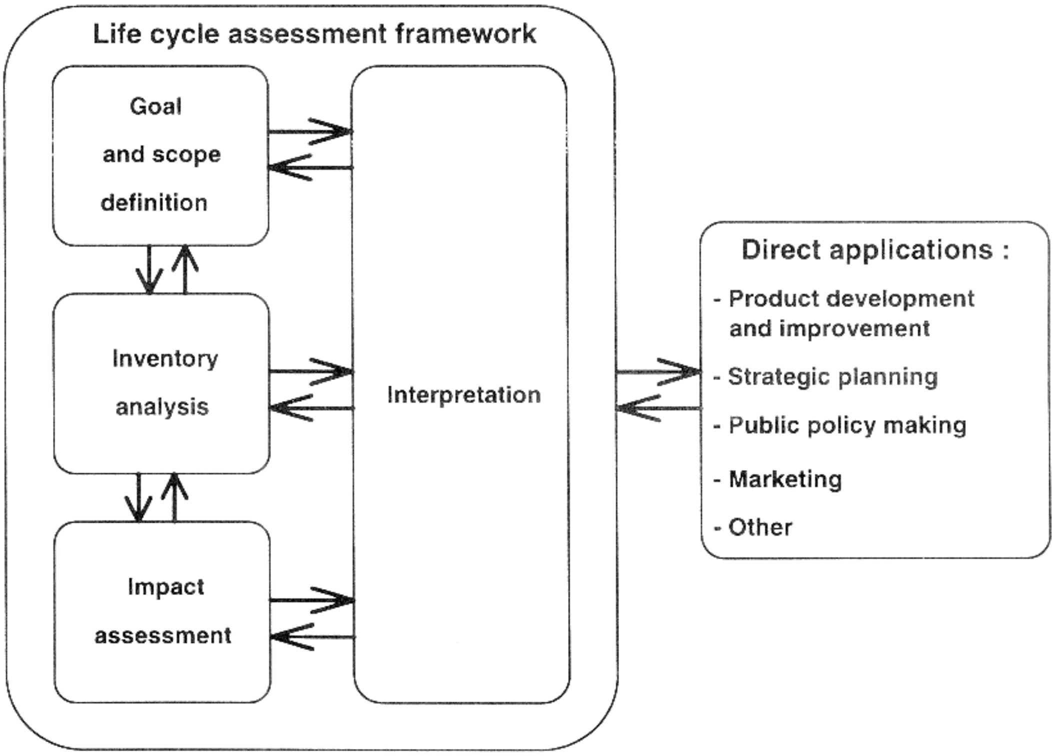

Fig. 3.1 Phases of an LCA (International Organization for Standardization (ISO) 2006a)

Focus of the ecoinvent studies was on the compilation of life cycle inventories, predominantly for basic commodities. Nevertheless, the ecoinvent data v2.0 contain impact assessment results too. However, the work was limited to the implementation of already developed LCIA methods such as the ecological scarcity 1997 or the Eco-indicator 99. No new ("ecoinvent") method has been developed (except for the cumulative energy demand, CED, for which no "official" or unified implementation exists) and no particular LCIA method is favoured. The implementation of the methods was done with the aim of giving guidance on how to combine ecoinvent LCI results with damage or weighting factors of currently available LCIA methods.

4 Scope and modelling principles for processes

4.1 Introduction

The goal and scope definition phase of an LCA includes several decisions that are of relevance for all subsequent steps. That is why a detailed and extensive description of the scope and the modelling principles of the LCA studies performed within the ecoinvent projects was necessary. The common settings for all LCA's are described in the following sections.

4.2 Temporal and geographic scope

The selection of products and services to be analysed mainly relies on the market (and consumption) situation in Europe (RER) and Switzerland (CH) in the year 2000. It was also necessary to describe certain production processes which take place outside Europe because these products play an important role for the European market. This is mainly the case for the extraction of mineral and energy resources. For all these the reference year 2000 was applied, if ever possible. Due to reduced data availability older data has been used in exceptional cases.

During the course of the update, the reference year of electricity mixes and power plant performances is 2004/2005. The same reference year is also applied on all new datasets such as bioenergy supply, the new transport service systems, electronics or mechanical engineering.

Following the LCA approach, the geographical system boundary comprises the entire world. No region is excluded in advance. For some regions however, data availability is rather poor. In such cases processes could not be modelled with actual, country-specific data and assumptions as well as approximations were needed.

4.3 Technical scope

The processes included in the ecoinvent database represent in most cases the average of currently used technology. In some cases the average of technologies on the market (e.g., for gas boilers), the best available technology (e.g., gas combined cycle power plant), or even near future best available technology (e.g., photovoltaic cells, low-sulphur fuels) are modelled.

4.4 Temporal system boundary

Emissions from the past (infrastructure construction), the present (e.g. heating) and the future (e.g. disposal options) are all included in the inventory analysis, virtually without temporal boundaries. Emissions that occur over large time frames of substantially more than 100 years are assigned to specific subcategories (labelled "long-term"). Such long-term emissions occur in landfill sites (leaching), in uranium mining and milling sites (radon emissions) and – probably – final repositories of nuclear waste. For landfill emissions and uranium mining and milling sites a timeframe of 60'000 and 80'000 years, respectively is chosen. These processes release pollutants to "air, low population density", to "water, river" and to "water, ground-" during very long time scales. The ecoinvent database contains corresponding long-term subcategories in order to distinguish these long-term emissions from the ones occurring within the first 100 years.

4.5 Modelling principles for processes

4.5.1 Unit process raw data

As far as possible, the database contains data on a unit process level that are neither vertically nor horizontally aggregated (aggregating two or several subsequent process steps, and aggregating two or several different processes delivering the same (intermediate) products/services, respectively). One exception is the APME plastics and basic chemicals data where only cumulative LCI results data were available.

Besides that, average data for a country or a region are calculated with the available data from different suppliers if they use comparable processes. For instance, only one refinery dataset is created for the two refineries operated in Switzerland, and power plants using one particular fuel (such as hard coal or natural gas) are modelled as national averages.

In general, inputs and outputs of several distinct unit processes are aggregated only if *a)* individual data are not available, and *b)* individual data are confidential.

4.5.2 Cut off rules

The analyses of technical processes required to manufacture products and deliver services are based on pure environmental process chain analysis. Results from enlarged economic input-output analyses are only used in exceptional cases. Hence, data shown in the reports and the ecoinvent database are based on process life cycle inventories (and neither input-output nor hybrid life cycle inventories).

According to ISO 14044 (International Organization for Standardization (ISO) 2006b) several criteria are used to decide which inputs to be studied, including a) mass, b) energy, and c) environmental relevance.

No strict quantitative cut-off rule is followed in the ecoinvent project. Environmental knowledge of the people involved in compiling LCI data is used to judge whether or not to include the production of a certain input or whether or not to include the release of a certain pollutant.

Sometimes it can be more relevant to investigate process specific emissions rather than the energy requirements because the latter may be of only little environmental relevance. Specific environmentally relevant issues (e.g., the emission of a particular pollutant) shall be included at the cost of the completeness of a unit process' mass and energy flows.

Special focus has been put on extraction process information of metals such as lead, copper, iron, nickel, platinum group metals and the like. Although some of these metals are often used in small quantities only, they might contribute substantially to the environmental impacts of a product or service.

4.5.3 Assumptions in case of missing information

Preliminary unit process raw data can be evaluated using current impact assessment methods (and current LCI results). This procedure helps to identify inputs and outputs that contribute substantially to the overall score of the unit process at issue. In a second turn, information about the identified inputs and outputs can be refined if necessary.

If data availability is poor, stoichiometric balances are used to determine the raw materials demand. Hereby, a 95% yield is assumed, if no specific information is available. The "Ullmans Encyclopedia of Technical Chemistry", the "Handbook of petrochemicals and processes" (Wells 1991) and others are used for that purpose.

If no information about the amount of a release or if no specific information about the exact substance emitted is available, an educated guess is made based on plausibility considerations. In cases where such an assumption dominated the LCA result, further and more detailed investigations were carried out and some of the values were reconsidered. If the rough assumption does not influence the result, it does not harm and is kept in the inventory.

4.5.4 Market situation

Products and services are distinguished on a level of economic regions within which such a distinction is meaningful. For cement for instance, a national distinction is useful and meaningful because cement is hardly traded across national borders and trade movements are rather easy to identify. For globally traded products such as aluminium, a distinction on the level of continental economies (Europe, Asia, Northern America) is sufficient, because these commodities can hardly be traced back on a national nor regional level.

The situation in the year 2000 (partly 2005) is used to determine the supply and production mixes. Hereby the consumption of Europe and Switzerland defines the supply mixes of energy carriers (such as crude oil, oil products, hard coal, natural gas), metals, chemicals, etc. Best available technologies or future technologies are only shown for some selected products and services (such as for example an improved photovoltaic appliance).

The production and trade situation of the year 2004/2005 is also used for electricity mixes although here meteorological variance may influence the share of hydroelectric power production. For oil and gas supply, the situation of the year 2000 is used although here large changes in the import situation of countries may occur as well. The choice of one single year increases the transparency and facilitates future updates.

4.5.5 Electricity mixes

Electricity is modelled based on the delivered mixes and as far as possible according to the economic situation. In particular situations, individual electricity mixes may be applied.

Tab. 4.1 Electricity demand and its modelling within the ecoinvent data v2.0

electricity demand	applied electricity mix [1])
covered by In-house power plant (mix)	In-house power plant (mix)
in a particular industry	Industry's mix (e.g. aluminium industry)
in Switzerland	Swiss supply mix (incl. electricity trade)
in a European country	Country's supply mix (incl. electricity trade)
in Western Europe	UCTE electricity mix
in Eastern Europe	CENTREL electricity mix
in Northern Europe	NORDEL electricity mix
anywhere in Europe	UCTE electricity mix [2]) [3])
in Brazil, in USA	BR, US electricity mix [2])
in Northern America	UCTE electricity mix [2])
in China, in Japan	CN, JP electricity mix [2])
in Asia	UCTE electricity mix [2])
anywhere in the world	UCTE electricity mix [2])

[1]) The voltage level has to be considered.

[2]) relevance to be checked before applying. If useful, one can also apply an appropriate mix of UCTE, CENTREL & NORDEL electricity or the mix of one particular country.

[3]) the new EU 27 mix may be more suitable in certain cases

The database distinguishes between production and supply mixes. Processes with country-specific electricity demand use the corresponding supply mix. The production mix is only used within the electricity sector's model. Additionally, four different voltage levels are distinguished:

Supply and production mix, respectively, electricity from power plants: This product corresponds to the electricity fed into the grid by power plants. Electricity on this level is not directly purchased by other processes but only via one of the following three voltage levels.

Electricity, high voltage, (production in country X), at grid: This product corresponds to electricity transported via the high voltage network (>24 kV). This dataset will only be used in exceptional cases (e.g., where the power plant is directly located on the production site at issue).

Electricity, medium voltage, (production in country X), at grid: This product corresponds to electricity transported on the high voltage network and transformed to and transported on the medium voltage network (1 kV – 24 kV). This dataset is used by industrial processes such as steel mills, automobile factories, chemical industries.

Electricity, low voltage, (production in country X), at grid: This product corresponds to electricity transported on the high and medium voltage networks and transformed to and distributed to the low voltage customers. The voltage is below 1000 V. These datasets are used by agricultural processes (farmers), households and commercials.

The correct voltage level is selected mainly based on the information source (do the electricity consumption figures reported for a process refer to low or medium voltage, respectively?).

4.5.6 Transport services

Transports happen nearly between any two process steps of a product system. They are investigated according to the real market situation as far as possible.

Transport distances of road transports can be calculated on www.reiseplanung.de. Distances of overseas transports are estimated as follows in order to consider transports in the exporting and importing countries to and from the harbours / airports:

- Import by freight ship: twice the distance in Europe from Tab. 4.2 plus overseas distance according to www.dataloy.com.
- Import by plane: distance in Europe plus distance Switzerland from Tab. 4.2 plus air distance according to www.dataloy.com.

However, means of transportation and transport distances are hardly known for all individual intermediate products. For that purpose, standard distances are applied (see Tab. 4.2 to Tab. 4.4). For individual consumers/households an additional 50 km van is included.

Tab. 4.2 Densities and standard transport distances of materials (from the place of production to its use)

	Density	consumption in Europe		consumption in Switzerland	
	kg/m³	km train	km lorry 32t	km train	km lorry 28t
mineral products:					
gravel / sand	2'000	-	50	-	20
cement	3'150	100	100	100	20
concrete (w/o reinforcing steel)	2'200	-	50	-	20
float glass	2'500	600	100	600	50
metals:					
steel/ cast iron	7'900	200	100	600	50
copper	8'900	200	100	600	50
aluminium	2'700	200	100	200	50
plastics:					
PVC	1'400	200	100	200	50
PE	950	200	100	200	50
PP	900	200	100	200	50
wood (from Swiss forests):					
sawn timber (softwood)	450 [1]	100	50	-	50
structural timber (softwood)	450 [1]	-	100	-	50
particle board	680 [1]	200	50	200	50
basic chemicals, inorganic (carrier substance to be considered additionally):					
caustic soda	1'045	600	100	600	50
soda (sodium carbonate)	2'532	600	100	600	50
hydrochloric acid	909	200	100	200	50
sulphuric acid	1'840	600	100	600	50
nitric acid	1'383	600	100	600	50
phosphoric acid	1'685	600	100	600	50
hydrofluoric acid	993	600	100	600	50
basic chemicals, organic:					
ethylene		600	100	600	50
naphtha		600	100	600	50
refrigerants		600	100	600	50
organ. solvents		600	100	600	50
pesticides		600	100	600	50
gases (if not produced on the spot)					
if bought in cylinders: doubling of transport distances (due to tare weight)					
oxygen		100	50	100	50
nitrogen		100	50	100	50
hydrogen		100	50	100	50
helium		100	50	100	50

[1] absolutely dry.

The transport distances of agricultural means of production applied in Switzerland are described in Nemecek et al. (2007, see Tab. 4.3).

Tab. 4.3 Transport distances for agricultural means of production applied in Switzerland

	consumption in Switzerland		
	km train	km lorry 28t	km barge
N- fertiliser	100	100	900
P- fertiliser	100	100	400
K- fertiliser	100	100	100
Lime	120	120	-
NPK-fertiliser	100	100	600
PK-fertiliser	100	100	500
sewage sludge, compost		15	
feedstuffs		70	

Transport services required for wastes to their treatment facilities are registered within the process generating the waste. Standard distances and transport means are used as shown in Tab. 4.4.

Tab. 4.4 Standard distances with lorries for wastes to their treatment site

Waste treatment process	**(German)**	**km lorry [1])**
municipal waste incineration [2]**)**	Kehrichtverbrennung KVA	10
sanitary landfill	Reaktordeponie	10
residual material landfill	Reststoffdeponie	50
inert material landfill	Inertstoffdeponie	15
subsurface deposit	Untertagedeponie	500

[1]) 32t for Europe, 28t for Switzerland

[2]) for Municipal Waste Incineration of household waste and similar wastes both municipal collection and individual transport is possible. All burnable municipal waste must be incinerated in CH, so no municipal collection for landfills. All industrial wastes to incineration (e.g. waste wood, wastewater treatment sludge, burnable special waste) is transported directly. In 2000 approximately 70% of the household waste was collected and transported by municipal waste collection. For bagged waste of households and small businesses 100% is appropriate.

The conversion factors shown in Tab. 4.5 are used to recalculate the transport distance for a transport device if the amount of used fuel is known but not the distance driven. The values correspond to the fuel consumption figures used for modelling lorry transport within the ecoinvent project (see Spielmann et al. 2007).

Tab. 4.5 Fuel uses for passenger cars, delivery vans and lorries

Vehicle	Fuel		CH			RER		
			MJ	g	l	MJ	g	l
Car	gasoline, avg. 2005	vkm	2.89	67.9	0.091	2.55	60	0.081
	diesel, avg. 2005	vkm	2.62	61.3	0.073	2.61	61	0.073
	gasoline, avg. 2010	vkm	2.77	65.0	0.087	2.21	52	0.071
	diesel, avg. 2010	vkm	2.48	58.1	0.069	2.39	56	0.0665
delivery van	diesel / gasoline	vkm	3.7	87.5	0.1	3.1	74	0.085
Lorry 3.5-20t	diesel, avg. 2005	vkm	7.68	180	0.214			
Lorry 20-28t	diesel, avg. 2005	vkm	10.67	250	0.297			
Lorry >28t	diesel, avg. 2005	vkm	11.95	280	0.333			
Lorry 3.5-7.5t	diesel, avg. 2005	vkm				6.16	144.4	0.172
Lorry 7.5-16t	diesel, avg. 2005	vkm				9.46	221.7	0.264
Lorry 16-32t	diesel, avg. 2005	vkm				9.07	212.5	0.253
Lorry >32t	diesel, avg. 2005	vkm				12.48	292.4	0.348

Lower heating value: 42.5MJ/kg gasoline; 42.8MJ/kg diesel

Density of fuel: 0.75kg/l gasoline; 0.84kg/l diesel

Commuting to non-stationary working places such as natural gas pipeline construction sites are recorded. Research and development activities are always neglected. Mass and energy flows of administrative departments are included and recorded separately as far as data are available. Business flights are always excluded because of lack of information.

4.5.7 Means of production, infrastructure

Inputs and outputs required for the means of production and the infrastructure of a production process are recorded separately. As far as possible mass and energy flows of such equipment are shown on a per unit basis (e.g., one refinery of 5 Mio. tons of output, etc.). The ecoinvent database supports the calculation of results with and without infrastructure. For the time being only results including infrastructure are published.

Land occupation and transformation is normally included in the data representing the infrastructure processes. The separation between infrastructure processes and production processes was introduced in earlier LCA works. But the distinction is not always clear. One might consider for instance the construction of a borehole for oil production to be an infrastructure process because it is somehow similar to the construction of buildings or streets. On the other hand drilling is a continuous action on oil and gas fields. Thus it is similarly reasonable to consider the borehole as a part of the production process.

The differentiation between infrastructure and production processes was introduced for analytical reasons. It could be shown in a recent publication that the contribution of capital equipment to the overall environmental impact varies significantly and can be very relevant in certain sectors (Frischknecht et al. 2007a). It is recommended to use always inventory data including the infrastructure unless it is intended to make very specific analytical assessments. Due to the fact that land use for instance is reported in the infrastructure datasets in most cases, LCI and LCIA results of a product system excluding infrastructure may be substantially incomplete and special care must be taken when using these results.

4.5.8 Dissolved chemicals

Input and output data representing chemicals production refer to its active substance, but the carrier substance is stated in the name and considered as an input in the inventory. Thus the inventory for 1 kg “sodium hydroxide, 50% in H_2O, production mix, at plant” refers to the production of 2 kg NaOH with a water content of 50% (i.e., 1 kg pure NaOH plus 1 kg pure H_2O).

The concentration of the carrier substance in the product has an influence on the manufacturing requirements (purification) as well as on the transport service requirements (double the amount of tkm are required for a 25% caustic soda dissolved in water as compared to a 50% caustic soda dissolved in water, referred to 1 kg of pure NaOH).

The requirement of chemicals is quantified in terms of the pure active substance. For the computation of transport service requirements the mass of the carrier substance is added.

4.5.9 Thermal energy

When a process requires an energy carrier for (process or space) heating, two cases can be distinguished:

a) operational emissions, efficiency etc. of the boiler are known. In this case these particular data are used and eventually completed by generic information about infrastructure and / or generic emission factors (see Section 4.5.10). Additionally, a demand for the supply of the energy carrier like “light fuel oil, at regional storage, RER”, is registered.

b) If only the amount of energy and the kind of energy carrier is known, generic boiler datasets delivering useful heat are used. Boiler datasets such as "light fuel oil, burned in industrial furnace 1MW, non-modulating" and "heat, light fuel oil, at industrial furnace 1MW", respectively, are chosen depending on whether final or useful energy figures are available.

Energy carrier demand is converted from MJ to kg and back using the standard heating values listed in Tab. 4.6.

Tab. 4.6 Density, gross and net calorific value of energy carriers

	density kg/l	**net calorific value** MJ/kg	**gross calorific value** MJ/kg
agricultural biogas	0.00113	21.4	23.7
crude oil	0.86	43.2	45.8
diesel	0.84	42.8	45.4
gasoline	0.75	42.5	45.1
hard coal		28.9	30.4
hard coal, briquette		31.4	32.4
hard coal, coke		28.6	28.9
heavy fuel oil	1.0	41.2	43.7
kerosene	0.795	43.0	45.6
light fuel oil	0.86	42.6	45.2
lignite, briquette		19.5	20.9
lignite, hard		16.8	17.8
lignite, soft		8.4	9.5
methanol	0.792	20.0	22.7
naphtha	0.75	45.0	47.7
natural gas [1])	0.0008	45.4 (36.3)	50.4 (40.3)
petroleum coke	1.1 (0.650 to 1.3)	35.0	36.1
wood	Tab. 4.7		

[1]) values in brackets: MJ/Nm^3

The determination of the heating value for wood products and fuels is rather complex. The theoretical lower heating value is a function of the water content x.

$$lower\_heating\_value(x\%)[MJ/kg] = upper\_heating\_value[MJ/kg] - 1.32[MJ/kg] - \frac{20[MJ/kg]*x}{100+x} \quad (1)$$

The density of wood products also depends on the water content of the product. It is possible to calculate the density and lower heating value of a wood product with the following formula.

$$density(x\%) = density(0\%) + \frac{density(0\%)*x}{100} \quad (2)$$

The basic figure for the dry density is 450 kg/m^3 for soft wood and 650 kg/m^3 for hard wood. Tab. 4.7 shows the standard densities and heating values of wood products and fuels for this project. More detailed information can be found in the specific report (Werner et al. 2007).

Tab. 4.7 Density, gross and net calorific value of wood products

Wood type (humidity) [1]		density	net calorific value	gross calorific value
		kg/l	MJ/kg	MJ/kg
Construction wood	Softwood, round wood [2] wet (70%)	765	10.8	20.4
	Softwood, industrial wood [3] wet (140%)	1080	7.4	20.4
	Softwood air dried (20%)	540	15.7	20.4
	Softwood kiln dried (10%)	715	17.3	20.4
	Hardwood, round wood wet (70%)	1105	10.1	19.6
	Hardwood, industrial wood wet (80%)	1170	9.4	19.6
	Hardwood air dried (20%)	780	15.0	19.6
	Hardwood kiln dried (10%)	715	16.5	19.6
Energy wood	logs, softwood, 1 year dried(30%)	585	14.5	20.4
	logs, softwood, 2 years dried (20%)	540	15.7	20.4
	logs, softwood, in the forest (140%)	1080	7.4	20.4
	logs, hardwood, 1 year dried (30%)	845	13.7	19.6
	logs, hardwood, 2 years dried (20%)	780	15.0	19.6
	logs, hardwood, in the forest (80%)	1170	9.4	19.6
	wood chips, softwood, from sawmill (40%)	630	13.4	20.4
	wood chips, softwood, from forest (50%)	675	12.4	20.4
	wood chips, softwood, in the forest (140%)	1080	7.4	20.4
	wood chips, hardwood, from sawmill (40%)	910	12.6	19.6
	wood chips, hardwood, from forest (50%)	975	11.6	19.6
	wood chips, hardwood, in the forest (80%)	1170	9.4	19.6
	logs (CH unspec.) [4], 1 year dried (30%)	658	14.2	20.2
	logs (CH unspec.), 2 years dried (20%)	607	15.5	20.2
	logs (CH unspec.), in the forest (80 – 140%)	1105	8.4	20.2
	wood chips (CH unspec.), from sawmill (40%)	708	13.1	20.2
	wood chips (CH unspec.), from forest (50%)	759	12.2	20.2
	wood chips (CH unspec.), in the forest (120%)	1113	7.9	20.2

[1]) Moisture given in weight-% related to the dry mass of wood.

[2]) round wood = entire trunk before cutting

[3]) industrial wood = smaller pieces, branches

[4]) CH unspec. = Mix of 72 % soft- and 28 % hardwood. Corresponds to the shares of wood consumption in Switzerland 1998 (BfS 2002)

4.5.10 Additional air emissions from energy production

In some cases additional air emissions due to the use of different energy carriers have bean calculated based on the assumptions for industrial heating. This approach is documented in the report on paper production (Hischier 2007).

4.5.11 Waste treatment services

Waste treatment is part of the technical system and is therefore modelled like all other technical processes. It is part of the respective product systems. The processes deliver the service of waste treatment. If information about the treatment of specific wastes is not known, generic treatment processes are applied according to the list shown in Tab. 4.8.

Tab. 4.8 Material specific waste treatment processes in the case of missing particular information

material	standard disposal route
plastics	waste incineration
wood and particle board	waste incineration
cardboard and paper	waste incineration
concrete and other mineral building materials (incl. gypsum)	datasets "disposal, building, ..., to final disposal", include the dismantling/demolition of the building, waste goes to inert material landfill, without recycling nor sorting
glass	inert material landfill
oils	hazardous waste incineration
metals, if separable	recycling
coating on metals	recycling, disposal of the coating considered in the recycling process

For uncontaminated building materials the following default disposal is appropriate:

- All solid burnable wastes: disposal in municipal solid waste incineration (MSWI) (including transport)
- *Bulk* metals to recycling (no burden)

If recycling of building materials is known to occur to a significant amount (in Switzerland in the year 2000: maximal 25%), the respective datasets ... *in Sortieranlage / to sorting plant* or just the demolition energies can be inventoried alternatively. For industries known to produce contaminated infrastructure (e.g. chemicals, refineries, car repair...) decontamination procedures must be considered as far as possible additionally to the above datasets. However, no ecoinvent datasets on decontamination are available yet.

4.5.12 Incidents and accidents

LCA is an analytical tool which describes the existing impact of a product chain in a reliable manner. It differs from other methods like risk assessment in a sense that impacts from exceptional events are not considered. Accidents which might have very dramatic impacts, but which do occur only seldom are thus not considered. An example for this is the risk of a serious accident in a nuclear power plant like it happened in Chernobyl.

On the other side incidents happening more regularly are considered in the inventories. Examples are oil spills due to ruptures of transport pipelines. These spills occur frequently and are reported regularly. One can see that the total amount of spills per year is not influenced so much by individual accidents.

4.6 Naming rules for Products and Services

The names for products and services as well as the names of the elementary flows (emissions and resources, see Chapter 5.3 for naming rules applied on them) have been centrally collected and managed. The full list of names is available via the Internet (www.ecoinvent.org) and on this CD-ROM (filename "ecoinventData/ecoinventnames.xls”).

4.6.1 Names for Products and Services

Products and services are named according to the following naming rules (see examples in Tab. 4.9):

- Name of product/service to which the unit process raw data refers, production process, and treated product respectively, treatment level (like rolled, drawn or coated). Names of chemicals may contain the sum formula as well as their weight-% in water or the respective carrier material (e.g., solvent).
- Additional information, separated by commas, and in the following sequence: additional description of the manufactured or sold product (if different from the one analysed), additional description of the product preparation or product characteristics (if necessary for an unequivocal distinction), additional description of provenience/raw material (if necessary for an unequivocal distinction), system boundary.
- Destination (“at”, “to” or “in”) and level of value chain (factory gate, regional storage, landfilling, etc.).

British English is used as the default language for all names. The local language is German (Swiss spelling rules).

The time frame of the unit process data, the unit as well as the country/regional code are described in separate data fields and are not required in the name field (see Chapter 8 for a description of the data format). All information in the name field shall be written in full. Abbreviations are used only by exception, and consistently for all processes concerned. No brackets are used. Vowel mutations are accepted.

For materials' LCI data “at plant” is the common boundary and level of the value chain. Otherwise further specification on the level of “at regional storage” is made. The unit process raw data are normally provided for the Swiss and/ or European situation (CH and/ or RER). Waste treatment processes are named “disposal, …, to …” for solid wastes and "treatment, ..., to ..." for liquid wastes disposed via sewer.

Tab. 4.9 Examples of dataset names of products and services

Name (ID 401)	Location (ID662)	Infrastruc-tureProcess (ID 493)	Unit (ID 403)
ammonia, steam reforming, liquid, at plant	RER	no	kg
heavy fuel oil, at regional storage	RER	no	kg
anhydrite synthetic, at plant	CH	no	kg
electricity, medium voltage, production CH, at grid	CH	no	kWh
hard coal, at regional storage	ZA	no	kg
transport, lorry 16-32t, EURO3	RER	no	tkm
disposal, refinery sludge, 89.5% water, to hazardous waste incineration	CH	no	kg
refinery	RER	yes	unit

Countries are described using the ISO-Alpha-2 codes. Where ISO codes are not applicable (for continents etc.), the 3 letter UNDP codes are applied. For electricity mixes, the associations' abbreviation is applied (see Tab. A. 1 in the annexe for the full list of country codes used for the description of the location).

4.6.2 Units for Processes

For unit processes the units (always in English language) shown in Tab. 4.10 are used to describe the functional units. Other units shall base on basic SI units (such as m, kg, s, or MJ). Infrastructure is normally analysed on a unit basis (such as one unit of oil boiler)[1].

Tab. 4.10 Units used for processes, products and services

Unit	Term	Processes
a	annum – year	Multi-output processes for the total production in an area or of a facility
kg	kilogram	Building materials, basic chemicals, wastes (non radioactive), energy carriers from production to regional storage, (excl. electricity, natural gas), liquefied gases, tap water, decarbonised and deionised water, "kg SWU" (separative work unit) used for enrichment of uranium, agricultural machinery
m^3	cubic metre	Concrete and wood, wastewater, slurry, radioactive wastes (various categories), buildings
Nm^3	norm cubic metre (normalized for a specific temperature and pressure)	Natural gas, biogas, compogas, town gas
kWh	kilo watt hour	Electricity
MJ	mega joule	Final energy in boilers, useful energy at boilers, cooling energy
tkm, pkm, vkm	ton kilometre (Tonnenkilometer) person kilometre (Personenkilometer) vehicle kilometre (Fahrzeugkilometer)	Transport services
m^2	square metre	Paintings, coatings, buildings
ha	hectare = 10000 m^2	agricultural working processes
unit		Infrastructure (exceptions: kg machine, m^2 or m^3 building)
LU, pig place	Livestock unit (Grossvieheinheit, GVE) pig place (Mast Schwein Platz, MSP)	used for agricultural processes

4.7 Outlook

After describing the scope and modelling principles applied within the ecoinvent projects some important points are highlighted which need further improvements for future studies in these areas.

The assessment of transport distances is based mainly on assumptions. Further research is necessary on the true transport distances of materials. Because different materials have different standard distances the calculation is currently not very straightforward. Thus it would be good to further simplify this approach and to unify the transport distances given the rather low importance of these standard transport services in the LCI results.

[1] The dataset process operation asks for a (in most cases tiny) share of the entire infrastructure (reciprocal of yearly output times infrastructure lifetime).

Further attention should be given to business flights which were not investigated so far. These flights make up a relevant share of environmental impacts due to transports and show high growth rates. One practical obstacle seems to be the data availability in companies and attribution rules of flights to individual products and services.

So far a lot of LCI data representing infrastructures and capital equipments are based on very rough estimations. More data and information for this area would be necessary in future updates of the data.

5 Documentation of elementary flows

5.1 Introduction

In the ecoinvent projects no predefined list of elementary flows[2] is applied. Theoretically all kinds of elementary flows are registered. However, elementary flows contributing to the impact categories desiccation, depletion of biotic resources and casualties as well as social indicators are disregarded. This is mainly due to still unresolved methodological problems or due to reduced relevance within the scope of the ecoinvent projects (e.g., depletion of biotic resources).

First the naming rules applied on the elementary flows are described. Then the quality guidelines for the reporting of these flows are explained in detail. Special focus is put on the recording of land occupation and land transformation. Here a new approach was developed in the course of the first ecoinvent project which is supposed to allow for the application of various impact assessment approaches.

5.2 General recording rules

Elementary flows are only registered once and on the most detailed level for which information is available. Benzene emissions for instance are reported as such but not as "aromatic hydrocarbons", nor as "non methane volatile organic compounds". If benzene and NMVOC have been measured and reported, the amount of benzene emitted is subtracted from the total amount of NMVOC emission.

The only exception to this recording rule is the reporting for some sum parameters for water pollutants, i.e., the four parameters BOD_5, COD, DOC, and TOC (see Section 5.5.1).

5.3 Naming rules

Naming of elementary flows takes pattern from the work of the SETAC working group “Data availability and data quality” (de Beaufort-Langeveld et al. 2003; Hischier et al. 2001). CAS numbers, sum formulas and IUPAC names are recommended when new substance names are proposed to be added to the list.

The names for an element or a compound are the same for all environmental compartments. Binding forms and oxidation levels are considered in the name. Quite often chemical compounds are known under different names. A list of synonyms is available in the database. The information provided on http://www.chemfinder.com is used as the default source of information for the definition of further elementary flow names.

The full list of elementary flows is available via the Internet (www.ecoinvent.org) and on this CD-ROM (filename "ecoinventData/ecoinventnames.xls").

[2] Elementary flows are flows of pollutants and resources between technosphere and nature.

5.3.1 Units

The units (basically SI units) used to describe elementary flows are shown in Tab. 5.1.

Tab. 5.1 Units used for elementary flows

Unit	Description	Type of flow
kg	kilogram	All chemical substances
kBq	kilo becquerel	Radionuclide releases
m^3	cubic metre	Water as a resource
Nm^3	norm cubic metre (normalized for a specific temperature and pressure)	Gases as a resource
m^2	square metre	Land transformation
m^2a	square metre times year	Land occupation
MJ	mega joule	Waste heat, kinetic energy, potential energy, solar radiation energy

5.3.2 Categories and Subcategories

Elementary flows in the ecoinvent database are identified by a flow name (e.g. "Carbon dioxide, fossil"), its unit, a category and a subcategory. Tab. 5.2 shows the categories and subcategories which are used in the ecoinvent database. Categories describe the different environmental compartments air, water, soil and resource. Subcategories further distinguish subcompartments within these compartments which may be relevant for the subsequent impact assessment step.

The categories "air", "water" and "soil" describe the receiving compartment and are used for (direct) pollutants emissions whereas the category "resource" is used for all kinds of resource consumption. For instance, water consumption is recorded as an input in the category/subcategory "resource / in water". Land transformation and occupation is recorded as an input as well in the category / subcategory "resource / land".

For some subcategories a temporal differentiation was introduced. Emissions from landfills take place over a long time period after the waste placement. Emissions which take place 100 and more years after waste placement are named "long-term".

Tab. 5.2 Categories and subcategories for elementary flows in ecoinvent data v2.0

Catgory	SubCategory	Definition	Assigned in general to
air	low population density	Emissions in areas without settlements or protected areas in the direct surrounding	Resource extraction, forestry, agriculture, hydro energy, wind power, coal and nuclear power plants, municipal landfills, wastewater treatment, long-distance transports, shipping
	low population density, long-term	Emissions which take place in the future, 100 years after the start of the process.	Emissions from Uranium mill tailings.
	lower stratosphere + upper troposphere	Emissions from air planes	Air transport cruises.
	high population density	Emissions near settlements or protected areas which affect directly people or animals due to the local situation. Most important for particles.	Industry, oil and gas power plants, manufacturing, households, municipal waste incineration, local traffic, construction processes.
	unspecified		Only used if no specific information available.
resource	in air	Resources in air, e.g. Argon, carbon dioxide	Used for carbon uptake in biomass and gases produced by air separation.
	biotic	Biogenic Resource, e.g. wood	
	in ground	Resource in soil e.g. ores, but also for landfill volume	
	land	Land occupation and transformation	
	in water	Resource in water, e.g. magnesium, water	
soil	agricultural	Emission to soil used for the production of agricultural products	Agriculture
	forestry	Emission to soil used for plant production (forest, renewable raw materials) which do not enter the human food chain[1].	Forestry
	industrial	Emission to soil used for industry, manufacturing, waste management and infrastructure.	Industry, landfarming of wastes, built-up land.
	unspecified		Only used if no specific information available.
water	ground-	Ground water which will get in contact with the biosphere after some time.	
	ground-, long-term	Emissions which take place in the future, 100 years after the start of the process.	Long-term emissions from landfills
	lake	Lakes with sweet water	
	ocean	Ocean, sea and salty lakes.	Offshore works, overseas ship transports.
	river	Rivers	Discharge of effluents from wastewater treatment facilities.
	river, long-term	*Emissions which take place in the future, 100 years after the start of the process.*	*Long-term emissions; subcategory not used in ecoinvent database*
	fossil-	*Salty ground water that does not get into contact with the biosphere.*	*Re-injection of formation water from oil- and gas extraction; subcategory not used in ecoinvent database*
	unspecified		Only used if no specific information available.

[1] This was not applied in all cases, see eg. datasets on renewable fibres like cotton, kenaf and the like.

5.4 Airborne pollutants

5.4.1 Particulates

Particulate emissions are consequently separated according to the diameter class. Three categories are distinguished, namely less than 2.5 micron, between 2.5 and 10 micron, and more than 10 micron (see Tab. 5.3). With that, no double counting of particulate emissions occur. It has to be noted that these classes do not coincide with the standard measurements which distinguish between less than 2.5 micron (PM2.5), less than 10 micron (PM10) and total particulate matter (TPM). The values recorded in ecoinvent data v2.0 are derived from standard measurements with the calculation procedure explained in Tab. 5.3.

Tab. 5.3 Names and characteristics of particulate elementary flows as reported in ecoinvent data v2.0

Name	Formula	Remarks
Particulates, < 2.5 um	PM2.5	particulates with a diameter of less than 2.5 µm
Particulates, > 2.5 um and < 10 um	PM10-PM2.5	particulates with a diameter of more than 2.5 µm and less than 10 µm
Particulates, > 10 um	TPM-PM10	particulates with a diameter of more than 10 µm

PM2.5 particulate matter with a diameter of less than 2.5 µm
PM10 particulate matter with a diameter of less than 10 µm
TPM total particulate matter

As a first priority, particulate emission factors as well as information about its size distribution are taken from the particular information source. If no information is available about the size and / or its distribution, standard reference works are used according to the following fixed order:

1. The Co-ordinated European Programme on Particulate Matter Emission Inventories, Projections and Guidance (CEPMEIP) Database, (Berdowski et al. 2002),
2. A Framework to Estimate the Potential and Costs for the Control of Fine Particulate Emissions in Europe (Lükewill 2001),
3. Compilation of Air Pollutant Emission Factors AP-42, Fifth Edition, Volume I: Stationary Point and Area Sources, Appendix B.1: Particle Size Distribution Data and Sized Emission Factors for Selected Sources (US-EPA 1986).

5.4.2 Fossil and biogenic carbon

A distinction is made between fossil and biogenic sources of CO_2, CO and CH_4. For renewable (energy) sources, the amount of biogenic CO_2 is recorded separately. Process specific CO emissions lead to reduced CO_2 emissions. If relevant, this reduction is considered when calculating the CO_2-emissions. Carbon fixing during biomass growth is recorded as a CO_2 resource consumption.

An equilibrated carbon balance in bioenergy datasets was one main goal of the bioenergy project (Jungbluth et al. 2007). The approach used in the bioenergy datasets takes into account the complexity of biogenic feedstocks including by-products and waste on one hand and aimed at a maximum consistency with the existing approaches in the ecoinvent database.

A new elementary flow is introduced to account for the CO_2 emissions due to land transformation, in particular due to clear cutting of primary forests. Carbon losses from soil and carbon dioxide released by burning wood residues from clear-cutting are classified as "Carbon dioxide, land transformation". In line with the IPCC accounting rules, this elementary flow is treated like fossil CO_2 emissions in life cycle impact assessment methods (see Jungbluth et al. 2007). Additionally, the elementary flow (resource) "Carbon, in organic matter, in soil" is introduced. It balances the carbon dioxide emissions caused by soil degradation.

5.4.3 Volatile organic compounds - VOC

Because of its particular importance with respect to global warming, methane and non-methane volatile organic compounds (NMVOC) emissions are accounted separately. Further specifications within the NMVOCs are applied as far as possible.

Among the large number of polycyclic aromatic hydrocarbons, at least Benzo(a)Pyrene is recorded separately. Dioxins and furanes are recorded as TCDD-equivalents. The equivalency factors of the NATO/CCMS weighting schema are applied (see for instance Frischknecht et al. 1996, part III, p. 27).

5.4.4 Other air pollutants

SO_X and NO_X emissions are reported as SO_2 and NO_2, respectively. Information about the shares in SO_3^- or SO_4^{2-} emissions, and NO emissions, respectively is considered. These shares are subtracted from the total SO_X and NO_X emissions. This differentiation is also made in the impact assessment methods.

Trace element emissions into air are recorded as chemical compounds if information is available. They are recorded as e.g. "kg Sodium dichromate". In all other cases just the amount of chemical element released is recorded. A differentiation according to currently used impact assessment methods is aimed at. No sum parameters such as "metals" are used. Particulate metal emissions are inventoried as particulates and as specific metal emission.

5.4.5 Waste heat

Waste heat released from processes is recorded. No distinction is made between waste heat emissions from renewable and non-renewable sources. Waste heat is determined using the gross calorific value of fossil energy carriers and biomass, and the energy content of electricity. The datasets for useful and final energy supply such as "heat, light fuel oil, at industrial boiler", or "light fuel oil, burned in industrial boiler" already contain the waste heat emission. For electricity consumptions however, the equivalent amount of waste heat needs to be recorded in the process that uses the electricity.

In order not to account for renewable energy resources in the waste heat balance it is necessary to consider the uptake of energy by these systems. Different renewable energy resources are defined for that purpose, namely, kinetic energy (used for wind power), potential energy (used for hydroelectric power), solar energy (used for photovoltaic appliances and thermal solar collectors), and energy in biomass (used for wood, crops etc.). The renewable energy resources' input equals the energy that is actually converted by the system.

Datasets describing heat supply with solar collector systems include a waste heat emission as high as the converted solar energy. The inventory for photovoltaic does include a waste heat emission that equals the converted amount of solar energy minus the output of electricity. Waste heat emissions due to consumption of electricity produced in photovoltaic plants are considered in the dataset with the photovoltaic electricity as an input.

Energy which is used in processes and which is stored in the product is not subtracted in the waste heat balance. The production of steel for instance needs energy to modify the chemical binding form. This energy is actually not lost but it has been used to modify the chemical binding energy.

Waste heat emissions are not fully consistently modelled throughout the ecoinvent data v2.0. Cumulative results of waste heat emissions should therefore be interpreted with care. A revised approach, which still needs discussion within the ecoinvent team, is proposed in the section 5.9 “Outlook”.

5.5 Water pollutants

5.5.1 Sum parameters for carbon compounds (BOD_5, COD, DOC, TOC)

In the ecoinvent inventories all four sum parameters BOD_5, COD, DOC and TOC[3] are recorded in parallel (i.e., without any reductions due to separately reported individual substances). If necessary (no sum parameter measurements available) they are calculated from the information given for individual water pollutants. For that purpose the stoichiometric oxygen demand for the oxidation is calculated to quantify the COD and BOD_5, respectively. The amount of TOC and DOC is determined from the carbon content of the individual substance and based on the recommendations of de Beaufort-Langeveld et al. (2003).

Missing data are added according to the (worst case) relation DOC=TOC and BOD_5=COD. Additionally, all individual substances are additionally recorded in the inventory. For the assessment of the aquatic eutrophication or other impacts, it is sufficient to select one of the above-mentioned sum parameters. No double counting occurs as long as only one parameter and no individual substances are considered in this assessment.

5.5.2 Other sum parameters (AOX, etc.)

Individual substances are subtracted from other sum parameters used in the analytics of water, such as AOX or total nitrogen.

5.5.3 Oxidation form

The toxicology of chemical elements is dependent on the oxidation level. Some examples may illustrate this. Chlorine (oxidation 0) is a toxic gas. Chloride (oxidation = -1) is essential for the nutrition of human beings, but it might be toxic in high doses for animals and plants in rivers and lakes. Chromate (oxidation = 6) emitted to air is carcinogenic for humans when inhaled. Other forms of chromium (oxidation = 0, 2 or 3) are not. That is why the oxidation state of chemical elements and ions is considered in the description of the elementary flow. Different oxidation states (e.g. chromium, chromites, chromate) are distinguished in the list of elementary flows.

5.6 Soil pollutants

5.6.1 SubCategory “agriculture”

The subcategory “agriculture” for soil pollutants is only used for releases on agricultural soil that is used for the production of food, fodder products, animal feed and biomass for other uses (bioenergy, renewable materials).

5.7 Resource uses

5.7.1 Energy resources

In all cases the amount of energy harvested (or converted) is quantified. Non renewable energy resources like oil and gas are inventoried with their weight or volume, respectively. Renewable energy resources like wind, solar and hydro power are recorded with the converted share of direct energy in-

[3] BOD_5 Biological oxygen demand in five days
COD Chemical oxygen demand
DOC Dissolved organic carbon
TOC Total organic carbon

put from nature in MJ. For the hydro power this is equal to the converted amount of potential energy of the water, for wind it is the converted amount of kinetic energy of the air and for solar energy it is the amount of radiation energy converted by the technical device. Biomass is considered with the upper heating value of the extracted biomass.

5.7.2 Material resources

The extraction of metals and other minerals in ores is recorded as the amount of target material that is contained in the ore. Furthermore the description of the elementary flow shows also the content of material in the ore. Thus it is possible to calculate the total amount of ore which has been extracted. Tab. 5.4 shows some examples for the calculation of the extracted ore with the mineral content in the ore.

In metals mining often two or more metals are mined together. The corresponding resources are recorded on the level of individual resources (see examples in Tab. 5.4).

Tab. 5.4 Examples for the naming of ore resources' elementary flows

Amount	ElementaryFlow	Meaning of the flow
1 kg	Magnesite, 60% in crude ore, in ground	Extraction of 1 kg magnesite ($MgCO_3$ or 286 g magnesium) in 1.67 kg crude ore.
1 kg	Aluminium, 24% in bauxite, 11% in crude ore, in ground	Extraction of 1 kg aluminium in 4.17 kg bauxite, in 9.1 kg crude ore.
1 kg	Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore, in ground	Extraction of Nickel from a Nickel-Copper mine with a Nickel (and Copper) content of 0.76% (each) in the crude ore.

5.7.3 Land occupation and transformation

Land occupation and land transformation gets more and more attention in life cycle inventory analyses and life cycle impact assessment methods. It is especially important for agricultural and forestry products. However, consistent land occupation and transformation figures for unit processes of an economic sector or even complete process networks including agriculture, forestry, energy supply, transport and waste treatment services, material production, etc. are still rare. In the ecoinvent projects, one emphasis is put on a systematic registration and quantification of land occupation and transformation. For that purpose the ecoinvent project group developed a simplified methodology that allows for a relatively efficient data compilation and data handling while at the same time minimising information loss in view of future developments in LCIA. In order to develop a good solution for the integration of land use issues in the inventory a discussion forum has been organized. Different life cycle impact assessment (LCIA) experts gave their input to the solution of this problem (Frischknecht et al. 2001).

Land use and its impacts

Land use mainly has impacts on the following areas of protection:

- Natural resources,
- the natural environment and
- the man-made environment

In Lindeijer (2001) these impacts are classified in the following four groups:

- Increase of land competition[4]
- **Degradation of biodiversity**
- Degradation of life support functions
- Degradation of cultural values

The methodology used in the ecoinvent database concentrates on the second and - as far as possible - the third impact mentioned above.

Distinction between land occupation and land transformation

A distinction is made between

- *land occupation* (e.g., the operation of a power station hinders the occupied land from changing to a more natural state), and
- *land transformation* (e.g., a new assembly plant for airplanes requires the conversion of a former natural resort to industrial land; a gravel-pit is converted to a natural resort by active re-cultivation).

For land occupation the area as well as the duration required for the production of a certain amount of products and services are important. That is why land occupation is recorded in square metres times time (m^2a).

Clearly defined and relatively short changes in the land use type are recorded as land occupation (e.g., the construction of underground natural gas pipelines, which converts agricultural land to an excavation site). For these construction processes as well as for active restoration activities after decommissioning, the land use category "land occupation, construction site" is applied.

Land transformation links a state during an economic activity with a state before and in selected cases a state after that activity (road construction, power plant erection, active mine restoration, etc.)[5]. But it also may occur during the economic activity itself (open pit lignite extraction).

For particular processes the land use type before starting the activity may well be known. However, it is difficult to assess in detail all the land use types which have been converted by the production processes recorded within the ecoinvent project. If not known, the land use type "transformation, from unknown" is applied. Continental or regional statistics about land transformation over time may then be used in the impact assessment to attribute a specific land use type to this land use type "unknown".

Land transformation consists of an entry

1. land transformation, from *land use type X*, and
2. land transformation, to *land use type Y*.

For land transformation at the beginning of an economic activity the land use type encountered at that point in time is recorded. This starting state, such as "transformation, from forest", is recorded in m^2. Additionally, the transformation to the land use type valid during the economic activity is recorded as

[4] Land competition refers to the economic value of different land surfaces. Thus an estate in a big city has a much higher price and its use would have a higher impact that the use of land in remote area.

[5] Usually, the state after is not considered (no transformation from “industrial area” to “unknown” at the end of a plant’s life time).

well. For gravel extraction, for instance, the m^2 "transformation, to mineral extraction site" are recorded.

This land transformation needs to be attributed to the total amount of products and services delivered (the life time production of a power plant, one production cycle of a forest[6] or time period until the depletion of a mine, etc.). Tab. 5.5 shows the depreciation time periods applied in the ecoinvent data v2.0 if no specific information is available. Specific time periods used in particular processes are also described in the respective final ecoinvent report.

Active restoration at the end of an extraction activity is modelled as a separate unit process ("restoration, gravel-pit", "restoration, copper mine"). This process includes technical requirements such as diesel for construction machines, seeds, etc.. Additionally, land transformation to the final land use type, and from the land use type during the operation of the economic process are recorded (e.g., "transformation, from mineral extraction site", and "transformation, to pasture and meadow"). Such restoration processes may be required by an infrastructure process (although this modelling is only done in special cases such as a power plant: "restoration, power plant") or by the production process itself (in case land transformation and restoration takes place during the economic activity, e.g., lignite extraction).

Land transformation caused by a use of the land for new purposes is attributed to this future new uses[7]. No land transformation is recorded for land uses that are likely not to change in the future (such as transport infrastructure, agricultural land, industrial area) as well as for land abandoned and subjected to natural succession.

Land use classes in ecoinvent data v2.0

The definition of land use classes takes pattern from the CORINE land cover classes (Bossard et al. 2000). New, and partly more detailed land use classes have been added to the CORINE table using the same systematic. Only land cover classes required in the ecoinvent project have been added. The list in Tab. 5.5 may however easily be extended if required.

Land use classes do not include national or even regional differentiation. For instance, the land use class "pasture and meadow, extensive" covers land occupation (and transformation) by Alpine pastures as well as South American cattle pastures.

If the land use class before the operation phase of the economic activity is not known, land transformation is recorded with "transformation, from unknown". With that, the sum of all "transformation, to ..." equals the sum of all "transformation, from ...". From these figures the net transformation of land use classes can be calculated.

If, for instance, the total amount of m^2 "transformation, from forest" is larger than the amount of m^2 "transformation, to forest", calculated for the production of 1kWh of Swiss low voltage electricity, the production of this kWh reduced the total net amount of forest area.

[6] Although it is not very likely that the forest is transformed to another land use after one production cycle, the “transformation from unknown” and the “transformation to forest” is attributed to one single production cycle. Also areas transformed to “industrial area” are usually not occupied by industry for only 50 years. Thus these transformations are certainly overestimated.

[7] The decision, which use to attribute a transformation to is sometimes not unambiguous. If the initial state is “unknown”, it can be assumed that this initial land occupation has the same type like the actual use.

Tab. 5.5 Land occupation classes used in the ecoinvent database based on the CORINE land cover classes classification. The same classes are used for land transformation, according to the naming rules as described in the text. Default use period for depreciation of the initial land transformation

Land use class	CORINE class	Default use period
urban, continuously built	CORINE 111	80
urban, discontinuously built	CORINE 112	80
industrial area	CORINE 121	50
industrial area, built up	CORINE 121a	50
industrial area, vegetation	CORINE 121b	50
industrial area, benthos	CORINE 121c	30
traffic area, road network	CORINE 122a	100
traffic area, road embankment	CORINE 122b	50
traffic area, rail network	CORINE 122c	100
traffic area, rail embankment	CORINE 122d	50
mineral extraction site	CORINE 131	20
dump site	CORINE 132	10 [1])
dump site, benthos	CORINE 132a	1
construction site	CORINE 133	- [2])
arable	CORINE 21	1
arable, non-irrigated	CORINE 211	1
arable, non-irrigated, monotone-intensive	CORINE 211a	1
arable, non-irrigated, diverse-intensive	CORINE 211b	1
arable, non-irrigated, fallow	CORINE 211c	1
permanent crop	CORINE 22	20
permanent crop, vine	CORINE 221	25
permanent crop, vine, intensive	CORINE 221a	25
permanent crop, vine, extensive	CORINE 221b	30
permanent crop, fruit	CORINE 222a	15
permanent crop, fruit, intensive	CORINE 222a	15
permanent crop, fruit, extensive	CORINE 222b	20
pasture and meadow	CORINE 231	30
pasture and meadow, intensive	CORINE 231a	20
pasture and meadow, extensive	CORINE 231b	50
heterogeneous, agricultural	CORINE 243a	100
forest	CORINE 31	80
forest, extensive	CORINE 31a	100
forest, intensive	CORINE 31b	80
forest, intensive, normal	CORINE 31b1	60
forest, intensive, clear-cutting	CORINE 31b2	80
forest, intensive, short-cycle	CORINE 31b3	30 / 28
shrub land, sclerophyllous	CORINE 323	100
water courses, artificial	CORINE 511a	100
water bodies, artificial	CORINE 512a	100
sea and ocean	CORINE 523	- [2])
unknown	CORINE x	1
tropical rain forest	CORINE un-known	75

[1]) 30 years for sanitary landfill, slag compartment and residual material landfill.

[2]) No recording of transformation to and from this land use class in ecoinvent data v2.0.

Regional differentiation

Inventory data are in most cases collected on the level of national averages. Hence, no regional differentiation can be made. Unit processes are described by a geographic code, be it a country or a continent or an international organisation. This geographic code provides information about where the land occupation and transformation of the process at issue takes place. However, the ecoinvent database does not yet allow for an automatic evaluation of this information.

Naming rules

The differentiation between transformation and occupation is reflected in the naming of land use elementary flows. It takes pattern from the naming proposals of a Dutch project (Lindeijer & Alfers 2001) and deviates from the proposals of the SETAC Europe working group (de Beaufort-Langeveld et al. 2003; Hischier et al. 2001):

- Occupation, *class, subtype*
- Transformation, from *class of occupation*
- Transformation, to *class of occupation*

The different levels of details in describing the land use class are separated by commas, e.g.:

- Occupation, arable
- Occupation, arable, non-irrigated
- Occupation, arable, non-irrigated, monotone-intensive

The highest level of information detail is always used and recorded in the inventories.

Allocation issues

Land transformation and occupation may be allocated among several products or services. Roads for instance are built for personal and freight traffic. Allocation is done with regard to the influence of each of the products / services on the impact categories of land occupation and transformation listed above.

Attribution of land use to operation or construction/dismantling (infrastructure)

Land occupation and transformation may in some cases either be attributed to the construction phase or the operation phase of a process. The area of a greenhouse may rather be recorded in the infrastructure part whereas the farm land would rather be recorded in the operation of an agricultural process. As a rule, agricultural and forest property areas are attributed to the operation as long as they do not include buildings. Land use by buildings, greenhouses and the like are attributed to the infrastructure. Maintenance of forest roads is attributed to operation, construction of forest road is neglected.

Ecoinvent allows for calculation of results excluding infrastructure requirements. Hence, land transformed or occupied by infrastructure is neglected and may influence impact assessment results substantially. Care must be taken when comparing LCIA results computed without infrastructure contributions.

Example for an inventory of land use

The ecoinvent approach on land use is illustrated with the following simplified example of gravel extraction:

- total area 1'000'000 m^2,
- gravel-pit used during 20 years,

- 1'000'000 tons of gravel extracted per year,
- 2 years of restoration activities,
- diesel consumption of 500 t (21.3 TJ) per year during extraction and of 100 t (4.3 TJ) during restoration.

The inventory for the two processes "gravel, at extraction/kg/RER/0" and "recultivation, gravel-pit/m^2/RER/0" are shown in Tab. 5.6. Land occupation is calculated by dividing the total area by the total amount of gravel extracted per year. Land transformation is calculated by dividing the total area by the total life time production (1'000'000m^2 / 20a * 1'000'000'000 kg/a = $5.0 * 10^{-5}$ m^2/kg). The requirements for restoration are also evenly attributed to the life time production of the gravel-pit. Restoration leads to a forest (assumption). This restoration activity must not be included in the inventory of forestry products (e.g., timber). For future timber production, the correct land transformation before starting that activity would then be "transformation, from forest"[8]. In the column "LCI result" one can see that the total area transformed is $5.0 * 10^{-5}m^2$ per kg gravel extracted and that the net transformation is from "unknown" to "forest". The two transformations "to mineral extraction site" and "from mineral extraction site" cancel out each other.

Tab. 5.6 Example of unit process raw data including land transformation and land occupation

			unit process raw data		LCI result
			gravel, at extraction	recultivation, gravel-pit	gravel, at extraction
			kg	m^2	kg
Resource use	Occupation, mineral extraction site	m^2a	0.001		0.001
	Occupation, construction site	m^2a		2	0.0001
	Transformation, from unknown	m^2	5.00E-05		5.00E-05
	Transformation, to mineral extraction site	m^2	5.00E-05		5.00E-05
	Transformation, from mineral extraction site	m^2		1	5.00E-05
	Transformation, to forest	m^2		1	5.00E-05
Technosphere Inputs	recultivation, gravel-pit	m^2	5.00E-05		5.00E-05
	diesel, burned in building machine	MJ	0.021	4.3	0.0212
	...	...			
Output	gravel, at extraction	kg	1		1
	restoration, gravel-pit	m^2		1	

5.8 Neglected elementary flows

Because no standardised reporting method for noise emissions of all kinds of processes exists, these emissions are not yet included. They are planned to be implemented with ecoinvent data v2.1 in 2008.

Water vapour, nitrogen and oxygen releases to air are not recorded. Consequently combustion air is neither recorded as an input. That is why complete mass balances cannot be calculated from the ecoinvent data. However, mass balances for selected chemical elements were performed.

Water is usually not reported as an emission to air, soil or water. The only exception is the emission from air planes in high altitudes, because here the emission of water contributes to the effects of climate change.

[8] In contrast to timber production modelled in ecoinvent, where "transformation, from unknown" has been used.

5.9 Outlook

After describing the documentation of elementary flows applied within this project some important points are highlighted which need further improvements for future studies in these areas.

The subcategories used to distinguish the emissions of pollutants are sometimes difficult to determine. From the impact assessment point of view they still need further clarification. To distinguish agricultural and industrial soil seems to be useful for the LCIA methods existing so far. The subcategory "lake" (emissions to water) might be deleted for future studies as it is used rather seldom and difficult to distinguish from the impacts of emissions to rivers. Further refinement of subcategories is necessary for pollutants emitted to air. The help of impact assessment experts would be necessary to distinguish the relevant subcompartments. For the time being, the description is not clear enough which leads to differing interpretations by different analysts. For instance, air emissions are sometimes recorded as "unspecified" (steel mills), "low population density" (nuclear and coal power plants), and "high population density" (oil and gas power plants), without a clear indication that this differentiation is sensible. Emissions from steel mills are for instance recorded as unspecified, because data often represent average emissions of many (>100) different plants in different locations. With these data it is not possible to determine the fraction of the pollutants emitted to each of the subcompartments.

Problems did arise with the definition of the initial state of the land use class. Quite often the entry “Transformation, from unknown” had to be used in the inventories. Thus further research is necessary to give clear guidelines how to assess the transformation classes if only limited information is available. Also it is usually not possible to predict for how long an area transformed will remain in the new state. The choice of one (assumed) life time of the factory building or of one production cycle of a forest is quite arbitrary.

As described above in Section 5.4.5 waste heat emissions are not consistently modelled at the moment. If a consistent modelling is considered an important issue, the approach should be revised in future editions of ecoinvent data. An alternative approach is proposed here, where each flow of energy is only accounted once in order to avoid the duplication of information in the inventories.

Energy uptake of technical systems is recorded as a resource use, in the four categories gross calorific value of biomass, kinetic energy, potential energy and solar energy. Losses of the technical transformation system are recorded as a waste heat emission. E.g., if the hydro power plant has an efficiency of 95 %, 5 % of the input of potential energy are recorded as waste heat emission. The further modelling of waste heat emissions is also identical to that of ecoinvent data v2.0:

No distinction is made between waste heat emissions from renewable and non-renewable sources. Waste heat is determined using the gross calorific value of fossil energy carriers and biomass, and the energy content of electricity. The datasets of useful and final energy supply such as "heat, light fuel oil, at industrial boiler", or "light fuel oil, burned in industrial boiler" already contain the waste heat emission. For electricity consumptions however, the equivalent amount of waste heat needs to be recorded. If the process leads to a rise of the energy content of the product this should be subtracted from the waste heat emission recorded for the energy use of this process.

The waste heat balance of non renewable energy uses is then calculated by adding up the cumulative results of all waste heat emissions minus the cumulative results of the four categories of renewable energy resources. The sum of all waste heat flows can be used to assess the total conversion of energies within the product system at issue.

6 Multi-output processes and allocation rules

6.1 Introduction

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

However, in large background LCI databases one needs to consider all co-products at the same time because the LCI results of all of them are of interest. Furthermore, Heijungs claimed that LCI databases should include information about multifunction or multi-output processes *before* allocation (Heijungs 1997).

The ecoinvent team respected this suggestion and established a database system which can accommodate unallocated multi-output processes and their derived single (co-)product output processes (see also Hedemann & König 2003). Allocation factors are separately recorded and may be adjusted according to personal choices or new market situations. The ecoinvent software system tests whether 100% of all input and output flows of the unallocated process are attributed to its co-products. This guarantees that no emissions are lost or counted twice. This approach allows for some basic insights into the mechanisms of LCI allocation and its effects on the environmental competitiveness of co-products.

6.2 Example and problem setting

Within the product system of photovoltaic power plants the production of silicon wafers is one of the most important process stages (Jungbluth 2003). The purification of metallurgical grade (MG) silicon is especially energy intensive. The purification process leads to three products: electronical grade (EG) silicon, off-grade silicon and silicon tetrachloride (see Fig. 6.1).

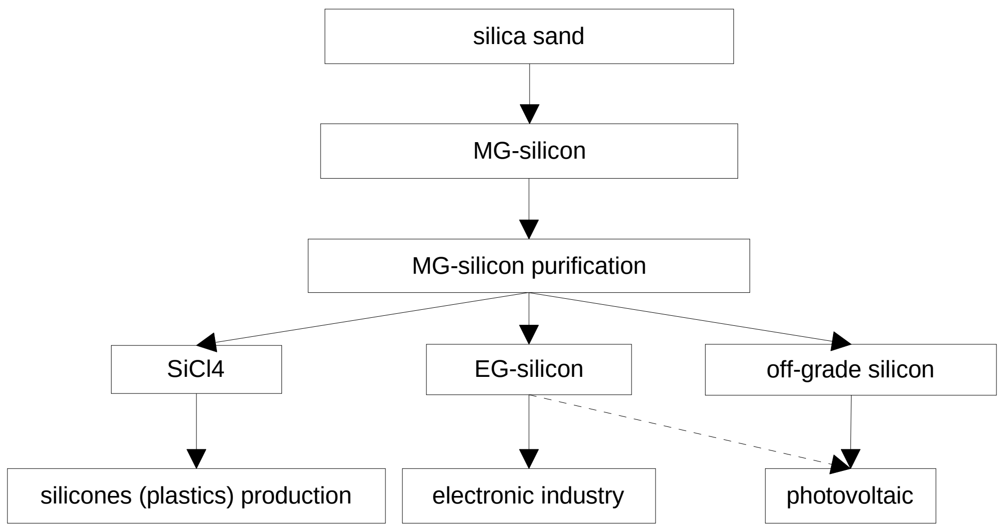

Fig. 6.1 Flow chart EG-silicon purification and the use of its co-products

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

According to ISO 14044 (subclause 6.5.2 allocation principles), "the sum of the allocated inputs and outputs of a unit process shall equal the unallocated inputs and outputs of the unit process" (International Organization for Standardization (ISO) 2006b). This is also known as the 100% rule.

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

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

6.3 Context-specific allocation criteria

J.S. Mill is often mentioned as one of the first economists who raised the question of an adequate procedure to allocate (private) costs to two jointly produced goods (Mill 1848). Criteria used today for the allocation of costs are for instance given in (Horngren 1991). They differentiate between the following criteria:

a) cause and effect,

b) benefits received,

c) fairness or equity, and

d) ability to bear.

Ad a) The criterion "cause and effect" relies on physical, chemical or biological causation. It may be applied for the analysis of combined production where the output of co-products can be varied independently such as an oil refinery producing oil products (light fuel oil, gasoline, bitumen, et cetera). This criterion corresponds to the second step of the ISO 14044 procedure and is not applicable to joint production processes.

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

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

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

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

6.4 Interdependence of co-product LCIs

Fig. 6.2 shows the interdependence of environmental burdens attributed to two co-products α and ρ (Frischknecht 2000). When about 60% of all input and output flows are allocated to commodity 2 (point A in Fig. 6.2), our co-product ρ shows lower impacts compared to competing products σ, τ, and υ of commodity 2. However, the environmental impacts of co-product α are still higher as compared to product δ of commodity 1. The graph shows that no allocation factors exist where both co-products α and ρ show lower environmental impacts as compared to their competing products. The combination of single output products δ / υ is environmentally preferable in this situation and sets the environmental benchmark.

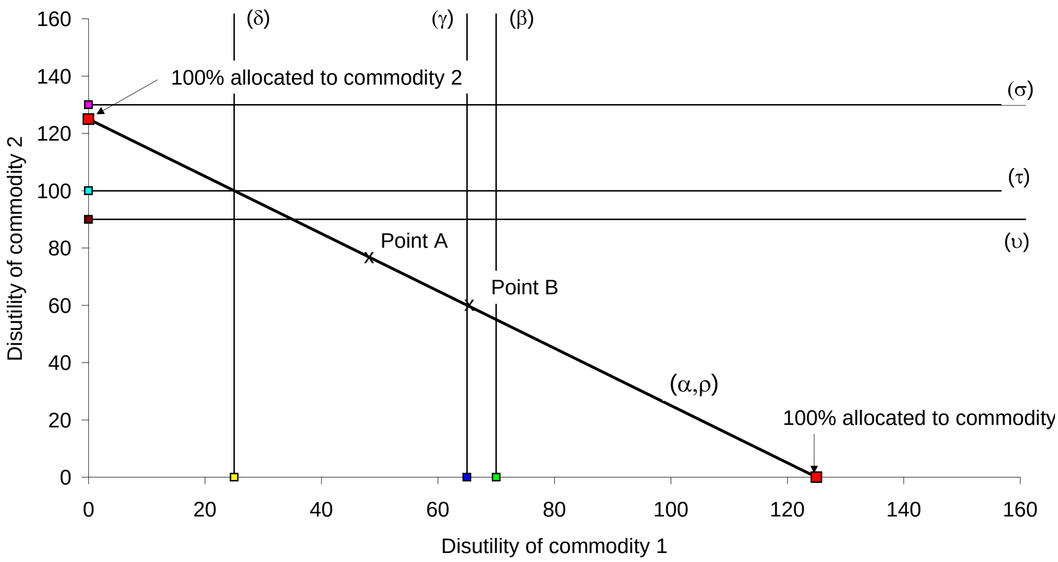

Fig. 6.2 Graphical solution for a comparison of the life-cycle based disutility (=environmental burden) of alternative combinations of products of commodities 1 and 2. The thick line shows the disutility of the joint products α and ρ. The points on the abscissa and the ordinate show the disutility of products from single output processes β, γ, δ, and σ, τ, υ, respectively. Intersections of the vertical and horizontal auxiliary lines above the thick line show combinations of single-output processes with a higher disutility than that of the joint products α und ρ. The scales show arbitrary units (Frischknecht 2000)

6.5 Modelling principle in ecoinvent

Multi-output unit processes are entered into the database *before* allocation. Additionally, the allocation factors applied are defined on the multioutput process level. The database creates single output processes with the help of multioutput process data and their allocation factors. The multioutput process and its co-products are named differently.

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

Tab. 6.1 shows an excerpt of the inputs and outputs of the MG silicon purification process and the allocation factors as modelled in the previous ecoinvent data v1.3. The first three lines show the co-products EG-silicon (0.68 kg), off-grade electronic grade silicon (0.084 kg) and silicon tetrachloride (1.2 kg). The next six lines show examples of inputs required during purification of 1 kg of MG-silicon. The three columns to the right show the allocation factors: For instance, 71.1 % of the input "MG-silicon, at plant" are allocated to the 0.68 kg of EG silicon, 8.9 % to 0.084 kg off-grade silicon and 20 % to 1.2 kg $SiCl_4$.

Tab. 6.1 Excerpt of the multi-output process raw data of the purification of 1 kg of MG silicon and allocation factors used for the three co-products (Jungbluth 2003)

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

Each multi-output dataset includes information about the allocation factors. This information is available per individual input and output, respectively. Each pollutant, each working material or raw material input may therefore have its individual allocation factor, if adequate or necessary. Additionally, the allocation method applied may be specified in the EcoSpold data format (descriptive purpose only). Hereby one may choose between:

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

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

System expansion is avoided wherever possible. This is not due to the fact that the ecoinvent database is rather descriptive in nature but rather due to principle reservations towards this approach (see also Section 6.8). In most cases allocation according to "other relationships" (according to the three step procedure in ISO 14044) is used. Where possible, processes are split up in order to avoid allocation. For oil refineries, for instance, allocation factors have been determined on the basis of detailed mass and energy flows of the individual subprocesses such as atmospheric distillation, etc.

Datasets with multi-output processes are imported into the ecoinvent database in XML-format (just like unit processes). However, when importing a multi-output process, unit processes describing the allocated inputs and outputs of the co-products are additionally generated. Tab. 6.2 shows an excerpt of the derived unit process raw data of the three co-products of MG-silicon purification.

When the dataset "MG silicon, to purification" is imported into the database, three additional datasets are generated, namely the unit process datasets of "silicon, electronic grade, at plant", "silicon, electronic grade, off-grade, at plant", and "silicon tetrachloride, at plant". Thereby, the amount of the inputs and outputs is multiplied by the respective allocation factor and divided by the respective amount of the co-product output.

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

Tab. 6.2 Derived unit process raw data for the three co-products of "MG-silicon, to purification". Input and output flow of the multi-output process times allocation factor divided by co-product output equals input and output flows of the derived unit processes (Jungbluth 2003)

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

6.6 Computing of LCI results

The ecoinvent database system uses matrix inversion to calculate LCI results. If the matrix contains multi-output processes, the matrix is no longer square and it gets impossible to compute meaningful results (see also Heijungs & Frischknecht 1998). The reference flow of the multi-output process (1 kg MG silicon to purification) is not available as input for other processes. Only their (co-)products may be used as inputs.

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

6.7 Cut-off for by-products and recycling

By-products which contribute nothing or only very little to the total proceeds of an economic activity but which are used in a subsequent process (re- or down-cycling) are not reported in the list of inputs and outputs of the database. Exceptions are different fractions of industrial residue wood which are used as fuel. To these materials the biomass (including CO_2 from air) and embodied energy are allocated by volume while all other flows are totally allocated to the main product. Thus the mass and energy balance equal out and the amount of CO_2 formed in burning the fuel corresponds to the amount of CO_2 taken up during the growth of the plant. Neither are credits granted, nor are a part of the inputs and outputs of the respective process allocated to these by-products.

In the bioenergy datasets introduced with ecoinvent data v2.0 great care was taken to establish balanced biogenic carbon inputs and outputs. The methodology applied in these datasets is described in Jungbluth et al. (2007). It is a further specification of the approach applied in all other datasets.

6.8 ecoinvent and the avoided burden approach

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

Let us apply this concept to the silicon example introduced before. Firstly, we need to determine the reference flow. We choose 1 kg of "silicon, electronic grade, at plant". Secondly, the co-product output flows of "silicon, electronic grade, off-grade, at plant" and "silicon tetrachloride, at plant" get a negative sign, namely –0.084 kg of off-grade EG silicon and –1.2 kg of $SiCl_4$. No allocation factors are applied[9].

The inventory table is calculated by subtracting the environmental burdens of alternative off-grade EG silicon and $SiCl_4$ production from the overall burdens caused by the multi-output process. How the alternative production processes may be identified has been described for instance by Ekvall (1999) and Weidema (2001). The computation of results is again easily done by matrix inversion. The LCI and / or LCIA results may be negative or positive. If negative, the currently analysed multi-output process shows a better environmental performance as compared to producing the three co-products with alternative (single output) processes. If the scores are positive, the multi-output process is still environmentally preferable, if the scores are lower as compared to a single output production of EG silicon.

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

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

6.9 Conclusions

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

- Input and output flows of multi-output processes are available before any allocation.
- Allocation factors can be determined per each individual input and output flow.
- The sum of all allocation factors of one particular flow always equals 100%.

[9] Although it is questionable whether all avoided inputs and outputs related to 1.2 kg $SiCl_4$ production shall be credited to the manufacturing of EG silicon. The buyer of $SiCl_4$ co-produced with EG silicon should profit from this joint production synergy as well and thus an allocation of the total credit is due.

- Unit processes of the co-products are derived when importing multi-output processes into the database.
- For calculation, the derived unit processes are used.

This approach has the following advantages:

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

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

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

7 Uncertainty considerations

7.1 Introduction

Within the life cycle inventory of a unit process the amounts of the inputs and outputs are described with single figures (the mean values). This quantitative description of the unit process includes uncertainty because the mean values are uncertain. In reality there might be a difference between the value that has been investigated (or measured and reported) and the "real" value.

Different types of uncertainty are present in the life cycle inventory data of a process:

- Variability and stochastic error of the figures which describe the inputs and outputs due to e.g. measurement uncertainties, process specific variations, temporal variations, etc.
- Appropriateness of the input or output flows. Sometimes an input or output does not perfectly match with the input or output observed in reality. This may be due to temporal and / or spatial approximations. For instance, the electricity consumption of a process that takes place in Nigeria is approximated with the dataset of the electricity supply mix of the European network (UCTE).
- Model uncertainty: the model used to describe a unit process may be inappropriate (using for instance linear instead of non-linear modelling).
- Neglecting important flows. Sometimes not all relevant information is available to completely describe a process. Such unknown inputs and outputs are missing in the inventory.

7.2 Implementation in the database

Only the first type of uncertainty can be expressed in quantitative terms on the level of individual inputs and outputs of unit processes. This type of uncertainty has been treated consistently and in a quantified way within the ecoinvent database. The ecoinvent software system offers four different uncertainty distributions, namely lognormal, normal, triangular and uniform. Lognormal distribution has been used for nearly all unit processes of ecoinvent data v2.0[10]. Tab. 7.1 shows how uncertainty information is reported in the EcoSpold data format illustrated with the help of some examples.

[10] According to Hofstetter (Hofstetter 1998 Hofstetter P. (1998) Perspectives in Life Cycle Impact Assessment: A structured approach to combine models of the technosphere, ecosphere and valuesphere. Kluwer Academic Publishers, Boston, Dordrecht, London.) several reports in the field of risk assessment and impact pathway analysis have shown that the lognormal distribution seems to be a more realistic approximation for the variability in fate and effect factors than the normal distribution. Because emission measurements may not show negative values, lognormal distribution was also applied on life cycle inventory data.

Tab. 7.1 Description of uncertainties in the ecoinvent database

EcoSpold data field		Probability function	Formula	Example	Unit	database input
3708	*uncertainty type*	*Lognormal*				1
3707	meanValue	Geometric mean	μ_g	1'540	kg	1'540
3709	standardDeviation95	Square of the geometric standard deviation	σ_g^2	2.7	-	2.7
3795	minValue	2.5% Figure	μ_g/σ_g^2	570	kg	n.i.
3796	maxValue	97.5% Figure	μ_g x σ_g^2	4'160	kg	n.i.
3797	mostLikelyValue	n.a.				n.i.
3708	*uncertainty type*	*Normal*				2
3707	meanValue	Arithmetic mean	μ	1'540	kg	1'540
3709	standardDeviation95	Two times standard deviation	2σ	420	kg	420
3795	minValue	2.5% Figure	$\mu-2\sigma$	1'120	kg	n.i.
3796	maxValue	97.5% Figure	$\mu+2\sigma$	1'960	kg	n.i.
3797	mostLikelyValue	n.a.				n.i.
3708	*uncertainty type*	*triangular*				3
3707	meanValue	Arithmetic mean	(a+b+c)/3	1'540	kg	1'540
3709	standardDeviation95	n.a.				n.i.
3795	minValue	Min.-figure	b	930	kg	930
3796	maxValue	Max.-figure	c	1'910	kg	1'910
3797	mostLikelyValue	most likely value	a	1'780	kg	n.i.
3708	*uncertainty type*	*uniform*				4
3707	meanValue	Arithmetic mean	(a+b)/2	1'540	kg	1'540
3709	standardDeviation95	n.a.				n.i.
3795	minValue	Min.-figure	a	1'210	kg	1'210
3796	maxValue	Max.-figure	b	1'870	kg	1'870
3797	mostLikelyValue	n.a.				n.i.

n.i. no input
n.a. not applicable

7.3 Pedigree matrix for uncertainty estimation

Quite often the uncertainty of the amount of a specific input or output cannot be derived from the available information, since there is only one source of information that provides only the mean value, without any information about the uncertainty of this value. A simplified standard procedure was developed to quantify the uncertainty for these (quite numerous) cases.

The simplified approach includes a qualitative assessment of data quality indicators based on a pedigree matrix. The pedigree matrix takes pattern from work published by (Pedersen Weidema & Wesnaes 1996).

Basic uncertainty factors are used for the kind of input and output considered. It is assumed that for instance CO_2 emissions show in general a much lower uncertainty as compared to CO emissions. While the former can be calculated from fuel input, the latter is much more dependent on boiler characteristics, engine maintenance, load factors etc. These basic uncertainty factors shown in Tab. 7.2 are based on expert judgements.

Tab. 7.2 Basic uncertainty factors (dimensionless) applied for technosphere inputs and outputs and for elementary flows; c: combustion emissions; p: process emissions; a: agricultural emissions

input / output group	c	p	a	input / output group	c	p	a
demand of:				**pollutants emitted to air:**			
thermal energy, electricity, semi-finished products, working material, waste treatment services	1.05	1.05	1.05	CO_2	1.05	1.05	
transport services (tkm)	2.00	2.00	2.00	SO_2	1.05		
Infrastructure	3.00	3.00	3.00	NMVOC total	1.50		
resources:				NO_X, N_2O	1.50		1.40
primary energy carriers, metals, salts	1.05	1.05	1.05	CH_4, NH_3	1.50		1.20
land use, occupation	1.50	1.50	1.10	individual hydrocarbons	1.50	2.00	
land use, transformation	2.00	2.00	1.20	PM>10	1.50	1.50	
pollutants emitted to water:				PM10	2.00	2.00	
BOD, COD, DOC, TOC, inorganic compounds (NH_4, PO_4, NO_3, Cl, Na etc.)		1.50		PM2.5	3.00	3.00	
individual hydrocarbons, PAH		3.00		polycyclic aromatic hydrocarbons (PAH)	3.00		
heavy metals		5.00	1.80	CO, heavy metals	5.00		
pesticides			1.50	inorganic emissions, others		1.50	
NO_3, PO_4			1.50	radionuclides (e.g., Radon-222)		3.00	
pollutants emitted to soil:							
oil, hydrocarbon total		1.50					
heavy metals		1.50	1.50				
pesticides			1.20				

Data sources are then assessed according to the six characteristics "reliability", "completeness", "temporal correlation", "geographic correlation", "further technological correlation" and "sample size" (see Tab. 7.3). Each characteristic is divided into five quality levels with a score between 1 and 5. Accordingly, a set of six indicator scores is attributed to each individual input and output flow (except reference product) reported in a data source (this set of six indicator scores is reported in the general comment field of each input and output). An uncertainty factor (expressed as a contribution to the square of the geometric standard deviation) is attributed to each of the score of the six characteristics. These uncertainty factors are also based on expert judgements and are shown in Tab. 7.4.

The square of the geometric standard deviation (95% interval – SD_{g95}) is then calculated with the following formula:

$$SD_{g95} := \sigma_g{}^2 = \exp^{\sqrt{[\ln(U_1)]^2+[\ln(U_2)]^2+[\ln(U_3)]^2+[\ln(U_4)]^2+[\ln(U_5)]^2+[\ln(U_6)]^2+[\ln(U_b)]^2}}$$

with :

U_1 : uncertainty factor of reliability

U_2 : uncertainty factor of completeness

U_3 : uncertainty factor of temporal correlation

U_4 : uncertainty factor of geographic correlation

U_5 : uncertainty factor of other technological correlation

U_6 : uncertainty factor of sample size

U_b : basic uncertainty factor

For some ecoinvent datasets slightly different approaches have been used. These approaches are described in the respective ecoinvent reports. In cases where enough samples are available, uncertainty distribution and standard deviation are determined using statistical methods.

Tab. 7.3 Pedigree matrix used to assess the quality of data sources, derived from (Pedersen Weidema & Wesnaes 1996)

Indicator score	1	2	3	4	5	Remarks
Reliability	Verified data based on measurements	Verified data partly based on assumptions OR non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert); data derived from theoretical information (stoichiometry, enthalpy, etc.)	Non-qualified estimate	verified means: published in public environmental reports of companies, official statistics, etc unverified means: personal information by letter, fax or e-mail
Completeness	Representative data from all sites relevant for the market considered over an adequate period to even out normal fluctuations	Representative data from >50% of the sites relevant for the market considered over an adequate period to even out normal fluctuations	Representative data from only some sites (<<50%) relevant for the market considered OR >50% of sites but from shorter periods	Representative data from only one site relevant for the market considered OR some sites but from shorter periods	Representativeness unknown or data from a small number of sites AND from shorter periods	Length of adequate period depends on process/technology
Temporal correlation	Less than 3 years of difference to our reference year (2000)	Less than 6 years of difference to our reference year (2000)	Less than 10 years of difference to our reference year (2000)	Less than 15 years of difference to our reference year (2000)	Age of data unknown or more than 15 years of difference to our reference year (2000)	less than 3 years means: data measured in 1997 or later; score for processes with investment cycles of <10 years; for other cases, scoring adjustments can be made accordingly
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from smaller area than area under study, or from similar area		Data from unknown OR distinctly different area (north america instead of middle east, OECD-Europe instead of Russia)	Similarity expressed in terms of enviornmental legislation. Suggestion for grouping: North America, Australia; European Union, Japan, South Africa; South America, North and Central Africa and Middle East; Russia, China, Far East Asia
Further technological correlation	Data from enterprises, processes and materials under study (i.e. identical technology)		Data on related processes or materials but same technology, OR Data from processes and materials under study but from different technology	Data on related processes or materials but different technology, OR data on laboratory scale processes and same technology	Data on related processes or materials but on laboratory scale of different technology	Examples for different technology: - steam turbine instead of motor propulsion in ships - emission factor B(a)P for diesel train based on lorry motor data Examples for related processes or materials: - data for tyles instead of bricks production - data of refinery infrastructure for chemical plants infrastructure
Sample size	>100, continous measurement, balance of purchased products	>20	> 10, aggregated figure in env. report	>=3	unknown	sample size behind a figure reported in the information source

Tab. 7.4 Default uncertainty factors (contributing to the square of the geometric standard deviation) applied together with the pedigree matrix

Indicator score	**1**	**2**	**3**	**4**	**5**
Reliability	1.00	1.05	1.10	1.20	1.50
Completeness	1.00	1.02	1.05	1.10	1.20
Temporal correlation	1.00	1.03	1.10	1.20	1.50
Geographical correlation	1.00	1.01	1.02		1.10
Further technological correlation	1.00		1.20	1.50	2.00
Sample size	1.00	1.02	1.05	1.10	1.20

7.4 Limitations of the uncertainty assessment

The approach for the assessment of uncertainties does not take into account the following factors which determine also the overall uncertainty for the life cycle inventory of a unit process:

- Missing information in the inventory table.
- Inappropriate modelling for the necessary inputs and outputs, e.g. demand for a similar but not exactly right product or service (e.g., consumption of 1kWh "electricity, medium voltage, NG (Nigeria)" approximated with 1kWh "electricity, medium voltage, UCTE").
- Mistakes imposed by human errors, i.e. human errors included in the information source used or errors made by the analyst during modelling.

7.5 Monte-Carlo simulation and results

The uncertainty estimations are given on a unit process level. The 95 % confidence interval of cumulative LCI results is calculated with the help of Monte-Carlo simulation (see Hedemann & König 2003). The 2.5 % and the 97.5 % values calculated with Monte-Carlo simulation are shown for each individual elementary flow.

The probabilistic mean values (i.e. the cumulative results determined with Monte Carlo simulation) differ slightly from the deterministic mean values (i.e. the cumulative results derived from the mean values of the unit process raw data only without use of the uncertainty factors). It was decided to show the deterministic mean values in the ecoinvent database. This has the advantage that the mean values of the LCI results are reproducible. Furthermore, the reliability of the mean values of the unit process raw data is judged to be much higher as compared to the roughly estimated geometric standard deviation.

For the time being no minimum and maximum values are shown in the impact assessment results. Current impact assessment methods (except i.e. Goedkoop & Spriensma 2000; Huijbregts 2001; Steen 1999) do often not provide uncertainty information. The contribution of the uncertainty in the damage factors to the overall impact assessment results is judged to be at least as important as the uncertainty in the LCI results. Showing minimum and maximum values on the level of LCIA results without considering the LCIA uncertainties would be misleading.

7.6 Outlook

After describing the uncertainty assessment applied within this project some important points are highlighted which need further improvements for future studies in this area.

The basic uncertainty factors used in the project have been assessed before hand by a group of analysts working in the project. The experiences with variations that were found in the literature during the project make it probable that these basic uncertainties tend to underestimate the "real" uncertainty. Especially for pollutants which are only seldom measured and which depend on impurities rather than on product properties the range found in the literature might be considerably higher. Furthermore sometimes uncertainties add up. The emission of water pollutants for instance can depend on concentration *and* flow of waste water which might have been derived from different sources. This was observed for example for the emissions of heavy metals during fuel combustion or for the elements emitted with the wastewater streams from crude oil extraction.

The score of the characteristic “sample size” in the pedigree matrix does not very well correlate with the uncertainty of found figures. Sometimes the sample size might be small (less than 10); nevertheless the information is quite reliable. On the other hand there are sectors, like agriculture, where even a sample size of e.g. 20 or 100 might not be sufficient. This indicator also overlaps with the indicator “Completeness” and these two might be unified for an improved approach.

Quite often the amounts of inputs and outputs of a unit process (and thus their uncertainties) are dependent on each other. For instance, fuel input and CO_2 emissions show a linear relationship. They are treated as independent in the current uncertainty calculations, which tends to overestimate the real uncertainty of the processes.

Further work is also necessary in order to appropriately consider the types of uncertainties not considered so far (see above) in the assessment.

Concerning the Monte-Carlo Simulation, it would be desirable to identify the most sensitive parameters. This would enable the tracing back of the most important sources of uncertainty in an LCA.

8 EcoSpold data format and matrix calculation

The ecoinvent data v2.0 consists of about 4'000 unit processes which are interlinked by material and energy flows. It describes a model of economic activities in several sectors (such as energy, chemicals or agriculture). In this chapter, the data format and the calculation routines used in this database are described. Fig. 8.1 shows an overview for this so called EcoSpold data format briefly described in this chapter. For a more extensive description we refer to Hedemann & König (2003) and to the three data-set schemes available via the Internet.

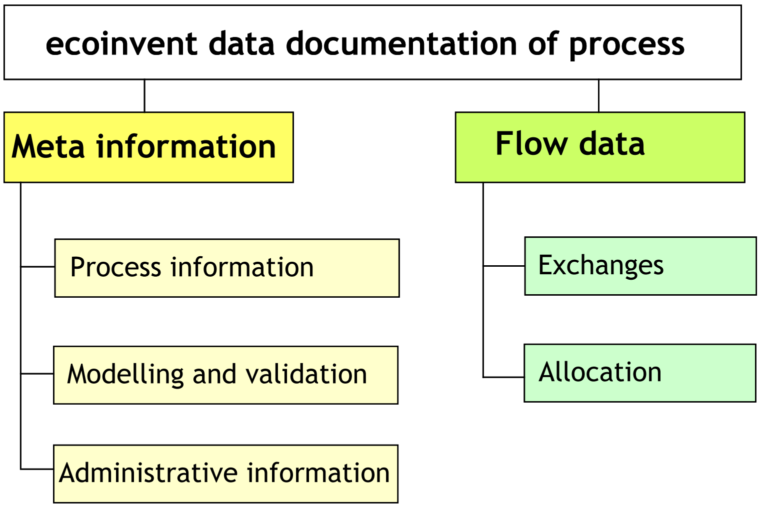

Fig. 8.1 General structure of the EcoSpold data format, used by the ecoinvent database

8.1 Dataset documentation

A process, its products and its life cycle inventory data are documented using the EcoSpold data format with the basic structure shown in Tab. 8.1.

Tab. 8.1 Structure of the EcoSpold data format

Meta information			
	Process		
		ReferenceFunction	defines the product or service output to which all emissions and requirements are referred
		TimePeriod	defines the temporal validity of the dataset
		Geography	defines the geographical validity of the dataset
		Technology	describes the technology(ies) of the process
		DataSetInformation	defines the kind of process or product system, and the version number of the dataset
	Modelling and validation		
		Representativeness	defines the representativeness of the data used
		Sources	lists the literature and publications used
		Validations	lists the reviewers and their comments
	Administrative information		
		DataEntryBy	documents the person in charge of implementing the dataset in the database
		DataGenerator AndPublication	documents the originator and the published source of the dataset
		Persons	lists complete addresses of all persons mentioned in a dataset
Flow data			
		Exchanges	quantifies all flows from technical systems and nature to the process and from the process to nature and to other technical systems
		Allocations	describes allocation procedures and quantifies allocation factors, required for multi-function processes

The different elements are used for the description of unit processes, elementary flows, impact assessment methods and results. Tab. 8.2 shows the mandatory and optional areas of the EcoSpold format for the different types of datasets (unit processes, results, elementary flows and impact assessment methods).

Tab. 8.2 Mandatory and optional areas of the EcoSpold format for different types of datasets

Area	Unit processes (raw data)	product systems (LCI results)	Elementary flows	Impact assessment methods
ReferenceFunction	Always	Always	Always	Always
Geography	Always	Always	Never	Never
Technology	Always	Always	Never	Never
TimePeriod	Always	Always	Never	Possible
DataSetInformation	Always	Always	Always	Always
Representativeness	Possible	Possible	Never	Never
Sources	Always	Always	Never	Always
Validations	Possible	Possible	Possible	Possible
DataEntryBy	Always	Always	Possible	Always
DataGeneratorAndPublication	Always	Always	Never	Always
Persons	Always	Always	Possible	Always
Exchanges	Always	Always	Never	Always
Allocations	Possible	Never	Never	Never

Customers have the possibility to check the content of processes on-line (see excerpt in Fig. 8.2). This helps to judge whether or not the process is of interest and whether or not it is worthwhile to download the corresponding dataset. Links within the html-documents facilitate the navigation. A detailed technical specification for the different data fields in this data exchange format can be found in the section "Publications" on the ecoinvent website.

Meta information	platinum, primary, at refinery, RU, [kg]
Process information	platinum, primary, at refinery, RU, [kg]
Reference function	platinum, primary, at refinery, RU, [kg]
name	platinum, primary, at refinery
localName	Platin, primär, ab Raffinerie
infrastructureProcess	no
unit	kg
category	metals
subCategory	extraction
localCategory	Metalle
localSubCategory	Gewinnung
amount	1
includedProcesses	The module includes a mining and a beneficiation step with the mining infrastructure and disposal of overburden and tailings. Subsequently it includes the metallurgy step with the disposal of slag, the infrastructure and the separation of the co-products nickel and copper, and the refining step yielding the desired PGM-mix inclusively the refining infrastructure. Production, application and emissions of most agents used in beneficiation and metallurgy are also included.
generalComment	The multioutput-process "PGM-Production, primary" delivers the co-products "platinum, primary, at refinery", "palladium, primary, at refinery", "rhodium, primary, at refinery", "nickel, primary, from platinum group metal production" and "copper, primary, from platinum group metal production" in the Russian Federation (RU). The module is designed for the use of the metal in technical systems, where it plays a minor role like the use in manufacturing of electronic or technical chemistry using certain catalysts. It is not to be used if the impact of the PGM within the modelled process in scope is considered to be high. In such cases, a more detailed analysis depending on scope and allocation procedures has to be conducted. The data used is mainly based on a LCA study for autocatalysts in Germany.
infrastructureIncluded	yes
datasetRelatesToProduct	yes

Fig. 8.2 Excerpt of online dataset documentation in ecoinvent data format

Datasets were elaborated using the MS-EXCEL software. Fig. 8.3 shows an example. These data can be translated with the EcoSpold Access tool into the XML format. The example shows all necessary information for the flow data like field IDs, flow names, categories and subcategories and uncertainty information including the data quality indicator scores derived from the pedigree-matrix.

	ID	3503	3504	3702	3703	3506	3507	3508	3706	3707	3708	3709	3792
	401	InputGroup	OutputGroup	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	*sulphur hexafluoride, liquid, at plant*	UncertaintyType	StandardDeviation95%	GeneralComment
	662			Location						*RER*			
	493			InfrastructureProcess						*0*			
	403			Unit						*kg*			
output		-	0	sulphur hexafluoride, liquid, at plant	RER	-	-	0	kg	1.00E+0			
technosphere		5	-	fluorine, liquid, at plant	RER	-	-	0	kg	7.81E-1	1	1.35	(3,4,2,3,3,5); Other energy carriers possible
		5	-	secondary sulphur, at refinery	RER	-	-	0	kg	2.19E-1	1	1.26	(3,4,2,3,1,5); Literature
		5	-	chemical plant, organics	RER	-	-	1	unit	4.00E-10	1	3.90	(5,na,1,1,5,na); Rough estimation
		5	-	transport, freight, rail	RER	-	-	0	tkm	1.32E-1	1	2.09	(4,5,na,na,na,na); Standard distance 600km
		5	-	transport, lorry 32t	RER	-	-	0	tkm	2.19E-2	1	2.09	(4,5,na,na,na,na); Standard distance 100km
emission water, river		-	4	Heat, waste	-	water	river	-	MJ	7.51E-9	1	1.35	(3,4,2,3,3,5); Literature
emission air, unspecified		-	4	Sulfur hexafluoride	-	air	unspecified	-	kg	5.00E-3	1	1.35	(3,4,2,3,3,5); Literature

Fig. 8.3 Example of the documentation of inventory data in MS-EXCEL

8.2 XML technology

Once datasets are chosen for download, one or several datasets are converted to one XML-file[11] and saved on the local computer. The XML schemes facilitate the data exchange between different LCA-databases and -software. All leading LCA software tools are able to exchange and partly edit data in the EcoSpold format. It is the most widespread and most used LCI data format world wide. The EcoSpold format can easily be extended by LCA-software-specific requirements and upwards and downwards compatibilities pose no major problems.

[11] XML: extended markup language.

For a flexible application of a data exchange between commercial LCA software tools and the ecoinvent database, a data exchange format in XML-technology is used. For that purpose XML schemes are applied. On the one hand schemes have a much higher performance than Document Type Definition (DTD) and on the other they themselves use the XML language (as opposite to DTD, which uses its own proper language).

Schemes are used for validation and for documentation purposes. The scheme provides information about the general structure of an EcoSpold dataset. Furthermore, all elements of a scheme may be completed with documentation information and comments. More technical information on the database and the data format can be found in the final report "Technical documentation of the ecoinvent Database" (Hedemann & König 2003).

8.3 Matrix-Calculation with sparse matrices

A unit process is the smallest portion of a product system for which data are collected when performing a life cycle assessment (International Organization for Standardization (ISO) 2006a). Unit processes are linked by energy and material flows with

- the technosphere (technical systems or the economy) and
- the biosphere (nature or the life-supporting ecosystem).

The first link comprises exchanges with the economic system such as the purchase of intermediate goods (machinery, working materials, etc.) or services (waste treatment, transportation, telecommunication). Direct resource extraction (e.g., supply of river water) and direct emissions to air, water or soil are relations of the second kind.

Accordingly, the directly caused energy and material flows of a unit process form a vector that is divided into an economic and an ecological sector **a** and **b**, respectively. The vector includes m economic exchanges a_i and n ecological exchanges b_j.

$$\begin{pmatrix} \mathbf{a} \\ \mathbf{b} \end{pmatrix} = \begin{pmatrix} a_1 \\ \ldots \\ a_i \\ \ldots \\ a_m \\ b_1 \\ \ldots \\ b_j \\ \ldots \\ b_n \end{pmatrix}$$

The next step is to create a model of that part of the world economic system which comprises all processes required to produce a certain product or for the delivery of a certain service. Such a model will - among others - certainly include the energy supply sector, the transportation sector, the waste treatment sector and certain parts of the mining sector (minerals). All unit process vectors together form a matrix with an economic part A and an ecological part B.

$$\mathbf{P} = \begin{pmatrix} \mathbf{A} \\ \mathbf{B} \end{pmatrix} = \begin{pmatrix} a_{11} & \ldots & a_{1l} & \ldots \\ \ldots & \ldots & \ldots & \ldots \\ a_{i1} & \ldots & a_{il} & \ldots \\ \ldots & \ldots & \ldots & \ldots \\ a_{m1} & \ldots & a_{ml} & \ldots \\ b_{11} & \ldots & b_{1l} & \ldots \\ \ldots & \ldots & \ldots & \ldots \\ b_{j1} & \ldots & b_{jl} & \ldots \\ \ldots & \ldots & \ldots & \ldots \\ b_{n1} & \ldots & b_{nl} & \ldots \end{pmatrix}$$

By calculating the inverse of the economic part A of the matrix P one gets the cumulative demand of intermediate goods and services required to produce each of the unit processes (economic part of the cumulative matrix called C). In order to be able to invert the matrix, it must be square and non-singular. These two conditions are normally fulfilled when modelling real economic systems.

The cumulative amounts of resource extractions and emissions (cumulative ecological part D) are calculated by multiplying the ecological part B of Matrix P with the computed cumulative economic part C.

In our model the vectors of the unit processes contain the relation of a unit process with itself (i.e., the process 1kg of steel from blast furnace, for instance, produces 1kg of steel from blast furnace). Matrix A can be rewritten as

$$A = I - Z$$

where $Z \in R^{mxm}$ and their diagonal is composed of zero values. The inverse can be written as

$$C = A^{-1} = (I - Z)^{-1} = \sum_{k=0}^{\infty} Z^k$$

and the cumulative resource extraction and emission matrix D is computed as follows

$$D = BC = B(I - Z)^{-1}$$

The inventory matrix **P***, composed of *C* and *D*,

$$\mathbf{P^*} = \begin{pmatrix} \mathbf{C} \\ \mathbf{D} \end{pmatrix}$$

contains information about the total (cumulative) requirements of economic entities (intermediate goods and services) and about the total (cumulative) flows of ecological entities (elementary flows, i.e. resource extractions and emissions) of all unit processes the matrix is composed of.

For the numerical implementation of the matrix inversion direct methods are usually applied that make use of publicly available source code libraries. These methods base on the Gauss-elimination and use the LU factorisation creating a lower left triangular matrix L and an upper right triangular matrix U.

The factorisation is done with a partial pivot strategy in order to guarantee the numerical stability. Because the size of the real figures in the matrix P varies between 10^{-6} to 10^{6} (and even more), the scaling of rows and columns should be done in a way that all new figures are about in the same order of magnitude.

For fully occupied matrices the calculation requirements are proportional to the third power of the size (m) of the matrix. For sparse matrices as the ecoinvent matrix, the use of renumeration and elimination strategies helps to dramatically reduce the calculation effort. The use of partial pivoting and an eventual rescaling of the matrix guarantee the numerical stability.

8.4 Outlook

After describing the database format applied within this project some important points are highlighted which need further improvements for future studies in this area.

The database contains about 4'000 different datasets in its current release v2.0. For some users it might be difficult to decide which dataset is most appropriate in a specific context. Therefore it would be good to have an additional marker in the data format which makes it possible to distinguish between datasets which are intended for a broad range of applications and datasets which are only relevant for experts in this field or for specific modelling issues. For the time being it is referred to the Code of Practice (the booklet accompanying the CD-ROM), where practical hints are given for an appropriate choice of frequently used datasets.

9 Good practice

9.1 Introduction

In this chapter further quality control measures applied in the ecoinvent work flow are described. They cover the documentation of process data, the internal review of datasets and reports, as well as the version and error management. Finally, the way LCI and LCIA results are presented is explained.

9.2 Documentation of process data

The data used to describe the inputs and outputs of a particular process shall be discussed within the context of values from various sources. The ecoinvent values shall not be used without comments. The "general comment" data field ID 3792 of the EcoSpold data format (see Chapter 8 and Hedemann & König 2003) can be used to describe the individual figures and their estimation.

9.3 References

References in the final reports are given on the most detailed level possible (attributed to the inputs and outputs of a particular process, attributed to a particular elementary flow within process data, etc.). When citing large reference works, chapters, table numbers and / or page numbers shall be included. In the ecoinvent database itself, reference is only made to the corresponding final report of the ecoinvent projects.

9.4 Internal review of dataset and reports

All reports and all datasets were read and commented prior to the storage of the datasets in the database. A person from another ecoinvent institute was responsible for the internal review or validation. The datasets are also validated prior to their import into the ecoinvent database by the same person. A validation comment is added to the dataset. Fig. 9.1 shows an overview of the internal review and data quality control process.

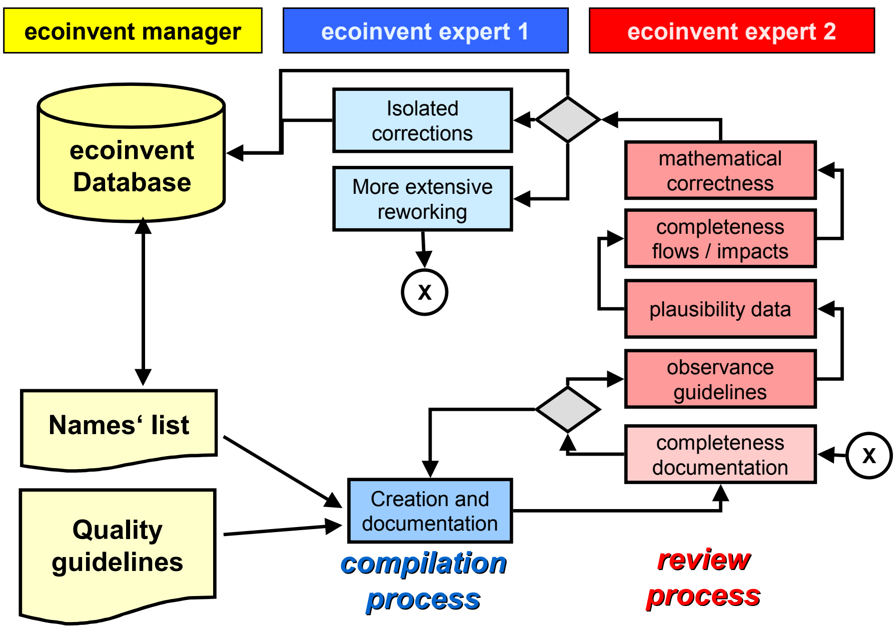

Fig. 9.1 Overview of the internal review and data quality control within the ecoinvent project

In this review the following five issues (shown on the right hand side of Fig. 9.1) are checked in points:

- Completeness of the documentation. All investigated datasets should be described in the report, and all necessary meta information and flow data should be available for each dataset.
- Consistency with the quality guidelines. It is checked whether the unit processes have been modelled according to the ecoinvent quality guidelines. The quality guidelines cover for example the estimation of transport distances or the calculation of energy demands in the inventory (see chapters 4 to 7).
- Plausibility check of the life cycle inventory data. Selected input and output flows are controlled for plausibility.
- Completeness of inputs and outputs. The completeness of flows is based on the environmental and technical knowledge of the reviewing person. Reviewers are not necessarily technical experts of the processes reviewed. If necessary they were supported by the person responsible for the report.
- Mathematical correctness of calculations. Selected inputs and outputs are controlled in view of mathematical correctness, e.g. the transport service inputs, the waste heat or CO_2 emissions.

The reviewer gave a feedback to the analyst. This includes a proposal for the further procedure:

- dataset import in database without changes
- dataset import in database after (minor) corrections of the data
- dataset import in database after a major revision of the data and after a second review (see X in Fig. 9.1)

The review procedure is not comparable to the peer review specified in the ISO standards. The reviewers have normally a good expertise in LCA, but they are not necessarily experts in the specific themes of the reports.

It has to be emphasised that the responsibility for the contents of all datasets remains with the person and institute who investigated the data. The reviewer helped to improve the quality of datasets and reports with his or her suggestions. But it was the final decision of the dataset "owner" whether or not to consider all proposals for corrections of the data.

9.5 Versions and errors

A version number of the datasets can be found in the electronic data format and on the title page of the reports. Discovered errors will be corrected in a next intermediate version. The members of the ecoinvent database are informed about errors and its expected date of correction via the Internet ("News" on the ecoinvent website, "Changes" report), and via the ecoinvent Newsletter.

9.6 Discussion of results and life cycle impact assessment

The ecoinvent project does not aim at providing full LCA information (i.e., including a complete interpretation phase) of all investigated products. In general the discussion of results is kept quite short or even missing. Only some selected LCI results and the LCIA values of the cumulative energy demand (CED) are presented and discussed in some of the reports. Thus only a small part of the more than 1'000 elementary flows is presented. The selection of the elementary flows shown in the tables is not based on their environmental relevance. It rather allows showing by examples the contributions of the different life cycle phases, or specific inputs from the technosphere to the selected elementary flows. The complete LCI results are only available from the ecoinvent database or with commercial LCA software tools.

Tab. 9.1 shows an example of such a result table of selected LCI results and the cumulative energy demand of some metals processing datasets. In the first rows the cumulative energy demand (LCIA results) are shown. Eight categories of energy resources are distinguished (fossil, nuclear, primary forest, biomass, geothermal, solar, water, wind). The first, second and third represent non renewable energy resources while the others describe the use of renewable energy resources. Care must be taken when summing them up in order to compare these results with the ones from other LCA or CED studies. The conversion factors applied are described in Frischknecht *et al.* (2007b).

Further below, a selection of elementary flows is listed. In the ecoinvent database these flows are listed separately for each subcategory. In the results chapter, however, elementary flows to one compartment but into different subcompartments are shown as totals only (see, e.g., "Carbon dioxide, fossil", or "NMVOC").

The different types of land occupation have been added up (unweighted). The results table includes some well known air pollutants, at least one example of emissions to water (the sum parameter biological oxygen demand) and at least one emission to soil (Cadmium). Additional elementary flows may be added by the responsible analyst depending on their appropriateness for the description of the product system at issue.

The shown selection is not intended to represent the complete result of a life cycle assessment of the analysed processes and products. The use of the data presented in the results tables is strongly discouraged. For further calculations and the use of ecoinvent data in LCA studies, the data directly downloaded from the database (or available in commercial LCA software) should be used. Besides their completeness, the data presented in the results tables may possibly deviate from the one in the database due to corrections and changes in background data after the publication of the final reports.

The ecoinvent database also contains life cycle impact assessment results. Assumptions and interpretations were necessary to match current LCIA methods with the ecoinvent inventory results. They are described in Frischknecht *et al.* (2007b). It is strongly advised to read the respective chapters of the implementation report before applying LCIA results.

Tab. 9.1 Selected LCI results and the cumulative energy demand (LCIA result) for cold impact extrusion of aluminium

	Name		cold impact extrusion, aluminium, 1 stroke	cold impact extrusion, aluminium, 2 strokes	cold impact extrusion, aluminium, 3 strokes	cold impact extrusion, aluminium, 4 strokes	cold impact extrusion, aluminium, 5 strokes
	Location		RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0
	Infrastructure		kg	kg	kg	kg	kg
CED	fossil fuels	MJ-Eq	11.2	15.4	19.6	23.8	28.0
CED	nuclear	MJ-Eq	4.2	6.9	9.7	12.5	15.2
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	0.2	0.3	0.4	0.5	0.6
CED	geothermal, converted	MJ-Eq	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	0.5	0.8	1.1	1.4	1.7
CED	kinetic (in wind), converted	MJ-Eq	0.1	0.1	0.2	0.2	0.3
land occupation	resource	m2a	5.6E-2	6.3E-2	7.1E-2	7.9E-2	8.6E-2
CO2, fossil	air	kg	8.6E-1	1.2E+0	1.5E+0	1.8E+0	2.2E+0
NMVOC	air	kg	3.3E-4	4.0E-4	4.7E-4	5.4E-4	6.1E-4
nitrogen oxides	air	kg	1.3E-3	1.9E-3	2.5E-3	3.0E-3	3.6E-3
sulphur dioxide	air	kg	1.9E-3	3.1E-3	4.2E-3	5.3E-3	6.5E-3
particulates, <2.5 um	air	kg	1.6E-4	2.4E-4	3.3E-4	4.1E-4	5.0E-4
BOD	water	kg	1.7E-3	1.9E-3	2.0E-3	2.1E-3	2.3E-3
cadmium	soil	kg	7.2E-10	8.7E-10	1.0E-9	1.2E-9	1.3E-9

Abbreviations

a	annum = year
ART	Agroscope Reckenholz-Tänikon Research Station
BOD_5	Biological oxygen demand in five days
COD	Chemical oxygen demand
DOC	Dissolved organic carbon
DTD	Document Type Definition
EAWAG	Swiss Federal Institute for Environmental Science and Technology
EMPA	Swiss Federal Laboratories for Materials Testing and Research
EPFL	Swiss Federal Institute of Technology Lausanne
ESU	Energie – Stoffe – Umwelt (energy – materials – environment)
ETHZ	Swiss Federal Institute of Technology Zürich
FAL	Swiss Federal Research Station for Agroecology and Agriculture
FAT	Swiss Federal Research Station for Agricultural Economics and Engineering
ha	hectare
IPP	Integrated Product Policy
kBq	kilo becquerel
kg	kilogram
kWh	kilo watt hour
LU	Livestock unit (Grossvieheinheit, GVE)
m^2	square metre
m^3	cubic metre
MJ	Mega joule
MSWI	municipal solid waste incineration
Nm^3	norm cubic metre
NMVOC	Non-methane volatile organic carbon
PGM	platinum group metals
pkm	person kilometre (Personenkilometer)
PM10	particulate matter with a diameter of less than 10 µm
PM2.5	particulate matter with a diameter of less than 2.5 µm
PSI	Paul Scherrer Institute
SD_{g95}	square of the geometric standard deviation (95% interval)
SWU	Separative work units
tkm	ton kilometre (Tonnenkilometer)
TOC	Total organic carbon
TSP	total suspended particulates
vkm	vehicle kilometre (Fahrzeugkilometer, Fzkm)
VOC	Volatile organic compounds
XML	extended markup language

Appendix

Country codes in ecoinvent data v2.0[12]

Tab. A. 1 List of region and country codes (the latter based on ISO-Alpha-2 codes)

CountryCode	Country
AD	Andorra
AE	United Arab Emirates
AF	Afghanistan
AFR	Sub-Sahara Africa
AG	Antigua and Barbuda
AI	Anguilla
AL	Albania
AM	Armenia
AN	Netherlands Antilles
AO	Angola
AQ	Antarctica
AR	Argentina
AS	American Samoa
AT	Austria
AU	Australia
AW	Aruba
AX	Åland Islands
AZ	Azerbaijan
BA	Bosnia and Herzegovina
BB	Barbados
BD	Bangladesh
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BH	Bahrain
BI	Burundi
BJ	Benin
BM	Bermuda
BN	Brunei Darussalam
BO	Bolivia
BR	Brazil
BS	Bahamas
BT	Bhutan
BV	Bouvet Island
BW	Botswana
BY	Belarus
BZ	Belize
CA	Canada
CC	Cocos (Keeling) Islands
CD	Congo, The Democratic Republic Of
	The
CENTREL	Central european power association
CF	Central African Republic
CG	Congo
CH	Switzerland
CI	Cote D'ivoire
CK	Cook Islands
CL	Chile
CM	Cameroon
CN	China
CO	Colombia
CPA	Centrally Planned Asia and China
CR	Costa Rica
CS	Serbia and Montenegro
CU	Cuba
CV	Cape Verde
CX	Christmas Island
CY	Cyprus
CZ	Czech Republic
DE	Germany
DJ	Djibouti
DK	Denmark
DM	Dominica
DO	Dominican Republic
DZ	Algeria
EC	Ecuador
EE	Estonia
EEU	Central and Eastern Europe
EG	Egypt
EH	Western Sahara
ER	Eritrea
ES	Spain
ET	Ethiopia
FI	Finland
FJ	Fiji
FK	Falkland Islands (Malvinas)
FM	Micronesia, Federated States Of
FO	Faroe Islands
FR	France
FSU	Independent States of the Former Soviet Union
GA	Gabon
GB	United Kingdom
GD	Grenada
GE	Georgia
GF	French Guiana
GH	Ghana
GI	Gibraltar
GL	Greenland
GLO	Global
GM	Gambia

[12] ISO 3166 (2005): information retrieved from http://www.iso.org/iso/country_codes/iso_3166_code_lists/english_country_names_and_code_elements.htm

CountryCode	Country
GN	Guinea
GP	Guadeloupe
GQ	Equatorial Guinea
GR	Greece
GS	South Georgia and The South Sandwich Islands
GT	Guatemala
GU	Guam
GW	Guinea-bissau
GY	Guyana
HK	Hong Kong
HM	Heard Island and Mcdonald Islands
HN	Honduras
HR	Croatia
HT	Haiti
HU	Hungary
ID	Indonesia
IE	Ireland
IL	Israel
IN	India
IO	British Indian Ocean Territory
IQ	Iraq
IR	Iran, Islamic Republic Of
IS	Iceland
IT	Italy
JM	Jamaica
JO	Jordan
JP	Japan
KE	Kenya
KG	Kyrgyzstan
KH	Cambodia
KI	Kiribati
KM	Comoros
KN	Saint Kitts and Nevis
KP	Korea, Democratic People's Republic Of
KR	Korea, Republic Of
KW	Kuwait
KY	Cayman Islands
KZ	Kazakhstan
LA	Lao People's Democratic Republic
LB	Lebanon
LC	Saint Lucia
LI	Liechtenstein
LK	Sri Lanka
LR	Liberia
LS	Lesotho
LT	Lithuania
LU	Luxembourg
LV	Latvia
LY	Libyan Arab Jamahiriya
MA	Morocco
MC	Monaco

CountryCode	Country
MD	Moldova, Republic Of
MEA	Middle East and North Africa
MG	Madagascar
MH	Marshall Islands
MK	Macedonia, The Former Yugoslav Republic Of
ML	Mali
MM	Myanmar
MN	Mongolia
MO	Macao
MP	Northern Mariana Islands
MQ	Martinique
MR	Mauritania
MS	Montserrat
MT	Malta
MU	Mauritius
MV	Maldives
MW	Malawi
MX	Mexico
MY	Malaysia
MZ	Mozambique
NA	Namibia
NC	New Caledonia
NE	Niger
NF	Norfolk Island
NG	Nigeria
NI	Nicaragua
NL	Netherlands
NO	Norway
NORDEL	Nordic countries power association
NP	Nepal
NR	Nauru
NU	Niue
NZ	New Zealand
OCE	Oceanic
OM	Oman
PA	Panama
PAO	Pacific OECD (Japan, Australia, New Zealand)
PAS	Other Pacific Asia
PE	Peru
PF	French Polynesia
PG	Papua New Guinea
PH	Philippines
PK	Pakistan
PL	Poland
PM	Saint Pierre and Miquelon
PN	Pitcairn
PR	Puerto Rico
PS	Palestinian Territory, Occupied
PT	Portugal
PW	Palau
PY	Paraguay

CountryCode	Country
QA	Qatar
RAF	Africa
RAS	Asia and the Pacific
RE	Reunion
RER	Europe
RLA	Latin America & the Caribbean
RME	Middle East
RNA	North America
RNE	Near East
RO	Romania
RU	Russian Federation
RW	Rwanda
SA	Saudi Arabia
SAS	South Asia
SB	Solomon Islands
SC	Seychelles
SD	Sudan
SE	Sweden
SG	Singapore
SH	Saint Helena
SI	Slovenia
SJ	Svalbard and Jan Mayen
SK	Slovakia
SL	Sierra Leone
SM	San Marino
SN	Senegal
SO	Somalia
SR	Suriname
ST	Sao Tome and Principe
SV	El Salvador
SY	Syrian Arab Republic
SZ	Swaziland
TC	Turks and Caicos Islands
TD	Chad
TF	French Southern Territories
TG	Togo

CountryCode	Country
TH	Thailand
TJ	Tajikistan
TK	Tokelau
TL	Timor-leste
TM	Turkmenistan
TN	Tunisia
TO	Tonga
TR	Turkey
TT	Trinidad and Tobago
TV	Tuvalu
TW	Taiwan, Province Of China
TZ	Tanzania, United Republic Of
UA	Ukraine
UCTE	Union for the Co-ordination of Trans-mission of Electricity
UG	Uganda
UM	United States Minor Outlying Islands
US	United States
UY	Uruguay
UZ	Uzbekistan
VA	Holy See (Vatican City State)
VC	Saint Vincent and The Grenadines
VE	Venezuela
VG	Virgin Islands, British
VI	Virgin Islands, U.S.
VN	Vietnam
VU	Vanuatu
WEU	Western Europe
WF	Wallis and Futuna
WS	Samoa
YE	Yemen
YT	Mayotte
ZA	South Africa
ZM	Zambia
ZW	Zimbabwe

Standard terminology used in the ecoinvent reports

English			German	
Term	**synonyms**	**definition**	**Begriff**	**Synonyme**
ancillary input *		material input that is used by the unit process producing the product but does not constitute a part of the product. *	Betriebsstoff-Input *	
cumulative energy demand (CED) §		The cumulative energy demand (CED) states the entire demand, valued as primary energy, which arises in connection with the production, use and disposal of an economic good (product or service) or which may be attributed respectively to it in a causal relation. § *Comment: To be applied only if such information is provided in a source based on which the unit process inventory is compiled.*	Kumulierter Energieaufwand (KEA) §	
energy carrier		Substance or phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes. £	Energieträger	
energy flow *		input or output from a unit process or product system, quantified in energy units. *	Energiefluss *	
feedstock energy *		heat of combustion of raw material inputs, which are not used as an energy source, to a product system (or unit process). *	Energetisch bewerteter Primärrohstoffeintrag *	Indirekte Energie, stofflich verwendete Energie
final energy §		Energy content of all primary and secondary energy carriers supplied to consumers, reduced by the non-energy demand, by the conversion losses and, in case of self generation of electricity or gas by the final user, by the auxiliary energy demand. §	Endenergie §	
final product *		product which requires no additional transformation prior to its use. *	Endprodukt *	
fuel		synonym for final energy carriers.	Brennstoff, Treibstoff	
fugitive emission *		uncontrolled emission to air, water or land (e.g., material released from a pipeline coupling) *	unkontrollierte Emission *	
intermediate product *		input or output from a unit process which requires further transformation. *	Zwischenprodukt *	
kind of energy		general term when describing the kind of energy used in a certain process.	Energieform	
life cycle inventory analysis result; LCI result *		outcome of a life cycle inventory analysis that includes the flows crossing the system boundary and provides the starting point for life cycle impact assessment. *	Sachbilanzergebnis *	

English			German	
Term	**synonyms**	**definition**	**Begriff**	**Synonyme**
primary energy §		Energy content of energy carriers that have not yet been subjected to any conversion. §	Primärenergie §	Rohenergie §
process emissions		in situ emissions of a unit process	Prozessemissionen	Produktionsemissionen
process energy *		energy input required for a unit process to operate the process or equipment within the process excluding energy inputs for production and delivery of this energy. *	Prozessenergie *	Direkte Energie
production and delivery energy $		energy required for the production, treatment and delivery of energy. *Comment: To be applied only if such information is provided in a source based on which the unit process inventory is compiled. Could as well be applied for cumulative energy demand of other products than just energy.*	Kumulierter Energieaufwand für die Bereitstellung von Prozessenergie $	
reference flow *		measure of the needed outputs from processes in a given product system required to fulfil the function expressed by the functional unit. *	Referenzfluss *	
secondary energy §		Energy content of energy carriers that have been obtained through the conversion of primary energy carriers or other secondary energy carriers. §	Sekundärenergie §	
unit process inventory	unit process raw data	Inventory of energy and material flows (in- and outputs) which are used by an unit process.	Sachbilanz eines Einheitsprozesses	
useful energy §		Energy which is available for the respective purpose of the end-user after the last conversion. This is the technical form of energy which the consumer finally requires for the respective purpose, e.g., heat, mechanical energy, light, useful electricity (e.g., for galvanising and electrolysis) and electromagnetic radiation. §	Nutzenergie §	
useful heat		Heat which is available for the respective purpose of the end-user after the last conversion.	Nutzwärme	

Sources:

*: ISO 14040 and 14044, Environmental management - Life cycle assessment

§: VDI 4600, Cumulative Energy Demand

£: ISO 13600, Technical energy systems - Basic concepts

$: DIN Deutsches Institut für Normung e.V., Englisch - Deutsche Fachwörterliste zur EN ISO 14040er-Serie, Stand 13.10.98.

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