Overview and methodology

Data quality guideline for the ecoinvent database version 3

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Acknowledgements v3

This data quality guideline builds upon the previous ecoinvent reports 1 and 2 (Frischknecht et al. 2007b, 2007c). A short history of the ecoinvent database is reported in Chapter 17.

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Structure of this guideline

This guideline provides an introduction to the ecoinvent database developed by the Swiss Centre for Life Cycle Inventories (Chapter 1), the applied LCA methodology (Chapter 2), and the general structure of the database (Chapter 3).

The main part of the report is the specific quality guidelines (chapters 4 to 11), established in order to ensure a coherent data acquisition and reporting across the various activity areas and data providers involved. This encompasses definitions of the different types of datasets, the level of detail required, how completeness is ensured, good practice for documentation, naming conventions, and rules for the reporting of uncertainty.

Chapters 12 and 13 describe the procedures for validation, review, and embedding new datasets into the database.

The calculation procedures for linking datasets into product systems, and for arriving at the accumulated results for product systems, are described in Chapter 14.

Chapter 15 and 16 give advice to the database users and those who wish to contribute to the database.

Finally, Chapter 17 gives a short history of the database development.

Examples from the actual applications in the database will be available on the ecoinvent web-site.

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1 Introduction to the ecoinvent database v3

This chapter offers a short introduction to the ecoinvent version 3 database. It begins by explaining the purpose of the database and our reasons for updating the successful ecoinvent version 2 and introducing a new version number. It then describes the most important changes and fundamentally new concepts of version 3 in a brief summary, aimed especially at users accustomed to the database version 2, referencing the more detailed descriptions in the following chapters. The chapter ends with two sections on working with ecoinvent 3, the first from a user's perspective, the second with additional information for data providers.

1.1 The purpose of the ecoinvent database

The Swiss Centre for Life Cycle Inventories (the ecoinvent Centre) has the mission to promote the use and good practice of life cycle inventory analysis through supplying life cycle inventory (LCI) data to support assessment of the environmental and socio-economic impact of decisions.

The strategic objective is to provide the most relevant, reliable, transparent and accessible LCI data for users worldwide.

The ecoinvent database comprises LCI data covering all economic activities. Each activity dataset describes an activity at a unit process level. The complete list of all names of datasets, elementary exchanges, and of all regional codes is available at www.ecoinvent.org.

Consistent and coherent LCI datasets for different human activities make it easier to perform life cycle assessment (LCA) studies, and increase the credibility and acceptance of the LCA 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. Data quality is maintained by a rigorous validation and review system. The document at hand reports the data quality guidelines applied.

The ecoinvent LCI datasets are intended as background data for LCA studies where problem- and case-specific foreground data are supplied by the LCA practitioner. The LCI and life cycle impact assessment (LCIA) results of ecoinvent datasets may be used for comparative assessments with the aim to identify environmentally preferable goods or services, but should not be used without considering the relevance and completeness of the data for the specific assessment.

The ecoinvent datasets may also be useful as background datasets for studies in material flow accounting and general equilibrium modelling. The ecoinvent Centre is interested in a dialogue with such user groups, to improve the usability of the datasets in such contexts outside the narrower LCA field.

1.2 Fundamental changes in version 3 & differences to version 2

Our starting point for the development of version 3 of the ecoinvent database was the successful version 2, and our focus has been to ensure that version 3 will continue to satisfy the needs of LCA practitioners. At the same time, the new version 3 should allow significant advancements concerning data management, globalisation, and flexibility. One of the ways of achieving this was an overhaul of the underlying structure of ecoinvent. Since the initial versions of the ecoinvent database, database management has grown more complex. To ensure that the database can continue to grow without problems, several changes were implemented to allow an easier inclusion of new processes and alternative system models into the database. Other changes facilitate future updates of data. The development of ecoinvent, from its origins as a Swiss national database to a truly global database today, places new demands on the calculation software and the data format. The ongoing discussion on different modelling approaches (e.g. allocation vs. substitution, average vs. unconstrained suppliers) highlights the need for a flexible data structure that can easily be adapted to different modelling needs, while ensuring the consistency of the ecoinvent data. And of course, version 3 continues to increase our supply of reliable and transparent inventory data.

For the development of ecoinvent version 3, the ecoSpold data format has been extended and updated, so while ecoinvent version 1 and version 2 used the ecoSpold 1 data format, ecoinvent version 3 uses the ecoSpold 2 data format. The specification of the new data format and a converter from ecoSpold 1 to ecoSpold 2 are available at www.ecoinvent.org, along with the freeware 'ecoEditor for ecoinvent version 3', which allows users to view, create, and modify ecoSpold 2 files, and submit them for review. The update of the data format was necessary for the implementation of several new concepts in the way data are stored and linked, such as:

1.2.1 System models

Newly introduced is the distinction between the unlinked ecoinvent datasets and the linked system models. In the ecoinvent database version 2, only one system model existed, following an attributional approach, using allocation rules for multi-output processes according to the recommendations of the individual data providers. The difference in version 3 is that there are now several system models, all of which are used to create fully independent and self-contained model implementations out of the same unlinked ecoinvent data. As an ecoinvent database user, your first important choice is therefore to determine which system model you want to use, according to the goal and scope definition of your project. The system model "Allocation, ecoinvent default" uses the same attributional approach as ecoinvent version 2. The other main system model is "Substitution, consequential, long-term", using substitution (also known as 'system expansion') to substitute by-product outputs and taking into account both constrained markets and technology constraints. More system models are or will be made available for specialized use, e.g. "Allocation by revenue", a model consistently using economic data for allocation. It is vital to be aware of which system model version you are using in your projects, and to communicate this openly when talking about results based on these data.

See Chapter 14 for more information on the system models provided in ecoinvent version 3, and for recommendations on which system model to choose for different application areas.

1.2.2 The linking of datasets into system models

To allow the application of different system models, the underlying ecoinvent database service layer (see Chapter 3) has been expanded with the ability to automatically create the system model implementations out of the unlinked ecoinvent datasets. For the ecoinvent database version 2, data providers had to specify where their input of e.g. cement came from. Sometimes, country-specific consumption mixes were created, but often the sources were directly linked to the consuming process. For ecoinvent database version 3, it is sufficient to say where an activity is located, e.g. USA, to allow the database service layer to determine that the input of cement must come from the U.S. market activity dataset (basically an extended consumption mix, now available for each product in the database), which describes the origins of cement consumed in the U.S. The inputs to the market activity dataset are calculated from the production volumes of the various cement-supplying activities located within the boundary of the market, i.e. USA.

The database service layer can calculate both the average supply and – using additional information on the technology level provided in each supplying dataset – the unconstrained supply, as used in consequential system models.

Market activities also include the transport types and distances required to supply a specific product, simplifying the situation for data providers and allowing an easy, centralized way of updating the transport assumptions in ecoinvent. The ubiquitous transport inputs to production activities in version 2 have therefore disappeared, and most production activities now have no inputs of transport at all.

Note that direct linking of an input to a specific good or service from a specific activity is still possible – in these cases transport is added manually, just like in version 2.

See Chapters 4.3 to 4.9 for more information on the functions of market activities in the ecoinvent database version 3.

1.2.3 Regionalisation

The ecoinvent database version 3 includes new features for improved support of regionalised inventories and impact assessment. The new data format supports regions of any shape and size. Regional shapes are given by a series of coordinates, but the database also allows the use of shortcut names, ranging from countries to states, watersheds, etc. Should you require new regions to be defined, these can be created in a simple, free tool, available from the ecoinvent web-site.

1.2.4 Parameterisation

The new ecoSpold 2 data format allows the use of formulas to calculate the amounts of flows and other entities in the datasets. As a database user, you may encounter this when analysing unit processes; for example, the amount of carbon dioxide emissions of a coal burning activity may be expressed as a function of the mass and carbon content of the coal burned in the process. Calculations and models that were previously only available in the background can now be incorporated into the datasets directly. This enhances consistency, removes a potential source of errors, and reduces database maintenance efforts. As a user, you are also able to directly observe the origins of the amounts in ecoinvent datasets instead of simply seeing a number and having to refer to background reports for the reasoning behind the number. During the calculation of aggregated system datasets or impact assessment results, the formulas are automatically resolved. The use of parameterisation allows many exciting new options for data providers and helps to ensure the consistency and transparency of the database.

1.2.5 Global datasets

Many users have been missing international data in many areas of the ecoinvent database version 2. For ecoinvent version 3, we have prepared a framework for international datasets, to improve the international coverage of ecoinvent. One of the steps we have taken is to ensure that all activities in the ecoinvent database have a global dataset covering the average global production.

Such datasets existed also for some datasets in version 2 of ecoinvent; new is the step to introduce global datasets for all activities covered by ecoinvent version 3. While we have made efforts to collect new data for these datasets and these efforts are ongoing, it is important to realise that currently, many of these datasets are just extrapolated from one of the existing, regional datasets. These datasets are described as extrapolated in their comments fields and it is important to pay attention to the quality of these data. The increased uncertainty from these extrapolations is quantified by the pedigree matrix approach, which is generally used in the ecoinvent database to describe uncertainty resulting from less than perfect data quality. It is more important than ever to consider these uncertainties in your work.

The decision to offer these global datasets was not an easy one. On the one hand, ecoinvent has always been dedicated to high-quality data, and for those global datasets that are based solely on extrapolation, important information may be missing. On the other hand, the widespread use of ecoinvent version 2 in developing countries demonstrated the need for a more consistent approach. Users in these countries often applied European datasets to their region without adjusting the uncertainty information. Clearly, global datasets with a true and transparent assessment of their data quality are a better solution for these users. Meanwhile, users in regions well covered by high-quality data will not be negatively influenced by these datasets. Ecoinvent version 3 therefore offers these extrapolated datasets, with the goal of continuously improving their data quality.

1.2.6 Parent/child datasets and inheritance

The new ecoSpold 2 format allows inheritance between datasets: to create a dataset as a child of a parent dataset. This approach is optional, but will be used for groups of closely related datasets. In ecoinvent 3, we only implement inheritance for geography: A local dataset can be created as a child of the global parent dataset. But we will continue to develop this feature and test its usefulness in other areas, especially to create datasets for time series and scenarios.

Inheritance has the advantage that the child dataset inherits all flows from the parent unless otherwise specified – ensuring consistency of datasets for the same activity in different regions. For example, the operation of a certain type of truck can be described and edited only once in the global parent, while the German, Polish, Japanese, etc., datasets only report the difference to the global dataset. The database stores the parent dataset and the difference datasets, and the child datasets are then calculated by combining the parent dataset with a specific difference dataset. Child datasets may inherit values for flows, use parent values as a parameter in a formula, or replace parent values entirely.

As a database user, you will most likely not come in contact with this concept much, since a calculated child dataset will appear fully functional and self-contained, as any other dataset.

See Chapter 4.2 for more information on parent and child datasets.

1.2.7 No cut-offs

Ecoinvent version 2 followed the cut-off approach for modelling of recycling processes, in many cases cutting off product flows of recyclable materials completely. As more data are now available on treatment and recycling processes, the decision was made to abandon this approach and consistently seek to report all datasets as completely as possible, including all by-products and potentially recyclable materials, and consistently include these in allocation and/or substitution calculations.

See Chapters 4.10 and 5.10 for more information on recycling and cut-offs.

1.3 The editorial board and the review procedure

To handle the increased number of datasets, and the resulting increased demand for quality control and review, an editorial board has been established. It is made up of more than 50 editors, all experts in their fields. Each editor covers an area of economic activity (e.g. agriculture, mining, chemicals production, etc.), a specific geographical region, a specific type of emission, or specific database fields such as uncertainty, to ensure consistent reporting in the datasets across different industrial activities. Each new dataset passes at least 3 editors, at least one for the economic activity and at least two cross-cutting editors. The database administrator functions as chair of the editorial board, which thereby functions as a critical review panel according to ISO 14040. The review process and all reviewer comments are documented and stored by ecoinvent. The names and final review comments of the editors are stored in the datasets. The current list of editors is available at the ecoinvent web-site.

1.4 Using ecoinvent version 3

There are many further, smaller changes in ecoinvent 3. The data quality guidelines describe these in detail, but the summary in this chapter, and the general introductions and FAQs on the ecoinvent website, should provide you with everything you need to know to start working with ecoinvent 3.

The most important aspect to understand from a user perspective is that there are now different implementations of the ecoinvent database, referred to as system models. All system models are based on different fundamental assumptions and linking rules, and results will therefore vary depending on the choice of system model. For users familiar and satisfied with ecoinvent version 2, the system model “Allocation, ecoinvent default” will be the most appropriate. It is an attempt at a consistent implementation of the modelling principles of ecoinvent version 2. By default, it allocates exchanges from multi-output processes according to their revenue. However, the many updated and new datasets in version 3 will have changed the results to some extent compared to ecoinvent version 2. This is an effect independent of the introduction of the system model approach and is a consequence of our continued efforts to expand and improve ecoinvent. For an overview of the system models in ecoinvent version 3, please see Chapter 14.

Apart from the choice of the system model, little will change for database users. If you access the Life Cycle Impact Assessment results on the web-site or download them as Excel files, there will be no difference to working with the previous version. Inventories include more details and information than in ecoinvent version 2, but will otherwise look similar. The datasets can also be integrated into any software tool with import functionality for ecoSpold 2 files. We have been working with leading LCA software providers to assist them in the implementation of the ecoSpold 2 format.

1.5 Supplying data to ecoinvent version 3

Our goal has been to make it more comfortable to provide high-quality data for version 3. If you are new to the idea of supplying data to ecoinvent, you will appreciate the many beginner-friendly features included in the new ecoEditor tool, the main tool to provide data to ecoinvent. The ecoEditor is a freeware that can be downloaded from the ecoinvent web-site. Once you have submitted a dataset to ecoinvent via the ecoEditor, the feedback from the review is also shown directly in the ecoEditor in a separate Review Comments view, while highlighting the commented field. In general, the review process is streamlined and simpler than before, and the costs for data review are now covered by the ecoinvent centre, no longer by the data provider. In some areas, additional data are now asked for, while some automatic calculation, e.g. of uncertainty from the data quality scores and the automatic linking of datasets via markets, relieve data providers from work that previously had to be done manually. The new features of ecoSpold 2 format allow data providers to include their calculations in the datasets, giving them more control and more ways to ensure the consistency of the data and giving the database users more insight into the origin of the data. Further information for potential data suppliers can be found on the ecoinvent website.

2 LCA methodology

2.1 LCI, LCIA and LCA

The ecoinvent database builds on the method of life cycle assessment (LCA) as standardised by International Organisation for Standardisation (International Organization for Standardization (ISO) 2006a; International Organization for Standardization (ISO) 2006b). LCA studies systematically and adequately address the environmental aspects of product systems, from raw material acquisition to final disposal (from "cradle to grave"). The method distinguishes four main steps, namely (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation (see Fig. 2.1).

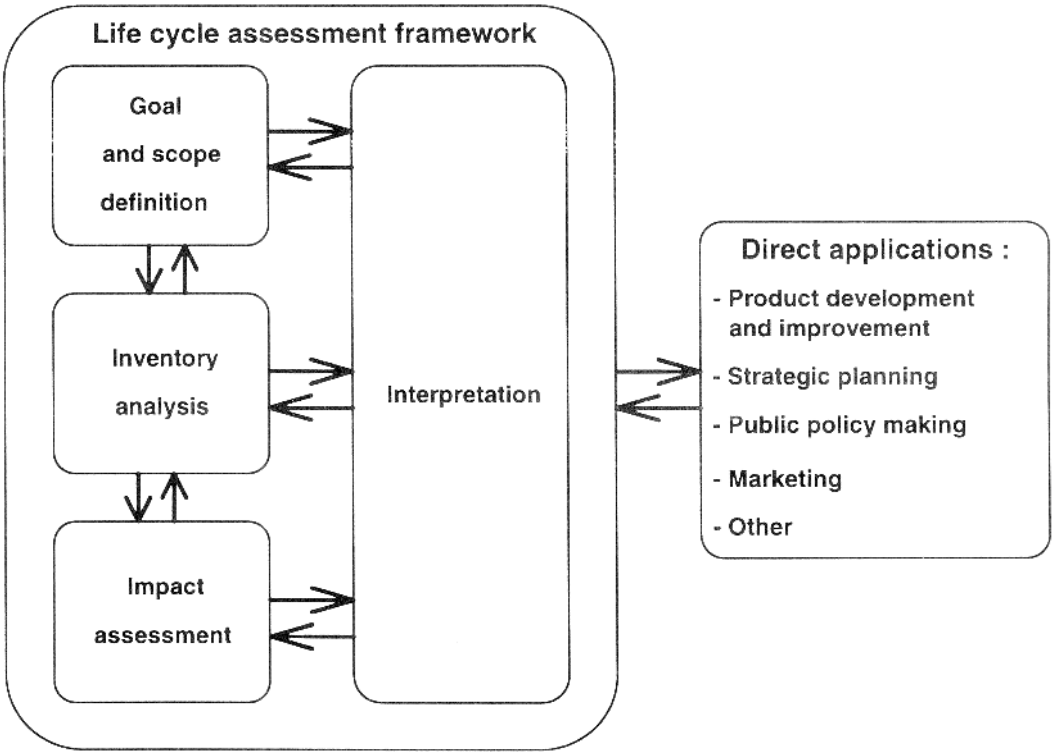


Fig. 2.1 Phases of an LCA (International Organization for Standardization (ISO) 2006a)

Focus of the ecoinvent database is on the compilation of the basic building blocks (LCI datasets), representing the individual unit processes of human activities and their exchanges with the environment, and the combination of these LCI datasets through the use of system models in life cycle inventory analysis (LCI), thus constructing life cycle inventories. Nevertheless, the ecoinvent database also contains data on impact assessment (LCIA) methods and results of applying these methods to the LCI data. However, the work on LCIA is limited to the implementation of already developed LCIA methods, such as the ecological scarcity or the Eco-indicator methods. No new ("ecoinvent") method has been developed (except for the cumulative energy demand, CED, for which no "official" or unified implementation exists). The implementation of the LCIA methods is done with the aim of giving guidance on how to combine ecoinvent LCI results with characterisation, damage or weighting factors of currently available LCIA methods.

2.2 Attributional and consequential modelling

For life cycle inventory analysis it is common to distinguish between consequential and attributional modelling (see Ekvall 1999; Frischknecht 1997; Guinée et al. 2001; Weidema 2003, Weidema & Ekvall 2009). The ecoinvent database with its modular structure supplying multi-product unit process raw data is suited to support both types of system modelling.

LCA system models differ in two aspects:

- The linking of inputs to either average or unconstrained suppliers.
- The procedures to arrive at single-product systems in situations of joint production of products, which apply either *partitioning (allocation)* of the multi-product system into two or more single-product systems, or *substitution (system expansion),* which eliminates the by-products by including the counterbalancing changes in supply and demand on the affected markets.

To allow calculation of the different system models, the following data are required for each activity:

- Amounts of the product properties that are applied for allocation (e.g. price, exergy, dry mass, carbon content).
- The distinction of reference products (determining products) from by-products, since the latter must be eliminated from models using substitution.
- Market trends, since consequential models distinguish different suppliers to be affected on shrinking and growing markets.
- Technology level, since consequential models regard only activities with specific technology levels to be affected by changes in demand.

The specific way these data are included in the individual datasets is described in Chapters 4 to 6. More details on the construction of different system models are provided in Chapter 14.

3 The basic structure of the ecoinvent database

The basic building blocks of the ecoinvent database are LCI datasets, representing the individual unit processes of human activities and their exchanges with the environment. For a more detailed description of the concept of datasets and exchanges, see Chapter 4.1. However, the ecoinvent database is not just a library of unlinked LCI datasets. The datasets are also interlinked, so that all intermediate goods and service inputs to a unit process, be it the consumption of electricity, the demand for working materials, or the use of capital equipment, are linked to other unit processes that supply these intermediate goods and services. The accumulated LCI result for a dataset is calculated by following the supplies of intermediate inputs of each dataset and summing up the environmental exchanges of these interlinked datasets. The calculation is done by matrix inversion, see Chapter 14.8 for details. This implies that any change in one unit process dataset will influence the accumulated LCI results of almost all other datasets.

In addition to the unit process LCI datasets and the accumulated LCI results for these datasets, the ecoinvent database also contains data on impact assessment (LCIA) methods and results of applying these methods to the LCI data.

A large, network-based database and efficient calculation routines are required for handling, storage, calculation and presentation of data. These components are partly based on preceding work performed at ETH Zurich (Frischknecht & Kolm 1995).

The following text refers to Figure 3.1 and describes first the different sections of the database itself, and next the flow of a dataset through the editorial process.

The database consists of several separate sections. Besides the ones mentioned here, which concern only the datasets, there is also a section for administration of access rights etc. of data providers, reviewers and end users. Also not shown in the figure is the ‘service layer’ of the database, consisting of functionalities for import, export, validation etc. that are common for more than one of the satellite components. Many of the functionalities are in practice placed in this service component, and shared by the different user interfaces.

From the top down in the figure:

The first section contains incomplete datasets, which gives a data provider the option to use the validation functions of the database service layer during the editing and before the final submission to review.

The second section contains datasets currently under review, in their different stages of commenting and revision.

The third section contains the production version of the database, which contains all datasets that have currently passed the review and are therefore uploaded by the final editor for integration into the database, but which are not yet part of the current official version.

The fourth section only exists temporarily, when the database administrator initiates the preparation of a new release. At this point in time, a copy of the current production version becomes the pre-release candidate, which is closed for further entries. The result calculations are made on this version, and when this has been successfully completed, the pre-release candidate becomes the new ‘Current official version’, while the previous official version is retained together with all other older versions.

The current official version is the one accessed by the end-users and resellers through ecoQuery (the web-interface at www.ecoinvent.org), while they – depending on user rights – also have access to the older versions.

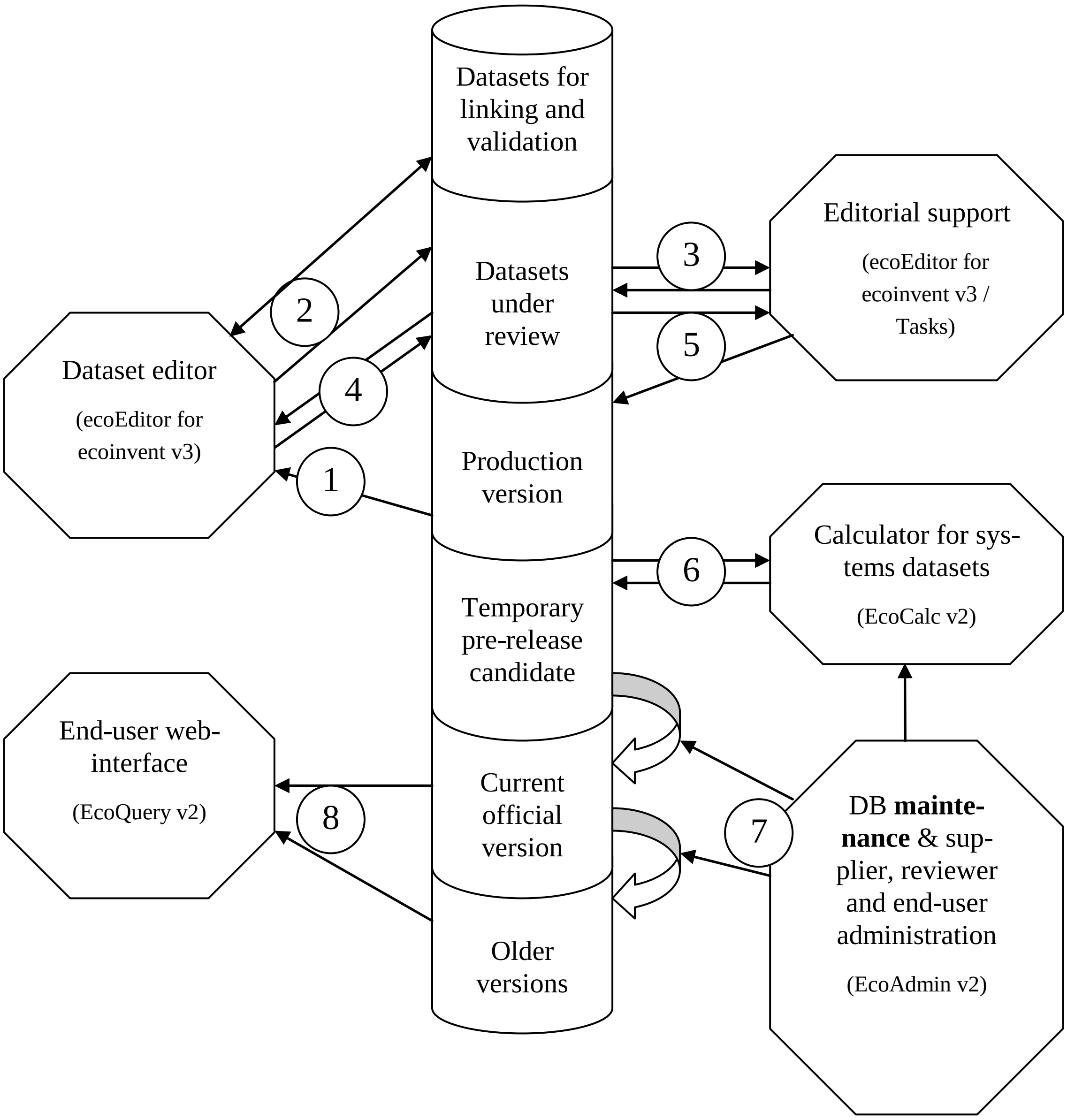


Fig. 3.1 The basic structure of ecoinvent database system

The flow of a dataset through the editorial process (numbers refer to Figure 3.1) is:

Creating a template for editing: To create new datasets in ecoSpold 2 data format and to edit existing datasets, data providers use the ecoEditor software, specifically developed for ecoinvent version 3. This software is provided by the ecoinvent centre free of charge and includes some tools for a first automatic validation. The data provider may use the ecoEditor with a blank template, load a dataset from the production version of the database (1) or work from an imported, externally sourced XML-file in ecoSpold v1 or v2 format. The ecoSpold data exchange format has evolved from the international SPOLD data exchange format (Weidema 1999) and is available as Open Source (www.spold.org).

Editing the data: The ecoEditor software includes validation routines to assist in identifying errors in the data before datasets are submitted for review. Some of these validation routines require on-line access to the central database (2). As part of the validation, the data provider may download and check the single-product, interlinked datasets that the database service layer generates from the multi-product, unlinked datasets received from the data provider.

Having finished the dataset and having applied the available pre-validation functions, the data provider submits the dataset(s) to review, i.e. to the 'Datasets under review' part of the database. During this upload, a final automatic validation is performed in interaction with the production version of the database.

Editorial process: The editors access the datasets for review through a special read-only-but-add-comments mode of the ecoEditor software. The procedural management of the review process (which persons, when) and the monitoring of this, is software-supported (3), and both data providers and editors access the datasets and review comments via a Tasks view in the ecoEditor software, which also provides access to a log of the review workflow.

During the review process, the dataset(s) may pass back and forth between data provider and reviewers several times (4), until all assigned reviewers have approved the dataset(s). Each dataset will pass at least 3 independent reviewers before upload to the database.

After the final approval: The main activity editor uploads the dataset to the production version of the database (5).

When the database administrator initiates the preparation of a new release, the database service layer (ecoCalc v2) performs the result calculations on the pre-release candidate (6).

The database administrator releases the new 'Current official version', while the previous official version is retained together with all other older versions (7).

The end-users and resellers access current and older versions through the ecoQuery v2 web-interface (8). Data can be viewed or downloaded, depending on users' rights.

4 Types of datasets

The term dataset can refer to activity datasets and impact assessment (LCIA) datasets. LCIA datasets are described in Chapter 4.13. All other sections of this Chapter deal exclusively with activity datasets.

4.1 Activity datasets, exchanges and meta-data

An ecoinvent activity dataset represents a unit process of a human activity and its exchanges with the environment and with other human activities. Several types of datasets are described in the following sub-chapters, but they all have in common that they have exchanges on the input side and on the output side, see Figure 4.1.

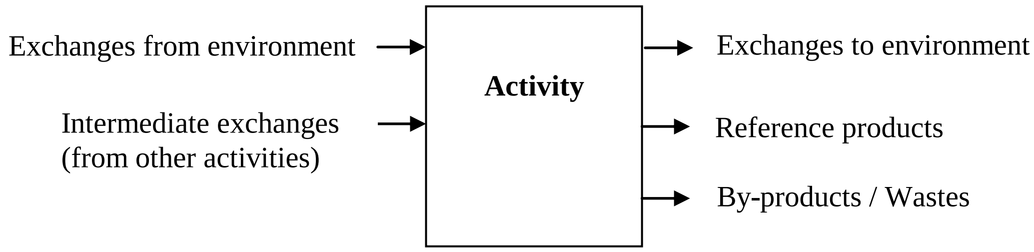


Figure 4.1. An activity dataset with its categories of exchanges

Exchanges from and to the environment, also called *elementary exchanges*[1], are placed on the input side and the output side respectively.

All other exchanges are intermediate exchanges, i.e. exchanges between activities. On the output side we distinguish between:

- Reference products
- By-products / Wastes

The distinction between reference products and by-product/wastes is activity-specific, i.e. the same product can be a reference product of one activity and a by-product/waste of another activity.

These distinctions are described in more detail in the following sub-chapters.

On the input side, the ecoSpold v2 format allows to differentiate intermediate exchanges into materials/fuels (with mass), electricity/heat (in energy units, without mass) and services (without mass or energy properties), but this distinction is *not* actively used in the ecoinvent database. On the output side, the ecoSpold v2 format allows further to differentiate materials for treatment and stock additions. These distinctions are only used internally in the ecoinvent database when creating interlinked datasets, see Chapter 4.14.

In addition to the exchanges, the dataset is described in terms of meta-data, i.e. data identifying the activity itself, in terms of its geographical, technological and temporal validity, the origin, representa-

[1] Exchange with the natural, social or economic environment. Examples: Unprocessed inputs from nature, emissions to air, water and soil, physical impacts, working hours under specified conditions.

tiveness and validation of the data, and administrative information. All relevant aspects of these metadata are described in later Chapters of this report.

4.1.1 Exchanges from and to the environment

Exchanges *from* the environment are resources extracted and chemical reactants from the air (e.g. CO_2, O_2, N_2), water or soil that enter into a human activity or into biomass harvested in the wild. Also land transformation, land occupation, and working hours are recorded as exchanges from (services provided by) the natural, social or economic environment. Also inputs of primary production factors of the economy (labour costs, net taxes, net operation surplus, and rent, see Chapter 6.4) are recorded as exchanges *from* the environment although measured as the economic *expenditures* for these inputs.

Exchanges *to* the environment are emissions to the different environmental compartments (e.g., air, water).

To distinguish human activities from their environment, two principles are followed in combination:

1) "The natural background", i.e. to include everything that would not have occurred without the activity, and to exclude anything that would have occurred even without the activity.
2) "Human management", i.e. to include everything that takes place under human management and exclude anything that takes place after human management has terminated.

These principles, their limitations, and their practical implementation are further described in Annex A.

4.1.2 Reference products

If the activity has only one product output, this is the reference product. The reference product is either a good or a service.

An activity with more than one product also has only *one* reference product, except:

- if the activity is a combined production, where the output volumes of the (combined) products can be varied independently, and the activity therefore can be sub-divided into separate activities, each having only one reference product, see Chapter 5.3,
- if there are more products from the activity that have no alternative production routes. If more than one product from a joint production has no alternative production routes, all of these are reference products.

The reference products are those products for which a change in demand will affect the production volume of the activity (also known as the determining products in consequential modelling, see Weidema & Ekvall 2009).

In most situations, by-products can easily be distinguished from reference products. Often by-products are close to waste and are therefore not even fully utilised, for example straw.

The distinction between reference products and by-products is necessary due to its relevance for identifying products that require additional treatments, e.g. for recycling, and in particular for system models with substitution, where the supply of by-products are counterbalanced to arrive at single-product activities.

Additional advice for data providers:
For treatment activities, see Chapter 4.8, the reference product is a negative physical flow of the material received for treatment, corresponding to the service of treating this material.

Whether an output is a reference product or not can depend on local conditions and can change over time.

Examples of situations with more than one reference product, and additional advice for data providers are provided in Chapter 11.1.

[**Changes relative to ecoinvent version 2:** The distinction between reference products and by-products is new. All multi-product activities in version 2 have been reviewed and the reference products identified. A number of treatment activities were missing their reference product. These have been added based on information in the original ecoinvent reports. A number of activities in version 2 have reference products that are not goods or services, but refer to a fuel input, e.g. "diesel, burned in building machine". Often these reference products are used by an activity producing heat. For these activities, all with the term "burned in" in their name, reference products of heat or work have been added, calculated from existing information in the database when available, and the dataset merged with the corresponding heat producing activity, when available. The revised reference products have reviewed by the original dataset authors and/or the editors.]

4.1.3 By-products and wastes

The ecoinvent database does not discriminate between by-products and wastes and does *not* apply any specific waste definition. Different database users may therefore apply their own waste definitions, if they wish to distinguish wastes from by-products.

Both wastes and by-products may be – or be transformed to be – valuable inputs to other product systems. Depending on their need for further treatment or transformation, they may be linked to different treatment activities, see Chapter 4.8.

It follows from the definition of reference products in Chapter 4.1.2, that by-product/wastes (any output that is neither a reference product nor an exchange to the environment) *must have* either an alternative production route or a treatment activity that transforms the by-product/waste either into a product with an alternative production route or into an exchange to the environment.

[**Changes relative to ecoinvent version 2:** In ecoinvent version 2, waste treatments are recorded as service inputs to the activities supplying the waste. All such waste treatment services have been reviewed and expressed as negative outputs of wastes. The name changes have been reviewed by the original dataset authors and/or the editors. For a number of products in version 2 that have now been identified as by-products (e.g. straw, sodium hydroxide), the activities that have the by-product as its reference product or as an input for treatment were missing. These activities have now been added.]

4.2 Global reference activity datasets and parent/child relationships between datasets

The geographical, temporal, and technological scope of the datasets is described in each individual dataset. Some datasets are extrapolated on the basis of data from another geography or year. Such extrapolations are described in the datasets, and will result in these datasets having a larger reported uncertainty.

To avoid artificial introduction of differences between datasets for the same technology, each technology is described in the form of a global *reference activity dataset*, intended to be close to the global average for the activity for the most recent year for which data is available. Other datasets for the same technology, but for specific geographical locations, can then be described in child datasets, using the reference activity dataset as parent dataset. In this way, an improved description in the reference activity dataset will automatically be transferred to the specific datasets, while geographical differences can be reported in these.

The ecoinvent data network does not require non-global activity datasets to be described as child datasets, but data providers are encouraged to consider the advantages of supplying the data in this form.

More details on the implementation of parent/child dataset inheritance and the restrictions applied to this feature are provided in Annex B, including a description of the options for using inheritance to provide forecasted data by creating child datasets for future time periods and/or different macro-economic scenario settings.

Additional advice for data providers:
Data providers that supply data for a specific local, non-reference activity, for which a global reference dataset for the same time period does not yet exist, are required to provide such a global reference dataset, but this does not have to be different from the non-reference dataset, if only data for the specific local non-reference activity is available. Although such data providers are encouraged to consider providing a more representative global reference dataset, data providers may as a default assume that the non-reference dataset is representative for the global situation, if no better data are available. It is recommended to simultaneously consider the global and the local dataset for the activity and to consider which specific data are most relevant to add to each of these datasets. It may be most simple at first to create a stand-alone local dataset with the available data and in a second step split it up in the global parent and the local child, which will then supersede the stand-alone dataset. It is also recommended to consider existing global and other local datasets for the same activity and to adapt the flow lists of new submissions to match the existing datasets or to harmonize them. If a local activity features flows not present in other regions and the global average, the situation can clearly not reflect reality, and data providers are urged to adapt the data to best fit the actual situation.

[**Changes relative to ecoinvent version 2**: The option to apply inheritance is new. Existing geographically differentiated datasets will not be changed to child datasets automatically. The decision to do so rests with the active dataset author. There is no requirement to use the inheritance option, but dataset authors are asked to consider revising the reference activity dataset to be more appropriate as a global reference, and to implement corresponding child datasets.]

4.2.1 Geographical localisation

The geographical location of an activity can be:

- At one or more specific points, when the location of specific production facilities is known.
- Along one or more lines, e.g. for transport activities.
- Within one or more areas, as in farming, fishery and forestry, or when the location of the specific activity is unknown

Each geographical location (whether point-, line-, or area-based) is described by a short, unique name that links via a unique identifier to a more detailed description for each location, see Chapter 9.9. As part of the detailed description, the location is described in terms of geographical information system coordinates (longitude, latitude) in the Keyhole Markup Language (KML) used by e.g. Google Earth. KML is an open standard regulated by the Open Geospatial Consortium (www.opengeospatial.org). This allows the database to identify which activities are located within a given area, and thus to link the activities to their geographically defined markets (see Chapter 4.4) and to flexibly provide geographically differentiated data for site-dependent impact assessment methods.

The geographical location indicated in this way is the location for which the dataset is intended to be valid. The data may be originally collected for a different geographical location, and inter- or extrapolated to the geography of validity. Such extrapolations are described in the dataset under “Extrapolations”.

To ensure completeness, the ecoinvent database contains a *global reference activity dataset* (a dataset with the geographical setting “Global”) for each of the included activities.

Geography child datasets may be constructed for any geographical location by entering a geographical location in a delta dataset referring to the corresponding reference dataset (using the “parentActivity-

Id" field of the ecoSpold format). This implies that the parent dataset of a geography child dataset is always the global dataset for the same time period.

To avoid double-counting, overlapping geographical *areas* for datasets for the same activity are not allowed in the ecoinvent database, except that

- A global dataset is allowed to co-exist with datasets for smaller areas.
- Production and supply mixes (see Chapter 4.5) can be established for any area of interest, since these mixes are not used in further modelling.

All point and line locations belong to an area. This implies that a point location cannot be placed on the border of an area, a line location cannot be placed along (on top of) borders (but may cross borders, i.e. belong to more than one area), and a border cannot be placed exactly on top of a point or along a line location. For the purposes of ecoinvent, locations are recorded with a maximum resolution of 0.001 degrees (about 100 meters at the equator, smaller towards the poles).

When a global dataset is the only dataset in the database for a given activity, time period, and macro-economic scenario, this global dataset is included like any other dataset in automatically calculated production, supply, or consumption mixes, interlinked and aggregated system datasets.

When both a global dataset and one or more non-global datasets are available for the same activity, time period, and macro-economic scenario:

- The global dataset is not included in any of the above-mentioned calculations, but can serve as a parent dataset for other datasets.
- A dataset with the geographical location *Rest-Of-World* (ROW) can be calculated as the residual difference between the global dataset and the non-global datasets, when all datasets are scaled to the production volume of their reference product. In the ecoinvent database, this calculation is performed automatically.

[**At the time of the release of version 3.0:** When new local data have been added after the initial generation of a global dataset, the global dataset should ideally be updated in order to remain representing the global average. This updating has therefore not always done. In some cases this leads to negative amounts for some exchanges in the subsequently generated ROW datasets. Since such negative amounts are obviously artefacts, they are automatically eliminated by setting the amounts to zero instead, and marking this in the comment field. In some cases the discrepancies between global datasets and the sum of local datasets were handled with a procedural exception in which the ROW dataset has been created as a direct copy of the GLO dataset, i.e. without the above-described averaging procedure. This option is only used sparingly as a solution supervised by the ecoinvent LCI Expert Group, since it creates an inconsistency between the production-volume-weighted sum of all datasets and that provided by original the global dataset. All datasets generated with this exception are listed in the Change report (Moreno Ruiz et al. 2013).]

Additional advice for data providers:
Since the ecoinvent database does not allow overlapping datasets, adding a dataset (whether point-, line-, or area-based) fully located within the geographical area of an existing dataset for the same activity, is effectively a disaggregation of the existing dataset, and requires that the existing dataset is modified to represent the residual of the original dataset, in terms of geography, production volume, and otherwise.

[**Changes relative to ecoinvent version 2:** The use of KML, and the options for automatic dataset handling that this provides, is new. All ecoinvent v2 geographies have been defined in KML in the new geographies master file. For version 2, geographical location was sometimes used as proxy for a specific technology. Such instances have been identified as far as possible and the original authors involved in suggesting or reviewing corrections, so that geographical location is no longer used as proxy for anything else.]

4.2.2 Temporal specification and time series

The time period for which an activity dataset is valid is described as an interval with a start date and an end date (e.g. 2005-01-01 and 2005-12-31). Datasets valid for whole years can be specified by the year(s) alone. Time periods of less than one year are currently not used in the ecoinvent database. Recurring time periods, such as peak seasons or peak hours, are distinguished by the activity name and product name.

The time period indicated in this way is the time period for which the dataset is intended to be valid. The data may be originally collected for a different time period, and inter- or extra-polated to the time period of validity. Such extrapolations are described in the dataset under "Extrapolations".

When calculating production, supply, or consumption mixes, interlinked datasets and aggregated system datasets, datasets from the same time period are linked. If a global dataset for an activity is missing for a specific time period, the activity dataset for the nearest preceding time period is applied.

To avoid double-counting, overlapping time periods for datasets for the same activity and geographical location is not allowed.

[**Changes relative to ecoinvent version 2:** The option to have several temporal versions of the same dataset, and that separate linking is performed of datasets from the same time period, are new. However, for the basic implementation of the database, only the current year will be calculated, using the most recent data available for each activity and geography. Time series and calculation results for specific years may be provided as a separate database product. When datasets are extrapolated to the current year from datasets for earlier years, the original temporal setting is placed as text in the field "extrapolations" and the pedigree is automatically adjusted to reflect the correct additional uncertainty. A few datasets for emerging technologies in the database version 2, with the suffix "future" in their name, have not had their time period changed and still carry the word "future" in the name field.]

4.2.3 Macro-economic scenarios

A macro-economic scenario setting provides an option to have more than one dataset describing the same activity, for the same geographical location and time period. Macro-economic scenarios are only relevant for datasets for future years, since datasets for the current and historical years are intended to reflect the actual known situation.

The ecoinvent database currently operates with one default reference scenario only: "Business-as-Usual". The introduction of new macro-economic scenarios in the ecoinvent database is only done centrally after a decision by the ecoinvent Centre. More details on this can be found in Chapter 11.2.

[**Changes relative to ecoinvent version 2:** The option to add macro-economic scenarios for datasets for future years is new. However, this feature is not applied for the calculation results of the basic implementation of the database, but may be provided as a separate database product.]

4.3 Market activities and transforming activities

The ecoinvent database (and the ecoSpold 2 data format) distinguishes a number of special activity types, including market activities, production and supply mixes (see Chapter 4.5), import and export activities (see Chapter 11.5), and correction datasets (see Chapter 11.7).

All activities that are not of these special types are "ordinary" transforming activities. Transforming activities are human activities that *transform* inputs, so that the output of the activity is different from the inputs, e.g. a hard coal mine that transforms hard coal in ground to the marketable product hard coal. In contrast, market activities do not transform their inputs, but simply *transfer* the intermediate output from a transforming activity to the transforming activities that consume this intermediate output as an input, e.g. from hard coal at the supplier to hard coal at the consumer.

Transforming activities are here understood in the widest possible sense, including extraction, production, transport, consumption and waste treatment activities, i.e. any human activity where the intermediate output is different from the intermediate input. The concept "transforming activities" is introduced here simply to distinguish – in the further modelling and linking of activities; see Chapter 4.4 – these "ordinary" activities from the market activities, production and supply mixes, import and export activities, and correction datasets.

Market activities typically mix similar intermediate outputs from different transforming activities. Market activities therefore supply *consumption mixes* of the intermediate outputs. The term consumption mix is not part of the name of the output, but is a consequence of the activity being a market activity (as specified in the ecoSpold field 115 specialActivityType). However, in graphical presentations (see Figure 4.2) the term (consumption mix) in brackets may be added after the name of the output. When only one transforming activity is supplying a specific intermediate output to a market, the term consumption *mix* may seem a bit strange, but is nevertheless maintained for consistency reasons.

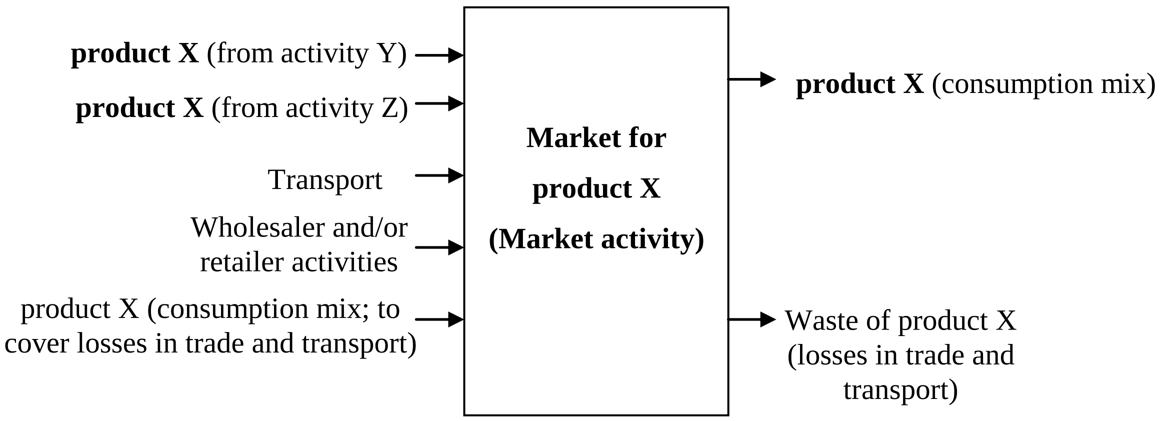


Figure 4.2. A market activity with its intermediate exchanges. Texts in brackets are not part of the name of the exchange.

Market activities may be global or geographically delimited, as indicated by the ecoSpold field 410 locationShortname. As a default, markets are assumed to be global, since this is the most general situation, unless specific information is available to justify a geographical market boundary. The delimitation of markets, and their justification, is described in more detail in Chapter 4.4.

In its simplest form, a market dataset consists of a reference product, representing a consumption mix, and one or more inputs of the same product from the different transforming activities that are located within the geographical delimitation of the market. The ecoinvent database service layer automatically identifies these transforming activities based on the name of the reference product and the geographical location of the transforming activity, links the product inputs to the market from each transforming activity by adding the corresponding ActivityLinkId (ecoSpold field 1520), calculates the amount of input from each transforming activity in proportion to its available production volume, based on the entries in the ecoSpold field 1530 productionVolumeAmount of each transforming activity (see Chapter 5.4), and sums up these production volumes, which then becomes the production volume of the market activity. A market dataset can only be created if the resulting production volume is larger than zero.

In addition to providing consumption mixes of the intermediate outputs from different transforming activities, market activities play a role in adding average transport activities (Chapter 4.6), wholesaler and retailer activities (Chapter 4.7), and product losses in trade and transport. Product losses in trade and transport are added to the market activity datasets as waste outputs. To balance the waste output, an equivalent amount of product input is added. Since the loss is an average of the products traded, this compensating input is the consumption mix, i.e. the output of the market activity itself. Losses of a specific input to the market are recorded in the specific supplying activity. The mentioned activities and losses also imply economic costs to the market activities and - together with product taxes and subsidies - these costs change the prices of the products from the basic prices of the inputs to the purchaser's prices of the outputs (Chapter 5.6.5).

Market activities are placed in between any two transforming activities, unless a direct link is made between two specific transforming activities, thus avoiding the market (see Chapter 4.4). This implies that market activities may also be placed *within* an enterprise if the enterprise performs several separate, subsequent activities in the life cycle of a product. This depends entirely on the level of detail to which the transforming activities are represented (see also Chapter 5.1). In such cases, the markets should be understood as enterprise-internal markets, i.e. as supplying reference products between different parts or production lines of the same enterprise. This degree of sub-division in LCI data is only relevant if the product could alternatively be used outside the enterprise (or be supplied from outside the enterprise).

Additional advice for data providers:
Data providers to the ecoinvent database are not required to supply market datasets. When missing, a simple, global market dataset will be auto-generated by the database service layer, including default values for price, transport, trade margins, and product losses per product group. [**Feature considered for implementation later:** The auto-generated global market dataset may also include default prices, trade margins and product losses.]

[**Changes relative to ecoinvent version 2:** A market dataset is now required for every reference product. When missing, a simple market dataset will be auto-generated by the database service layer. The editor for trade reviews existing market datasets for consistency.]

4.4 Linking transforming activities directly or via markets

4.4.1 Direct links between transforming activities

Goods and service inputs to a transforming activity are described in terms of the product name. Furthermore, a specific supplier of this product may be indicated (in the ecoSpold field 1520 ActivityLinkId), if the input is linked to this specific supplier. This may be the case if a specific group of enterprises are so closely linked in a supply chain that the production volumes of the specific suppliers can be shown to fluctuate with the demand of the specific customers. Examples of this situation are:

- When products do not store or transport easily, or have a low price compared to their weight, so that transport costs prohibit all other than the local producers. Examples are thermal heat, chlorine gas, and straw for heat and power production, where only the farmers closest to the power plant will supply the straw. Other examples of this can be found in the forestry sector and the building- and glass-industries.
- When two or more companies are tied together by tradition, or when a supplier has developed its product to meet specific demands of the customer. An example is an aluminium industry that specifically co-locates with a specific electricity source.
- When the choice of supplier is not subject to normal market conditions.

The reason for linking directly to a specific supplying activity is provided in the comment field for the linked exchange.

When transforming activities are linked directly, thus avoiding the market activities, the activities and data that are normally included with the market activities, are instead added directly to the activity requiring the input. This includes transport activities, production losses, wholesaler and retailer activities, and product taxes and subsidies for the directly linked input.

[**Changes relative to ecoinvent version 2:** In version 2, all datasets were linked directly and no specific justification for this was required. In version 3 direct links require a justification.]

4.4.2 Linking via markets

As a default, when there is no information available to justify the placement of a direct link to reflect that the production volumes of a specific supplier (or group of suppliers) fluctuate with the demand of the specific customers, it is assumed that the input is provided by the local market. When no specific supplier is specified for the product input (in the ecoSpold field 1520 ActivityLinkId), the ecoinvent database automatically provides the specific link to the local market, i.e. the market that geographically is equal to or covers the activity that demands the input. If the activity is defined for a geography or time that spans over more than one local market, each of the market activities contribute in proportion to their production volume.

Markets are typically differentiated

- geographically,
- temporally, and
- in customer segments.

4.4.3 Geographical market segmentation

The geographical segmentation of markets may be determined by differences in:

- Natural geography (climate, landscape, transport distances etc.)
- Regulation or administration (regulation of competition and market transparency, legislative product requirements, product standards, taxes, subsidies)
- Consumer culture.

Geographical segments are identified and documented (in the ecoSpold field 420 Geography comment) by the lacking or constrained import of the product across the geographical boundary.

Three situations can be distinguished:

- No import, no export: The geographical segment is modelled by a single market activity for the geographical area.
- No import, but no restrictions on export: In addition to the market activity for the geographical area (X), the exports from this market to other markets are specified as separate transforming activities "product Y, import from market X" with the geographical specification of the receiving market and with direct links (specified in ecoSpold field 1520 ActivityLinkId) to the consumption mix of market X.
- Administratively constrained import: The contribution of import is modelled separately and added as an input to the market activity for the geographical area.

The three situations are described in more detail in Chapter 11.5, where the linking of geographical markets is discussed.

[**Changes relative to ecoinvent version 2:** Non-global market activities (consumption mixes) now require a justification.]

4.4.4 Temporal market segmentation

Temporal segmentation of markets is common for service products (e.g. peak hours and night hours in electricity consumption, rush hours in traffic and telecommunication, seasons in the tourist industry). For physical goods, markets are generally only segmented temporally when adequate supply or storage capacity is missing, either due to the nature of the product (e.g. food products), or due to immature or unstable markets, as can been found for treatment of some recycled materials.

Although the ecoSpold format allows time periods to be specified at a higher resolution than years, the format does not have any way to specify recurring time periods such as peak hours that occur at the same time every day. Temporal markets are therefore specified as part of the product name, e.g. “electricity, peak” and “electricity, non-peak” as opposed to an average “electricity”. At the time of publication of the database version 3.0, the ecoinvent database does not include temporal market segments, but data providers are not restricted from contributing such data when available.

The temporal segmentation should be distinguished from the fact that markets generally develop in time, e.g. governed by developments in fashion and technology, and that both geographical and temporal segmentation and customer segmentation therefore may change over time. In general, there is a tendency for markets to become more transparent and geographically homogenous with time, but at the same time more segmented with regard to customer requirements and thus product differentiation.

4.4.5 Customer segmentation

Customer segmentation within each geographical market is defined in terms of clearly distinct function-based requirements, i.e. based on the needs fulfilled by the products rather than based on the physical products themselves. This can be expressed in terms of the *obligatory product properties*, i.e. properties that the product *must have* in order to be at all considered as a relevant alternative. Very similar products may serve different needs and hence serve different markets. And very different products may serve the same need, thus being in competition on the same market.

As for temporal markets, customer segments are expressed in the name of the product, so that each customer segment has its own product. The name includes as far as possible all relevant aspects of the obligatory product properties. Product properties may be related to:

- Functionality, related to the main function of the product
- Technical quality, such as stability, durability, ease of maintenance
- Additional services rendered during use and disposal
- Aesthetics, such as appearance and design
- Image (of the product or the producer)
- Costs related to purchase, use and disposal
- Specific environmental properties

Functionality, aesthetics, and image characterise the primary services provided to the user. Technical quality and additional services ensure the primary services during the expected duration of these. Of the above-mentioned properties, price is the only one that can be put into well-defined terms. Technical quality and functionality can be described a little less well defined, but still quantitatively. Other properties, such as aesthetics and image, cannot be measured directly, but can only be described qualitatively. Some of these properties can seem very irrational, since they are not present in the product, but in the buyer’s perception of it. These properties can be greatly influenced by commercial activities of the supplier. Differences in customer requirements may be based on differences in the purchase situation, the use situation, customer scale, age, sex, education, status, “culture”, attitudes etc.

To have a practical relevance, market segments must be of a size that can provide adequate revenue to support a separate product line, and *clearly distinct with a minimum of overlap*, so that all products targeted for a segment are considered substitutable by the customers of this segment, while there should be low probability that a product targeted for another segment would be substitutable, implying that product substitution from segment to segment can be neglected.

As a default, if no information is available to justify a market boundary, it is assumed that no market boundary exists, since this is the most general situation.

4.4.6 Market niches

Market segments may be further sub-divided into market niches. A *market niche* is a sub-category of a market segment, where a part of the customers consider only niche products substitutable, although the majority of the customers allow substitution between products from the niche and other products in the segment. Thus, the difference between a segment and a niche is that between segments substitution is negligible, while a large part of the customers in a segment will allow substitution between niche products. Niche products are aimed at a smaller group of consumers within a segment, for whom specific product properties are obligatory, while the same properties in the broader market segment are only *positioning product properties*, i.e. properties that are considered *nice to have* by the customer and which may therefore position the product more favourably with the customer, relative to other products with the same obligatory properties.

When market niches exist, the niche product has its own, separate name, indicating the additional obligatory product properties of the niche, e.g. “vegetable oil, sunflower” to separate this market niche from the general “vegetable oil”. As only some of the niche product is consumed by niche consumers, the remaining amount is channelled into the general market segment through separate re-labelling “niche product to generic market” transforming activities, e.g. “sunflower oil to generic market for vegetable oil”, which have as its input the niche products and as output the products of the general market segment. Besides the change in name of the product, the “niche product to generic market” activities will also include a change in the price of the products, see Chapter 5.6.5. If the properties of the niche product affect downstream use or disposal activities differently from the other products in the general market segment, these downstream differences must be added separately to the niche production, as described in Chapter 11.7.

4.5 Production and supply mixes

The database distinguishes between production, supply and consumption mixes.

A production mix represents the production-volume-weighted average of the suppliers of a specific product within a specific geographical area. A supply mix is a production mix with the addition of the import of the specified product to the specified geographical area. A consumption mix is the output of a market activity, as described in the previous section. Consumption mixes represent production-volume-weighted averages of the suppliers to a specific market. Market boundaries may or may not be congruent with the geographical areas for which production and supply mixes are provided.

Production mixes are automatically generated by the ecoinvent database service layer in the same way as consumption mixes (as described in Chapter 4.3): The database automatically identifies the relevant transforming activities based on the product name and the geographical location of the transforming activity, links the product inputs of the production mix to each transforming activity by adding the corresponding ActivityLinkId (ecoSpold field 1520), calculating the amount of input from each transforming activity in proportion to its production volume, as indicated in the ecoSpold field 1530 productionVolumeAmount of each transforming activity, and sums up the production volumes, which then becomes the production volume of the production mix.

A supply mix is automatically generated by the ecoinvent database service layer by adding the import (see Chapter 11.5) for the geographical area as an input to the corresponding production mix.

Production and supply mixes are not systematically provided for all products and all geographical areas. For compatibility with the ecoinvent database version 2, production and supply mixes are provided in most situations where these were supplied in the ecoinvent database version 2. Production mixes may be provided in specific cases for comparisons, or to represent the export from a geographical area, but are not used in the further modelling of LCI results, except when required to reduce the matrix size before calculation of accumulated systems results, see Chapter 14.8.

[**Changes relative to ecoinvent version 2:** Datasets in version 3 are linked exclusively via well-defined and justified direct links or via market datasets providing consumption mixes. Since production and supply mixes can be generated for any geographical area, irrespective of the market boundaries, they are no longer applied in the further modelling.]

4.6 Transport

Freight transport occurs for most physical flows between activities in a product system. Transports are added as inputs to the market activity datasets based as far as possible on data for the real market situation. When specific data are not available, default transport amounts are applied, relative to the ISIC class and kg wet mass of the product. The default transport data are based on transport statistics, according to a methodology developed by Borken & Weidema (2013), whereby the total amount of freight services provided by the road, rail, ship and air transport industries are divided over the transported products, based on the average transport distance and modal distribution. For products that are known to be typically used at the production location, such as aluminium hydroxide, the transport distances have been set to zero.

Transports are assumed to be weight-limited when the packed product has a density above 250 kg/m^3 and volume-limited when the density is below 250 kg/m^3.

For intermediate inputs that are not provided via markets, i.e. where a using activity is directly linked to a supplying activity, the transport is added directly as an input to the receiving activity. Additional transport between markets (international transport) is added as an input to the import datasets (see Chapter 11.5) for the geographical area of each market.

If the transport distance and mode of an intermediate input to a specific activity is known to be different from the market average, the intermediate input is modelled either as being supplied by a separate market with this specific transport input, or using a direct link to the supplying activity, adding the specific transport as an input to the receiving activity.

The transport datasets have names beginning with “transport, …”. The freight transport products describe the transport services in metric ton-kilometres with average load factors that include the average share of empty return trips.

[**Changes relative to ecoinvent version 2:** An algorithm has been implemented in the database service layer, adding default transport inputs to the market datasets, replacing the former transport inputs to transforming activity datasets. Non-default values from the version 2.2 datasets, as well as exceptions to the default values are listed in the Change report, Table 6.1. [**At the time of the release of version 3.0:** The datasets for waste building products (in version 2.2 named 'disposal, building,...'), and for wastewater, which is transported in sewers, have not been updated, but may be updated later by the ecoinvent editor for waste treatment.]

4.7 Trade margins and product taxes/subsidies

The wholesale and retail industries perform trade activities, which involve e.g. re-packaging, advertising, use of office machinery, warehousing, retail stores, with their use of electricity, heating and cooling. Also, some of the transports of goods cannot be specified on products and are indirectly included via the purchase of freight services by the wholesale and retail industries. Like other service industries, trade involves relatively large wage expenditures.

Altogether these activities result in a price difference also known as the trade margin, which together with the transport costs makes up the difference between the producer's prices and the purchaser's prices reported in the market activity datasets.

If product taxes less subsidies are subtracted from the producer's prices, we arrive at the basic price reported in the transforming activity datasets. We thus have:

basic prices + product taxes - product subsidies + trade margins + transport costs = purchaser's prices

[Feature considered for implementation later: The trade margins may be, in parallel to the transport services, added as service inputs from the wholesale and retail industries to the market datasets. Product taxes less subsidies may be added as primary inputs (monetary elementary exchanges, see Chapter 6.4) to the market activity datasets. Only packaging discarded before re-packaging is to be included as input to the wholesale or retail activity and thereby in the trade margin, while consumer packaging should be reported as a separate input to the receiving activity where the packed product is used.]

4.8 Treatment activities

A treatment activity is a transforming activity with a reference product with a *negative sign*, which effectively means that the activity is supplying the service of treating or disposing of the reference product.

Most treatment activities are waste treatment activities, including recycling activities. However, some by-products that are normally not regarded as wastes may also need treatment before they can enter into a market where they can compete with or substitute reference products from other activities. Such by-products and wastes are called *materials for treatment* to distinguish them from those materials that can immediately – without further treatment – substitute a reference product as an input to an activity. Note that it is not the economic value that determines whether a material is a material for treatment, but exclusively its need for treatment.

Any transforming activity can be(come) a treatment activity, if one of its inputs is a material for treatment, but in general, treatment activities are activities dedicated to treatment, i.e. having treatment as their original main purpose.

Additional advice for data providers:
If no dedicated treatment activity exists in the database for a newly added material for treatment, this must be added before upload of the activity supplying the material for treatment, or alternatively, at least one of the activities that currently use the material must be identified by the data provider as a treatment activity for this material, implying that the original reference product of this activity is changed to be a by-product. To avoid loops or cascades of by-products in the system models with partitioning, the latter may best be done by adding a constrained market for the material for treatment, see Chapter 11.4.

Treatment activities are modelled like any other technical service activities. Material characteristics like elemental composition, heating value, combustibility, and degradation rates, are used to calculate material-specific outputs and expenditures of treatment activities.

In general, the treatment activities are modelled so that each activity has one and only one material for treatment as input. However, the *same* material for treatment can have different compositions (e.g. the fraction of paper in municipal waste may differ, while the material may still be named municipal waste) and properties (e.g. elemental composition, degradability, burnability) when supplied from different activities (see Chapter 11.11 for details on this modelling). If the treatment of two materials are co-dependent, i.e. if the amount of a material that can be treated depends on the amount of another material for treatment, for example when both a carbon- and nitrogen-rich waste is required for waste fermentation, one of these materials is identified as the reference product, using the same procedure as for other transforming activities (see Chapter 11.1), while the treatment of the other waste is identified as a by-product.

An activity that has a material for treatment as an input, but which is not a treatment activity (i.e. it has a positive reference product), is a *speciality production*. The modelling of speciality productions is described in Chapter 11.6.

The treatment technologies are as far as possible modelled with variables (see Chapter 5.7), so that e.g. the average values for DeNOx-equipment in municipal waste incineration plants can be changed by the user according to the extent of installation of this equipment in a particular situation.

Treatment services (the product outputs with negative signs) are inputs to treatment markets, i.e. the market activities that in turn provide the treatment services to the activities that provide the materials for treatment, see Chapter 4.9.

In principle, it does not matter whether a waste supplying activity records its waste as a physical output or as a negative physical input from a waste treatment service. In both situations, the database will calculate the waste as a negative input and as a result the appropriate amount of waste treatment service is supplied to the waste supplying activity. A positive output is the same as a negative input, so the mass balance for the waste supplying activity is maintained.

[**Changes relative to ecoinvent version 2:** The distinction between materials for treatment and other by-products is new. The definition of treatment activities is new.]

4.9 Treatment markets

Treatment markets are a specific kind of market activities (see Chapter 4.3), which operate on negative reference products, i.e. on the services of treating or disposing of the reference product. The reference products of the treatment activities and of the treatment markets are the materials for treatment arising as waste or by-product outputs of other activities, identifiable as wastes or by-products that cannot immediately – without further treatment – substitute a reference product as an input to an activity.

The treatment markets distribute the materials for treatment over the available treatment activities and speciality productions, in the same way as a normal market activity distributes the demand over different suppliers in proportion to their production volume. Treatment markets therefore supply *treatment mixes* for specific materials for treatment. The term treatment mix is not part of the name of the output, but is a consequence of the activity being a market activity (as specified in the ecoSpold field 115 specialActivityType) with a *negative* reference product. In graphical presentations, the term (treatment mix) in brackets may be added after the name of the output.

As for normal market activities, the ecoinvent database automatically identifies the treatment activities and speciality productions that contribute to a specific treatment market, based on the name of the reference product (the material for treatment) and the geographical location of the activities, links the negative inputs to the treatment market from each treatment/speciality production activity by adding the corresponding ActivityLinkId (ecoSpold field 1520), calculates the amount of input from each treatment activity or speciality production in proportion to the available production (treatment) volumes (based on the data in the ecoSpold field 1530 productionVolumeAmount; see Chapter 5.4) of each of these negative outputs of material for treatment, and sums up these production volumes, which then becomes the production volume of the treatment market. Note that the production (treatment) volumes of the treatment markets do not necessarily match the generated amounts of material for treatment, unless also accounting for the material arising from decommissioning of stocks, see Chapter 11.10.1.

As for normal market activities, treatment markets add average transport activities (incl. collection of the material for treatment) and any activities related to the trade of the material for treatment. The price of a material for treatment, i.e. the negative reference product, may be positive or negative: A positive price for the material for treatment implies that the activity that supplies the material receives this price, while a negative price implies that the activity that supplies the material pays this price for the treatment. [**Feature missing at the time of publication of ecoinvent v3.0:** As for normal market activities, the output price of the treatment market is in purchaser's prices, while the (negative) inputs of the material for treatment to the treatment market (and the outputs from the treatment activities) are in basic prices, see Chapter 5.6.5. At the time of publication of ecoinvent v3.0, the price propagation described in Chapter 5.6.5 and thus the distinction between purchaser's prices and basic prices, has not yet been implemented.] Waste or treatment taxes are added to the treatment market, unless they are specific to specific treatments.

Treatment markets reflect as far as possible the specific local situation of the treatment of specific materials for treatment. If information about the treatment of specific materials is not available, generic treatment activities are applied, based on waste treatment statistics and similar generic data sources.

4.10 Recycling

All possible situations of recycling, including energy recovery, are exhaustively covered by the description of treatment activities in Chapter 4.8:

Recycling activities, i.e. treatment activities that directly or indirectly supply outputs of by-products that can substitute a reference product as an input to an activity, are modelled in exactly the same way as treatment activities that do not provide such by-products.

Likewise, materials for recycling, i.e. materials for treatment that enable the treatment activities to generate by-product outputs that can substitute a reference product as an input to an activity, are treated in exactly the same way as other materials for treatment, as described in Chapter 4.8.

[**Changes relative to ecoinvent version 2:** The ecoinvent database no longer operates with a priori cut-offs for recyclates. Thus, all outputs of wastes and by-products, for recycling or not, are treated in the same way and are linked to the relevant market activities. Because cut-offs were applied for version 2, some transforming datasets may be missing adequate outputs of minor by-products. When revising these datasets, missing by-product outputs should be added, together with their necessary treatment activities.]

4.11 Infrastructure / Capital goods

Infrastructure (also known as capital goods or investments) are products with a lifetime exceeding one year, and not intended for consumption. Consumption here implies either final use by the receiving activity or incorporation into its products. The lifetime is the period between the time of production and the time of initiating waste treatment of the product.

The activity datasets for infrastructure production (*infrastructure datasets*) normally include the maintenance of the infrastructure during its lifetime, its land occupation and land transformation, and its decommissioning for waste treatment. Since the mass of the infrastructure products thus leaves the infrastructure dataset as wastes, the reference products of these datasets do not have any mass, but must be regarded as services providing production capacity. Therefore the reference product of the infrastructure production activities have the property "capacity" or "lifetime capacity", and the wastes of the infrastructure have the property "lifetime" exceeding one year (see also Chapter 4.21.1 on how by-products and wastes with a lifetime exceeding 1 year are identified as additions to stock).

As far as possible, infrastructure is provided in terms of lifetime capacity at full utilisation. For example:

- An activity "lignite power plant construction, 500 MW" has the reference product "lignite power plant" expressed by the infrastructure lifetime (34 year or 300'000 hour) with the property "capacity" of 500MW (or 139kWh/s), of which an activity "electricity production, lignite" with the reference product 1 kWh electricity and a capacity utilisation of 0.68 will require 1kWh/(0.68*139kWh/s) = 0.01058 s (or 2.94E-6 hour). Alternatively, the infrastructure product can be expressed in the dimensionless "1 unit" with the property "lifetime_capacity" 1.5E11 kWh (corresponding to 300'000 hour * 500MW). The electricity production activity will require 1kWh/(0.68 * lifetime_capacity) = 9.8E-12 unit of this input to produce 1 kWh electricity.
- An activity "oil mill construction, 68.5 metric ton oil/day" has the reference product "oil mill" expressed by the infrastructure lifetime (50 year or 1.58E9 s) with the property "capacity" of 0.79kg/s (or 68.5 metric ton/day), of which an oil mill activity with the reference product 1 kg oil and a capacity utilisation of 0.9 will require 1kg/(0.9*0.79kg/s) = 1.406 s (or 4.46E-8 year). Alternatively, the infrastructure product can be expressed in the dimensionless "1 unit" with the property "lifetime_capacity" 1.25E9 kg (corresponding to 50 year * 68.5 metric ton/day). The oil mill activity will require 1kg/(0.9 * lifetime_capacity) = 8.89E-10 unit of this input to produce 1 kg oil.
- An activity "milking parlour construction, 4 milking units" has the reference product "milking parlour" expressed by the infrastructure lifetime 55'000 hours of milking with the property "capacity" of 335 litre/hour, of which a milking activity with the reference product 1 litre and a capacity utilisation of 0.4 will require 1 litre/(0.4*335 litre/hour) = 0.0075 hour of milking parlour. Alternatively, the infrastructure product can be expressed in the dimensionless "1 unit" with the property "lifetime_capacity" 1.84E7 litre (corresponding to 55000 hours * 335 litre/hour). The milking activity will require 1 litre/(0.4 * lifetime_capacity) = 1.36 E-7 unit of this input to provide milking service for 1 litre milk.

In the above examples, lifetime is expressed in time units. In some cases, it may be relevant to express the lifetime in other terms, as in the following example, where the lifetime of a vehicle is expressed in kilometres:

- An activity "lorry production, 16 metric ton" has the reference product "lorry, 16 metric ton" expressed by the infrastructure lifetime (540'000 km) with the property "capacity" of 9200 kg payload (16 metric ton minus 6800 kg net weight), of which a transport activity with the reference product 1 metric ton*km and a capacity utilisation of 0.1065 will require 1 metric ton*km/(0.1065*9200 kg) = 1.0206 km. Alternatively, the infrastructure product can be expressed in the dimensionless "1 unit" with the property "lifetime_capacity" 4.97E6 metric ton*km (corresponding to 540'000 km * 9200 kg). The transport activity will require 1 metric ton*km/(0.1065 * lifetime_capacity) = 1.89E-6 unit of this input to produce 1 metric ton*km.

Additional advice for data providers:
For new datasets, it is recommended to express the infrastructure products by the infrastructure lifetime at full capacity and provide the production capacity as a property, typically per time unit.

[**Changes relative to ecoinvent version 2:** The definition and description of infrastructure is now more precise. Infrastructure activities are now identified by the property "capacity" or "lifetime_capacity". The recommendation to present the assumptions on lifetime, production capacity, and capacity utilisation more explicitly in the datasets, makes it easier to review these assumptions for consistency and to adjust them when better data are available. Datasets transferred from ecoinvent version 2 may not all be updated to the new description at the time of release of version 3. The assessment of infrastructures and capital equipments are still most often based on very rough estimations.]

4.12 Operation, use situations and household activities

Activity datasets with the term "operation" as part of their name signifies activities that use specific infrastructures, e.g. "mine operation" as opposed to "mine construction". Operation datasets therefore always have inputs of infrastructure. Thus, "operation" is used as a synonym for "use". The term is used both for industrial activities and household activities.

Different products may be distinguished for the same use situation and modelled as separate transforming activities. For example, the operation of desktop computers is modelled by separate activity datasets for the use situations "active mode", "standby/sleep mode" and "off mode" for different types of computers. The average use mix of these products may then be represented by a market activity (consumption mix) for the generic computer in each use situation, e.g. "operation, computer, desktop, active mode". These average use situations may be further combined in transforming activities for e.g. "operation, computer, desktop, office use", which has a different combination of the use situations than "operation, computer, desktop, home use". [**At the time of the release of version 3.0:** The modelling of electronic equipment in the current database is not exactly equal to what is described here with computers as an example].

In order not to introduce artificial differences between similar use situations, the ecoinvent database generally classifies household activities together with the similar activities in industries, i.e. using the ISIC rev. 4 classification of activities. For example, home gardening of potatoes is classified under "Growing of vegetables and melons, roots and tubers" (ISIC class 1.13), although in national statistics, this class will only contain market-oriented activities.

When a distinction is required between the way the same product is used in large industries and in small businesses and households, this is done by naming the activity "industrial …", "home and small business …" or "private …", and if needed by introducing similar distinctions in the product of the activity. Furthermore, the tag (see Chapter 9.8) "household activity" is added when it is necessary to distinguish household activities from commercial activities.

[**Changes relative to ecoinvent version 2:** In version 2, the modelling of datasets with the term "operation" as part of their names was sometimes in accordance with the above described, sometimes not. The following groups of datasets need to be reviewed, to ensure consistency with the above description: Metal working, forestry, transport, road, rail and port operation and maintenance.]

4.13 Impact assessment data

4.13.1 Impact assessment datasets

Impact assessment datasets are available for various impact assessment methods, and their constituent impact categories.

[Feature not implemented at the time of the release of version 3.0, but considered for implementation later: The ecoSpold 2 format for LCIA data is still in development by a committee, and is planned for implementation for a later ecoinvent version. Until then, the old impact assessment data from ecoinvent version 2 will be applied. The new format will distinguish between *impact assessment method datasets* containing a grouping of impact categories, and documentation for this grouping, and *impact category datasets* containing impact pathway characterisation and/or weighting factors that describes the relative contribution to an impact category from one or more environmental exchanges or intermediate impact assessment results.]

[**Changes relative to ecoinvent version 2:** The separate datasets for impact assessment methods and categories allows a more flexible combination and sharing of impact categories across methods.]

4.13.2 Impact assessment results

When the impact assessment data are combined with the amounts of exchanges from a specific activity or accumulated system dataset (see Chapter 4.15), the result is a list of impacts for that activity or product system.

Impact assessment results (LCIA results) can be viewed for any accumulated system dataset for which environmental exchanges are available, including the allocated activity datasets of system models with partitioning. **[Feature considered for implementation later:** Impact assessment results (LCIA results) can be viewed for single activities as well.]

4.14 Interlinked datasets

In the preceding sub-Chapters (4.1 - 4.12), the activity datasets have mainly been described as stand-alone datasets, each representing a specific human activity as it can be observed "in real life". No specific model has been described to explain how these stand-alone datasets can be combined into contiguous, isolated product systems (life cycles). Since practically all human activities influence and link to each other, isolated product systems do not exist "in real life". They are artificial thought constructs that isolate some human activities from the rest, and define these as a product system, related to one specific product.

It is the purpose of *system models* to provide rules for linking the activity datasets into contiguous product systems, each one isolated from all other product systems.

In the stand-alone description of an activity, which can be validated against its real life counterpart, the system model (ecoSpold field 3005 systemModelName) is *undefined*. These activity datasets will typically have more than one product output and cannot be immediately linked, unless all intermediate inputs are already specified with a supplying activity (ecoSpold field 1520 ActivityLinkId). When the activity is to be linked into a product system, a choice of a system model therefore has to be made, which provides the information on how to generate single-product datasets from multi-product datasets and which supplying activities to link to each specific intermediate input.

Two classes of system models can be distinguished: System models with substitution (system expansion) and system models with partitioning (allocation). Within each of these two classes, several instances can be defined. The ecoinvent database supports currently two system models with substitution:

- *Substitution, consequential, long-term (short name: 'Consequential')*
- *Substitution, constrained by-products (short name: 'Substitution, ILCD A')* ***[not available at the time of publication of v3.0]***

and four system models with partitioning:

- *Allocation, ecoinvent default (short name: 'Allocation, default')*
- *Allocation by revenue (short name: 'Allocation, revenue')* ***[not available in v3.0]***
- *Allocation by dry mass (short name: 'Allocation, dry mass')* ***[not available in v3.0]***
- *Allocation by carbon (short name: 'Allocation, carbon')* ***[not available in v3.0]***

These system models, and the rationales behind them, are explained in more detail in Chapter 14. For each system model, a set of linking and/or allocation rules is applied, described in Chapter 14, that allows the database service layer to add the missing direct links to each input of each activity, and to generate single-product datasets from multi-product datasets.

Additional advice for data providers:
The resulting database-generated dataset implementations, each with the name of their system model in the field systemModelName, are *not* intended for further editing by the data provider. If, upon inspection of a database-

generated interlinked dataset, an error or unintended link or allocation is discovered, the corresponding correction must be made in the underlying dataset with system model *undefined*.

4.15 Accumulated system datasets

An accumulated system dataset shows the aggregated environmental exchanges (LCI results) and impacts (LCIA results) of the product system related to one specific product from one specific activity. This implies that accumulated datasets are calculated for each product output of each activity dataset in the database (for system models with substitution, only for reference products). The calculation of accumulated system datasets is performed by the database service layer according to the algorithms described in Chapter 14.8.

The product systems include all upstream activity datasets, as linked by the intermediate exchanges, and therefore do not themselves have any intermediate exchanges, only environmental exchanges (LCI results) and accumulated impact assessment results (LCIA results).

5 Level of detail

5.1 Unit process data level

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 activities in a supply chain, and aggregating two or several different activities delivering the same intermediate outputs, respectively)[2].

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

However, we seek to avoid the separate reporting of unit processes when this does not add any useful information in an LCA context. This is the case when one unit processes always supplies all of its products directly to another specific unit process at the same location, so that the product of the first unit process never appears as a marketable product, and cannot be supplied by an external supplier. In such cases, the use of parameterisation is preferred to further subdivision of unit processes, see Chapter 5.7.

The necessary degree of detail in unit process descriptions as well as in naming of products depends on whether meaningful markets are identified for the different reference products. The lowest level of market segmentation is the market niche (see Chapter 4.4.6) and the obligatory product properties in this niche defines how detailed the reference product needs to be described to distinguish it from other products in other niches or market segments. For example, the product name "argon, crude, liquid" includes the necessary specification to distinguish it from the purified “argon, liquid", while the term “liquid” is only relevant if argon is also marketed in other forms. If products on the same market differ in terms of non-obligatory properties, these differences are not reported in the name, but may be reported as product properties (see Chapter 5.5). Obviously, the necessary level of unit process description follows from this, since it is the unit processes that provide the reference products and each unit process typically only provides one reference product.

When data for different exchanges are representing incongruent system boundaries, e.g. when VOC emissions are measured for unit process A separately and for unit processes B+C together, while energy use is measured for unit process A+B together and for unit process C separately, a separate description for each unit process can only be obtained by partitioning the data, separating from the original measurements that part of the energy and emissions that belong to unit process B. In this situation, the uncertainty in the partitioning must be held up against the need for separate data for each unit process, as opposed to provide only one dataset for A+B+C together (Weidema et al. 2003).

It should be noted that when individual data for an activity are available at different levels of detail (e.g. data on energy use may be available at production line detail, VOC emissions only available at plant level, while other emissions are only available at industry level), reporting at the highest level of detail (i.e. production line detail) implies an assumption that the data with a low degree of detail (data at industry level) are representative for the more specific situation, i.e. that the population is homogeneous. However, given the available data, this assumption appears to provide the best possible estimate.

[**Changes relative to ecoinvent version 2:** The desired level of detail is now described more precisely, seeking to avoid unnecessary sub-division of activities]

[2] *Outlook:* The intention is to replace old aggregated datasets by unit process data.

5.2 Confidential datasets

An activity dataset that includes confidential information may be kept inaccessible as a unit process dataset while still being included in calculations of accumulated systems datasets. This is achieved by setting the ecoSpold field accessRestrictedTo to an option different from the default "Public" or "Licensees". Access may be further protected by passwords and encryption, but these forms of protection are not part of the ecoSpold format as such.

Confidential datasets are subject to the same data quality guidelines as any other ecoinvent dataset, but the review procedure will be performed under the direct management of the ecoinvent database administrator that signs and/or manages the necessary confidentiality agreements, also in case of re-delegation of the review to independent reviewers.

This option is only applicable when there are less than three producers of a product, or for branded and single enterprise datasets, see Chapter 11.3, when an individual enterprise wishes to present its activity not as a unit process, but as an accumulated dataset only. When at least three independent data providers have provided confidential datasets for the same type of product, the ecoinvent Centre may include the supplied data in an averaged dataset for the generic product.

5.3 Sub-dividing activities with combined production

Multi-product activities are ubiquitous in LCA product systems. The ecoinvent database accommodates unallocated multi-product activity datasets as well as their derived single-product datasets.

A distinction is made between combined and joint production. In *combined production* the output volumes of the (combined) products can be independently varied, while in *joint production* the relative output volume of the (joint) products is fixed. For joint production, the single-product datasets are automatically calculated by the database service layer according to the procedures described in Chapter 14.4.

In many production activities where one raw material is used to produce several outputs, the production parameters can be adjusted to give different relative yields of the products, but only within certain limits. For example, in oil refining, the output of pitch (synonyms: bitumen; asphalt) varies between 7% and 79% depending on the origin of the raw oil. Thus, for each individual raw oil type, the output of pitch is not variable, but for refineries as a whole, pitch can be regarded as a variable output as long as the demand as a whole does not fall below 7% of the total demand for the refinery products. In general, the ecoinvent database does not support modelling of large changes (see Chapter 14.6.2), and the datasets therefore reflect only operation within the current limits.

Some activities may appear as allowing individual variation in output, but when subjected to a closer analysis it is only possible to keep the output of the other products constant by adjusting sub-processes not involved in the original production. Thus, what appears at the superficial level to be a case of individually variable products may in fact be a joint production requiring use of the procedures described in Chapter 14.4. For example, if an oil refinery is regarded as a black box, the outputs of different fuels, olefins and other refinery fractions may be individually varied, so that practically any desired relation between the outputs can be obtained. The only fixed fractions are refinery gas and pitch. However, when having access to data for the individual processes within the refinery, it becomes clear that this flexibility in outputs is achieved by allowing simultaneous changes in a large number of individual processes and alternative production routes, for which the choice depends on the price relations, constraints on raw material availability, and the demand for the different products.

When the output volumes can be independently varied, all exchanges can be related to the combined products by a mathematical relation (see Chapter 5.7). For example, factors for sub-dividing oil refineries have been determined on the basis of detailed mass and energy flows of the individual sub-processes, such as atmospheric distillation, etc. The products can often be expressed in terms of the physical parameter that is limiting the combined production activity, e.g. weight or volume for a combined transport of different products with different densities, where the amount of products that can be transported is either weight or volume limited.

When each of two or more intermediate outputs of an activity dataset is referenced to by a mathematical relation from at least one exchange, and each of the other exchanges is related to at least one reference product, the mathematical relations are then used to sub-divide the multi-product activity (manually or by the database service layer, see Chapter 14.1, linking rule no. 4) into an equivalent number of separate datasets, each with one of these intermediate outputs as its reference product. The other exchanges of the sub-divided datasets are determined by the mathematical relations provided in the original dataset, so that each sub-divided dataset describes only the part of the multi-product activity that changes with a change in output of that specific product. Thus, the modelling of combined production involves only the internal working of the multi-product activity and is modelled in the same way for system models with substitution and system models with partitioning. No allocation is required beyond what is implied by the mathematical relations.

Only positive additive elements (summands) of the mathematical relations are used. This implies that if one of the combined products involves a reduction in an input, the reduction is modelled as a positive output, and reductions in outputs are modelled as positive inputs. For example, an input of an inert waste to a combined waste combustion activity will reduce the potential heat output of the combustion activity. Instead of subtracting the heat requirement related to the inert waste reference product from the energy output, it is added as an input of heat. The heat output will thereby represent the gross heat output, while the heat output minus the heat input will represent the net heat production.

Datasets with combined products may be sub-divided manually by the data provider, in which case the original multi-product dataset is not available in the ecoinvent database. If the dataset is supplied as a multi-output dataset (recommended) with all other exchanges expressed as mathematical functions of the amount of the combined products, the multi-product dataset will be available as such. The sub-division is then performed by the database service layer, and the sub-divided datasets are only available in the database-generated interlinked datasets (see Chapter 14). When the subdivision is performed by the database service layer, the subdivided datasets have the same activity ID as the original dataset, which implies that the product name is required to distinguish the datasets from each other.

[**Changes relative to ecoinvent version 2:** In version 2, some datasets with combined production (ethanolamine production, gravel and sand quarry operation, petroleum refinery operation, hydroformylation of butane and propylene, benzene chlorination, sheep production) were not sub-divided, but allocated. These multi-product activities are now instead sub-divided.]

5.4 Production volumes

All transforming datasets include data on the production volume of the production facility, or from statistical sources on supply when the dataset represents several facilities. When statistical sources on supply are not available, the production volumes may be indirectly estimated from the demand.

Data is always *annual* production volumes relating to the time period and geographical area of the dataset and the unit of the product. This implies that

- When calculating total production volumes, e.g. for market datasets, the data can be utilised unmodified even when the time period of the dataset is different from a full year.
- When more than one activity produces the same product within the same market area, the production volume of each activity reflects that activity alone, i.e. the production volumes are additive.

Production volumes of market datasets are automatically calculated by the database service layer and are available in the interlinked market datasets of the system models with partitioning. If provided in the datasets with system model *undefined*, production volumes for market activities are provided only as text in the comment field.

Production volumes of treatment activities include treatment of wastes from previous years and will therefore not (necessarily) equal the total amount of waste generated in the time period of the treatment datasets. In parallel, production volumes of average operation/use datasets reflect the use of the current "fleet" of equipment, which may not be identical to the equipment currently produced. For an LCI of a specific type of equipment, the corresponding specific operation/use dataset should therefore be applied.

[**At the time of the release of version 3.0:** For some datasets converted from the ecoinvent version 2.2, the real production volumes have not yet been added and a dummy value (typically "1" or "4") have been used instead and documented in the comment field for the production volume. However, for all important products with more than one producing dataset, the production volume data have been added and reviewed, meaning that the production volume amounts are not affecting the results.]

5.5 Technology level of activities

The technology level of each transforming activity is classified in one of these five classes:

"New" for a technology assumed to be on some aspects technically superior to modern technology, but not yet the most commonly installed when investment is based on purely economic considerations.

"Modern" for a technology currently used when installing new capacity, when investment is based on purely economic considerations (most competitive technology).

"Current" for a technology in between modern and old.

"Old" for a technology that is currently taken out of use, when decommissioning is based on purely economic considerations (least competitive technology).

"Outdated" for a technology no longer in use.

Market activities, production/supply mixes, import/export activities and correction datasets do not have a technology level.

It should be noted that the terms used do not necessarily reflect the *age* of the technologies. A modern technology can be a century old, as long as it is still the most competitive technology, and an old technology can be relatively young, if it is one that has quickly become superseded by other more competitive ones.

The technology level relates to the year for which the dataset is valid, as given under temporal validity; see Chapter 4.2.2. In a time series, the same technology can move between different technology levels over time. For forecasted datasets, the technology level can also depend on the macro-economic scenario. The same technology can also be given different technology levels in different geographical locations, even in the same year.

The technology level is of particular importance in system models that take into account technology constraints, where the setting of the technology level determines whether an activity is included as an unconstrained supplier to the markets, depending on the specific rules for the particular system model (see Chapter 14.3). For example, in the system model "Substitution, consequential, long-term", an activity is identified as unconstrained if its technology level is "Modern" for increasing, stable, or slowly decreasing market volumes of its reference product, while for rapidly decreasing market volumes, the activity is identified as unconstrained if its technology level is "Old". The other technology levels may come into play if the database does not contain any datasets with the required technologies.

Since a modern technology may be a technology not yet in operation, its current production volume may be zero. However, in order for this technology to be included in the consumption mix of the system models with linking to unconstrained suppliers, it must be given a small production volume, e.g.

comparable to a pilot plant or less, small enough not to influence the current average production volume used in other system models.

The distinction between technology levels is based on an economic rationale since capacity adjustments typically are decided on the basis of long-term competitiveness as determined by the expected production costs per unit over long-term. With respect to geographical location, it is assumed that competitiveness is determined by the cost structure of the most important production factor (labour costs for labour intensive products, else energy and raw material costs). When comparing labour costs, local differences in productivity and labour skills are taken into account. If producers are distinguished by their cost structure and location, the most competitive supplier for a specific localised demand can be assessed by adding the specific transport costs.

Additional advice for data providers:
Unless manually changed by the data provider, the technology level is by default set to “current.

[**Changes relative to ecoinvent version 2:** The classification according to technology level is new. By default all datasets in the ecoinvent version 2 are set to “current”. A list of datasets for which the technology level has been manually adjusted to something different from “current” is available in the change report (Moreno Ruiz et al. 2013).]

Outlook: For electricity markets, most of the electricity generation activites supplying the markets are currently specified as “modern”, with technology- and geography-specific exceptions, which are explained on the ecoinvent Editor's pages. A more sophisticated and detailed modelling of the marginal supply to each national electricity market is considered for coming database versions.

5.6 Properties of exchanges

5.6.1 Mass and elemental composition

All exchanges are provided with data on wet mass, dry mass, and water mass, given per unit of the exchange, and water and carbon content per dry mass, the latter subdivided in fossil and non-fossil carbon. The content of other elements may be provided in addition. If the product output is specified in terms of elemental composition, these elements are also specified in the inputs that provide these elements.

For substances other than water, dry mass is *not* the same as ash content, but is calculated as the wet mass minus the water mass, and thus includes chemically bound H and O. Inputs or outputs of water may therefore, somewhat counter-intuitively, have a dry mass, when the water is incorporated into or released from chemical reactions involving chemically bound H and O.

Elemental composition is always given per dry mass. This implies that if the elemental composition is required per amount of an exchange, e.g. for use as an allocation property, the elemental composition shall be multiplied by the dry mass, before multiplying with the amount of the exchange.

Additional advice for data providers:
Data providers to the ecoinvent database are not required to supply data on mass and elemental composition. If data on wet mass, dry mass, water mass, water and carbon content per dry mass is missing for a newly supplied exchange, values will be added to the master file by the responsible editor.

[**Changes relative to ecoinvent version 2:** Wet mass, dry mass, water mass, and water and carbon content (the latter divided in fossil and non-fossil) now provided for all relevant exchanges.]

5.6.2 Fossil and non-fossil carbon

A distinction is made between fossil and non-fossil sources of CO_2, CO and CH_4. The sources of fossil carbon are the resource inputs of fossil fuels, peat, and mineral carbonates.

The resource consumption of “Carbon dioxide, in air” is calculated from the carbon in harvested plants and wild animals and increases in carbon stored in soils and plants. The latter is recorded as an output of “Carbon dioxide, to soil or biomass stock”. “Carbon dioxide, in air” is the only source of non-fossil carbon, which is mainly captured through the biological photosynthesis.

Reductions in the carbon stored in soils and the release of carbon from the burning of biomass residues in connection to land transformation, e.g. the clear-cutting of primary forests, are recorded in the elementary exchange (resource) “Carbon, organic, in soil or biomass stock”. All of this input is included in the corresponding emissions of Carbon dioxide, Carbon monoxide, and Methane, all with the addition “…, from soil or biomass stock”, and therefore does not contribute to any carbon content of any intermediate exchanges.

The properties carbon_content_nonfossil and carbon_content_fossil are used by the database service layer to calculate the properties carbon_content and carbon_allocation for use in the carbon allocated implementation of the ecoinvent database, see Chapter 14.7.3.

[**Changes relative to ecoinvent version 2:** The exchanges “Carbon, organic, in soil or biomass stock” and “Carbon dioxide, from soil or biomass stock” replaces the exchanges “Carbon, in organic matter, in soil” and “Carbon dioxide, land transformation” used in version 2. All datasets with these exchanges have been revisited to ensure that carbon balances are correct.]

5.6.3 Energy content

Energy content is not a required property of exchanges in the ecoinvent database.

If reported, the property “energy content” is accounted for in gross heating value (gross calorific value, higher heating value, upper heating value) in energy units per unit of the exchange.

Heat and electricity are measured directly in energy units.

Due to the significant energy losses or costs in transporting steam or hot air, the necessary heat is always produced in close geographical proximity to the activity requiring heating or cooling energy, often in an in-house boiler or purchased from a local heat producer. Thus, for site-specific datasets, the fuel type, boiler efficiency and operational emissions will typically be known and can be modelled specifically.

For the more generic datasets in ecoinvent, covering several – possibly unspecified – locations, typically only the amount of heat or the amount of fuel required will be available, sometimes with a specification on fuel type. For these situations, the generic heat inputs are used. When specific data are unavailable, a distribution with 1/3 of the heat input from natural gas and 2/3 from other fuel sources is applied.

The gross calorific value is the amount of heat generated by a given substance when it is completely oxidised. Calorific values are measured experimentally with a bomb calorimeter and can be calculated as the difference between the standard enthalpy of formation (also known as the standard heat of formation ΔH_f^Θ or $\Delta_f H^\Theta$; the change of enthalpy that accompanies the formation of 1 mole of the substance in its standard state from its constituent elements in their most stable form at 1 bar of pressure and 298.15 K or 25 degrees Celsius) of the oxidation products and the substance before oxidation. The gross calorific value includes the heat of condensation of water in the oxidation products. In contrast, the net (or lower) calorific value assumes that the enthalpy of vaporization of water (40.65 kJ/mol) is not recovered. It is useful in comparing fuels where condensation of the oxidation products is impractical, or heat at low temperatures cannot be put to use.

When specific data are unavailable, the gross calorific values in Table 5.1 are applied. The Table also gives densities for some common fuels for conversion from MJ to kg and back.

Data on standard enthalpy of formation are generally obtained from the thermochemistry data in the NIST Chemistry WebBook <http://webbook.nist.gov /chemistry/>. All elements in their standard states (e.g. oxygen gas) have a standard enthalpy of formation of zero, as there is no change involved in their formation.

Table 5.1. Default values for gross and net calorific values and density of some common fuels.

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

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

[**Changes relative to ecoinvent version 2:** The use of energy efficiencies for renewable energy inputs and the inclusion of waste heat have been discontinued. Boiler datasets such as "light fuel oil, burned in industrial furnace 1MW, non-modulating" are revised to have instead heat as an output, i.e. integrating with datasets such as “heat, light fuel oil, at industrial furnace 1MW", specifying the input of fuel in both MJ and other relevant physical units as product properties of the output. The conversion and re-linking of the datasets, including revising the datasets that demanded inputs such as "light fuel oil, burned in industrial furnace 1MW, non-modulating" have been done as a database-wide automatic routine.]

5.6.4 Density

Activity datasets for solid wood and semi-finished wood products are modelled per m^3. Bulk wood products such as wood chips are modelled per kg dry mass. The density and the heating value of wood strongly depend on the moisture content. The water content on a dry mass basis (referred to as the u-value in ecoinvent version 1&2) is given as a property rather than being included in the names of the activities and/or products. Some default values used for density of wood products are provided in Table 5.2.

Table 5.2 Default values for density of wood product

	Wood type (water content on dry mass basis) [1])	density
		kg/l
Construction wood	Softwood, round wood [2]) wet (70%)	0.765
	Softwood, industrial wood [3]) wet (140%)	1.080
	Softwood air dried (20%)	0.540
	Softwood kiln dried (10%)	0.715
	Hardwood, round wood wet (70%)	1.105
	Hardwood, industrial wood wet (80%)	1.170
	Hardwood air dried (20%)	0.780
	Hardwood kiln dried (10%)	0.715
Energy wood	logs, softwood, 1 year dried (30%)	0.585
	logs, softwood, 2 years dried (20%)	0.540
	logs, softwood, in the forest (140%)	1.080
	logs, hardwood, 1 year dried (30%)	0.845
	logs, hardwood, 2 years dried (20%)	0.780
	logs, hardwood, in the forest (80%)	1.170

[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

[**Changes relative to ecoinvent version 2:** Bulk wood products, such as wood chips, are now modelled per kg dry mass, instead of per m^3, which avoids the distinction between solid and bulk volume.]

5.6.5 Price of products and wastes

The property "price" is usually obtained from statistical sources and reported for the outputs of market activity datasets as the purchaser's price in currency units per unit of the exchange. [**At the time of publication of ecoinvent v3.0:** Thoroughly reviewed prices have not been added to all intermediate exchanges.]

[**Feature missing at the time of publication of ecoinvent v3.0:** As part of the linking of the datasets by the database service layer, see Chapter 14, these price properties are transferred to the corresponding inputs to the transforming activity datasets. The price property for the inputs of the same product to the market activities is reported as the basic price (i.e. without product taxes), calculated from the purchaser's price of the output according to this formula:

purchaser's price - trade margins - transport costs - product taxes + product subsidies = basic price

Product taxes less subsidies are added as primary inputs (monetary elementary exchanges, see Chapters 6.4) to the market activity datasets, while the trade margins and transport costs are determined by the prices of the intermediate inputs to the market activities from the wholesale, retail and transport industries.

When the datasets are linked by the database service layer (see Chapter 14), the basic prices calculated above are transferred to the corresponding outputs of transforming activities, and finally the price property of any directly linked intermediate inputs (see Chapter 4.4.1) are transferred from the corresponding supplying activity. This allows the calculation of monetary balances for the transforming activity datasets.]

For exported products, the purchaser's price of the exporting area is also known as FOB (Free On Board). International transports costs (CIF = Cost Insurance and Freight) are then added as inputs to the import activity in the importing country, resulting in a "CIF" price at the border of the importing area corresponding to the basic price of that area. The imported product then contributes to the local market (consumption mix) and there will have the same purchaser's price as the products produced domestically in the importing area.

The above price relationships are also applicable to treatment markets, i.e. the output price of a treatment market is in purchaser's prices (a negative price of the negative reference product implies a cost of treatment, while a positive price implies a payment from the treatment activity to the supplier of the material for treatment), while the outputs from the treatment activities are in basic prices.

When niche markets exist, see Chapter 4.4.6, these will typically support higher prices than the corresponding general market segments. When part of a niche product is sold on the general market segment, this therefore involves a price reduction. Furthermore, the "mixing of niche product" activities, which transform the niche products to be inputs to the general market segments, receive the niche products in purchaser's prices of the niche markets and supply them in basic prices of the general market segments. Thus, the "mixing of niche product" activities will, besides changing the name of their products, imply a price reduction of the products, both because the general market segments do not support the higher price of the niche products, and because the activities transform the prices from purchaser's prices back to basic prices. This price reduction implies that a "mixing of niche product" activity has a corresponding *negative* net operating surplus (see Chapter 6.4).

Additional advice for data providers:
Data providers to the ecoinvent database are not required to supply price data. If data on price is missing in a supplied market dataset, values will be suggested by the responsible editor, and can then be entered by the data provider when the dataset is returned from the editor.

[**Changes relative to ecoinvent version 2:** The consistent inclusion of price information is new.]

5.6.6 Allocation properties

An allocation property is a property used for calculating allocation factors, either for a transforming activity dataset (master allocation property) or for a single exchange (specific allocation property).

The property *"true value relation"* is a property specifically added for allocation purposes. The "true value relation" property is set by the database service layer as identical to the price, unless the property "true value relation" is specifically provided in the original, manually edited dataset (the dataset with system model *undefined*). Thus, allocation by true value is a variant of the allocation using "price" as allocation property, introduced to correct for some problems identified in the latter approach in two specific situations:

- When there is a very high annual variation in the relative average prices of the joint products, the "true value relation" property may be set to the same ratio as the ratio of the average prices for a longer time period.
- When the joint products have a shared functional property that should determine their relative value if not affected by market imperfections or perverse regulation, the "true value relation" property may be set to the same ratio as the amounts of this property. An example of this is the price of heat as a joint product from electricity production. Here, it is possible to argue that exergy, i.e. the ability of the products to perform work, is a shared property of the two products that reflects the true, functional value of the products, and that in a perfect market this would be reflected in the relative prices of the products. Thus, when both electricity and useful heat are products of the same activity, the "true value relation" results in the same allocation factors for the two products as if the property "exergy" had been used, while the sum of the "true value" of the two products equal the sum of the revenue from these two products, so that allocation based on the price can still be made for any other joint product.

For simple identification of activities for which "true value relation" properties are provided in the original dataset, the ecoinvent database automatically adds a tag "with true value" to such activities.

[**Changes relative to ecoinvent version 2:** While maintaining the same options as in the ecoinvent database version 2, the ecoSpold 2 format provides a simplified option to use properties for allocation.]

5.6.7 The designation “Defining value”

In the master file in which an exchange is defined, a property of the exchange can be designated as a “defining value”. This implies that its value is a part of the definition of the exchange and therefore has a fixed relation to the amount of the exchange that cannot be changed for individual instances of the exchange in different datasets, for example, the sulfur content of the elementary exchange Sulfur dioxide.

5.7 Use of variables within datasets

Values for exchange amounts and properties can be expressed as mathematical relations, using an ecoinvent-adapted version of the Open Document Formula Language[3]. For each field, where a mathematical relation is used, there is also a comment field, in which the mathematical relation is documented.

Variables for use in mathematical relations can be defined as specific parameters, valid within the individual dataset only. In addition, any exchange amount and property within a dataset can be used as a variable in mathematical relations of the same dataset. Exchange amounts and properties can be given a specific variable name, but also the unique identifiers (UUID’s) of each exchange amount and property can be used as a variable directly, using the REF function, i.e. REF('UUID').

Parameters and other variables can themselves be defined via mathematical relations including variables, i.e., nested variables are allowed, to the extent that circular references are not created.

Variables are unique to each dataset, i.e. it is not possible to define global variables valid for more than one dataset, except when a property of an exchange is designated as a “defining value”, see Chapter 5.6.7. However, in combination with the option of parent/child datasets (see Chapter 4.2), also variables are inherited, which implies that relations between exchanges and/or properties are preserved from parent dataset to child dataset. Each variable in each child dataset can of course have a different value from the variable value in the parent dataset.

The use of mathematical relations allows entry of data directly copied from original data sources, in their original units, and therefore contributes to reduce data conversion as a source of error and provides a more transparent documentation of the calculations that have been performed upon the primary data.

Additional advice for data providers:
It is recommended to define variables in parent (reference) datasets first, before creating delta/child datasets. Variables can be applied to reduce the effort when creating and maintaining datasets for very similar activities, e.g. extrusion of different metals: Although separate datasets are still needed for extrusion of steel and extrusion of aluminium, the same generic dataset can be applied as a starting point, expressing the specific differences in exchanges as conditional upon the Boolean parameters “steel” and/or “aluminium”, e.g., the electricity use per deformation stroke can be expressed as “Alu*0.115 + Steel*0.527” kWh, where the value will be 0.115 if Alu is true and Steel is false, and 0.527 in the opposite situation. All the exchanges that are identical to the two forms of extrusion then do not have to be entered twice.

[3] Described in the documentation to the ecoSpold format: Schemas/AdditionalDocumentation in the zip-file for the ecoSpold format version 2 available at http://www.spold.org/ecospold-v2/

[**Changes relative to ecoinvent version 2:** The option to use variables is new.]

5.8 Text variables

Some ecoSpold fields of the type TTextAndImage (the fields general comment, allocation comment, geography comment, technology comment, and time period comment) allow the use of *text* variables.

Text variables are used to include, exclude or edit specific text strings within an inherited text field. This allows easy changes of parts of texts for the child activity datasets. See also Chapter 4.2 for more details on inheritance.

A text variable is defined in a parent dataset and included in a text string by placing the variable name in {{curly brackets}} For example, in the text string: “This dataset is includes the {{metal}} extrusion”, the variable ‘metal’ may be given the value ‘metal’ in the parent dataset, but other appropriate values such as ‘steel’ and ‘aluminium’ in different child datasets. Thereby, only the difference between parent and child text has to be edited, while keeping the rest of the parent text intact.

5.9 No double-counting

5.9.1 Activity datasets

The ecoSpold field includedActivitiesStart describes the starting point of the activity. For unit processes, the starting point may be described in terms of the nature of the inputs and the point of reception, e.g. "From reception of raw materials [possibly further specified] at the factory gate [possibly further specified]" or "Service starting with the input of [e.g. labour and energy]”. For aggregated system datasets, the starting point is always "From cradle, i.e. including all upstream activities".

The ecoSpold field includedActivitiesEnd describes the included activities to the extent that this is not self-explanatory from the activity name, as well as activities or inputs that are intentionally excluded, e.g. if the activity “application of pesticides” as a service excludes the pesticide, in order to be applicable for many different active ingredients, or if the quality of the available data for the inputs is inadequate; see Chapter 13. The description ends by mentioning the last activity and/or point of delivery, e.g. “until and including loading of the product on lorries”.

Additional advice for data providers:
In the text in the includedActivities fields, especially if raw materials inputs are specified, ensure that inputs are not described in such a way that it can be misunderstood whether the production and supply of these inputs are part of the activity described. For example “Machine infrastructure is included” or “Inputs of are XX are considered” can be misunderstood to mean that the production of the machine infrastructure and/or the input XX is part of the described activity, when they are in fact simply inputs to the activity, and recorded as such under exchanges. See the wording suggested above for good practice.

The clear description of the start and end of each activity reduces the risk of overlapping datasets or gaps between datasets. If temporal markets are defined (see Chapter 4.4.4), the sum of all temporal markets should equal the average market. For geographically distinct datasets for the same activity, the database validation procedures ensure that the sum of the production volume of all datasets for the same activity equals the global production volume. Double-counting is also generally avoided by the completeness of the database, which implies that any new activity dataset added to the database is effectively a disaggregation of an existing activity dataset, see Chapter 13.

[**Changes relative to ecoinvent version 2:** In some ecoinvent v2 datasets, the field includedActivities contains redundant information that should be removed when updating, for example information on which raw materials, infrastructure or transport is included or which emissions are included, both types of information already being provided in the information on the exchanges.]

5.9.2 General principles for elementary exchanges

Elementary exchanges (exchanges with the environment) 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 total NMVOC emissions have both been measured and reported, the amount of benzene emitted is subtracted from the amount of NMVOC emission, to avoid double counting.

Elementary exchanges are classified with the help of compartments and sub-compartments. Compartments describe to where elementary exchanges are emitted (air, water, soil). Within these compartments, sub-compartments further distinguish issues relevant for the subsequent impact assessment step, e.g. population density.

Each elementary exchange is recorded only once. Hence, if appropriate, one may add up the elementary exchanges of all sub-compartments to get the total amount of an elementary exchange of the compartment. For example, one might add up the amounts of all "Carbon monoxide, fossil" emitted to "air/high population density", "air/low population density", air/lower stratosphere + upper troposphere", and air/unspecified" to get the total amount of fossil CO emitted to air.

The particulate emissions are reported in classes of <2.5 μm, between 2.5 μm and 10 μm, and >10 μm. In order to get the amount of PM10 emitted, one may add up the results of particulates emissions of <2.5 μm, and between 2.5 μm and 10 μm (named "Particulates, < 2.5 um" and "Particulates, > 2.5 um, and < 10um").

The only exception to this rule is the reporting for some sum parameters for water pollutants, i.e., the four parameters BOD_5, COD, DOC, and TOC (see Section 5.9.7), and the (minor) double-counting of mass implied by reporting particulate emissions as both particulates *and* as specific substance emissions (see section 5.9.4), both in mass units.

5.9.3 Resources

[**Feature considered for implementation later:** The extraction of metals and other minerals in ores is recorded as the amount of target material that is contained 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, e.g. 0.12 kg “Phosphorus, in ground” and 0.03 kg “Fluorine, in ground”. The additional content of non-used (gangue) material is added as a separate input, e.g. 0.85 kg “Gangue, fluorapatite ore, in ground”, so that the total amount of extracted material (here 1 kg) is recorded.]

Non-renewable energy resources like oil and gas are provided in weight or volume units and with the properties dry mass and energy content in energy units.

[**Changes relative to ecoinvent version 2:** In version 2, different ores are reported separately with their composition of different metals. For version 3, the nature of the ore (mineral/concentration) is now [planned to be] given as a property for each metal resource. The necessary translation from the old to the new format is performed as a central database maintenance task. Affected dataset authors and editors will be informed.]

5.9.4 Airborne particulates

Particulate emissions are 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 Table 5.3). With that, double counting of particulate emissions is avoided. 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 the ecoinvent database are derived from the standard measurements with the calculation procedure explained in Table 5.3.

Tab. 5.3 Names and characteristics of particulate elementary exchanges as reported in the ecoinvent database.

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 and less than 100 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

Particulate emissions are inventoried as particulates *and* as specific substance emissions, implying a (minor) double-counting of mass.

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).

5.9.5 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).

5.9.6 Other air pollutants

SO_X and NO_X emissions are reported as SO_2 and NO_2, respectively. When information is available, the shares of SO_3^- or SO_4^{2-} emissions, and NO emissions, respectively, are subtracted from the total SO_X and NO_X emissions, and reported separately. 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.

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

In the ecoinvent datasets all four sum parameters BOD_5, COD, DOC and TOC[4] 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. The amount of TOC and DOC is determined from the carbon content of the individual substances and based on the recommendations of de Beaufort-Langeveld et al. (2003).

Missing data are added using best estimates. DOC = TOC in a filtered sample, and in general the rules of thumb COD (g O_2) = 2.7*TOC (g C) and BOD_5 = 0.5*COD can be applied to untreated waste water. The BOD/COD ratio depends on the biodegradability of the organic material. At full biodegradability BOD = COD. For domestic wastewater values up to BOD_5 = 0.75*COD can be found and for food industries BOD_5 = 0.9*COD. For wastewaters with low nutrient content relative to carbon, such as from chemical plants and in cleaned wastewaters, the ratio can be as low as BOD_5 = 0.2*COD and when having passed a nutrient elimination step BOD_5 = 0.05*COD.

All individual substances are additionally recorded in the inventory. For the assessment of 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.

[**Changes relative to ecoinvent version 2:** The worst-case assumption BOD = COD has been removed as recommendation.]

5.9.8 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.

5.10 No cut-offs

No strict quantitative cut-off rule is followed in the ecoinvent database. Datasets are as complete as the knowledge of the data providers allow.

No cut-offs are applied for recycling. Recycled by-products are treated as any other by-product.

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

The ecoinvent database does not operate with cut-off levels for minor inputs or outputs. In principle, all known inputs and outputs are recorded as such.

This approach does imply some risk of bias in the results if comparing activities or product systems where detailed information is available for one while not for the other. The ecoinvent Centre currently carries out research to minimise such bias by increasing the completeness of the reporting of specific toxic exchanges, as well as other exchanges that contribute significantly to the overall environmental impact of human activities.

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

[**Changes relative to ecoinvent version 2:** In version 2, cut-offs were applied to by-products for recycling.]

6 Completeness

This Chapter is concerned with completeness of individual datasets. The completeness of the database is discussed in Chapter 13 on “Embedding new datasets into the database”.

6.1 Stoichiometrics

If data availability is poor, stoichiometric balances are used to determine the raw materials demand. If no specific information is available, a 95% yield is assumed. Such modelling choices are documented in the datasets.

6.2 Mass balances

For each activity, the law of conservation of mass and energy applies. This implies that the mass and energy in and out of each activity is the same, when taking into account changes in stocks. Only for activities involving nuclear reactions these balances interact. This is also true for each element. Thus, separate mass and elemental balances apply to all activities except those involving nuclear reactions.

Dry mass and water mass are available (reported or calculated) for each resource input, for each intermediate exchange of products and wastes, as well as for emissions. This includes water resource use, and nitrogen and oxygen from air entering into activities involving combustion, photosynthesis and biological metabolism, and the air emissions of water vapour and oxygen and nitrogen from these activities as calculated from the reaction equations. For example, the oxygen demand for combustion is calculated from the oxides (notably CO, CO_2, SO_2, NO_2, and N_2O) in combustion exhaust. Thus, complete mass balances (sum of outputs minus sum of inputs) for the unit processes can be calculated and any deviations reported, either in the validation report or as an “unspecified output, from mass balance”. Note that a dry matter balance may include water when this is incorporated as or released from chemical reactions involving chemically bound H and O, and that this water is not included in water balances.

In addition to the dry matter balance, mass balances for selected chemical elements can be performed when specific information on the content of these elements is provided for all relevant inputs and outputs to an activity. Currently, this is only done systematically for fossil and non-fossil carbon.

Mass balances have been implemented as a validation feature, and the sums and their difference (e.g. "Input > output by X [unit] (0.01% of output)" is displayed as a warning in the validation result. There is currently no minimum requirement for the deviation.

Conditional exchanges are not included in mass balances; see Chapter 11.4.

[**Changes relative to ecoinvent version 2:** Mass balancing is a new option, enabled by the option to add properties to all exchanges. There is currently no requirement for datasets to be mass balanced.]

6.3 Energy balances

Energy content is not a required property of exchanges in the ecoinvent database. Therefore, it is also not possible to provide complete energy balances of all activities or product systems. The total fossil and nuclear fuel inputs and Cumulative Energy Demand (fossil and nuclear) may still be calculated from the resource inputs of fossil and nuclear fuels.

[**Changes relative to ecoinvent version 2:** Waste heat emissions and energy content of renewable energy resource inputs have been removed.]

6.4 Monetary balances

Although there is no "law of conservation of money", a monetary balance applies to each activity, expressed in the so-called *accounting equation*, which is the foundation for the double-entry bookkeeping system. Thus, all revenue earned must also be spent, when taking into account changes in savings.

Using the price information reported for each intermediate input and output, monetary balances can be established for each activity. The balancing element accounting for the difference between the value of the outputs (revenue) of an activity, and the value of the inputs of intermediate products (including investments) to this activity, is the elementary input *"Expenditures on primary production factors"*, measured in monetary units, which may be calculated as the unspecified residual in the monetary balance. When more information is available, this may be divided in the following components:

- *Labour cost* (wages and other remunerations), possibly further sub-divided on income group or education level of the workers
- *Net tax* (taxes minus subsidies)
- *Net operating surplus* (entrepreneur's income or profit)
- *Rent* (payment to resource owners)

The *"Expenditures on primary production factors"* are also called *value added*. In national accounting practice, rent is included with the net operating surplus and the term value added is used for the payments to the primary production factors *including* investments, although the value added of investments is already counted once in the industries supplying the investment goods. In national accounting, the value added of an activity is the same as its contribution to the gross domestic product (GDP).

To ensure their inclusion in the monetary balance, the *Expenditures on primary production factors* and/or its components all have "price" as a property, even when the amounts of these exchanges are already measured in monetary units. When expressed in the same units as the amount of the exchanges, the amount of the price property is 1. *Labour cost* has the additional property 'working time' which is related to the price via the cost per hour.

An activity does not necessarily pay for all its inputs; some may be supplied to the activity "for free", e.g. as a public service such as road infrastructure or hospital services. The physical relationship (causality) is then not matched by a direct economic relationship. However, a service or a good supplied "for free" typically means that someone else has paid for the costs of this good or service, which is thus an economic externality; see Chapter 6.11. To avoid double-counting, such externalities are not reported as externalities in the ecoinvent database, but are instead included directly (internalised) as intermediate inputs to the activity. When internalising an economic externality, the activity that originally paid for the good or service is relieved of this cost, which instead adds to the total intermediate costs of the activity that previously received this input for free. The economic balances of the activities are maintained by adjusting the *Net tax* of the activities, which is equivalent to modelling a subsidy.

Note that internalisation is also relevant when the good or service is already covered specifically by a dedicated tax, reported under *Net tax* of an activity, since this tax is not linked to any physical inputs. In fact, any dedicated tax or subsidy, i.e. a tax or subsidy that is dedicated to be used for a specific activity, should be internalised in this way, to correctly model the physical causalities.

However, whether a "free" good or service is included as input to an activity or not is sometimes dependent on a judgement of what constitutes a physical causality. For example, it is obvious that road infrastructure is to be included as an in input to road transport even when it is not paid for directly by the vehicle operators, rather than being a stand-alone final consumption item (as it is in many national accounts), but it may be less obvious whether or to what extent the road transport dataset should have an input of health care in proportion to the additional health care required to treat victims of road incidents, or an input compensating for the time lost in queuing from other users of the same infrastructure. For details of such modelling decisions, the database user must consult the relevant individual datasets. In general, the ecoinvent database strives to include (internalise) all well-documented physical causalities, disregarding whether they are matched by a direct economic relationship.

[**Changes relative to ecoinvent version 2:** The option to make a monetary balance is new, and is related to the requirement that price information is added to all intermediate exchanges.]

6.5 Elementary exchanges

In the ecoinvent database no predefined, limited list of elementary exchanges is applied. Completeness in elementary exchanges is aimed for. Specific development projects are performed by the ecoinvent Centre to fill gaps in the data.

6.6 Water

Water enters from the environment into human activities as a resource input like any other resource, specified by its location or origin (distinguishing groundwater, surface water, sea water, and rain water). The quality of the water resource can be further specified by its properties. Relevant properties may be COD, BOD, TSS, TDS, and faecal coliform bacteria. Water resources and water transferred from other watersheds are reported in volume, while the ‘water mass’ property is used to quantify the mass of water inputs for use in water balances. Water balances also include water bound in extracted minerals, water bound in biological material harvested in the wild, and water in intermediate inputs, all quantified in the ‘water mass’ property of these exchanges.

The input of water can be balanced with an equivalent output in intermediate outputs, water transferred to other watersheds, and outputs to different environmental compartments (air, soil, groundwater, ocean and surface water, see Chapter 9.4.2). Note that any pollution/contamination of the water emitted *to the environment* is not specified as properties of the water, but only as separate exchanges (including e.g., COD, BOD, faecal coliform bacteria, and temperature, when relevant), in order to avoid double-counting in the impact assessment.

If the exact origin and/or destination of the freshwater exchanges are unknown, they are entered as inputs from and/or outputs to the environmental sub-compartment ‘water, unspecified’.

[Feature considered for implementation later: It is considered to include inputs and outputs of water used for cooling in separate activities that produce cooling rather than in the activities that require cooling.]

6.7 Land occupation and land transformation

Land occupation and land transformation receives increasing attention in life cycle inventory analyses and life cycle impact assessment methods. It is especially important for agricultural and forestry products.

Table 6.1 shows the land use classes used for the ecoinvent database. The land use classes and the descriptions in the Table are based on a draft version of the Handbook on LCIA of Global Land Use within the framework of the UNEP/SETAC Life Cycle Initiative.

Table 6.1. Land use classes used in the ecoinvent database. Table continues on next page.

Land use class	Description
Unspecified	
Unspecified, natural (non-use)	
Forest, unspecified	Areas with tree cover >15%.
Forest, primary (non-use)	Forests (tree cover >15%), minimally disturbed by humans, where flora and fauna species abundance is near pristine.
Forest, secondary (non-use)	Areas originally covered with forest or woodlands (tree cover >15%), where vegetation has been removed, forest is re-growing and is no longer in use.
Forest, extensive	Forests (tree cover >15%), with extractive use and associated disturbance like hunting, and selective logging, where timber extraction is followed by re-growth including at least three naturally occurring tree species, with average stand age >30 years and deadwood > 10 cm diameter exceeds 5 times the annual harvest volume.
Forest, intensive	Forests (tree cover >15%), with extractive use, with either even-aged stands or clear-cut patches exceeding 250 m length, or less than three naturally occurring species at plant-ing/seeding, or average stand age <30 years, or deadwood less than 5 times the annual harvest volume.
Wetland, coastal (non-use)	Areas tidally, seasonally or permanently waterlogged with brackish or saline water. Includes costal marshland and mangrove. Excludes coastal land with infrastructure or agriculture.
Wetland, inland (non-use)	Areas partially, seasonally or permanently waterlogged. The water may be stagnant or cir-culating. Includes inland marshland, swamp forests and peat bogs.
Shrub land, sclerophyllous	Shrub-dominated vegetation. May be used or non-used. Includes also abandoned agricul-tural areas, not yet under forest cover
Grassland, natural (non-use)	Grassland vegetation with scattered shrubs or trees (e.g., steppe, tundra, savanna).
Grassland, natural, for livestock grazing	Grasslands where wildlife is replaced by grazing livestock.
Arable land, unspecified use	Land suitable for crop production, in unspecified use
Pasture, man made	Arable land used for forage production or livestock grazing.
Pasture, man made, extensive	+ no artificial fertiliser applied, mechanically harvested less than 3 times per year or equiva-lent livestock grazing
Pasture, man made, intensive	+ artificial fertiliser applied, or mechanically harvested 3 times or more per year or equiva-lent livestock grazing
Annual crop	Cultivated areas with crops that occupy the land < 1 year, e.g. cereals, fodder crops, root crops, or vegetables. Includes aromatic, medicinal and culinary plant production and flower and tree nurseries.
Annual crop, non-irrigated	Annual crop production based on natural precipitation (rainfed agriculture).
Annual crop, non-irrigated, ex-tensive	+ Use of fertiliser and pesticides is significantly less than economically optimal.
Annual crop, non-irrigated, in-tensive	+ Fertiliser and pesticides at or near the economically optimal level.
Annual crop, irrigated	Annual crops irrigated permanently or periodically. Most of these crops could not be culti-vated without an artificial water supply. Does not include sporadically irrigated land.
Annual crop, irrigated, extensive	+ Use of fertilizer and pesticides is significantly less than economically optimal.
Annual crop, irrigated, intensive	+ Fertiliser and pesticides at or near the economically optimal level.
Annual crop, flooded crop	Areas for rice cultivation. Flat surfaces with irrigation channels. Surfaces regularly flooded.
Annual crop, greenhouse	Crop production under plastic or glass.
Field margin/hedgerow	Land between fields with natural vegetation.
Heterogeneous, agricultural	Agricultural production intercropped with (native) trees.
Permanent crop	Perennial crops not under a rotation system which provide repeated harvests and occupy the land for >1 year before it is ploughed and replanted; mainly plantations of woody crops.
Permanent crop, non-irrigated	Perennial crops production based on natural precipitation (rainfed agriculture).
Permanent crop, non-irrigated, extensive	+ Use of fertilizer and pesticides is less than economically optimal.
Permanent crop, non-irrigated, intensive	+ Fertiliser and pesticides at economically optimal level.
Permanent crop, irrigated	Perennial crops irrigated permanently or periodically. Most of these crops could not be culti-vated without an artificial water supply. Does not include sporadically irrigated land.
Permanent crop, irrigated, ex-tensive	+ Use of fertilizer and pesticides is significantly less than economically optimal.
Permanent crop, irrigated, inten-sive	+ Fertiliser and pesticides at or near the economically optimal level.
Cropland fallow (non-use)	Cropland, temporarily not in use (<2 years).
Urban/industrial fallow (non-use)	Areas with remains of industrial buildings; deposits of rubble, gravel, sand and industrial waste. Can be vegetated.

Table 6.1., continued. Land use classes used in the ecoinvent database.

Land use class	Description
Urban, continuously built	Buildings cover most of the area. Roads and artificially surfaced area cover almost all the ground. Non-linear areas of vegetation and bare soil are exceptional. At least 80% of the total area is sealed.
Urban, discontinuously built	Most of the area is covered by structures. Buildings, roads and artificially surfaced areas, associated with areas with vegetation and bare soil, which occupy discontinuous but significant surfaces. Less than 80% of the total area is sealed.
Urban, green area	Areas with vegetation within urban fabric. Includes parks with vegetation.
Industrial area	Artificially surfaced areas (with concrete, asphalt, or stabilized, e.g., beaten earth) devoid of vegetation on most of the area in question, which also contains buildings and/or areas with vegetation.
Mineral extraction site	Areas with open-pit extraction of industrial minerals (sandpits, quarries) or other minerals (opencast mines). Includes flooded gravel quarries, except for riverbed extraction.
Dump site	Landfill or mine dump sites, industrial or public.
Construction site	Areas under construction development, soil or bedrock excavations, earthworks.
Traffic area, road network	Motorways, including associated installations (stations).
Traffic area, rail network	Railways, including associated installations (stations, platforms).
Traffic area, rail/road embankment	Vegetated land along motorways and railways.
Bare area (non-use)	Areas permanently without vegetation (e.g., deserts, high alpine areas).
Snow and ice (non-use)	Areas permanently covered with snow or ice considered as undisturbed areas.
Inland waterbody, unspecified	Freshwater bodies.
River, natural (non-use)	Natural watercourses.
Lake, natural (non-use)	Natural stretches of water.
River, artificial	Artificial watercourses serving as water drainage channels. Includes canals.
Lake, artificial	Reservoir in a valley because of damming up river.
Seabed, unspecified	Area permanently under seawater.
Seabed, natural (non-use)	Natural seabed.
Seabed, bottom fishing	Seabed disturbed by bottom trawling or fishing dredge
Seabed, sediment displacement	Seabed disturbed by dumping or shellfish- or sediment-dredging
Seabed, infrastructure	Seabed disturbed by infrastructure like harbours or platforms
Seabed, drilling and mining	Seabed disturbed by drilling and mining, including cuttings and tailings disposal

It should be noted that the land use classes are not intended to capture specific emissions, such as the CO_2 emissions after forest clearing. Such emissions are therefore separately included in the datasets for the specific crops that are grown on such recently transformed land.

Outlook: It is currently being researched if continuous indicators such as NPP can be used as the basic variables of the land exchanges, so that the land use classes are only provided as default options (i.e. with their specific description in terms of the continuous variables). This would allow data providers to define new land use classes as long as they are defined in terms of the underlying variables.

[**Changes relative to ecoinvent version 2:** New land use classes have been added, and some previously separate categories have been aggregated. The definitions of the land use classes have been improved.]

The ecoinvent database covers both direct and indirect (upstream) land use effects, in the same way as the indirect (upstream) uses of all other resources are covered. In fact, the distinction between direct and indirect land use is only relevant when seen from the perspective of one particular unit process, since all exchanges are direct to the specific activity in which they occur, and indirect for all downstream activities.

Land use is inventoried through the use of data on:

- *Land occupation* for the current land use (the occupied land is prevented from changing to a more natural state).

- *Land transformation* (from previous land use and to current land use, e.g., the conversion of a former natural area to industrial land; the conversion of a gravel quarry to a natural area by active re-cultivation).

For land occupation, both the area and the duration required for the production of a certain amount of products and services are important. Therefore, land occupation is recorded in area*time (m^2*year). Clearly defined and relatively short temporary changes in the land use are also recorded as land occupation (e.g. the construction of underground natural gas pipelines, which temporarily converts agricultural land to an excavation site). For these construction activities as well as for active restoration activities after decommissioning, the land use category "land occupation, construction site" is applied.

A land transformation consists of two entries:

1. Land transformation, from *land use class X*, and

2. Land transformation, to *land use class Y*.

Example: "Transformation, from forest", in m^2 and "transformation, to mineral extraction site", also in m^2. Land transformation thus records a state before and after a transformation.

An activity that requires land for a specific use may obtain the land tenure rights on a general market for land tenure that is supplied by all the different land classes available for this market, including land already in use, newly transformed land, and efficiency improvements on outputs from current land uses (which substitute for land). Land with different productivity (potential net primary productivity, NPP, measured in kg carbon per m^2*year) can be inputs to the same markets for land tenure. Land tenure is therefore generally expressed in kg C. The same default modelling rules are applied for land tenure markets as for all other market activities in ecoinvent (e.g. that unless local market boundaries can be justified, a global market is assumed, etc.).

The land tenure markets may be common to more specific land uses. For example, the ‘market for arable land tenure’ may supply land to both an annual crop production and a gravel quarry (since gravel quarries are most often placed on land suitable for agriculture). While the more general ‘transformation, to arable land, unspecified use’ and ‘occupation of arable land, unspecified use’ are recorded in upstream inputs to the ‘market for arable land tenure’, the more specific transformation from ‘arable land, unspecified use’ to ‘annual crop’ or ‘mineral extraction site’ as well as the more specific ‘occupation, annual crop’ and ‘occupation, mineral extraction site’ are recorded directly in the activities with these land uses. Thereby, the transformation and occupation recorded by these more specific land use classes can be used in impact assessment to represent the additional transformation impact or the difference in occupation impacts relative to the more general impacts of the unspecific transformation and occupation recorded upstream.

While land tenure (and possibly more specific transformation and occupation) is generally included as an input to the infrastructure production activities, agricultural and forest land requirements are recorded as inputs to the operation activities as long as they do not include buildings. Land tenure required by buildings, greenhouses and the like are recorded as inputs to the infrastructure dataset.

For particular activities the land use class before starting the activity may well be known. However, it is often difficult to assess in detail all the land use classes which have been converted by the activities recorded within the ecoinvent database. If the land use class before the operation phase of the activity is not known, no specific transformation is recorded, and only the average transformation is provided by the relevant land tenure market.

Land transformation at the end of an activity may be relevant for some activities such as road construction, power plant erection, active mine restoration, land abandoned and subjected to natural succession, etc.). However, the transformation at the end is usually not considered, i.e. when the following activity is assumed to start from the state of the current activity or when it can be assumed that the land use is not likely to change at the end of the activity (no transformation from “industrial area” to “unknown” at the end of life of a factory, transport infrastructure, or agricultural land).

The above-described approach is illustrated with the following simplified example of gravel extraction:

- The output of the infrastructure dataset "gravel quarry construction, with active recultivation" is given in m^2, and the land use is thus directly related to this unit.
- Potential net primary productivity (NPP) of the arable land used for the quarry is 0.5 kg C / m^2*year.
- The gravel quarry is utilised for 20 years, followed by 2 years of restoration activities, resulting in secondary forest.
- The recultivation uses 0.02 kg fertiliser-N and 4.3 MJ diesel per m^2.

The resulting inventory for the infrastructure activity "gravel quarry construction, with active recultivation" is shown in Table 6.2.

Table 6.2. Example of unit process raw data for gravel quarry construction, including direct and indirect (upstream) land transformation and land occupation.

		unit process raw data					Intermediate LCI result
		gravel quarry construction, with active recultivation	market for land tenure, arable land	intensification, arable land	clear-cutting, primary forest to arable land	land already in use, arable land	gravel quarry construction, with active recultivation
		1 m^2 gravel quarry	1 kg NPP-C arable land tenure	1 kg NPP-C arable land tenure	1 kg NPP-C arable land tenure	1 kg NPP-C arable land tenure	1 m^2 gravel quarry
Resource inputs:	**Unit:**						
Occupation, mineral extraction site	m^2year	20					20
Occupation, construction site	m^2year	2					2
Occupation, arable land, unspecified use	m^2year					1.64	17.6
Transformation, from forest, primary (non-use)	m^2				1.37		0.075
Transformation, to arable land, unspecified use	m^2				1.37		0.075
Transformation, from arable land, unspecified use	m^2	1					1
Transformation, to mineral extraction site	m^2	1					1
Transformation, from mineral extraction site	m^2	1					1
Transformation, to forest, secondary (non-use)	m^2	1					1
Intermediate inputs:							
land tenure, arable land	kg NPP-C	11					
land tenure, arable land (from intensification, arable land)	kg NPP-C		0.02				
land tenure, arable land (from clear-cutting, primary forest to arable land)	kg NPP-C		0.005				
land tenure, arable land (from land already in use, arable land)	kg NPP-C		0.975				
nitrogen fertiliser, as N	kg	0.02		0.023			0.025
Diesel	MJ	4.3					4.3
...	...						...

The land tenure requirement is calculated by multiplying the area by the NPP and by the quarry lifetime, including the 2 years of restoration: 1 m^2 * 0.5 kg C/m^2*year * 22 year) = 11 kg C/m^2 quarry. In this simplified example, these 11 kg C are supplied by the “market for land tenure, arable land” with 97.5% from “land already in use, arable land” (which includes the “indirect” part of the occupation, calculated from the NPP of average arable land of 0.61 kg C / m^2*year), 2% from intensification of production on this land (requiring 0.023 kg N to increase production equivalent to 1 kg NPP-C) and with 0.5% from deforestation (which carries the “indirect” land transformation, calculated from the NPP of average deforested land of 0.73 kg C / m^2*year). The two transformations "to mineral extraction site" and "from mineral extraction site" cancel each other out. In the column "LCI result", one can see that the net transformation is 1 m^2 to secondary forest with 0.075 m^2 coming from primary forest (the “indirect” land transformation) and 0.925 m^2 from arable land.

[**Changes relative to ecoinvent version 2:** Transformation at the end of an activity is now added also for land abandoned and subjected to natural succession. The use of ‘default use periods’ (standard assumptions for lengths of production cycles) has been abandoned. The land occupation and land transformation is now typically included in separate datasets delivering ‘land tenure’ expressed in g NPP-C, which is then an input to the specific transforming datasets that require land tenure. Thereby, indirect land use is seamlessly included in complete parallel to all other upstream resource uses. In version 2 datasets, tropical wood from clear-cut was modelled as co-product of land transformation from forest to agricultural land. This is revised so that each cause of land transformation is modelled separately, i.e. ‘forestry’ and ‘clear-cutting, primary forest to arable land’ are separate activities with each their own land use impacts.]

6.8 Noise

Outlook: Noise is one of the new elementary exchanges that are considered to be added to the ecoinvent database.

6.9 Incidents and accidents

Accidents are unexpected, unusual, unintended and unpredictable events, and are not included in the ecoinvent database. Examples of accidents which are not considered are the serious accidents in nuclear power plants, e.g. Chernobyl, which might have very dramatic impacts, but which occur only seldom.

On the other hand, incidents that can be calculated probabilistically and occur so frequently that the annual average is not influenced significantly by each individual incident, are considered in the ecoinvent activity datasets. An example of an incident is an oil spill due to rupture of a transport pipeline. Such spills occur frequently and are reported regularly.

Enterprises with additional safety measures may have lower occurrences of incidents and this may warrant a separate dataset for such enterprises.

6.10 Litter

Although litter is by its nature an exchange to the environment, since it does not undergo any further treatment, recording litter as such would imply the addition of many new elementary exchanges with little added value for the impact assessment. Therefore, the further fate of litter in nature is added as human treatment activities, similar to surface landfills and/or aquatic deposits.

6.11 Economic externalities

Economic externalities are costs paid or benefits received by parties not operating or in control of the reported activities, and not part of the price of the products.

Examples of such external costs for e.g. a road transport activity are the use of public infrastructure, time lost in queuing by other users of the same infrastructure, and accident and health services, to the extent that this is not covered by insurances or specific taxes paid by the transport activity. Examples of external benefits (typically reported as negative costs) are e.g. the free provision of infrastructure ("free rider" situations), education and other public services. External benefits are most often related to public production or voluntary private provision of such services. It is also possible to find examples of private goods and services where it is simply impossible for the supplier to ensure that all parties that benefit from the good or service actually pay for this.

An external cost of one activity is typically an external benefit provided by another activity and vice versa. In the ecoinvent database such externalities are therefore included directly (internalised) as intermediate inputs to the activities, see Chapter 6.4, rather than being separately reported as economic externalities.

6.12 Social externalities

Social externalities, i.e. changes in social pressures that may affect human well-being but are not of a biophysical or economic nature (i.e. not covered via the use of natural resources, emissions, or transfer of economic costs and benefits) may be added as elementary exchanges.

Examples of social externalities are occupational health issues (lost work-days), excess work (hours worked in excess of 48 per week), work-place stress, un-organised labour, and injuries (not limited to work-related injuries).

Positive social externalities can be e.g. provision of access to pensions and social security, where these benefits are not provided by the public authorities, efforts to alleviate poverty by provision of products that are targeted the poor, recruitment of workers in long-term unemployment, and support to terminated workers.

In contrast to the economic externalities described in Chapter 6.11, social externalities are not paid for or provided by other activities, e.g. the lost work-days are not compensated, but are simply lost. This implies that the same issue can sometimes be an economic externality and sometimes a social externality. For example, education provided for free can be an economic externality, since it is paid for by someone and provided by a specific activity, while lost education opportunities (e.g. due to child labour) can be a social externality.

Data on social externalities are currently not included in the ecoinvent database, but we encourage data providers to suggest systematic inclusion of new indicators for social externalities.

7 Good practice for documentation

7.1 Detail of documentation

The data used to describe the exchanges of a particular activity are discussed within the context of values from various sources. Values are generally not supplied without comment.

Comments and references to sources (see Chapter 7.5) are given on the most detailed level possible (i.e. attributed to the particular exchanges of an activity, attributed to a particular property of an exchange, if possible and relevant), describing the individual values and their estimation. Comments and references that are general to more than one entry are provided in the comment field most relevant for the nature of the value. The "technology comment" field is used for comments and references general to the specific technology and the "general comment" field for comments and references of more general nature that cannot be placed in any of the more specific comment fields.

In general, the information in the dataset should be sufficient to judge the appropriateness of a dataset for a specific application. Background information that is common for many datasets are available on www.ecoinvent.org under the web-page for the ISIC activity class in question (see Chapter 9.7) or sub-pages to this, as indicated in the "general comment" field of the dataset.

Additional advice for data providers:
Information that is required to judge the appropriateness of a specific dataset for a specific application shall be placed in the dataset. The web-pages only contain less essential background information common to several datasets. This implies e.g. that the dataset should *not* contain references such as "For exceptions, see [web-page]".

[**Changes relative to ecoinvent version 2:** The content of the reports from version 2 are placed partly in the datasets, partly on web-pages with the same structure as the ISIC activity classification. Web-pages will also be available for methodological issues, structured in the same way as this data quality guideline. In some ecoinvent v2 datasets, the *General comment* field contains redundant information that should be removed when updating, for example: "Inventory refers to the production of 1 kg …", which is already given in the exchange information for the reference product.]

7.2 Images

Images may be included in any of the "TextAndImage" fields of a dataset and additionally a Dataset Icon may be available, serving as a quick identification of the specific dataset (may also be used for product brands and company logos).

7.3 Copyright

ecoSpold reference: isCopyrightProtected (field 3540)

When supplying a dataset to the ecoinvent database, the data provider confirms that the data are free from prior copyright, and makes a non-exclusive transfer of the right of use to the ecoinvent Centre.

In general, all ecoinvent datasets are subject to copyright. However, with the assistance of sponsors it has become possible for some ecoinvent datasets to be provided as open access datasets, which can be freely shared, see Chapter 7.4.4. Use of these open access datasets is still subject to the normal rules for citation.

7.4 Authorship and acknowledgements

7.4.1 Commissioner

The ecoSpold data format does not have a separate field for information on the commissioner for a specific dataset, i.e. the person or organisation paying for the data collection.

When such information is available, it is placed in the *General comment* field, which may refer to an entry in a *Person* field (can also be used for organisations).

7.4.2 Data generator

The data generator is the person or organisation that collected, compiled or published the original data. This may or may not be the same person as the author (see 'DataEntryBy'; Chapter 7.4.3).

The intention of this field is to acknowledge and reference the origin of the data and the person or organisation that performed the majority of the work in data collection. Minor changes and adjustments by subsequent authors do not make these persons data generators, unless this involves a new publication of the entire dataset in a context outside the ecoinvent database.

7.4.3 Author (Data entry by)

The field dataEntryBy refers to the author of the dataset, i.e. the person that entered data into the database format and provided it to ecoinvent and thereby is the person responsible for the data. The dataset author may or may not be different from the data generator; see Chapter 7.4.2. The author may make minor modifications or adjustments to the datasets to fit the data to the ecoinvent requirements, without this implying that the author then also is the data generator.

Authors are subject to authorisation by the ecoinvent database administrator before being allowed to upload datasets to the ecoinvent validation and review procedure. The uploaded data are automatically stamped with the identity of the author. As part of the submission procedure, the author confirms that the data are free from prior copyright and makes a non-exclusive transfer of the right of use to the ecoinvent Centre, see Chapter 7.3. For modifications to datasets with an active author, see Chapter 16.3, the review procedure includes a request to the active author for the right to perform the modifications. The original author may then decide to perform the extrapolation and thereby maintain authorship also to the extrapolated dataset. If creating a new dataset, e.g. an update, which is largely an extrapolation from an existing dataset, it is good practise for the new data provider to seek permission from the original author.

7.4.4 Open access sponsors

A part of the ecoinvent database is made freely available to the public. The free public access to the datasets in this part of the ecoinvent database is made possible through sponsorships. The sponsored datasets are free of copyright (see Chapter 7.3), but are subject to the normal rules for citation (see Chapter 15.5).

The sponsored datasets are labelled with the following sentence in the general comment field: “The kind contribution of [sponsor name] has made it possible to make this dataset freely available to the public. The sponsors have no influence on the content and/or validation procedure for the sponsored datasets.”

Datasets are made freely available for a minimum period of 3 years. The sponsored datasets stays in the free part of the database also after the termination of the 3-year period. Any later updates (i.e. improvements made after the 3-year period or new versions of the same dataset for later years) will only be made freely available if a new sponsorship agreement is made.

The ecoinvent Centre retains the right to refuse sponsors without stating any reason for this refusal.

Technical disclaimer: If parent/child relationships between datasets applies (e.g. the same dataset for several countries), the sponsorship applies either to the parent dataset alone, or to one specific instance of a child dataset.

7.5 Referencing sources

Source references are centrally collected and managed in a master file for the entire ecoinvent database.

When the source is not a scientific article, book-chapter or separate publication, the title field is reused to refer to e.g. "Measurement documentation of company XY" (for measurements on site), "Oral communication, company XY" or "Personal written communication, Mr./Mrs. XY, company Z". Citations of large reference works include chapter numbers, table numbers and/or page numbers.

[Changes relative to ecoinvent version 2: References to sources are now placed directly in each dataset, and data sources are publicly available, preferably in the master file for sources. For datasets transferred from ecoinvent version 2, the sources may not all be transferred to the master file for sources but may temporarily be placed as free text, either in the dataset or on a referenced web-site (for sources used for many datasets).**]**

7.6 Version management

The ecoSpold format defines two version numbers for each dataset: Release and Revision, each with a major and minor component.

The release number defines the version of the ecoinvent database that the dataset is part of. A new release number is only entered by the database administrator when a new production database is created in preparation of the next official release (see Chapter 3). Both the major and minor release component can be changed when a new database is created. All datasets of one database must have the same release number and once this is entered on database creation it is not changed later on.

The revision number is specific to each dataset and is independent of the overall database release version. The major revision component reflects the amount of accepted changes to the dataset. It is increased automatically by the database software when changes to the dataset have been accepted by the ecoinvent review procedure and the revised dataset is uploaded to the production database. It will only increase over time and must not be changed manually. The minor revision component describes versions of the dataset during the editing process before it is submitted for review. It is increased automatically by the ecoEditor software every time the data provider saves changes made to the dataset either locally or as a draft on the ecoinvent server. The minor revision component is reset to “1” each time the major revision component is increased (when changes to a dataset are accepted by a reviewer).

The revision number may also be used to notice concurrent editing of the same dataset by two data providers. If two data providers request the same dataset for editing, one will finish the editing before the other. If the reviewer accepted the changes of the first data provider, the major revision component will have increased by the time the second data provider submits changes for review. The review process must then reject the second changes because they are not based on the current version of the dataset. The data provider would have to request the current version of the dataset for editing and enter the necessary changes again.

[**Changes relative to ecoinvent version 2:** The version management is more stringent and automatically controlled than in version 2.]

8 Language

8.1 Default language

British English is used as the default language for all names and text fields.

8.2 Language versions

Outlook: Language versions of the ecoinvent database are foreseen and supported by the ecoSpold 2 format. However, the implementation of this has been postponed beyond the release of version 3.0.

Language versions of datasets are produced by translating all text fields and storing the translated text fields with the appropriate 2 letter ISO 639-1 language code, as provided in the language master file.

The language versions are all stored in the same dataset, and can be viewed by choosing the corresponding language code as default when requesting to view a dataset.

We encourage data providers to provide translations and initiate systematic translation projects.

[**Changes relative to ecoinvent version 2:** German names of activities and classifications from version 2 are not maintained in version 3.]

9 Naming conventions

9.1 General

It is strived for to use the most common technical nomenclature and units, and avoiding the use of abbreviations. All information in the name fields is written in full. Considering that the database is used by people from many different technical and non-technical fields, it is strived for to make the names generally understandable and provide adequate context, e.g. rather “electrical connector, peripheral component interconnect buss” than “bus, PCI”. No brackets are used, except when required by other conventions, e.g. in chemical formulas. Singular is used as far as possible, e.g. “barley grain”, not “barley grains”.

The lists of names for activities, intermediate exchanges, elementary exchanges, units, classifications and tags, geographical locations, macro-economic scenarios, and system models, are centrally collected and managed. The full list of names is available via the ecoEditor software. Likewise, master files are centrally collected and managed for persons, default properties and parameters, and sources.

9.2 Activities

An activity dataset is identified uniquely by its activity name, the geographical location (see Chapter 4.2.1), the time period (see Chapter 4.2.2), the macro-economic scenario (see Chapter 4.2.3), and the system model (see Chapter 4.13.2). The first four of these identifying fields, i.e. all except the system model, are represented by a universally unique identifier (UUID) for easy machine identification. This implies that the UUID of an activity dataset is the same in all system models, which facilitates the linking of the datasets in different system models, see Chapter 14. In addition, all activities are classified according to the ISIC classification with further sub-divisions made by ecoinvent (see Chapter 9.7).

Activity names are spelled with lower case starting letter, i.e. “lime production”, not “Lime production”.

The simplest form of an activity name is generated from the name of the reference product (see below) with the addition “production”, e.g. “lime production” after the product “lime”. Further specifications of the product, raw material or production route are added after a comma, e.g. “lime production, from carbonation”. The term “construction” is used instead of “production” for activities that have buildings, transport infrastructure, factories and facilities as their product outputs.

If the activity has multiple products, the activity can instead be named after the nature of the process, e.g. “air separation, cryogenic” with the products “oxygen”, “nitrogen” and “argon”.

When an activity is described in terms of the process of converting a raw material to a product, the order [process], [raw material], [detail of process] is preferred, e.g. “leaching of spodumene with sulphuric acid”, not “sulphuric acid leaching of spodumene”, thus avoiding to place the raw material in the beginning of the activity name.

Whenever possible, the “…ing” ending is reserved for services and avoided for activities with a material product.

For infrastructure, the name “factory” or “facility” is preferred to “plant”, except in traditional combinations such as “power plant”.

Dedicated treatment activities are preferably named “treatment of [material treated], [nature or output of the treatment]”, e.g. “treatment of waste paint, sanitary landfill“, “treatment of slaughterhouse waste, rendering” or “treatment of biogas, purification to methane 96 vol-%”.

Production and supply mixes end with the terms ", production mix" and ", supply mix" respectively. Market activities start with the term "market for ".

Activity datasets with the term "operation" as part of their name signifies activities that use specific infrastructures, e.g. "mine operation" as opposed to "mine construction". Operation datasets therefore always have inputs of infrastructure. Thus, "operation" is used as a synonym for "use". The term is used both for industrial activities and household activities.

The geographical and temporal locations of activities are described in separate data fields and are not required in the name field.

[Changes relative to ecoinvent version 2: The naming conventions are more stringent in some aspects. The unit is no longer an identifying field, i.e. the same dataset cannot exist with different units for the reference product. Different units can instead be applied for properties of the reference product. Datasets in version 2, which are found in duplicate units, have been merged to one dataset, choosing the most appropriate unit as the main unit and adding a property with the secondary unit.]

9.3 Intermediate exchanges / Products and wastes

Names of intermediate exchanges are spelled with lower case starting letter, i.e. "lime", not "Lime".

Product names begin with the most generic form of the product that is generally recognized as a product, e.g. "cement, blast furnace slag" rather than "blast furnace slag cement", but avoiding artificial names, e.g. not "fertiliser, nitrogen" but "nitrogen fertiliser". This should make searching for a specific product easier. The alternative name may be added as a synonym. It is difficult to make product names unambiguous. The general rules may be interpreted differently by different data providers, so that the two examples just provided may be reversed by different data providers. Therefore, it is always a good idea to search the database for different possible spellings and ordering of product names, especially before adding a new product and/or activity name to the database.

Following the product name, additional specifications are added if necessary for an unequivocal distinction. These are separated by commas, and in the following sequence: treatment level (like rolled, drawn or coated), additional description of the product characteristics or intended application, additional description of unit, additional description of provenience/raw material. Indication of the production route or specific product characteristics are only included if this is part of the marketable product properties, i.e. if there is a market or market niche where the production route or property is a part of the obligatory product properties, see Chapter 4.4.5. For example, the product "straw" is named as such, not with separate names for "barley straw" and "wheat straw", since the market for straw does not distinguish between these two products. Temporal markets, customer segments and market niches are reflected in the product name, so that each temporal and customer segment or niche has its own product. The product name includes as far as possible all relevant aspects of the obligatory product properties required by the supplied market, customer segment or niche.

Additional description of the unit is only included when this is not obvious from the context. This is especially relevant when the unit is dimensionless, e.g. "unit", and this relates to a specific interpretation, e.g. "per pig place", which is then included in the name.

For dissolved chemicals, the traditional nomenclature of the chemical industry is to indicate the active substance and then add the water separately, so that e.g. 1 kg of "sodium hydroxide, without water, in 50% solution state", refers to the production of 2 kg NaOH solution with a water content of 50%, i.e., 1 kg pure NaOH plus 1 kg pure H_2O (by specifying "without water" we seek to avoid the possible confusion that occurred with the naming convention in ecoinvent v1 & v2 where the name of this dataset was "sodium hydroxide, 50% in H_2O").

The concentrations applied in the ecoinvent database are those typically found as commercial concentrations. The concentration of the product has an influence on the manufacturing requirements (purification) as well as on the transport service requirements (double the amount of transport work is required for a 25% caustic soda dissolved in water as compared to a 50% caustic soda dissolved in water). To allow the user to model other concentrations than the default, the concentration may be defined as a variable, and the water content and other related inputs and outputs expressed in relation to this variable.

Treatment activities provide services to other activities to treat their material outputs, in particular wastes. Since the service and the input are intimately linked, the service output is named by the treated material, and the exchange is negative. Thus, the activity "treatment of blast furnace gas" has as its determining (reference) product -1 MJ "blast furnace gas" and as a by-product 0.06 kWh "electricity, high voltage". In this way, it is ensured that the output "blast furnace gas" from the pig iron production can link to its treatment process.

Market activities, production mixes, supply mixes, export and re-export activities have the same products as inputs and outputs, e.g. "market for barley grain" has "barley grain" as input and "barley grain" as output. For graphical presentations, the terms (consumption mix) for markets, (treatment mix) for markets for treatments, (production mix) for production mixes, (supply mix) for supply mixes, (export) for export activities, and (re-export) for re-export activities may be used as additions to the name, but are not formally part of the product name in the ecoSpold2 data format, where the information that the product output is a consumption mix, production mix, supply mix, export or re-export is carried in the separate field 115 specialActivityType.

Special naming conventions for correction datasets are provided in Chapter 11.7.

[**Changes relative to ecoinvent version 2:** The naming conventions are more stringent in some aspects. The naming convention for dissolved chemicals has been revised. The naming convention for treatment services is changed.]

9.4 Elementary exchanges / Exchanges from and to the environment

Naming of elementary exchanges 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). Sum formulas and IUPAC names are recommended when new substance names are proposed to be added to the list. CAS numbers are required, when available. Names of elementary exchanges are spelled with Capital starting letter, i.e. "Chlorine", not "chlorine", as opposed to names of intermediate exchanges.

The name for an element or a compound is the same for all environmental compartments.

Binding forms and oxidation states are considered in the name. The toxicology of chemical elements is dependent on the oxidation state. 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 exchange. Different oxidation states (e.g. chromium, chromites, chromate) are distinguished in the list of elementary exchanges.

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 exchange names.

9.4.1 Land transformation and occupation

The differentiation between transformation and occupation is reflected in the naming of land use elementary exchanges. It takes pattern from the naming proposals of a Dutch project (Lindeijer & Alfers 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, annual crop
- Occupation, annual crop, non-irrigated
- Occupation, annual crop, non-irrigated, intensive

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

Names and definitions of the different land use classes are provided in Chapter 6.7.

9.4.2 Environmental compartments

Elementary exchanges in the ecoinvent database are identified by an exchange name (e.g. "Carbon dioxide, fossil"), its unit, a compartment and a sub-compartment.

Table 9.1 shows the compartments and sub-compartments which are used in the ecoinvent database. Compartment and sub-compartment names have a lower case initial letter. Compartments and sub-compartments can only be added and edited centrally via the ecoinvent database administrator.

Compartments describe the different environmental compartments, like air, water, soil and natural resource. Sub-compartments within these compartments make further distinctions which may be relevant for the subsequent impact assessment step.

The compartments "air", "soil", "water" and "direct human uptake" describe the receiving compartment and are used for (direct) pollutants emissions, whereas the compartment "resource" is used for all kinds of resource consumption. For instance, water consumption is recorded as an input in the compartment / subcompartment "resource / in water". Land transformation and occupation is recorded as an input as well, in the compartment / subcompartment "resource / land". Emissions directly to biomass are included in the compartment "soil".

As recommended in USETOX < http://www.usetox.org/>, the border between urban and non-urban ((high and low population density) is the U.S. Census Bureau "urban area" definition <http://www.census.gov/geo/www/ua/ua_2k.html> of 400 persons per km^2. Approx. 50% of the global population lives in urban (high population density) areas. In establishing the population density for a particular point, an area of 12 km^2 (2 km radius from the point) is applied.

Contaminants in food, medicine, hygiene products and clothing are described as an emission at the point of human uptake. Until then, the contaminants are included as properties of the products.

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".

Outlook: The issue of how best to include long-term emissions is currently under consideration.

The subcompartment "agricultural" for soil pollutants is only used for releases on agricultural soil that is used or suitable for the production of food, fodder products, or animal feed, which enters the human food chain.

Table 9.1 Compartments and subcompartments for elementary exchanges in the ecoinvent database

Compart-ment	SubCompartment	Definition	Assigned in general to
air (output to)	non-urban air or from high stacks	Emission in areas with a population density below 400 persons per km^2 or from stacks higher than 100 m	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	Emission which take place in the future, >100 years after the start of the activity	Emissions from uranium mill tailings
	lower stratosphere + upper troposphere	Emission from airplanes	Air transport, cruising
	urban air close to ground	Emission below 100 metres in areas with a population density above 400 persons per km^2	Industry, oil and gas power plants, manufacturing, households, municipal waste incineration, local traffic, construction activities
	indoor	Emission inside closed buildings and outside of dedicated fume hoods with intake speed >0,5 m/s	Use stage of products for indoor use
	unspecified		Only used if no specific information available
natural resource (input of)	in air	Natural resource 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	Natural resource in soil e.g. ores; landfill volume	
	land	Land occupation and land transformation	
	in water	Natural resource in water, e.g. magnesium, water	
soil (output to)	agricultural	Emission to soil that is used for or is suitable for the production of agricultural products that enter the human food chain.	Agriculture, agricultural biomass production
	forestry	Emission to soil that is used for plant production (wood, renewable raw materials), but which is not used or suitable for production of agricultural products that enter the human food chain (permanent forest land, marginal lands)	Forestry
	industrial	Emission to soil used for industry, manufacturing, waste management and infrastructure	Industry, land-farming of wastes, built-up land
	unspecified		Only used if no specific information available
water (output to)	ground-	Groundwater which will get in contact with the biosphere after some time	
	ground-, long-term	Emission which take place in the future, >100 years after the start of the activity	Long-term emissions from landfills
	ocean	Ocean, sea and salty lake	Offshore works, overseas ship transports
	surface water	River and lake	Discharge of effluents from wastewater treatment facilities
	unspecified		Only used if no specific information available
direct human uptake (output to)	unspecified	Contamination in products used for oral intake or with skin contact	Food products and medicine at the point of human intake, hygiene products and clothing at the use stage
economic (input of)	primary production factor	Labour cost, net tax, net operating surplus, rent	All net expenditures except those paid for goods and services purchased
social (input of)	unspecified	Change in social pressure	All externalities affecting human welfare and/or productivity, not elsewhere covered

[**Changes relative to ecoinvent version 2:** Category/Subcategory (version 1&2) has changed name to Compartment/Subcompartment. Text description on emissions to soil, agricultural, has been brought in line with actual practice in ecoinvent 2 (biomass production on agricultural land has emissions to soil, agricultural). Resource has been changed to Natural resource. The sub-compartments Lake and River have been merged to Surface water. Some definitions have been made more precise. New compartments have been added for indoor air, direct human uptake, economic and social exchanges.]

9.5 Synonyms

Synonyms may be added for all names of activities and exchanges. We seek to make the synonyms lists as complete as possible.

Additional advice for data providers:
Synonyms are different names for the same item, *not* instances of the item. For example, *sheep husbandry* is a synonym for *sheep production*, while *animal production* and *Merino production* are *not* synonyms, but respectively a wider class of activities and a specific instance referring to a particular kind of sheep.

9.6 Units

The units shown in Table 9.2 (always in English language) are used. As far as practical, SI-units are applied, with the SI-prefixes shown in Table 9.4.

Exceptions are:

- The traditional measure ton, with the specification metric ton (= 1000 kg = 1 Mg), when used in the combination metric ton*km.
- The traditional area measure ar (a), as in hectar (ha), which should not be confused with the SI-prefix atto- or the Latin abbreviation for year.
- Popular units for time (year, month, week, day, hour), written out fully, since multiples of the SI-unit seconds (s) appears awkward.

Ideally, datasets that do not have a material output should not be provided in mass units, although this may sometimes be the only relevant function that can be referred to. Especially for datasets transferred from ecoinvent version 2, there are still some datasets that have the output of 1 kg, although this refers only to “processing of 1 kg of metal”, not to the metal material itself. We strive to rename the functional unit of these datasets whenever possible.

Currencies are reported in ISO three-digit code. As currencies change values over time, it is necessary to apply a subscript to indicate the year that the currency refers to, e.g. EUR_{2000} or EUR_{2003}. For large numbers, the SI-prefixes (see Table 9.4) have been used, e.g. MEUR = 1’000’000 EUR, GEUR = 1’000’000’000 EUR. Currencies are converted with the International Monetary Fund mid-year SDR exchange rates.

Table 9.2 Units used for activities and products

Unit	Term	Usage examples
m^2	square metre	Surface treatments, buildings, sites, boards, plates, reception surfaces,
ha	hectare (hecto-are) = 100 a = 10000 m^2	agricultural working activities
m^2*year		Roads, ventilation systems
kg/s l/hour MW	kilogram per second litres per hour mega Watt = MJ/s = 3.6 kWh/s	Capacity of weight Capacity of volume Capacity of energy conversion
kg/l	kilogram per litre	Density
m	metre	Cables, belts, chimneys, ducts, tape, welding, wells
metric ton*km person*km	metric ton*kilometre (Mg*km) person-kilometre	Transport services. The term vkm or vehicle-km (synonymous to km) is not applied
m*year	metre-year	Roads, railway track
unit	unit, piece, number	Infrastructure (exceptions: kg machine, m^2 or m^3 building), agricultural activities involving livestock units etc.
kWh	kilo Watt hour	Electricity
MJ	mega Joule	Final energy in boilers, useful energy at boilers, cooling energy
hour	hour = 3600 s	Usage time of equipment
year	year (annum)	Multi-product activities for the total production in an area or of a facility
l	litre = dm^3	Liquid products
m^3	cubic metre	Concrete and wood, wastewater, slurry, radioactive wastes, buildings; for natural gas, biogas, compogas, town gas: normal cubic metre = cubic metre of gas at 15 °C; 101.325 kPa (ISO 13443)
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, agricultural machinery, "kg SWU" (separative work unit) used for enrichment of uranium

The units (basically SI units) used to describe elementary exchanges are shown in Table 9.3.

Table 9.3 Units used for elementary exchanges

Unit	Description	Type of exchange
kg	kilogram	All chemical substances
kBq	kilo Becquerel	Radionuclide releases
m^3	cubic metre	Water as a resource, Gases as a resource; normal cubic metre = cubic metre of gas at 15 °C; 101.325 kPa (ISO 13443)
m^2	square metre	Land transformation
m^2*year	square metre year	Land occupation

Table 9.4 SI-prefixes

P	peta-	1.0E+15
T	tera-	1.0E+12
G	giga-	1.0E+9
M	mega-	1.0E+6
k	kilo-	1.0E+3
h	hecto-	1.0E+2

[**Changes relative to ecoinvent version 2:** Several changes in unit spellings. In ecoinvent v2, the units GVE and MSP were used: „1 GVE entspricht dem Futterverzehr und dem Anfall von Mist und Gülle einer 650 kg schweren Kuh in der Schweiz“. 1 MSP is 0.15 GVE. These units are now changed to „unit” and explained in the datasets. Mass units avoided for service products (e.g. rather 1 metre wire-drawing for steel, than wiredrawing of 1 kg of steel; using e.g. the extent of transport, transformation, shape, distortion, reduction, rather than the weight of the material treated). In version 2, some datasets also have outputs of kg of material removed (e.g. by drilling) and inputs of the material “lost” by this operation, which implies that to avoid double counting, the activity they are inputs to must have an input of an untreated object with the same weight as the treated object. Such datasets need to be changed so that the treatment activity has the full input of the material treated and an output of a treated object and the material removed. This should preferably be done in consultation with the original data provider and/or editor.]

9.7 Classifications

All activities are classified according to the ISIC classification (Rev. 4), <http://unstats.un.org /unsd/cr/registry/>, with some additional sub-divisions necessary for ecoinvent. The additional classes added by ecoinvent (listed in Table 9.5) are sub-divisions, using as far as possible the explanatory language from the original ISIC class.

Table 9.5 Additions to the ISIC Rev. 4 classification of activities, for use in the ecoinvent database

Class	**Name**
19a	Liquid and gaseous fuels from biomass
2011a	Manufacture of nuclear fuels
2420a	Smelting and refining of uranium
2710a	Manufacture of electric motors, generators, for liquid fuels
2811a	Manufacture of engines and turbines for liquid fuels, except aircraft, vehicle and cycle engines
2815a	Manufacture of furnaces and boilers for liquid fuels
2815b	Manufacture of permanent mount non-electric household heating equipment
3011a	Construction of drilling platforms
3510a	Electric power generation based on liquid fuels
3510b	Electric power generation, photovoltaic
3530a	Steam and air conditioning supply based on liquid fuels
3530b	Solar collectors operation
4100a	Construction of factory buildings for the metal industry
4220a	Construction of utility projects for electricity production, except for liquid fuels
4220b	Construction of utility projects for electricity production, for liquid fuels
4290a	Construction of infrastructure for petroleum refining and distribution
4322a	Installation of solar collector systems

The classification is used to identify the responsible ecoinvent editor (see Chapter 12.2) and can be used to create residual datasets for an industry, relative to data from national statistics (see Weidema 2013).

For products, the optional CPC Ver. 2 classification is recommended < http://unstats.un.org/unsd/>.

For datasets transferred from version 2 of the ecoinvent database, the activity classification of version 2 is applied as an additional classification, but this classification system is no longer maintained by the ecoinvent Centre.

New, optional classification systems can be added on request to the ecoinvent database administrator.

[**Changes relative to ecoinvent version 2:** New classification systems for activities. Option to add more classifications for both products and activities. The ISIC and CPC classifications are available in the classification master file.]

9.8 Tags

One or more tags can be added to any activity and to any exchange. Tags can be seen as an optional, user-defined classification system, to group specific activities or exchanges together.

Some pre-defined tags for datasets, used in the ecoinvent database, are listed in Table 9.6.

Table 9.6 Pre-defined tags for datasets, for use in the ecoinvent database

Name	Comment
branded dataset with logo	dataset for a named brand or from a named enterprise, with logo
branded dataset without logo	dataset for a named brand or from a named enterprise, without logo
complementary product	product needed for the proper functioning of a main product, but not part of this product, e.g. packaging or maintenance
consumption adjustment	dataset representing a change in consumption as a result of market constraints
goods transport	dataset representing a goods transport activity
household activity	dataset representing an activity taking place in private households
packaging	
quality difference adjustment	dataset representing downstream changes due to quality differences in products on the same market
single enterprise data	dataset representing one single, anonymous enterprise
with true value	dataset for which true value properties are defined (reserved; added by database)

Additional advice for data providers:
Tags can be added individually to an activity or an exchange. If you wish to add the same tag to many datasets or exchanges (or several, similar tags to many datasets or exchanges), this may be too cumbersome a procedure. For this situation, contact the ecoinvent database administration for a “fast track” procedure.

[**Changes relative to ecoinvent version 2:** The option to add tags is new.]

9.9 Geographical locations

The ecoinvent master file for geographical locations contains all countries, the continents Asia and Europe, the UN regions and subregions, European and North American electricity grids and some economic regions (e.g. North American Free Trade Agreement (NAFTA) and the Commonwealth of Independent States (CIS)).

All locations are described in the Keyhole Markup Language (KML), an OGC standard for geospatial data used in GIS software including Google Earth. More detailed information on the ecoinvent master geographies files is available in a separate ecoinvent report.

The global geography (GLO) is used for global datasets, and has no KML description of its shape.

The designation ROW (Rest-Of-World) is a dynamic concept that exists in the situation when both a global dataset and one or more non-global datasets are available for the same activity, time period, and macro-economic scenario. The definition is specific to each activity and depends on what defined geographies are available for the specific activity name. The Rest-Of-World dataset is defined as the difference between the global reference dataset and the datasets with defined geographies.

Additional advice for data providers:
New geographical locations, either point sources, line sources or area sources can be defined by the data providers on the ecoinvent geography website: http://geography.ecoinvent.org/. They can be added to the database with the following procedure:

1. Geographic metadata such as the name is entered in the dataset in the EcoEditor software.
2. The spatial definition of the location is then created on the ecoinvent geographies website: http://geography.ecoinvent.org. If the new location is already available in a common geospatial format, this can also be mailed to the geographies editor: geography@ecoinvent.org
3. The ecoinvent geography editor performs a quality assessment of the submitted data, and asks for revisions from the data provider if needed. The ecoinvent geography editor will also edit shapes to conform to boundaries that already exist in the database, e.g. political or geographical boundaries. The geography editor uploads the final geography spatial definition to the ecoinvent database.
4. The data provider is notified that their geographical shapes are ready in the database, and the datasets that use them can be submitted to the normal dataset review process.

Since the ecoinvent database does not allow overlapping datasets, adding a dataset (whether point-, line-, or area-based), which is fully located within the geographical area of an existing dataset for the same activity, is effectively a disaggregation of the existing dataset, and requires that the existing dataset is modified to represent the residual of the original dataset, in terms of geography, production volume, and otherwise. The geography for the residual dataset will be produced by the ecoinvent geography editor in Step 3.

In addition to the preferred ecoinvent website, http://geography.ecoinvent.org, KML files for new geographic shapes can be defined in a dedicated GIS program such as ArcGIS or QuantumGIS, or in a consumer program or web page such as online maps or Google Earth. KML definitions should meet the following criteria:

- New geographies should not duplicate geographic areas already present in the ecoinvent master geographies file.
- Composite geographies (such as a union of several countries) should be derived from the definitions of the original geographies already present in the ecoinvent master geographies file.
- Borders that are already present for other geographies in the ecoinvent master geographies file should be copied from this file, to avoid small deviations for the same border in different geographies.
- Coordinates should only be defined to eight digits past the decimal point.
- All geographic shapes should be valid, as defined by the OGC KML standard.

While the KML format allows the addition of additional metadata, such as text and pictures, all such metadata shall be removed for inclusion in ecoinvent, and data providers should only include the geographic shape definitions to be included in geography files.

9.10 Persons

Names and contact details on all persons referred to in ecoinvent datasets are centrally collected and managed in a master file. A name and an e-mail are the only required fields, but adding further address information is encouraged.

9.11 Other master files

Master files for the ecoinvent database are also available for default properties and parameters. Default properties include the elemental composition (Al_content, etc.), water content, density, dry mass, exergy, lifetime, etc.

Other master files are available for scenarios (see Chapter 4.2.3), system models (Chapter 4.14), languages (Chapter 8.2), and sources (Chapter 7.5). Only the latter can be amended by the data providers directly. The others are edited via the database administrator only.

Master files are used for validating datasets (see Chapter 12.1) and to create look-ups for the ecoEditor software (so that previous entries can be selected rather than created anew).

9.12 Variables

Variable names must start with a character (a-z). Variables may contain characters, numbers and underscores (_). Variable names are not case sensitive (calorific_Value equals Calorific_value).

10 Uncertainty

Uncertainty expresses the general problem that an observed value can never be exactly reproduced, but when an adequate number of observations have been made, certain characteristic features of their distribution can be described, such as mean and standard deviation. A *probability distribution* is the mathematical and/or graphical function giving the probability that an observation will take a given value.

Many different concepts are used to describe uncertainty. When applicable, we use statistical terms as defined in ISO 3534. *Uncertainty* is the general term we use to cover any distribution of data within a population, caused by either random variation or bias.

Variation is the general term used for the random element of uncertainty. This is what is typically described in statistical terms as variance, spread, standard deviation etc., see definitions below. It is the randomness of the observations, which allows a statistical treatment, since this describes the probability distribution of the observations.

Bias is the skewness introduced into a distribution as a result of systematic (as opposed to random) errors in the observations, e.g. when the observations are made on a specific sub-set of a non-homogenous population.

The population is the total number of items under consideration, from which only a sample is typically observed. The *arithmetic mean* or average value is the sum of the observed values divided by the number of observations. The *error* of an observation is the deviation of the observed value from the mean value, i.e the value of the observation minus the mean value. *Variance* is a description of variation defined as the sum of the squares of the errors divided by the number of observations less 1. The *standard deviation* (σ) is the positive square root of the variance. The *median* (ε) is the value for which 50% of the distribution is smaller and 50% of the distribution is larger, also known as the 50% fractile. The *mode* or *most likely value* is the value that has the largest probability within the distribution. A two-sided *confidence interval* is the central part of a distribution that lies between two values chosen so that the interval includes a required percentage of the total population. For example, a 95% confidence interval includes 95% of the population, i.e. it excludes 2.5% of the population on both extremes.

Table 10.1 shows how uncertainty information is reported in the ecoSpold 2 format, illustrated with some examples. In some cases, the values used for calculations which don't consider uncertainty are not the average value of the distribution, like the mode for the triangular distribution. This effect is especially pronounced for the lognormal distribution, where static calculations use the median value. In these cases, it is the judgment of the ecoinvent Centre that the data available should be used to derive the most representative value of the distribution, even if this is not the mathematical average value of the distribution. As the average value of a lognormal distribution is always higher than the median value, the average value of a Monte Carlo LCA calculation where a large number of lognormal distributions are present will be biased higher than the static calculation result. Table 10.2 shows the values used in static calculations for the distributions in the Table 10.1.

The choice of distribution has limited influence on the overall uncertainty of a product system, since the aggregation of a large number of independent variables each with their distribution will always approach a result with normal distribution. This is called the "central limit theorem". Many real life phenomena are caused by a large number of independent random effects, and the central limit theorem explains why we so often find real life data to be approximately normally distributed.

The *normal* distribution is a symmetrical distribution (as opposed to a skewed distribution, see the lognormal and triangular distributions below), which implies that the arithmetic mean, the median, and the mode all appear at the same place. An interesting feature of the normal distribution is that 68% of the data lies within one standard deviation either side of the mean, 95% of the data lies with two standard deviations of the mean, and 99.7% of the data lies within three standard deviations of the mean. Thus, it is easy to compare confidence intervals and standard deviations.

Table 10.1. Description of uncertainties in the ecoinvent database, with examples

EcoSpold data field		**Probability function / parameter**	**Formula / symbol**	**Example**	**Unit**	**Database input**
2100	*Uncertainty type*	*Lognormal*				1
2101	geometricMean	Median (geometric mean)	μ_g	1540	kg	1540
2102	AritmeticMeanOfLogtransformedData	Arithmetic mean of underlying normal distribution	μ	7.3	-	7.3
2103	varianceOfLogtransformed Data	Unbiased variance of the underlying normal distribution	σ_b^2	0.25	-	0.25
2104	varianceWithPedigreeUncertainty	Unbiased variance of the underlying normal distribution, basic uncertainty with pedigree uncertainty	σ^2	0.46		0.46
2110	*Uncertainty type*	*Normal*				2
2111	meanValue	Arithmetic mean	μ	1540	kg	1540
2112	variance	Unbiased variance	σ_b^2	44100	-	44100
2120	*Uncertainty type*	*Triangular*				3
2121	minValue	Minimum value	B	930	kg	930
2122	mostLikelyValue	Mode	A	1780	kg	1780
2123	maxValue	Maximum value	C	1910	kg	1910
2130	*Uncertainty type*	*Uniform*				4
2131	minValue	Minimum value	A	1210	kg	1210
2132	maxValue	Maximum value	B	1870	kg	1870
2140	*Uncertainty type*	*BetaPERT*				5
2141	minValue	Minimum value	a	1210	kg	1210
2142	mostFrequentValue	Most frequent value	m	1600	kg	1600
2143	maxValue	Maximum value	b	1870	kg	1870
2150	*Uncertainty type*	*Gamma*				6
2151	shape	Shape parameter	K	3	-	3
2152	scale	Scale parameter	Θ	1.5	-	1.5
2153	minValue	Minimum value (location parameter)	M	2.5	kg	2.5
2160	*Uncertainty type*	*Binomial*				7
2161	n	Number of independent yes/no experiments	N	10	-	10
2162	p	Probability of success	P	0.6	-	0.6
2170	*Uncertainty type*	*Undefined (range)*				8
2171	minValue	Minimum value		1	kg	1
2172	maxValue	Maximum value		7	kg	7
2173	standardDeviation95	The value, extended from both sides of the mean, that would be necessary to cover 95% of the population		2.5	kg	2.5

Table 10.2. Values used in static calculations, with examples

Uncertainty type	Statistical parameter	Value used (formula)	Example value (relating to Table 10.1)
Lognormal	Median	μ_g	1540
Normal	Mean	μ	1540
Triangular	Mode	A	1780
Uniform	Mean	(B+A)/2	1540
BetaPERT	Mode	(a+4m+b)/6	1580
Gamma	Mean	KΘ + M	7
Binomial	Mean	NP	6
Undefined (range)		(Minimum + maximum)/2	4

The *lognormal distribution* is a the probability distribution where the natural logarithm of the observed values are normally distributed. The lognormal distribution is the predominant distribution used to model uncertainties in the Ecoinvent database for a number of reasons:

- The lognormal distribution is frequently observed in real life populations (Koch 1966). One reason for this is that many real life effects are multiplicative rather than additive, and in parallel to the central limit theorem for additive effects, it can be shown that multiplicative effects will result in a lognormal distribution.
- Most parameters for real life populations are always positive, and this constraint will result in a skewed distribution with a longer tail towards the higher values.
- The standard deviation of the underlying normal distribution is scale independent. This means that for a lognormally distributed vector of random values *X*, multiplying by a constant *a* does not change the standard deviation, also not the standard deviation of the underlying normal distribution:

$$s = stdev(\ln X)$$
$$stdev(\ln[aX]) = stdev(\ln a + \ln X) = stdev(\ln X)$$

As for the normal distribution, confidence intervals are related to the geometric standard deviation, but for the lognormal distribution, this relation is multiplicative: 68% of the data lies in the interval ε/σ_g to $\varepsilon\sigma_g$, 95% of the data lies in the interval ε/σ_g^2 to $\varepsilon\sigma_g^2$, and 99.7% of the data lies in the interval ε/σ_g^3 to $\varepsilon\sigma_g^3$, where the median (ε) is equal to the geometric mean μ_g. The *geometric mean* is the n^{th} root of the product of *n* observed values.

For backwards compatibility reasons, an "undefined" range distribution is also provided, with fields minimum, maximum, and standard deviation 95. Many distributions can be transformed to be represented by each other.

The probability distribution functions for all defined distributions in Table 10.1 are:

Lognormal:

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(\ln x - \mu)^2}{2\sigma^2}}$$

Normal:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

Triangular:

$$f(x) = \begin{cases} \frac{2(x-A)}{(B-A)(C-A)} & \text{for } A \le x \le C \\ \frac{2(B-x)}{(B-A)(B-C)} & \text{for } C \le x \le B \\ 0 & \text{otherwise} \end{cases}$$

Uniform:

$$f(x) = \frac{1}{B-A}$$

BetaPERT:

$$\alpha = 1 + 4\frac{m-a}{b-a}$$
$$\beta = 6 - \alpha$$
$$f(x) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} x^{\alpha-1} (1-x)^{\beta-1}$$

Gamma:

$$f(x) = x^{k-1} \frac{e^{-x/\theta}}{\theta^k \Gamma(k)}$$

Binomial:

$$f(x) = \frac{n!}{x!(n-x)!} p^x (1-p)^{n-x}$$

The ecoSpold 2 format allows the entry of uncertainty information, not only for the amounts of exchanges, but also for exchange properties, parameters, and transfer coefficients. This allows the reporting of the uncertainty on the primary data, which is of particular interest when the exchange amount is calculated by a mathematical relation involving these properties, parameters or coefficients. The uncertainty of the exchange can then be calculated from the uncertainty on its components.

In the ecoinvent database, two kinds of uncertainty are quantified for the amounts of the exchanges:

- Variation and stochastic error of the values which describe the exchanges, due to e.g. measurement uncertainties, activity specific variations, temporal variations, etc. This is expressed in the basic uncertainty. When relevant information to completely describe an activity in detail is unavailable, so that the exchanges are only reported in an unspecific way or at a high aggregation level of activities, the average data applied, with inadequate specification of important exchanges, will have a basic uncertainty that reflects the lack of knowledge on their precise nature.

- Uncertainty due to use of estimates, lacking verification, incompleteness in the sample, or extrapolation from temporally, spatially and/or technologically different conditions. For instance, if the electricity consumption of an activity that takes place in Nigeria is approximated with the dataset of the South African electricity consumption mix. These aspects of uncertainty would be reflected in the additional uncertainty in the approximated Nigerian dataset, estimated via data quality indicators; see Chapter 10.2.

Additional advice for data providers:
When the exchange amount is calculated by a mathematical relation purely consisting of references to other primary datapoints (amounts, properties, parameters), uncertainty need only to be added for the primary datapoints. [**Feature considered for implementation later:** The uncertainty of the calculated amount will then be calculated automatically in the ecoEditor software, using a Monte Carlo simulation. This calculation includes the additional uncertainty and results in an assumed lognormally distributed basic uncertainty without additional uncertainty. If the mathematical relation itself has additional model uncertainty, the pedigree scores (see Table 10.4) can be manually adjusted to reflect this.]

10.1 Default values for basic uncertainty

If the sample data are available, the probability distribution and standard deviation of the sample can be calculated directly. If the sample is small, an approximate standard deviation can be calculated from the range (the difference between the largest and the smallest observed value). For the normal distribution, the range is approximately 3, 4, and 5 times the standard deviation when the sample size is 10, 30, and 100, respectively. Life cycle data often result from a small number of observations, so it is reasonable to use the factor 3 when the number of observations is unknown.

Quite often the uncertainty of a specific value cannot be derived from the available information, when there is only one source of information and this only provides only a single 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 lognormal distribution is *always* assumed when applying the simplified standard procedure.

Table 10.3 gives basic uncertainty factors (variances of the *underlying* normal distribution to the lognormal distribution) are given for various types of exchanges. It is assumed that different types of exchanges differ in their uncertainty. For instance, CO_2 emissions show in general a much lower uncertainty than 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. The basic uncertainty factors are based on expert judgements.

For some ecoinvent datasets, different approaches have been used. These approaches are described in the respective datasets.

[**Changes relative to ecoinvent version 2:** In version 2, the confidence factor (the square of the geometric standard deviation of the lognormal distribution) was used in default uncertainty calculations. In version 3, the variance of the underlying normal distribution is used, which is mathematically identical, but closer to the format used with original data. This change was made to reduce the complexity of the formula for calculating the standard deviation, and to keep the parameters describing uncertainty in the same framework as the parameters that describe the distribution itself, i.e. all are directly related to the underlying normal distribution.]

Table 10.3. Default basic uncertainty (variance σ_b^2 of the logtransformed data, i.e. the underlying normal distribution) applied to intermediate and elementary exchanges when no sampled data are available; 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	0.0006	0.0006	0.0006	CO_2	0.0006	0.0006	
transport services (tkm)	0.12	0.12	0.12	SO_2	0.0006		
Infrastructure	0.3	0.3	0.3	NMVOC total	0.04		
resources:				NO_X, N_2O	0.04		0.03
Primary energy carriers, metals, salts	0.0006	0.0006	0.0006	CH_4, NH_3	0.04		0.008
Land use, occupation	0.04	0.04	0.002	Individual hydrocarbons	0.04	0.12	
Land use, transformation	0.12	0.12	0.008	PM>10	0.04	0.04	
pollutants emitted to water:				PM10	0.12	0.12	
BOD, COD, DOC, TOC, inorganic compounds (NH_4, PO_4, NO_3, Cl, Na etc.)		0.04		PM2.5	0.3	0.3	
Individual hydrocarbons, PAH		0.3		Polycyclic aromatic hydrocarbons (PAH)	0.3		
Heavy metals		0.65	0.09	CO, heavy metals	0.65		
Pesticides			0.04	Inorganic emissions, others		0.04	
NO_3, PO_4			0.04	Radionuclides (e.g., Radon-222)		0.3	
pollutants emitted to soil:							
Oil, hydrocarbon total		0.04					
Heavy metals		0.04	0.04				
Pesticides			0.033				

10.2 Additional uncertainty via data quality indicators

In addition to the basic uncertainty, either measured or estimated from Table 10.3, an additional uncertainty from data quality indicators is added to the lognormal distribution. These additional uncertainties are based on a pedigree matrix approach, taking pattern from work published by Weidema & Wesnaes (1996) and Weidema (1998).

Data sources are assessed according to the five independent characteristics "reliability", "completeness", "temporal correlation", "geographic correlation", and "further technological correlation" (see Table 10.4). Each characteristic is divided into five quality levels with a score between 1 and 5. Accordingly, a set of five indicator scores is attributed to each individual input and output exchange (except the reference products) reported in a data source. Table 10.4 is called a pedigree matrix (after Funtowicz & Ravetz 1990) since the data quality indicators refer to the history or origin of the data, like a genealogical table reports the pedigree of an individual.

Overall uncertainty is increased by the addition of normal distributions to the underlying normal distribution derived from the basic uncertainty. A normal uncertainty distribution is attributed to each score of the five characteristics. Each of these distributions has a mean value of zero, and a variance based on expert judgement, and shown in Table 10.5.

Table 10.4. Pedigree matrix used to assess the quality of data sources, modified from Weidema 1998)

Indicator score	**1**	**2**	**3**	**4**	**5** (default)
Reliability	Verified[5] data based on measurements[6]	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)	Non-qualified estimate
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
Temporal correlation	Less than 3 years of difference to the time period of the dataset	Less than 6 years of difference to the time period of the dataset	Less than 10 years of difference to the time period of the dataset	Less than 15 years of difference to the time period of the dataset	Age of data unknown or more than 15 years of difference to the time period of the dataset
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown ***or*** distinctly different area (North America instead of Middle East, OECD-Europe instead of Russia)
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study (i.e. identical technology) but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials	Data on related processes on laboratory scale ***or*** from different technology

[5] Verification may take place in several ways, e.g. by on-site checking, by recalculation, through mass balances or cross-checks with other sources.

[6] Includes calculated data (e.g. emissions calculated from inputs to an activity), when the basis for calculation is measurements (e.g. measured inputs). If the calculation is based partly on assumptions, the score would be 2 or 3.

Table 10.5. Uncertainty factors (variances of the underlying normal distributions) used to convert the data quality indicators of the pedigree matrix in Table 10.4 into additional uncertainty.

Indicator score	1	2	3	4	5
Reliability	0.000	0.0006	0.002	0.008	0.04
Completeness	0.000	0.0001	0.0006	0.002	0.008
Temporal correlation	0.000	0.0002	0.002	0.008	0.04
Geographical correlation	0.000	2.5e-5	0.0001	0.0006	0.002
Further technological correlation	0.000	0.0006	0.008	0.04	0.12

Since each normal distribution is assumed to be independent, i.e. their covariance is zero, the variance of the summed final distribution is then:

$$\sigma^2(X+Y) = \sigma^2(X) + \sigma^2(Y) + 2\operatorname{cov}(X,Y)$$

$$\sigma^2 = \sum_{n=1}^{6} \sigma^2{}_n$$

with:

$\sigma^2{}_1$: basic uncertainty (variance measured or estimated according to Table 10.3)

$\sigma^2{}_2$: uncertainty factor (variance) of reliability distribution

$\sigma^2{}_3$: uncertainty factor (variance) of completeness distribution

$\sigma^2{}_4$: uncertainty factor (variance) of temporal correlation distribution

$\sigma^2{}_5$: uncertainty factor (variance) of geographical correlation distribution

$\sigma^2{}_6$: uncertainty factor (variance) of other technological correlation distribution

Outlook: A separate ecoinvent project is ongoing to provide a better empirical basis for the uncertainty factors in Table 10.5. The preliminary results show that the current uncertainty factors for reliability and technological correlation may be too low.]

[**Changes relative to ecoinvent version 2:** The pedigree matrix has been slightly revised compared to version 2, and entries added for score 4 of geographical correlation and score 2 of technological correlation. In the ecoinvent 2 datasets, it was not possible to store the basic uncertainty separately. Therefore, the basic uncertainties have been back-calculated from the calculated additional uncertainty and the data quality uncertainty factors.]

10.3 Limitations of the uncertainty assessment

The approach for the assessment of uncertainties does not take into account the following factors that also contribute to the overall uncertainties:

- Model uncertainty: The model used to describe a unit process may be inappropriate (e.g. using linear instead of non-linear modelling).
- Mistakes imposed by human errors, i.e. human errors included in the information source used or errors made by the data provider during modelling, and not caught by the subsequent validation and review (see Chapter 11).

10.4 Monte-Carlo simulation and results

The uncertainty estimations are given for each data point on the unit process level. The 95 % confidence interval of cumulative LCI results is calculated with the help of Monte-Carlo simulation. The 2.5 % and the 97.5 % values, calculated with Monte-Carlo simulation, are shown for each individual elementary exchange of the LCI results. [**Feature considered for implementation later:** The display of uncertainty information for the accumulated LCI results may be resumed.]

The average probabilistic mean values (i.e. the cumulative results determined with Monte Carlo simulation) differ from the deterministic cumulative results. This difference occurs because deterministic cumulative results are not always calculated with the mean values of the underlying uncertainty distributions. For the *lognormal* distribution, deterministic calculations are made with the geometric mean (which is also the median); for the *triangular* distribution, deterministic results are calculated with the mode. It was decided to display the deterministic results in the ecoinvent database results, because they are regarded as more reliable than the probabilistic mean values often based on roughly estimated distribution parameters. In the case of the lognormal distribution, the geometric mean will always be less than the arithmetic mean; for the triangular distribution, there is no a priori relationship between the mode and the mean.

For the time being no uncertainty values are shown in the impact assessment results. Current impact assessment methods (except i.e. Goedkoop & Spriensma 2000; Huijbregts 2001; Steen 1999) often do 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 uncertainty values on the level of LCIA results without considering the LCIA uncertainties would be misleading.

11 Special situations

11.1 Situations with more than one reference product

In general, by-products can easily be distinguished from reference products and a joint production has only one reference product, while all other intermediate outputs are either by-products or wastes. However, in some situations, more stringent definitions and procedures may be needed to identify the reference product, and in some situations there are indeed more than one reference product, in which case additional modelling procedures are required. Additional advice for these situations of joint production is given below. Note that the situation of combined production, where the output of the reference products are independently variable, was alreay treated in Chapter 5.3.

Additional advice for data providers:
In most situations, by-products can easily be distinguished from reference products. For example, cork cannot be produced in any other way than from cork forestry, while the by-product wood fuel has many alternative suppliers. In such situations, the documentation or justification is limited to the standard text “This by-product has an application for which an alternative unconstrained production route exists”. Often by-products are close to waste and are therefore not even fully utilised, for example refinery sulfur.

In some situations, a more detailed justification and documentation is required.

If all the joint products have alternative production routes, and it is unclear which of these is the reference product, the following conditions may be required to identify which of the co-products is the reference product. The reference product is the one for which a change in demand will affect the production volume of the activity. Thus, to be the reference product, a joint product, either alone or as part of a combination of co-products, shall simultaneously fulfil these two conditions:

i) It shall provide an economic revenue that exceeds the marginal cost of changing the production volume.

ii) It shall have a larger market trend (relative change in overall production volume) than any other joint product or combination of joint products that fulfil the first condition (taking into account the relative outputs of the co-products). The reason for this is that the joint product (or combination) with the largest market trend provides a constraint on the ability of the other joint products to influence the production volume of the co-producing activity.

Example: Given two co-products A and B with alternative production costs of 100 and 50 per simultaneous produced amount, respectively, the first condition is fulfilled by both products if the co-producing activity has a marginal production cost lower than 50 for the combined amount of A+B. In this case, the revenue from the co-product with the *largest* market trend will cover the cost of the other co-product, and thus determine the production volume. If the co-producing activity has a marginal production cost between 50 and 100, co-product A will be the reference product, because it is the only product that meets the first condition. If the co-producing activity has a marginal production cost between 100 and 150, only the combination of the two products fulfil the first condition. Note that in this situation of a combination of co-products, the reference product is the co-product with the *smallest* market trend in the combination, since in order for the market to be cleared (for all products to be sold) this co-product will be sold at the lowest price that is possible without bringing the revenue below the marginal costs, thereby providing a constraint on the production volume.

Condition ii) above implies that if more than one joint product or combination of joint products fulfil condition i), then only that joint product or combination which has the relatively largest change in overall demand (market trend) actually is or contains the reference product, and within a combination only the product with the smallest change in overall demand is actually the reference product. This again emphasises that as long as alternative production routes exist for the joint products, there is only one of the joint products that can be determining for the production volume at any given moment. It follows from the conditions above that the determining reference product is not necessarily the product that yields the largest revenue to the activity (although this will often be the case), and that the reference product is not necessarily the product that is having the largest increase (or decrease) in overall market trend (because in a combination, the product with the lowest trend is determining the production volume).

That a joint production activity can only have *one* reference product, except if there are more products from the activity that have no alternative production routes, is the most restrictive assumption possible with respect to reference products, and is in accordance with the system model “Substitution, consequential, long-term”, see Chapter 14. The restrictive assumption follows from the long-term perspective of this model and its assumption that suppliers are price-takers (which means that they cannot influence the market price), so that the long-term marginal production costs of the alternative production routes for the respective products provide a constraint on the long-term market prices of the products, and thus their contribution to the overall revenue of the joint production activity. Thus, a change in supply or demand for a joint product with an alternative production route will not lead to a change in its (long-term) price and it will not affect the overall (long-term) revenue of the joint production activity. Note that the alternative production route may sometimes involve a product that has slightly different properties, as long as it has the same obligatory product properties as the product from the joint production, see Chapter 4.4.5.

If more than one product from a joint production has no alternative production routes, all of these are reference products. An example of this situation is rare earth oxides production from bastnäsite concentrate.

In system models with substitution, see Chapter 14.4.2, multi-product activities are not partitioned, but only scaled to the change in demand, and are therefore still multi-product activities. When there is more than one reference product, these joint products have no alternative production routes, and an additional output can therefore not displace any other production. Instead, the additional output leads to a specific increase in the marginal consumption activities, which must therefore be included in the model of the product system. This inclusion is achieved by providing for each reference product a direct link (with the activityLinkId, see Chapter 4.4.1) to the marginal consumption activities affected. See more details in Chapter 14.4.2 on how the database applies this information to include the marginal consumption activities.

Outlook: The ecoinvent database is prepared for alternative system models where the situation of more than one reference product per activity is more common than in the “Substitution, consequential, long-term” system model described above, see Chapters 11.4 and 14.6.3.

[**Changes relative to ecoinvent version 2:** The requirement is new that activities with more than one reference product shall have direct links to the marginal consumption activities affected for each reference product.]

11.2 Additional macro-economic scenarios

The ecoinvent database currently operates with one default reference scenario only: “Business-as-Usual”. This scenario can be described as the most likely if no other action is taken than already decided. As time passes, new decisions are incorporated into the Business-as-Usual scenario, which therefore eventually becomes identical to the actual situation. Datasets for current and historical years are therefore by definition “Business-as-Usual”.

For a macro-economic scenario to be meaningful, it must be implemented database-wide, i.e. for all activities, and be consistent, i.e. provide an overall description of a future economy in which all products produced are used and all income is distributed. Therefore, the introduction of new macro-economic scenarios in the ecoinvent database is only done centrally after a decision by the ecoinvent Centre. However, we do encourage potential data providers of macro-economic scenario data to suggest new scenarios and cooperate with the ecoinvent Centre in implementing these in the database.

Possible alternative scenarios could be “Optimistic” and “Pessimistic”, reflecting e.g. faster growth and technology development versus slower growth and technology development, relative to the Business-as-Usual scenario. See also Hornblow & Weidema (2007) for a review and classification of different possible scenarios.

Only datasets from the same macro-economic scenario are linked when calculating production, supply, or consumption mixes, interlinked and aggregated system datasets. If a global dataset for an activity is missing for a specific macro-economic scenario (once this is implemented in the database), the activity datasets for the reference scenario (Business-as-Usual) are used instead.

11.3 Branded datasets

A branded dataset is a dataset for a specific brand or a specific company, where the company or brand name is specifically mentioned as part of the activity and/or product name (see Chapter 9 for naming conventions). In addition to the brand and/or company name, the brand or company logo may appear as the dataset icon (Chapter 7.2). If a product is branded, a specific market activity is required for this product, and possibly a ‘niche product to generic market’ transforming activity (see Chapter 4.4.6). If a company name is part of the name of an activity, a global transforming activity is defined for this, and localised production sites may furthermore be specified.

Branded datasets are included in the ecoinvent database as part of an ecoinvent license or against additional payment from the owner of the brand or company. The financing thus obtained contributes to reduce the license costs of the database and/or increases the possibilities for ecoinvent to finance further data collection and development activities. However, the same data quality guidelines and the same independent review procedure apply to branded datasets as to any other ecoinvent dataset. In addition, branded datasets are on-site audited by an ecoinvent-approved auditor. The ecoinvent Centre retains the right to refuse branding of product datasets without stating any reason for this refusal.

Branded datasets may be unit processes (“gate-to-gate”) or accumulated system datasets (“cradle-to-gate”; see Chapter 4.15) with or without confidential data (Chapter 5.2).

Branded datasets are given the tag “branded dataset with logo” or “branded dataset without logo”, as relevant, for quick identification of such datasets in the database.

An ecoinvent dataset may represent a specific brand or company without being a branded dataset. The location of the enterprise or other information in the dataset may reveal this, but the name of the brand and/or company will not appear in the name of the dataset and the dataset icon will be brand neutral. Such datasets are given the tag “single enterprise data” for quick identification of in the database.

[**Changes relative to ecoinvent version 2:** Some version 2 datasets carry the name of a brand or company. Either these companies should pay (possibly for an updated dataset) or the datasets should be anonymised (the datasets in ecoinvent version 1&2 are not affected by this). Some version 2 datasets were representing single enterprise data without this being indicated in the name. Such datasets should be given the tag “single enterprise data” and the geographical location should be specified as closely as possible.]

11.4 Constrained markets

The typical assumption in LCI modelling is that markets are unconstrained and supply is fully elastic, so that an increase in demand is reflected in an equivalent increase in supply.

However, in system models with linking to unconstrained suppliers this assumption is challenged, and the supply may be modelled as more or less elastic, which implies that all or part of the increase in demand is not reflected in an increase in supply, but instead in a reduction in consumption elsewhere, typically in the application that has the least alternative costs from not using the product in question, and is therefore the most sensitive to changes in price (the marginal application).

For example, the market for sodium hydroxide is a constrained market, since its nearly exclusive production route of NaCl electrolysis is constrained by the demand for its reference product chlorine. The marginal application for sodium hydroxide is as a neutralising agent, where it can be substituted by sodium carbonate at the rate 1.325 kg per kg sodium hydroxide.

The share of the demand that is not met by increased supply is added to the market activity as a *conditional exchange*, i.e. an exchange that is only activated for particular, specified system models. The conditional exchange is added as a *negative by-product* output with the same name and unit as the reference product, and with a direct link to the affected consumption activity, see the example in Figure 11.1.

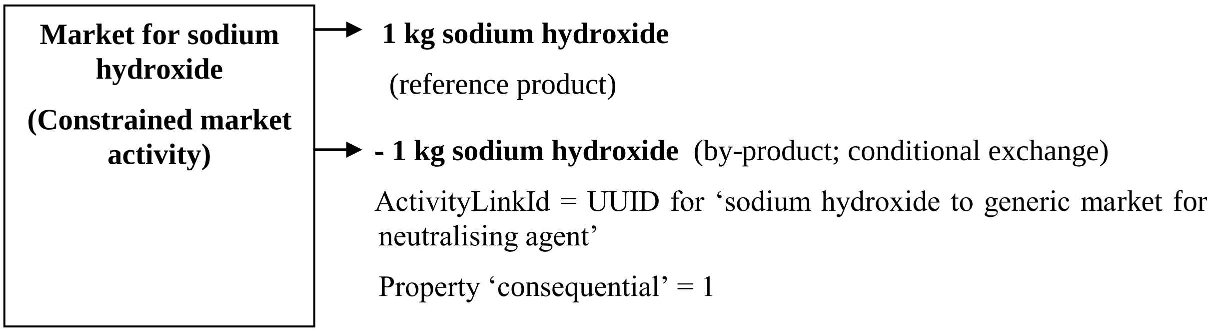


Figure 11.1. A constrained market (here for sodium hydroxide) where the share of the demand that is not met by increased supply (here: 100% = 1 kg) is added as a conditional exchange: a negative by-product with the same name and unit as the reference product, and with a direct link to the affected consumption activity (here the activity 'sodium hydroxide to generic market for neutralising agent'). The conditional exchange is normally ignored by the database calculations, but is activated (see Figure 11.2) for a particular system model via a dummy variable = 1 of a property with the short name of the system model (here: "consequential").

In general, such negative by-product outputs will be ignored by the database calculations, including mass and monetary balances for the activity. However, the negative output can be activated for use in a particular system model via a dummy variable, namely when the short name of the system model in question (e.g. "Consequential") is added as a property of the negative by-product and set to 1. The database then interprets – for this particular system model – the negative by-product output as a positive input to the market activity, resulting from the reduction in consumption as modelled by the affected consumption activity, see the example in Figure 11.2. This input is then subtracted from the required market output before the remainder (if any) is distributed over the unconstrained suppliers to the market.

This implies that different system models may operate with different extents of constraints and different elasticities for each constrained market.

Constrained markets only lead to actual changes in consumption when there is no alternative production route for the product in its most generic application. Often, market constraints apply only to a niche application that puts very high requirements on the product so that no alternatives are applicable, while the same product may be easily substitutable in the more generic market segment. In such situations, the niche applications can be supplied by a constrained niche market (see Chapter 4.4.6), while the general market segment is defined with a more generic product name that reflects the less specific obligatory product properties that are required in this market segment, in such a way that the alternative production routes are included. For example, while the constrained market for sodium hydroxide may initially appear to lead to a reduction in consumption, the reduced amount of sodium hydroxide in the marginal application as "neutralising agent" simply leads to an increase in the consumption of the alternative supply to this more generic market, namely sodium carbonate production. This implies that in the system model described here, you will obtain the same result from a demand of 1 kg sodium hydroxide as from a demand of 1 kg NaOH-equivalents of neutralising agent or 1.325 kg of sodium carbonate.

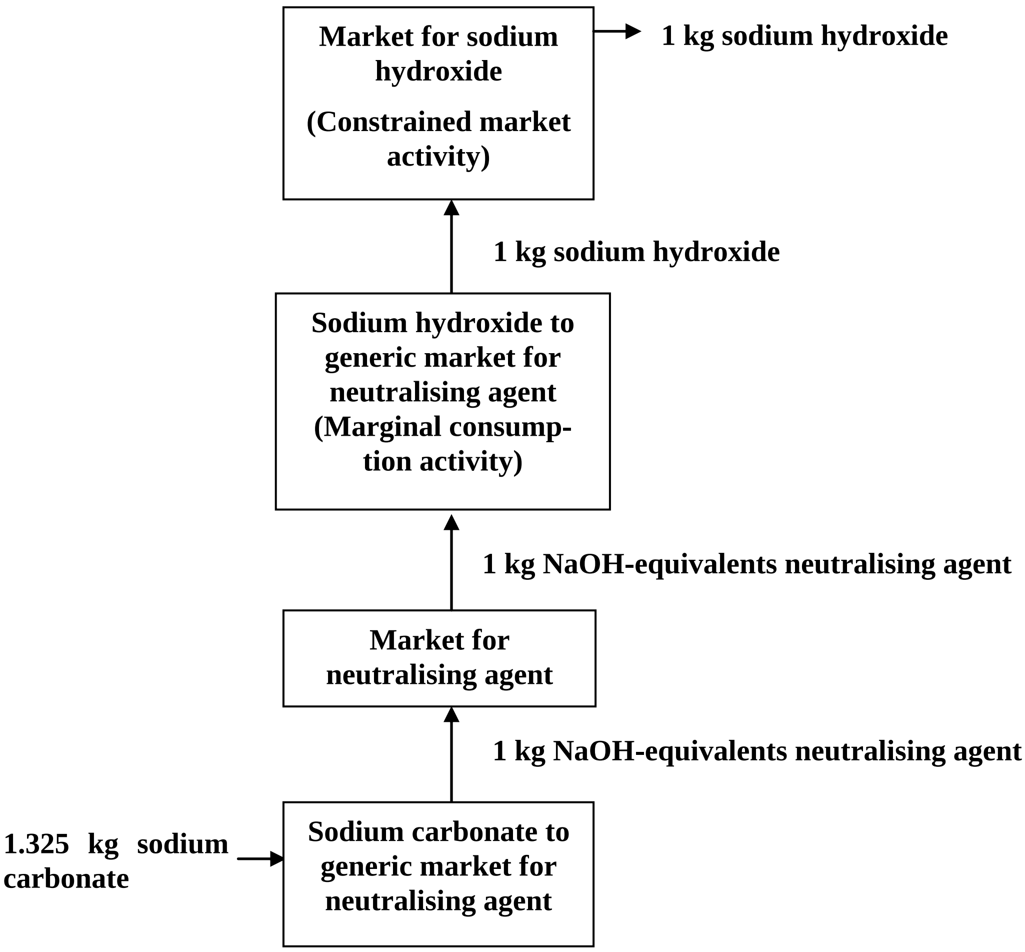


Figure 11.2. The database–generated model for the 100% constrained market in Figure 11.1. The reduction in consumption is obtained by reversing the consumption activity, in this case to have an output of sodium hydroxide, which then leads to an increased demand for neutralising agent. The neutralising agent is provided by sodium carbonate, the only unconstrained input to the market for neutralising agent.

If, in the example in Figure 11.2, the constrained market for sodium hydroxide had not existed, sodium hydroxide would have been identified as a material for treatment and all ordinary users of sodium hydroxide would have become “speciality productions” (see Chapter 11.6), i.e. activities with a material for treatment as an input, but which are not treatment activities (i.e. they have positive reference products that determine their production volumes). Since speciality productions are allocated (see Chapter 14.4.1) in the same way as treatment activities, i.e. in combination with the activity that supplies the material for treatment, this would lead to all users of sodium hydroxide ending up as being allocated together, at the point of substitution. The existence of the constrained market means that sodium hydroxide is *not* identified as a material for treatment and therefore will be allocated at the split-off point where it leaves the co-producing NaCl electrolysis activity.

In general, the potential existence of a speciality production is a good indication that a by-product is not fully substitutable in all applications, and that a constrained market for the by-product therefore exists. The constrained market then avoids the need to model the speciality productions as such. It should be noted that constrained markets are not applicable when the price of the by-product/waste is negative.

For the “Substitution, consequential, long-term” system model, only absolute, long-term constraints are considered. Empirical elasticities are generally not considered, since these typically represent short-term constraints only. There can be many different types of constraints to consider, notably regulatory or political constraints, and constraints in the availability of raw materials, waste treatment capacity, or other production factors. The ultimate market constraint is when there is only one supplier of the specific product (a monopoly). However, such situations are becoming more seldom as even the so-called natural monopolies, such as the railroads, telephone and electricity markets, which were long divided into regional monopolies, are now being opened up to competition. Still, patents and product standards may limit market entry of new suppliers, and transaction costs may be prohibitive for some potential suppliers to be involved in practise. Regulatory constraints typically take the form of minimum or maximum quotas on the activity or any of its exchanges, for example product quotas or emission quotas. The regulatory forced phasing out or in of specific technologies may also render these unavailable to respond to changes in demand. Taxes and subsidies may also constitute virtual constraints on production.

The justification for a market constraint is included in the comment field of the conditional exchange.

A specific situation of constrained markets occurs when an activity has more than one reference product, which happens when more than one of the products of an activity does not have an alternative production route. In this case, the activity only satisfies an increase in demand partly, namely with the same share of the demand as the share of the revenue obtained from the demanded product, see also Chapter 14.4.2. The missing part of the supply must therefore be obtained by reductions in use of the reference products in their marginal applications. The markets supplied by the reference products are therefore always constrained, and the missing shares of the supply are added to the market activities in the same way as described above.

Outlook: The ecoinvent database is prepared for alternative system models where the situation of more than one reference product per activity is more common than in the currently implemented system models, see also Chapter 14.3. For such models, by-products are declared as *conditional reference products* by the use of dummy variables in the same way as described above for conditional exchanges, namely by adding the name of the system model in question (e.g. “substitution_short”) as a property of the by-product and setting this to 1. The database then interprets – for this particular system model – the by-product as a reference product, and treats the supplied markets as constrained, as described above.

[**Changes relative to ecoinvent version 2:** The option to model constrained markets is new.]

11.5 Import, export, market balances, and national balancing

The basic concepts in national balancing of supply and use of products are illustrated in Figure 11.3. The national production and the import together constitute the supply, while the national consumption and the export constitute the use. Product losses are included as use. Total supply of a product must equal total use when calculated in the same units (if in monetary units, also in the same valuation, e.g. basic prices, see Weidema 2013) and when consumption includes losses and changes in stocks.

Part of the import may be separately described as destined for re-export.

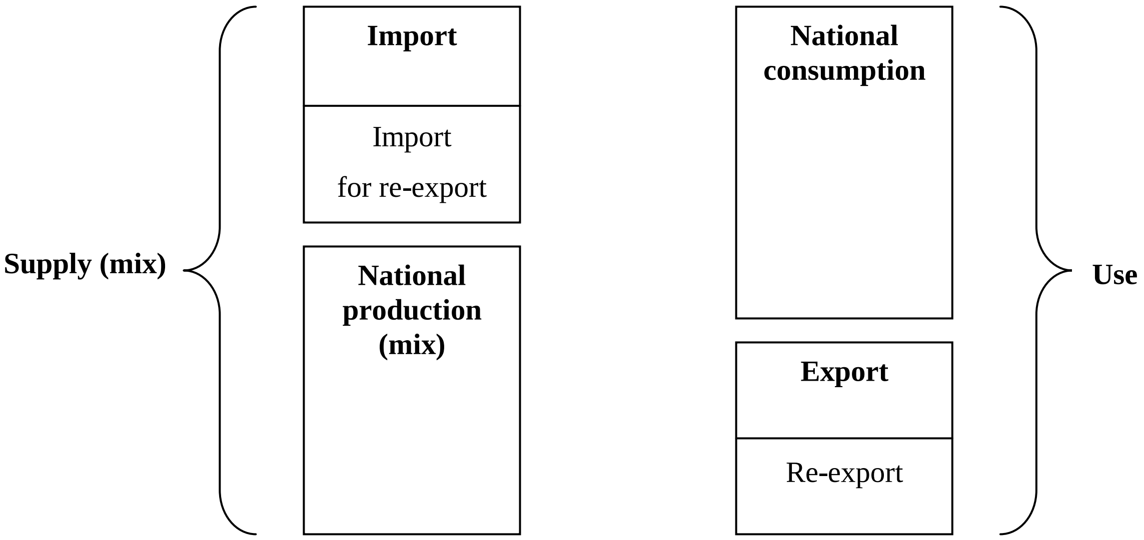


Figure 11.3. Basic concepts of national balancing of supply and use

In the ecoinvent database, supply and use are first of all balanced at the level of isolated markets, but balancing at the level of nations (or other administrative units), as in Figure 11.3, is supported. Administrative boundaries may or may not coincide with market boundaries. The following text first describes the linking of production and consumption of products in different market situations, and ends with a description of the additional modelling necessary to achieve a national balancing of products when the national boundaries are not identical to the market boundaries.

Figure 11.4 illustrate the simplest situation of a fully isolated market. This can be a single, global market, or it can be any other completely isolated market, without import and without export. Here, the product composition of the consumption mix equals that of the production mix.

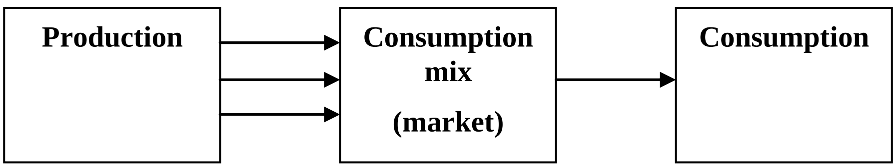


Figure 11.4. A fully isolated market. Composition of production mix and consumption mix is identical.

Figure 11.5 illustrates a partly isolated market where there is no import, but where there is export. In addition to the market activity for the geographical area, the exports from this market to other markets are specified as separate transforming activities "…, import from X" with the geographical specification of the receiving market and with direct links (specified in ecoSpold field 1520 ActivityLinkId) to the consumption mix of market X. The local consumption mix still has the same composition as the local production mix. This situation requires that the local production is flexible, so that an increase in local consumption does not influence the amount available for export. If this condition is not fulfilled, the market cannot be regarded as isolated, but is a part of a geographically larger market.

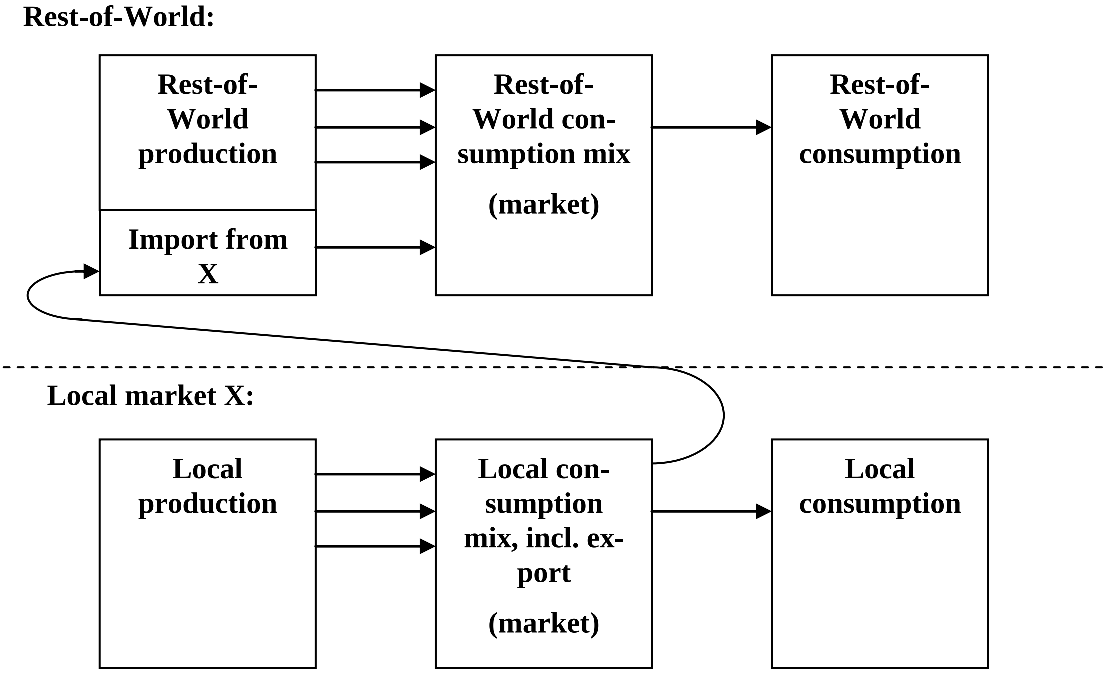


Figure 11.5. A partly isolated local market without imports but with exports. Composition of local production mix and local consumption mix is identical.

Figure 11.6 illustrates a national (or otherwise administratively delimited) isolated market where the import is administratively constrained, so that an increase in national consumption does not influence the import or only affects it in a specific proportion to the national consumption. The contribution of import is modelled as a separate transformation activity and added as a directly linked input to the market activity for the national area. If the import is affected in proportion to its share in the national supply mix, the national consumption mix is equivalent to the national supply mix. Note that the import activity here is an ordinary transforming activity, *not* a special import activity (ecoSpold field 115 specialActivityType), since the latter does not contribute to the auto-generated national consumption mix.

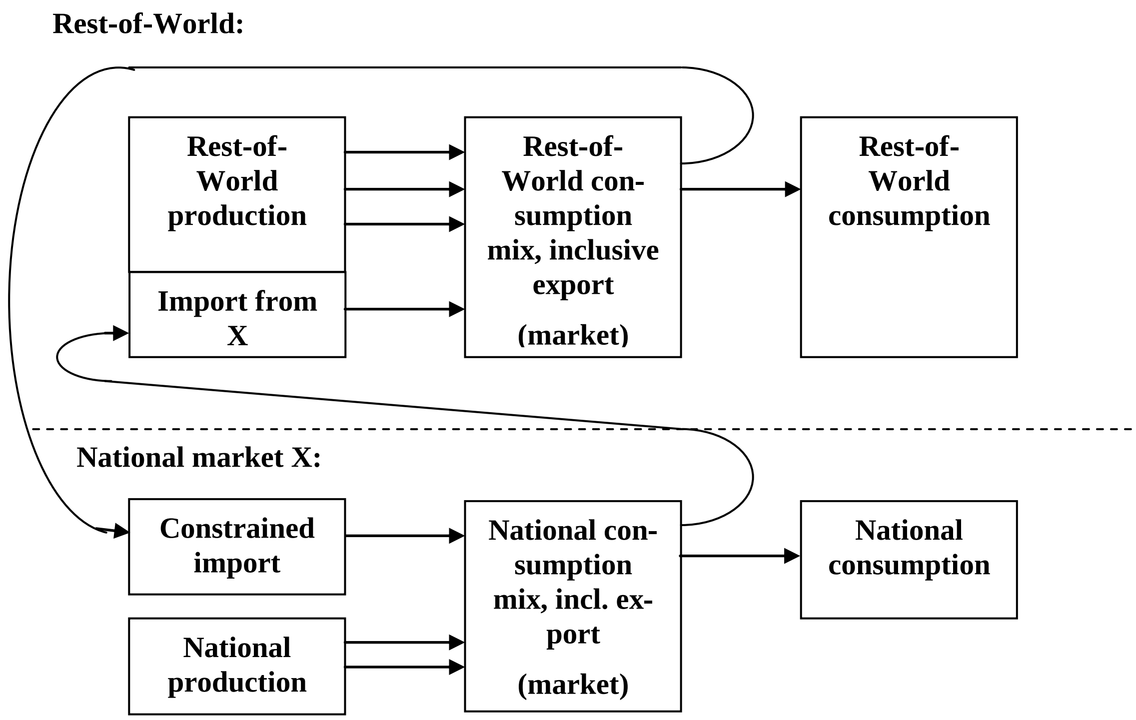


Figure 11.6. An administratively isolated national market, with constrained import.

In general, administratively isolated markets are becoming less common over time. However, as long as the national administration decides on the extent and/or technology of imports and/or national capacity adjustments, it is relevant to regard the market as administratively isolated. Administratively isolated markets are typically found for products of strategic national interest, such as weapons, food, and electricity, and where the local administration seeks to protect national producers, such as often found for the service sectors.

In LCA, the national administrative influence on the electricity markets is of particular interest, because of the important role of electricity as an input in many product life cycles.

The documentation for a market being isolated, either due to the lack of imports and exports, due to the lack of imports but with exports from a flexible national production, or due to administrative restrictions, is provided in the Geography comment field.

A national balancing of the supply and use of a product, as foreseen in Figure 11.3, can be obtained by complementing the LCI modelling in Figure 11.6 with the dotted boxes of Figure 11.7:

- Export is modelled not only as import in the receiving market, but also as a national production mix that has the national area as its geographical location (dotted Export boxes in Figure 11.7). Such export activities have the specialActivityType “export” (ecoSpold field 115) to avoid that their products are contributing to auto-generated consumption mixes. To give the correct value of the export, the same activities and data that are included with the market activities are added directly to the export activity. This includes transport activities, production losses, wholesaler and retailer activities, and product taxes and subsidies. The inputs of the exported product to the export activities are added by the database service layer, using the same production volume data from the activities located in the national area as used when constructing market activity datasets and production mixes.

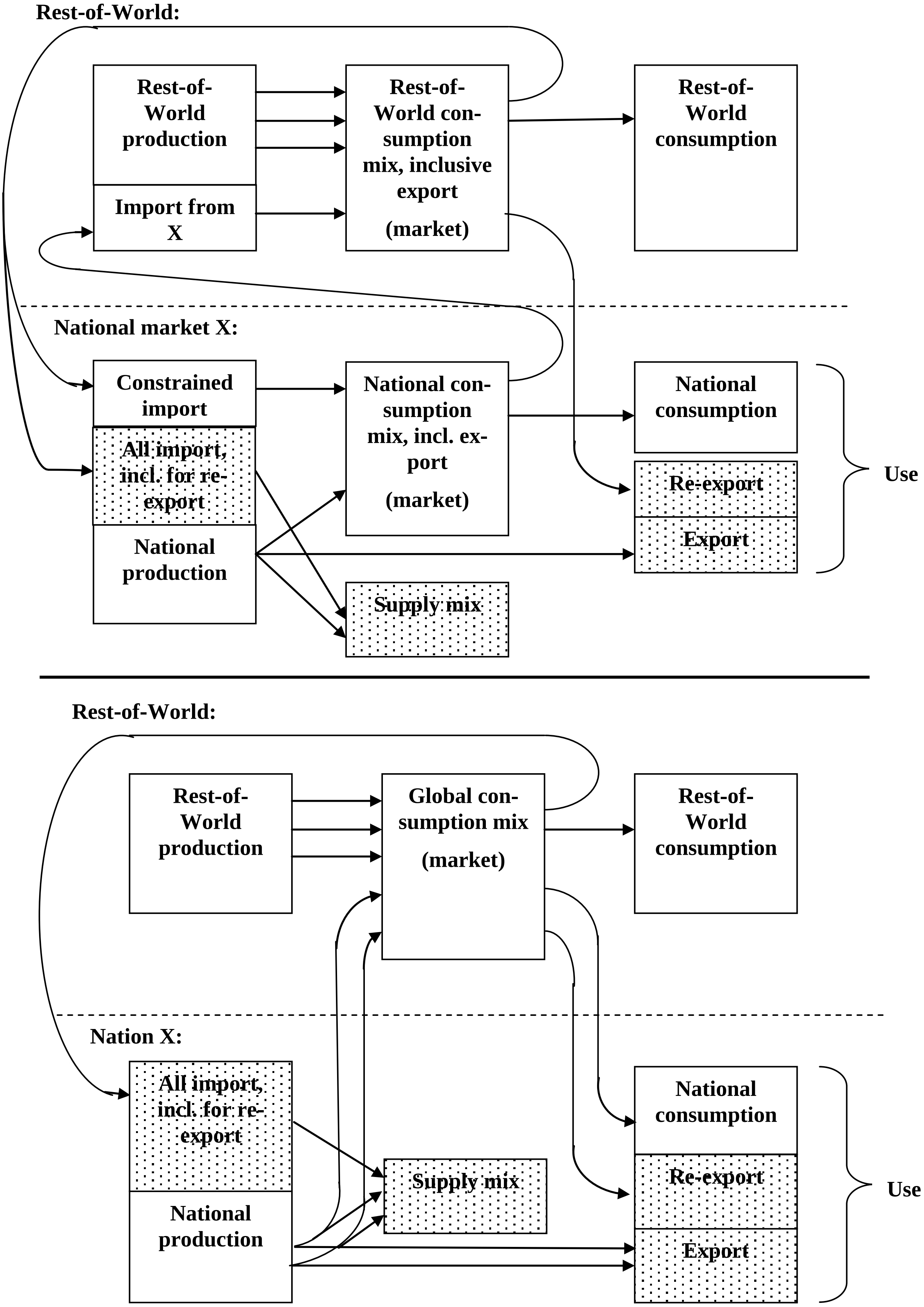


Figure 11.7. National balancing of supply and use in the situation with a partly and/or administratively isolated national market (top part of the Figure) and without (bottom part). The products of the dotted activities are not linked to any further activities in the database, but are included for national balancing only. However, because of their correct upstream linking, the products can be used as inputs in a specific model without causing any errors.

- Import is specified with its actual contribution to the national supply mix, disregarding any administrative constraints, and is available also in the situation without any national, administratively constrained market. Import is therefore also modelled as a special import activity (ecoSpold field 115 specialActivityType) which does not contribute to the auto-generated consumption mix, but is solely for use in national balancing.
- Re-export is added. Re-export activities are modelled as a special re-export activity (ecoSpold field 115 specialActivityType) to avoid that their products are contributing to auto-generated consumption mixes.
- The national supply, combining the output from the special import activity and the output from the transforming activities within the national boundaries, may be modelled as a supply mix (ecoSpold field 115 specialActivityType), which does not contribute to the auto-generated consumption mix, but is solely for use in national balancing.
- The national use can be calculated as the consumption by activities on the national territory plus the national export and re-export activities.

Additional advice for data providers:
Datasets for special import activities (ecoSpold field 115 specialActivityType) can only be uploaded to the database when the resulting national balance is correct, which implies that the datasets for national production, consumption, export and re-export must be added to the database before adding the special import activity.

[Changes relative to ecoinvent version 2: The clear distinction between market boundaries and administrative boundaries is new. The option for national balancing is new and is related to the (new) availability of production volume data for all activities. The editor for trade reviews all production mixes, supply mixes, import activity datasets, and market datasets (consumption mixes) from version 2, to ensure that they are consistent with the new, more precise definitions, and that they fulfil the new documentation requirements. Changes/additions are either performed or reviewed by the original dataset authors, when possible.]

11.6 Speciality productions

A *speciality production* is an activity that has a material for treatment as an input, but which is not a treatment activity (i.e. it has a positive reference product that determines its production volume). The production volume of such an activity will be ultimately constrained by the availability of the material for treatment, and if all the material for treatment available were eventually used by speciality productions, at least one of these (typically the least competitive) would necessarily be a treatment activity, since then its speciality product would no longer be the reference product that determines the production volume. An example of a speciality production is ethanol from sugar beet molasses, shown in Figure 11.8.

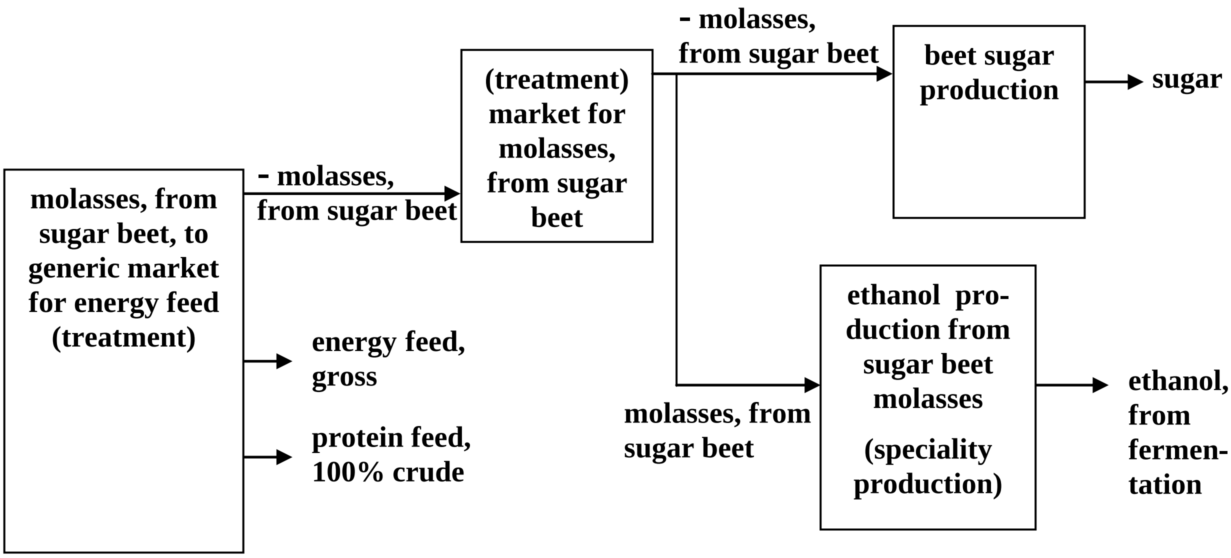


Figure 11.8. The database-generated model of the treatment of the by-product sugar beet molasses from sugar production with the speciality production of ethanol.

Additional advice for data providers:
Materials for treatment should as far as possible *not* be used as inputs to activities that are not treatment activities, i.e. speciality productions should only be used when unavoidable. This is due to the effect that speciality productions have in system models with partitioning. As explained in Chapter 14.4.1, the speciality productions are allocated in the same way as treatment activities, i.e. in combination with the activity that supplies the material for treatment. For example, in Figure 11.6, the ethanol will be allocated together with the sugar. If speciality productions are used too liberally, then large parts of the database may end up as being allocated together.

11.7 Downstream changes caused by differences in product quality

Since products are defined in terms of their obligatory product properties only, see Chapters 4.4.5 and 9.3, they may differ in terms of non-obligatory properties, and these non-obligatory properties may influence the later, downstream activities in which the product is used or disposed of, so that these downstream activities have larger, smaller or different intermediate and/or elementary exchanges. This is illustrated in Figure 11.9 (left).

In a database context, where products with the same obligatory properties are mixed in the market activities, it is not practically possible to separately model the downstream use and disposal activities as dependent of the specific products used, since this would require these products to be modelled separately throughout their entire life cycle, also for those parts of the life cycle where there is no difference between the products (dotted intersections in Figure 11.9, left). Such a separate modelling would also not reflect the actual market situation, where the products are not necessarily perceived as different by the users. The difference may be something completely irrelevant to the user, such as a contamination that first shows up in the final disposal after several rounds of recycling.

In the ecoinvent database, use and disposal activities are therefore only modelled as average activities that use consumption mixes as inputs. For a product that has non-obligatory properties that make it environmentally better or worse in the use and/or disposal stages, these downstream differences to the average use and/or disposal activities are therefore added specifically and directly as *correction datasets* to the transforming activity that gives rise to the difference, i.e. that produces the product that deviates in relevant non-obligatory product properties from the other products on its market (Figure 4.9, right, upper part). In this way, the difference is included in the product system of that particular product, even when modelling all downstream activities as average activities.

At the same time as a correction dataset is added upstream, it is subtracted from the downstream average activity by placing it as a direct negative input to the downstream average activity, since the content of the correction dataset is already included once in the downstream activity (Figure 11.9, right, lower part). Thus, the same correction dataset is added upstream and subtracted downstream. The upstream positive input and the downstream negative input of the correction dataset are scaled to the production volumes of the two activities that the inputs are provided to. From the perspective of the average user, these two correction datasets therefore cancel each other out.

A correction dataset has the activity name and reference product “difference to [downstream activity] caused by [transforming activity that gives rise to the difference], per [unit of reference product (of upstream or downstream activity)]”. This reference product has neither mass nor any other properties, since a correction dataset represents a balanced sub-activity of the downstream average activity dataset, without a separate reference product.

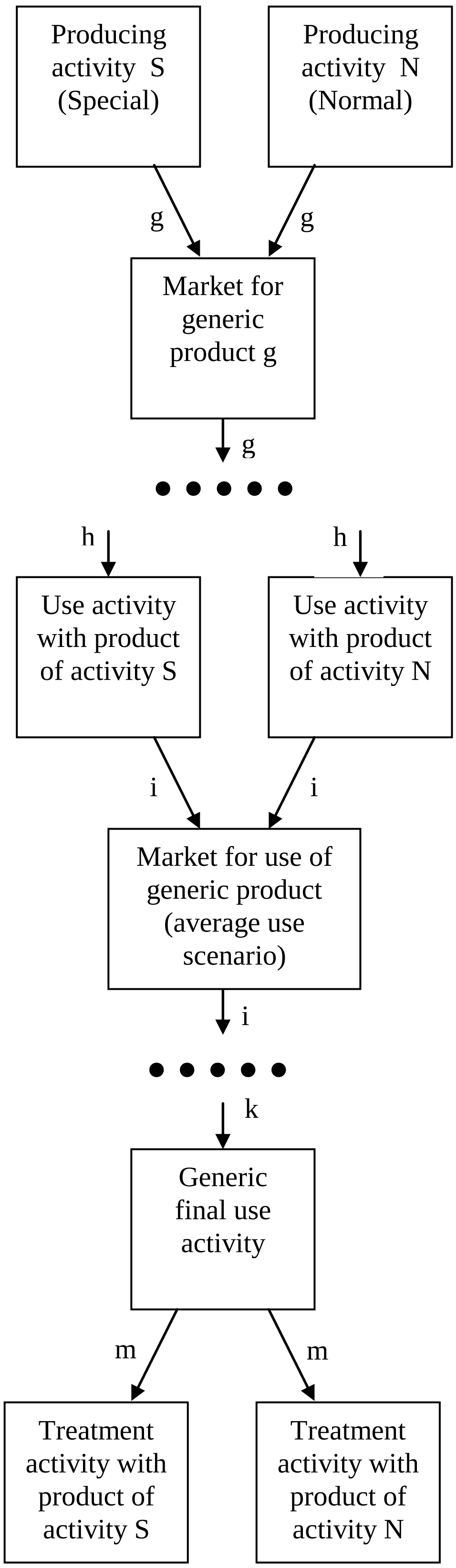


Figure 11.9 (left). The difference in non-obligatory properties of the products of activities S and N cause some downstream activities to be different.

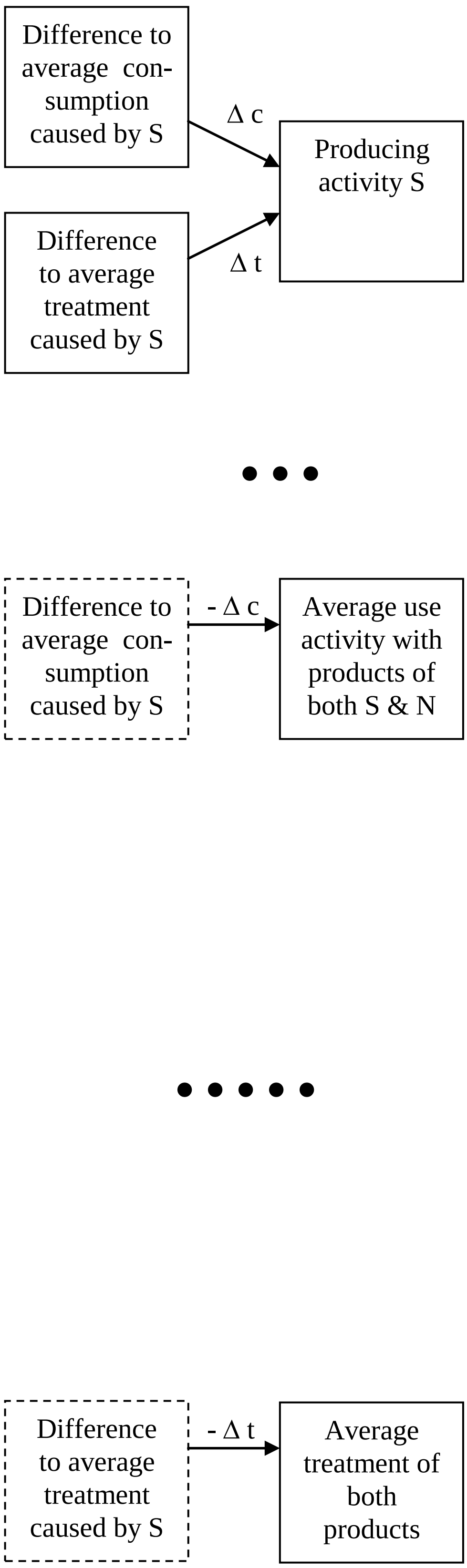


Figure 11.9 (right). Downstream activities are modelled as averages, and the differences are modelled with correction datasets, moving the differences up to the activities that cause them. Datasets with dotted lines are

negative.

Additional advice for data providers:
Correction datasets are most easily produced when all involved datasets (upstream and downstream) are scaled to their full production volumes, which also makes it most easy to check that the two corresponding correction datasets cancel each other out. The resulting correction dataset may then later be rescaled to any desired unit of reference product. If the deviating product causes differences in several parallel downstream activities, which is often the case at least for niche products and infrastructure products, it may be most practical to include the entire use and/or disposal activity in the correction dataset, so that these activities are completely subtracted from the downstream averages. Correction datasets can be added to any upstream activity that causes downstream differences, and is therefore not limited to production activities.

11.8 Outlook: Packaging

Packaging is a complementary product, typically not included in the description and mass of the packed products. For example, 1 litre of the product “milk, fresh, 3.5% fat by weight” reports the production of the milk alone, not its packaging, which is anyway variable. Milk is sold in glass bottles, plastic bottles and pouches, plastic-lines cartons, etc., each with their specific weights, production and disposal activities. Therefore, packaging is in general kept separate and added as a complementary input to (and waste output from) the receiving activity where the packed product is used or re-packaged. Packaging discarded before re-packaging is included as input to the wholesale or retail activity, while consumer packaging is reported as a separate input to the receiving activity where the packed product is used.

When the type and weight of consumer packaging is unknown, the default values from Tables 11.1 and 11.2 are applied. These values are the best that are currently available to us, but since their basis is rather specific (the Danish packaging statistics for 2004) they should only be used as indicative. More detail, e.g. on the specific types of plastic and paper packaging material, as well as data for secondary (transport) packaging, can be found in the background documentation on the ecoinvent website.

Product group / Packaging	**Alu**	**Steel**	**Plast**	**Paper**	**Glass**
Vegetables and nursery products			0.005	0.005	
Fruit, nuts and spices	0.001		0.011	0.003	
Meat products	0.001	0.006	0.008	0.002	
Processed and preserved fish and fish products	0.001	0.008	0.001	0.004	0.004
Processed and preserved potatoes		0.016	0.017	0.001	0.076
Fruit and vegetable juices		0.003	0.002	0.020	0.001
Processed and preserved fruit and vegetables		0.027	0.014	0.005	0.044
Crude oils and fats		0.001	0.003	0.001	
Refined oils and fats		0.005	0.018		
Margarine and similar edible fats		0.003	0.013		
Dairy products		0.001	0.002	0.005	
Prepared pet food	0.005	0.008	0.001	0.002	
Preserved pastry goods and cakes	0.002	0.019	0.012	0.007	
Cocoa; chocolate and confectionery	0.002	0.001	0.043	0.055	0.002
Noodles, couscous and similar products		0.001	0.021	0.004	
Coffee and tea	0.002		0.009	0.007	0.020
Condiments and seasonings	0.001	0.003	0.138	0.013	0.244
Homogenized food preparations and dietetic food				0.018	0.042
Other food products n.e.c.		0.004	0.006	0.009	
Distilled alcoholic beverages					0.879
Wines					1.364
Cider and other fruit wines					0.844
Other non-distilled fermented beverages					1.216
Beer	0.001	0.002	0.001		0.008
Mineral waters and soft drinks		0.001	0.021	0.005	0.001
Tobacco products	0.043	0.005	0.027	0.159	
Dyes and pigments		0.001	0.013	0.010	
Other basic organic chemicals		0.002	0.006	0.001	
Pesticides and other agro-chemical products		0.016	0.024	0.029	
Paints, varnishes and similar coatings; ink	0.001	0.009	0.016	0.001	
Basic pharmaceutical products		0.003	0.012	0.006	
Pharmaceutical preparations	0.019		0.214	0.054	0.103
Soap, detergents and polishing preparations	0.001	0.001	0.025	0.015	
Perfumes and toilet preparations	0.050	0.012	0.078	0.052	0.045
Glues and gelatines		0.002	0.013	0.026	
Essential oils		0.007	0.017	0.007	
Photographic chemical material	0.096		0.073	0.192	
Other chemical products n.e.c.		0.015	0.030	0.006	
Ceramic household and ornamental articles			0.002	0.009	
Weapons and ammunition			0.025	0.081	
Optical instruments and photographic equipment	0.002		0.042	0.035	

Table 11.1. Default values for packaging (kg per kg wet mass of product) for product groups that use different packaging materials. These are average values for these product types. When specific products are packed in only one of these materials, the amount per kg product should be relatively larger. See also the Table 11.2 on the following page.

Product group	**Plast**	**Paper**	**Product group**	**Plast**	**Paper**
Vegetables and nursery products	0.005	0.005	Hollow glass	0.002	0.007
Eggs		0.002	Other processed glass	0.009	0.014
Salt		0.001	Sanitary ceramic fixtures	0.005	0.003
Fresh and preserved meat except poultry	0.006	0.002	Ceramic insulators & fittings	0.001	0.007
Fresh and preserved poultry meat	0.010	0.004	Technical ceramic wares	0.027	0.016
Ice cream and other edible ice	0.037	0.035	Refractory ceramic goods	0.001	0.005
Grain mill products	0.002	0.007	Ceramic tiles and flags	0.004	0.007
Starches and starch products	0.003	0.002	Cement		0.004
Prepared animal feeds for farm animals	0.001	0.002	Precious metals	0.007	0.015
Sugar		0.001	Alu, copper, lead, zinc, tin	0.001	
Malt	0.001	0.001	Other non-ferrous metal	0.002	
Textile yarn and thread	0.013	0.001	Cutlery	0.002	0.002
Textile fabrics	0.012		Tools	0.021	0.041
Made-up textile articles except apparel	0.005	0.002	Locks and hinges	0.001	0.007
Carpets and rugs	0.042		Light containers of metal	0.002	0.005
Nonwovens, except apparel	0.021		Wire products		0.001
Knitted or crocheted fabrics	0.060	0.060	Fasteners, screws, chains	0.004	0.060
Knitted and crocheted hosiery	0.025	0.281	Other fabricated metal prod.	0.004	0.007
Pullovers, cardigans and similar articles	0.002		Pumps and compressors	0.007	0.007
Leather clothes	0.040		Taps and valves		0.027
Outerwear	0.004		Bearings, gears & similar		0.050
Underwear	0.016	0.008	Furnaces and machinery	0.003	0.005
Furs; articles of fur	0.020	0.013	Electric domestic appliances	0.014	0.021
Luggage, handbags; saddlery & harness	0.003	0.002	Office machinery	0.002	0.052
Footwear	0.013	0.053	Insulated wire and cable		0.023
Wood products	0.009	0.026	Accumulators & batteries		0.016
Paper and paperboard		0.007	Lighting equipment & lamps	0.043	0.050
Household and toilet paper	0.021	0.005	Electr. equipm. for engines		0.214
Paper stationery	0.002	0.022	Other electrical equipment	0.001	0.006
Wallpaper	0.050		Electronic components	0.014	0.038
Other articles of paper and paperboard	0.002	0.047	Television and radio equipm.	0.007	0.169
Newspapers	0.017		Medical & surgical equipm.	0.045	0.038
Sound recordings		0.014	Measuring equipment	0.011	0.050
Other basic inorganic chemicals	0.001		Parts for motor vehicles		0.010
Fertilizers and nitrogen compounds	0.002		Motorcycles	0.003	0.005
Explosives	0.017	0.037	Bicycles	0.007	0.044
Prepared unrecorded media	0.016	0.007	Chairs and seats	0.011	0.031
Man-made fibres	0.016		Other office & shop furniture	0.007	0.018
New and used rubber tyres and tubes		0.003	Kitchen furniture	0.013	0.037
Other rubber products	0.007	0.029	Other furniture	0.006	0.010
Plastic plates sheets tubes and profiles	0.001		Mattresses	0.016	0.004
Packaging products of plastics	0.002	0.008	Musical instruments	0.006	0.006
Builders' ware of plastics	0.009	0.015	Sports goods	0.011	0.034
Other plastic products	0.003	0.007	Games and toys	0.051	0.046
Flat glass	0.003	0.005	Brooms and brushes	0.018	0.026
Processed flat glass	0.020	0.025	Other manufactured goods	0.014	0.023

Table 11.2. Default values for packaging (kg plastic and paper packaging per kg wet mass of product) for product groups that use only plastic or paper for packaging.

11.9 Outlook: Final consumption patterns

When household activities are modelled explicitly as transforming activities, with inputs of raw materials and outputs of products, final consumption becomes the satisfaction of needs. For example, the home grown potatoes are combined with purchased food products in the household activity “meal preparation” that has the product “meal” which combines with the meals from restaurants in a “market for meal”, which finally may translate into the product “satisfaction of need for food”, which together with all other need satisfactions combine in a final aggregate consumption/need satisfaction.

The modelling of final consumption/need satisfaction is complicated by the existence of many different consumer types, which assign different properties as obligatory for what is accepted as e.g. a “meal”, so that it is necessary to operate with different markets and market niches for meals, which together with other specific preferences of the consumer types combine into final consumption or need satisfaction patterns per consumer type.

There are several suggestions on how to classify human needs. We apply the modification suggested by Weidema et al. (2005) to the Segal (1998) set of core economic needs, which has the advantage over other classifications that its applicability has been demonstrated in practical empirical work and that it provides a stronger linkage between consumption and affluence and its basis in products. The 11 need-based consumption groups are:

- Housing
- Food
- Leisure
- Social care
- Education
- Health care
- Security (including insurance)
- Communication
- Clothing
- Hygiene
- Other consumption not elsewhere classified (mainly “economic infrastructure” expenditures, such as interest etc. on financial investments, and economic affairs and services).

In national statistics, final consumption is typically recorded as the products directly or indirectly purchased by households. When recorded in this way, the household activities, e.g. the relation between shopping, car driving, fuel use and its emissions, are not included in the final consumption. However, at a more detailed level, statistics are available on the consumption patterns of different household types, depending on parameters such as household size, income level, dwelling type, etc. These data are interesting for understanding the driving forces behind consumption and for modelling changes in the household parameters. To take advantage of these data sources, the final consumption patterns from the statistics are translated into demands for the corresponding household activities per household type, thus integrating the household consumption patterns with those of the consumer types into one overall model of final consumption or need satisfaction.

11.10 Linking across time

11.10.1 Lifetime information / Stock additions

In life cycle inventory modelling, long-lived products are typically represented by steady-state models, e.g. a car will typically be modelled with the current production technology, the average life time emissions and the current waste treatment technology, all divided by the lifetime of the car. Effectively, this means that - in this LCI modelling - the net additions to stock of these long-lived products are simply contributing as physical inputs to the waste treatment activities of the current year.

When lifetime information is available for a product and/or waste, and waste treatment datasets are available for the period that the product becomes waste, the waste treatment and the accompanying emissions can be placed at their correct point in time.

It is strived for to make lifetime information available for long-lived products and to make waste treatment datasets available for future periods, so that current net additions to stock of these products can be modelled as becoming waste at the correct period, and thus use the waste market that corresponds to this period.

Outlook: It is possible to automatically identify by-products and wastes with a property "lifetime" in excess of one year[7] as an addition to stock (ecoSpold field OutputGroup option 5 = StockAdditions), thus distinguishing this "future waste" from the waste outputs of the current year. For such stock additions, the database service layer would then be able to identify the years in which the stock will become waste (using the lifetime and any uncertainty information provided on this) and link this waste directly to the corresponding future waste treatment markets. If a treatment market is missing for a specific year, the corresponding treatment market for the nearest preceding time period would be applied.

In LCI modelling, it is the consumption activities that demand the necessary upstream production activities. Therefore, a similar automatic linking of the future *consumption activities* of long-lived products cannot be made, since this would require that the consumption activities were *inputs* to the infrastructure activities in the same way as the waste treatments are. Thus, such dynamic modelling of the consumption activities of long-lived products still requires additional, manual linking by the database user of the relevant accumulated systems datasets across time.

However, inputs to an infrastructure dataset (a dataset with a reference product having the property "capacity" or "lifetime_capacity") may have a specific, direct link (using the activityLinkId) to a future activity. This may be relevant for maintenance activities or components of infrastructure that have a shorter lifetime than the composite infrastructure, e.g. windows in a building, or tyres on a car.

When linking to datasets of future years, only accumulated systems datasets would be linked to, to avoid an endless calculation task, since practically all datasets within a time period are linked to each other, and linking to just one dataset from a future year therefore would involve the entire economy in that future year, with the additional possibility that datasets of this year also link to even more future years.

Applying the output category "stock additions" will remove the requirement of direct equivalence between capital investments and waste in any given time period. When using the ecoinvent database in connection to data from national accounting (see Weidema 2013), this will allow to balance the com-

[7] This is relevant for by-products/wastes only, because reference products with a lifetime in excess of 1 year are always services, see Chapter 4.11, i.e. the stock addition/future waste occurs always directly as an output of the activity that produces the long-lived product.

plete economy for a given year, based on the actual investments in capital goods, and the actual waste amounts of that year, without any artificial requirement that these should match.

[**Changes relative to ecoinvent version 2:** In version 2, each dataset is only available for one time period, and all datasets are linked without regard to their indicated time period. In version 3, only datasets for the same time period are linked, except for the described situation of stock additions, which makes use of the new option to add lifetime as a numerical property to intermediate outputs, and if links across time are made using the activityLinkId.]

11.10.2 Long-term emissions

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 timeframes of 60'000 and 80'000 years, respectively, are chosen. These activities 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.

[The issue of how best to include long-term emissions is currently under consideration in a separate ecoinvent research project]

11.11 Using properties of reference products as variables

[**Feature considered for implementation later:** While the performance of the database service layer as described in this section has been implemented, additional experimentation and testing was found to be required before taking this feature into general use. It has therefore not been used in practice for any datasets in the version 3.0 release. Even without the software implementation, the specification in this chapter can be used for manual implementation.]

When one or more exchanges of an activity dataset are expressed as mathematical relations involving a property of the reference product, and this property is not a fixed property (see Chapter 5.6.7), the value of the property may change depending on the setting of the property in the dataset that has the reference product as an input. Each setting of the property value effectively represents a different product. This can be seen as a special case of combined production (see Chapter 5.3) in which each such property represents a combined product, with the important difference that the properties are not traded separately from the product that carries the properties. Like for other cases of combined production, a sub-division of the multi-product dataset is required, so that the specific dependencies of each variable property are expressed in separate datasets. For example:

- If a dataset for impact extrusion of aluminium, with the reference product "impact extrusion of aluminium, cold", has one or more of its exchanges defined as a mathematical relation to the property "number of deformation strokes" (variable name: "strokes") of the reference product, two datasets are required: One with the reference product "strokes of impact extrusion of aluminium, cold" and one with the reference product "impact extrusion of aluminium, cold, property independent", in which the first dataset contains all the mathematical relations that involve the property "strokes" and the second contains all the other exchange data that are not dependent on this (or any other) property of the reference product.
- If a dataset for waste incineration, with the negative reference product "waste", has one or more of its exchanges defined as a mathematical relation to the property "cadmium content" of the waste, two datasets are required: One with the negative reference product "cadmium content of waste" and one with the negative reference product "waste, property independent", in which the first dataset contains all the mathematical relations that involve the property "cadmium content" and the second contains all the other exchange data that are not dependent on this (or any other) property of the reference product.

For each new variable property of the reference product (i.e. a property included in a mathematical relation of another exchange), a new dataset is required (if there is at least one other activity dataset that has the reference product as an input with a different amount of the variable property). Each additive element (summand) of the mathematical relation can only contain one property of the reference product. Composite or nested properties can be used for situations where multiple relations exist (e.g. when an emission is dependent on both the degradability and the elemental composition of a waste).

Figure 11.10 illustrates the original and the derived datasets and how these are linked to the activities that require the reference products. The variable property is added as a by-product with the name "[property name] of [name of reference product]" and the mathematical relation is changed to refer to the amount of this new by-product, while the original property is deleted from the reference product, which is renamed to "[name of reference product], property-independent". All exchanges that were originally expressed as fixed amounts are re-formulated as mathematical expressions relating to the reference product, i.e. the fixed amount "40" translates to "40/A", where A refers to the amount field of the reference product. The market activity dataset for the reference products is likewise subdivided, with all other exchanges and properties remaining with the property-independent reference product, so that the new property-specific market activities have no additional exchanges besides the reference product.

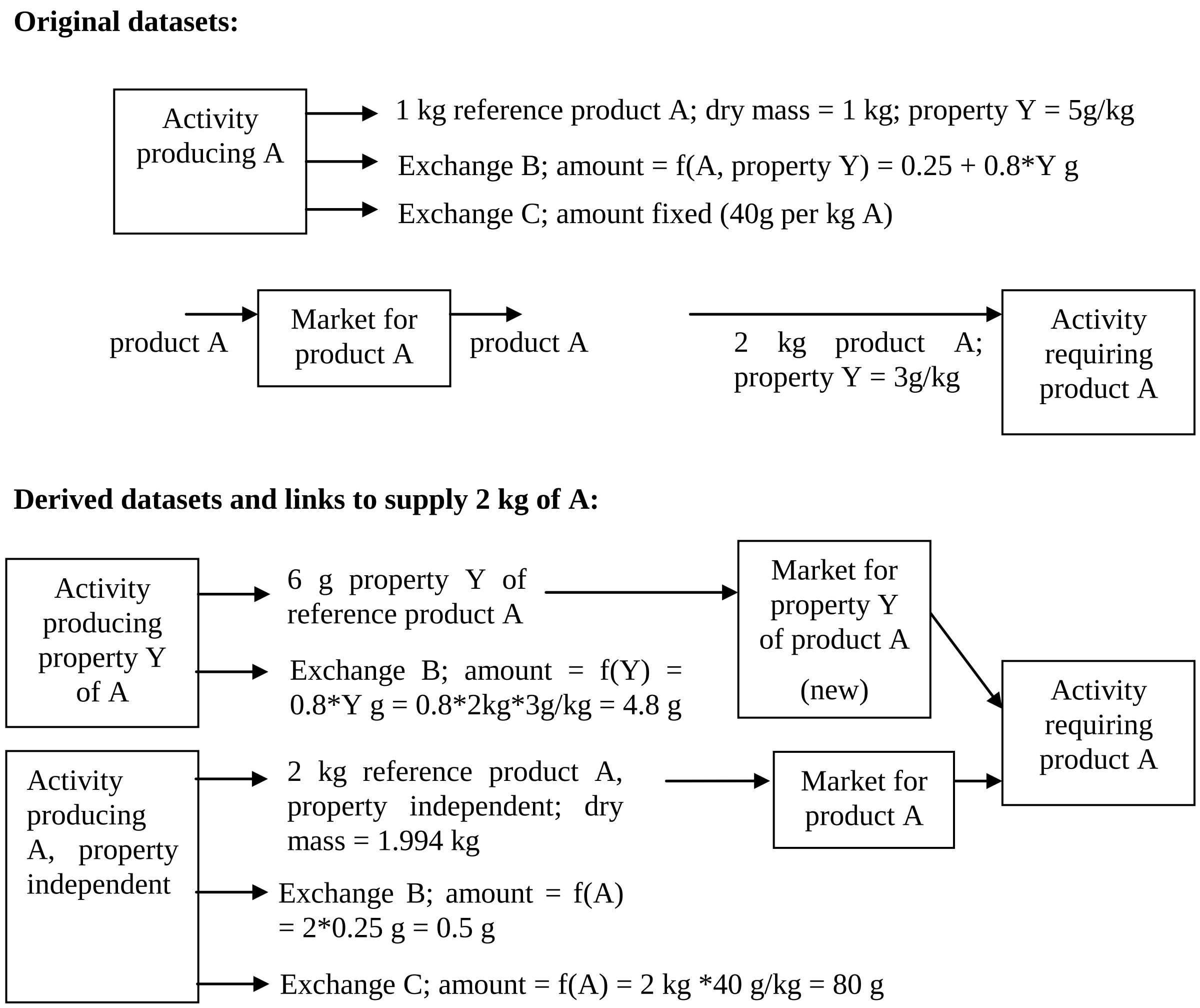


Figure 11.10. The original and derived datasets where a property Y of the reference product is used as a variable, and the original dataset requiring this reference product, but with a different value for Y, where the input is also subdivided. Note that the mass balance (and other balances) may be kept intact for the subdivided activities, (as illustrated by the change in dry mass of the reference product) when such adjustments are made during a manual sub-division, but since properties do not themselves have properties such as mass, such adjustments are not made when the sub-division is made automatically by the database service layer (see Chapter 14.1, linking rule no. 4). However, the aggregated systems results are not affected by this.

Other datasets supplying the same reference product to the same market are subdivided in the same way. If such datasets do not have the same property of the reference product as a variable property, the exchanges of this dataset are interpreted as independent of this property, and their fixed amounts thus simply re-formulated as mathematical expressions relating to the re-named reference product.

When the subdivision is performed by the database service layer, the subdivided datasets keep the same activity ID as the original dataset, which implies that the product name is required to distinguish the datasets from each other.

11.12 Market averages of properties

When a property of an output of an activity is not fixed (re. fixed properties, see Chapter 5.6.7), different transforming activities may supply the same product with different values for the same property. For example, different suppliers of lignite, even to the same market, may provide lignite with different sulfur contents.

This situation is more general than the specific situation described in Chapter 5.8.

As part of the linking of the different activities into product systems, see Chapter 4.14 and Chapter 14, the database service layer calculates the inputs to each market activity from different suppliers in proportion to their available production volumes, and calculates the resulting production volume of the market output. In addition, those product properties that are common to all the suppliers to the market are added as properties of the market reference product, and the values of these properties are calculated in proportion to the supplied production volumes (this calculation does not apply to the property "price", since market prices are not simple averages of production prices).

These properties of the market outputs can be applied in further calculations. For example, the sulfur content of lignite may be used to determine the emission of sulfur dioxide in the activities that use the lignite as a fuel. To avoid circular references in the database, the calculated properties of the market outputs are not automatically transferred to the activities that use the market outputs, but remain available in the market datasets for information purposes and possible manual adjustments of the properties in these receiving activities. This transfer of information is of course only relevant when there are different values of a property among the suppliers to the same market and the receiving activity uses the property values for calculations.

11.13 Use of transfer coefficients

Transfer coefficients is a feature of the new ecoSpold 2 format, but it has not yet been decided whether and when ecoinvent will support datasets with transfer coefficients.

12 Validation and review

Validation is the automatic software routine to check that data are valid according to the internal rules set for the ecoinvent database.

Review is the manual inspection of the data and commenting on any discovered errors or anomalous data that require additional explanation or justification.

12.1 Validation

The automatic validation of ecoinvent data covers the

- accordance with the ecoSpold 2 data format,
- accordance with additional ecoinvent-specific rules, as described in this document,
- plausibility of the data,

and takes place in several steps:

The ecoEditor software, used by data providers to create and edit data for the ecoinvent database, secures the validity of the data against the ecoSpold 2 data format already during editing. Likewise, some validations of accordance with ecoinvent-specific rules can also be performed directly upon data entry, e.g. “Time period shall be minimum one year”.

Other validation checks can be made off-line (i.e. without contact to the ecoinvent database) in the ecoEditor software, upon user request, typically before storing an edited dataset, e.g. “An ISIC class must be chosen”, and “More than one reference product in the same activity dataset”. The latter is an example of a validation check that does not lead to a rejection of the dataset (i.e. it can still be submitted to the database for review), but results in a warning to the user (here that “'It is unusual to have more than one reference product. This occurs only when no alternative production routes exist for these products. If you are in doubt which of the products is the reference product or if you think there should indeed be more than one reference product for this activity, please consult the ecoinvent Data Quality Guideline Chapter 11.1 for further advice.”).

Other validation checks require contact to the production version of the ecoinvent database, because they require a check against data that already exist in the database, e.g., “Global dataset must exist before non-global datasets can be uploaded”, and “Production volume of datasets for a specific activity, time period and macro-economic scenario must not exceed production volume of the corresponding global dataset”. Such validation checks also apply for deletion of datasets, e.g. “A parent dataset cannot be deleted” (deletion of datasets can only be done by the ecoinvent editors, see Chapter 12.2, but can be suggested on the relevant discussion boards on the Editor's pages, see Chapter 16.4.)

Validation checks that require contact to the database can either be performed via the ecoEditor software when this is in on-line contact with the database, [**Feature considered for implementation later:** or by submitting the dataset to the ecoinvent database for validation via a web-browser]. When using the ecoEditor on-line, the validation result will be inserted directly in the dataset (in the ecoSpold field 3340 Validation details). Only the latest validation result will be stored (i.e. any previous validation results will be over-written). If submitting a dataset via a web-browser, the validation result (a text message) will be returned by e-mail.

The plausibility checks generally do not lead to rejection of a dataset (i.e. it can still be submitted to the database for review), but results in a requirement to justify the anomalous value in the adjoining comment field, if the anomalous value is maintained. An implausible entry without an adequate justification will be returned by the reviewer.

Plausibility checks generally compare the data entries to similar entries in similar datasets. Thereby, the completeness of the data is checked (missing exchanges or missing entries in fields where all similar datasets have entries); it is checked that the entries fall within expected ranges (relative to the amount of the reference product or relative to well-established relations between different amounts and/or properties of specified exchanges). Results of mass and monetary balances are also reported in the validation results.

The plausibility checks obviously relate to the existing database, specific clusters of similar datasets within the database, and knowledge about what are typical and important errors and relationships between individual data values within each cluster. This knowledge is built up over time, and is based on a continuous learning cycle of learning from past errors, software-supported explorative data analysis, interaction with expert knowledge, and cluster analysis. Thus, the plausibility checks will improve over time, and will be implemented in the ecoEditor and the database software, as part of the continuous maintenance and updating. **[At the time of the release of version 3.0**: Plausibility checks are largely missing]

[**Changes relative to ecoinvent version 2:** Validation is more extensive.]

12.2 Review of dataset and documentation

All transforming activity datasets are reviewed by at least three experts prior to the storage of the datasets in the database. [**At the time of the release of version 3.0:** Not all datasets have so far been reviewed by at least three experts. Such datasets are to be submitted to a more extensive review at a later date.]

12.2.1 Types of editors

There are three overall types of ecoinvent editors: activity editors, cross-cutting editors, and LCIA editors. Cross-cutting editors can further be sub-divided in geographical editors, inventory indicator editors, meta-data editors and language editors. Each of these types of editors will be described in the following:

Activity editors: Activity editors are responsible for reviewing of data for a specific industry, technology or other human activity. The activity editor is the main reviewer for a dataset; she/he is the first to receive a submitted dataset, and the last to accept it for final upload to the current beta-version of the database. Activity editors are typically leading (LCA) experts within their activity area. The activity editors divide the work between them according to the ISIC (Rev. 4, ecoinvent-amended) codes of the datasets and/or the type of dataset. The main editor may re-assign a dataset to a co-editor with special expertise but still request to remain as main editor for the dataset. In this case, the dataset will first be reviewed by the co-editor and then by the main editor for overall consistency. An activity editor is in principle responsible for all datasets within an activity area, disregarding any geographical differences (exactly to ensure global consistency of activity datasets, i.e. across all geographies). When a dataset has been reviewed by the activity editor, it is passed on to the cross-cutting editors:

Geographical editors: A geographical editor is responsible for datasets that fall geographically within a specific country or other geographical area, ensuring that geographical variation in technologies are correctly and consistently captured and integrated across all datasets for that area. If the ecoinvent Centre cooperates with a national data collection initiative in a country, the geographical editor for that country will typically be appointed after suggestion by the national data collection initiative.

Inventory indicator editors: An inventory indicator editor is responsible for a specific emission (or group of emissions), e.g. particle emissions, or other environmental pressure indicators (e.g. resources, land use, noise, social aspects)[8], ensuring the consistency across all datasets.

Meta-data editors: A meta-data editor is responsible for ensuring the consistent use across all datasets of a specific database field (or group of fields) or master file entries, e.g. for name fields, statistical classifications, free documentation fields, supply-use data, geography fields, system models, scenarios, uncertainty fields, and product properties. Meta-data editors for required product properties, such as mass, carbon content and price, have the additional task to suggest data when these are not supplied by the data provider.

Language editors: A language editor is responsible for checking consistency and quality of translations within a specific language version of the ecoinvent datasets, and may maintain a vocabulary for automatic pre-translations. Language editors will only receive datasets for review when they contain translated fields in their specific language.

LCIA editors: LCIA editors are responsible for impact assessment datasets, not activity datasets. In this way, they work in parallel to the activity editors. There are two kinds of LCIA editors: LCIA method editors and LCIA pathway editors. An LCIA method editor is responsible for the maintenance of the ecoinvent version of a specific LCIA method (CML, Ecoindicator, etc.). The LCIA method editors are both responsible for the correctness of the mapping of the environmental pressure indicators ("Elementary exchanges") between the ecoinvent inventories and the specific LCIA method, and for the correspondence of the numerical entries in the ecoinvent implementation with those of the original published method. An LCIA pathway editor is responsible for the consistency of the implementation of a specific impact category and/or pathway (for noise, water resources, etc.) across all relevant LCIA methods. LCIA editors are involved both when an LCIA method is updated by the method developer, and when new environmental pressure indicators are added to the ecoinvent database. The only cross-cutting editors which are relevant for impact assessment datasets are the language editors. Thus, when an impact assessment dataset has been reviewed by the LCIA editor(s), and it contains translated fields, it is passed on to the language editor.

12.2.2 The flow of a dataset through the editorial process

When a data provider submits the dataset via the ecoEditor software [**Feature considered for implementation later:** or via the ecoinvent web-site], the software stores it and assigns it to the relevant editor. For a transforming activity dataset this will be determined by the statistical classification assigned to the dataset by the data provider. For production and supply mixes and market activity datasets this is the editor for wholesale and retail trade. For import datasets and supply-use data, this is the meta-editor for supply-use data. For an LCIA method dataset this will be determined by the name of the method or impact category.

The original data provider (author) of a dataset can ask to be 'active author' and will then be informed whenever there are other data providers that suggest modifying the dataset in question and can decide to take over the suggestion (and thus remain as author of the dataset) or comment on the suggested modifications before the dataset is passed on to the activity or LCIA editor.

If the dataset is an edited version of an existing parent dataset, the consequences for the child datasets are reviewed at the same time as the edited parent dataset.

The main editor may pass on the dataset and review responsibility to a co-editor if temporarily unavailable due to workload, holidays or illness, or if judging that the co-editor has more scientific exper-

[8] Environmental pressure indicators are called "Elementary Flows" in the ISO 14040 series, and "elementary exchanges" or "exchanges with the environment" in ecoinvent.

tise for the particular dataset in question. When passing on a dataset to a co-editor, the original responsible editor indicates whether the co-editor thereby becomes the responsible editor for this dataset or whether the original main editor remains as responsible editor, in which case the dataset will first be reviewed by the co-editor and then by the main editor for overall consistency. In case of conflicts of interests, any editor is required to pass on the dataset and review responsibility to a co-editor, and shall not demand to remain as responsible editor.

Having accepted the dataset for review, the responsible editor adds any review comments to the file. If a dataset is a delta/child dataset or a new version of an existing dataset, only those parts of the dataset are reviewed that are different from the parent or are affected by the changes. The purpose of the review is to check the dataset against the data quality guidelines in this document, to check that the result of the automatic validation has been adequately addressed, and to check the plausibility of the dataset against the “real life” activity that it is intended to represent. As part of the review, the editor may also compare the new dataset with an older version or a similar dataset. For delta/child datasets, the editor also considers whether entries correctly belong in the delta dataset, or should rather have been placed in the parent dataset.

If the review comments are of a nature that revision by the data provider is required, the commented dataset is returned to the data provider for re-submission. This procedure may continue until the responsible editor is satisfied with the quality of the submitted dataset.

When the responsible editor has accepted the dataset, the data provider is informed and the dataset now passes on to the cross-cutting editors. Depending on its content, the dataset can be passed on in parallel to several cross-cutting editors:

All activity datasets except global datasets are passed on to the relevant geographical editor.

Inventory indicator editors receive activity datasets if they contain data on their specifically monitored environmental pressure indicators (elementary exchanges). If the dataset is a new version of an existing dataset, it is only passed on if there are changes for the monitored indicators. More than one inventory indicator editor may be involved in the review of the same activity dataset.

Meta-data editors receive activity datasets if they contain information in one of the fields specifically monitored by them. If the dataset is a new version of an existing dataset, it is only passed on if there are changes for the monitored fields. More than one meta-data editor may be involved in the review of the same activity dataset.

Language editors receive datasets if they contain translated fields in their specific language. Datasets that have multiple languages may thus be passed on to several language editors in parallel. If the dataset is a new version of an existing dataset, it is only passed on if there are changes for the text or name fields, or when a new language has been added.

If responses are given by one or more cross-cutting editor, these responses are automatically accumulated into one review version, which is passed on to the data provider for corrections and resubmission. The resubmitted dataset is returned to the editors which have given comments. This procedure may continue until the cross-cutting editors are satisfied with the quality of the submitted dataset.

When the dataset has successfully passed the cross-cutting review, the data provider is informed and the dataset passes back to the responsible editor. If there has been changes made during the cross-cutting review, the responsible editor performs a final review. After this final review, the responsible editor uploads the dataset to the current production version of the database, and the data provider is informed.

Editors seek to process submitted datasets within 14 days of receipt, but may request a prolongation of the review period during peak load, in which case the data provider will be informed. The minimum time between submission of a dataset and its inclusion in the production database is one month, but will usually require more time due to several rounds of comments and replies between editors and data providers.

The review procedure is comparable to the critical panel review specified in the ISO standards.

It has to be emphasised that the responsibility for the contents of all datasets remains with the person and institute who supplies the data. The reviewer helps to improve the quality of datasets with his or her suggestions. But it is the final decision of the dataset author whether all proposals for corrections of the data are implemented, just as it is the decision of the activity editor whether a dataset can be included in the database or not. If an editor repeatedly returns a dataset, and this is regarded by the author as unfounded, the author may address a complaint to the ecoinvent LCI Expert Group that has the final decision authority on scientific matters raised by the Editorial Board or arising from complaints.

[**Changes relative to ecoinvent version 2:** Review is more extensive and now performed by domain experts.]

12.3 "Fast track" review for smaller changes

Outlook: For adding tags to a dataset and for smaller corrections to a dataset (e.g. correcting spelling errors, adding, editing or deleting single entries that are obviously wrong), which do not require a full review of the entire dataset, a "fast track" submission procedure via the ecoinvent web-site <www.ecoinvent.org> is considered. This will avoid the need to download and install the ecoEditor software if it is only single entries that are to be submitted for review. The review procedure for such submissions will also be streamlined, to limit the workload on the editors, and to reduce the time between submission and publication.

12.4 Confidentiality

Confidentiality concerns of a data provider and requests for confidentiality agreements should normally be referred to the ecoinvent database administrator. When the data provider has set the accessRestrictedTo to either "2 = ResultsOnly" or "3 = Restricted", the dataset will not even arrive at the editor's desk, but will be redirected to and handled by the ecoinvent administrator directly. Confidential datasets are subject to the same data quality guidelines as any other ecoinvent dataset, but the review procedure will be performed under the direct management of the ecoinvent administrator that signs and/or manages the necessary confidentiality agreements, also in case of re-delegation of the review to independent reviewers.

The ecoinvent Centre accepts no responsibility for confidentiality agreements made directly between editors and a data provider.

12.5 On-site auditing

Branded datasets require on-site review by an ecoinvent-approved auditor. A visit to the factory and auditing of the books is required to determine that the activity is correctly and completely represented in the dataset. Audits are performed according to ISO 19011 and with Weidema et al. (2003) as technical basis. On-site audits may require the signing of a confidentiality agreement, and is always organised with the assistance of the ecoinvent administration.

13 Embedding new datasets into the database

Outlook: The ecoinvent data are intended to cover all aspects of the societal economy, although in varying degree of detail. For industries where not all products are already specifically included in the database, at least one activity dataset should represent the production of unspecified products of that industry. For example, while the ecoinvent database contains a large number of individual pesticides, there is also an activity representing “pesticide production, unspecified” with the reference product “pesticide, unspecified”.

The implementation of this completeness would imply that any new dataset, which is not a delta dataset for a child to an existing dataset, would always be a disaggregation of an existing dataset. For example, adding a new pesticide production would be a disaggregation of the activity “pesticide production, unspecified”. The production volume of the “pesticide production, unspecified” would be reduced by the production volume and exchanges of the new, specified pesticide.

The disaggregation would also ensure that the ecoinvent database would remain complete and non-redundant, i.e. for any given activity there is only one dataset that is the relevant dataset.

For a data provider of a new dataset, this would imply that at least two datasets are to be supplied at the same time: The new, specific dataset and the residual of the original, more unspecific dataset. These two new datasets together sum up to the original dataset. If the original dataset is not believed to represent the correct sum of the disaggregated datasets, a corrected version of the original dataset has to be submitted before or together with the disaggregated datasets.

It is considered to support disaggregation in a future version of the ecoEditor software. Until then, the disaggregation and the check against the original dataset have to be performed manually.

A disaggregation of an activity also implies a disaggregation of its reference product. For example, the disaggregation of “knitted nets” into “knitted textile bags” and “fishing nets”. Since the reference product of the original activity is an input to other activities in the economy, the datasets for these activities will also have to be adjusted, so that they instead of having inputs of the original reference product now have inputs of one or more of the disaggregated reference products. By default, the ecoinvent database would assume that all activities that had inputs of the original reference product will have inputs of all the disaggregated products in proportion to their new production volumes. This implies that the receiving activities are unchanged, except for the higher resolution in the intermediate input, and will provide the same results for their accumulated systems. However, this does not take advantage of the additional information provided by the new disaggregated activities. The food industry will still receive a part of their textile bags in the form of fishing nets, and the fishing industry will still receive too many textile bags. The authors and/or editors of the affected datasets should therefore be informed about the availability of this additional resolution, and asked to confirm the default distribution of the new disaggregated inputs, or to provide another distribution, thus allowing e.g. the food and the fishing industry to remove the unwanted inputs and place them on the correct disaggregated activity that now has become available. Such consequent changes, resulting from the availability of new resolution in an input, would pass through the “fast track” review procedure, see Chapter 12.3.

The ecoinvent LCI Expert Group may decide that some datasets representing unspecified products may be of such low quality that they are not to be included as inputs to other activities, but should only be available in the ecoinvent database for information purposes. Such datasets are provided with a tag “low-quality unspecific dataset”. In the activities that require such inputs, the missing inputs are mentioned as excluded inputs in the field ‘IncludedActivitiesEnd’ and the input may be quantified by an elementary exchange “missing input from technosphere” with reference to the amount and unit of the excluded unspecified products. Further detail on the missing input may be described in the comment field of this exchange. This facilitates the inclusion of such inputs when data of better quality becomes available, allows the inclusion of the excluded inputs in mass and monetary balances, allows an estimation of the excluded part of any product system, and allows the database users to add the missing inputs manually.

14 System models and computation of accumulated system datasets

The ecoinvent database is not just an LCI data library but also an LCI data network. The unlinked datasets of the ecoinvent unit processes are interlinked by the database service layer. All intermediate goods and service inputs to a unit process, be it the consumption of electricity, the demand for working materials, the use of the road infrastructure, are linked to other unit processes that supply these intermediate goods and services. This means that any change in one unit process influences the accumulated LCI results for almost all other unit processes. Depending on the magnitude of the change, this influence may be negligible for the majority of the datasets, but it may also be significant to many or a few datasets.

The ecoinvent database stores the unit process datasets as unlinked, multi-product datasets, i.e. with inputs specified solely in terms of product names, without requiring specification of the supplying activities, and typically with more than one product output. This is the way the datasets are obtained and entered by the data providers and this is how the unit processes are normally presented to the end user.

For the purpose of calculating the accumulated system datasets, the database creates linked, single-product datasets from the unlinked, multi-product datasets, with the help of database-wide modelling rules. An unlinked, multi-product dataset and its derived linked, single-product datasets have the same universally unique identifier (UUID) and name, and are distinguished by the field "systemModelName" (and for subdivided datasets by the reference product).

Two classes of system models are distinguished: System models with partitioning (allocation) and system models with substitution (system expansion).

14.1 Rules common to both classes of system models

It is a prerequisite for linking of any dataset that a specific geography, time and macro-economic scenario is declared in the relevant fields. Linking only takes place within this specific context (linking to same or larger geography and time, and same macro-economic scenario).

Some linking rules are identical for both classes of system models:

1) By-products/wastes that are identified by the database service layer as materials for treatment (see Chapter 4.8) are always moved to be negative inputs of the same activities, in order to include the treatment activities for the materials into the product systems. Since a negative input is the same as a positive output, this operation does not affect the mass, energy and monetary balances of the activities.

2) An intermediate input to an activity, which does not already have an activityLinkId, is always linked directly to the local market activity dataset that supplies this input as its reference product. The database service layer identifies the local market activity dataset based on the geographical location of the activity, matching this location with the available market that is equal to or covers this location. Since markets do not overlap, there will generally only be one such market activity for each intermediate input. If the activity is defined for a geography or time that spans over more than one market, each of the market activities contribute in proportion to their production volume (calculated as described in Chapter 14.2), implying that the database service layer will duplicate the intermediate input to match the number of supplying markets and subdivide the amount of the intermediate input over these in proportion to the production volume of each market. For activities with the geographical location "Rest-Of-World" (ROW) the inputs are linked to those suppliers that are not used as suppliers by any of the corresponding geographically specified (non-

ROW) activities, and if all these suppliers are used, to the supplying activity with the largest production volume.

3) For situations of variable properties of the reference product, the reference product is subdivided by the procedure described in Chapter 11.11,
4) For situations of combined products, the dataset is subdivided into an equivalent number of datasets, by the procedure described in Chapter 5.3. This procedure applies both to the datasets of combined production and the datasets generated from the variable properties, as described in the previous point.

The modifications described by these four rules are performed by the database service layer in the described order, before any other modification or calculation of the datasets for linking to suppliers and partitioning or substitution, except for the calculation of market production volumes required by rule 2.

14.2 System models with linking to average current suppliers

In many system models, the inputs to each market activity are modelled as coming from all those transforming activities within the geographical area of the market activity, which have the market reference product as an output, in proportion to their available production volume.

In current practice, this linking to average current suppliers is applied in all system models with partitioning, although there is no formal connection between partitioning and any specific linking rule for suppliers.

The ecoinvent database service layer automatically:

- Identifies these transforming activities, based on geographical matching,
- Adds an input to the market activity from each of these transforming activities,
- Adds the corresponding unique IDs of the transforming activities to the ActivityLinkId (ecoSpold field 1520) of the market inputs, thereby directly linking the inputs to the transforming activities,
- Calculates the amount of input from each transforming activity in proportion to its production volume, as indicated in the ecoSpold field 1530 productionVolumeAmount of each transforming activity, subtracting any production volume that is required by transforming activities via direct links (ActivityLinkId; ecoSpold field 1520) and therefore not supplied via the market,
- Sums up the production volumes, and adds the sum as the production volume of the output of the market activity,
- Calculates the production-volume-weighted averages of any properties that are common to all the transforming activities (with the exception of the price property) and places these averages as properties of the output of the market activity,
- [**Feature considered for implementation later:** Propagates the price information throughout the linked datasets by: Copying the price property of market reference products to all intermediate inputs that are supplied from markets, calculating the price property of the corresponding inputs to the markets as ((price*amount of the market reference product - price*amount of any other intermediate or elementary input with a price property)/amount of the reference product), copying the resulting price property of the market inputs to all intermediate outputs that are supplied to the market, and finally adding the price property to intermediate inputs that are supplied directly from transforming activities by copying it from the corresponding intermediate outputs.]

In combination with the rule for linking transforming activities to their local markets (rule 2 in Chapter 14.1), the above rules for linking market activities results in a database that is fully linked upstream, i.e. all inputs to all datasets are directly linked to their specific supplying activities.

14.3 System models with linking to unconstrained suppliers

In some system models, production constraints are taken into account, so that only unconstrained suppliers are included. Besides this, the inputs to each market activity are modelled much in the same way as in models linking to average current suppliers.

The unconstrained suppliers to the market are identified by the database service layer as those transforming activities, within the geographical area of the market activity, for which the market reference product is a reference output (i.e. not a by-product, since the volume of a by-product is per definition constrained by the corresponding reference products), and which has a technology level (see Chapter 5.5) that corresponds to the specific rule for the particular system model, see Chapter 14.6.

For each of the identified unconstrained suppliers, the ecoinvent database service layer then:

- Adds an input to the market activity, with the corresponding unique IDs of the supplier as ActivityLinkId, thereby directly linking the input to the specific supplier,
- Calculates the amount of input to the market activity in proportion to the production volume of the supplier, subtracting any production volume that is required by transforming activities via direct links and therefore not supplied via the market,
- Calculates the production-volume-weighted averages of any properties that are common to all the suppliers and places these averages as properties of the output of the market activity,
- [**Feature considered for implementation later:** Propagates the price information throughout the linked datasets by: Copying the price property of market reference products to all intermediate inputs that are supplied from markets, calculating the price property of the corresponding inputs to the markets as ((price*amount of the market reference product - price*amount of any other intermediate or elementary input with a price property)/amount of the reference product), copying the resulting price property of the market inputs to all intermediate outputs that are supplied to the market, and finally adding the price property to intermediate inputs that are supplied directly from transforming activities by copying it from the corresponding intermediate outputs.]

Note that the production volume of the market activities does not have any meaning in a system model with substitution, and is therefore not provided in the database-generated market activity datasets of these system models.

If the system model is also taking into account also markets, see Chapter 11.4, i.e. if any conditional exchanges exist that should be taken into account for the specific system model, these are identified and treated by the database service layer before any of the above described operations. Each conditional exchange, with its direct link to the affected consumption activity, is moved from being a negative output to be a positive input, and the amount of the conditional exchange is subtracted from the market output before the remainder (if any) is distributed over the unconstrained suppliers[9] to the market as described above.

The consumption activity affected by a conditional exchange has the constrained product as an input. In order for this product to serve as an input to the constrained market, the consumption activity must have the product as its reference product. The database service layer achieves this by moving – for the particular system model in question – the specific product input of the consumption activity to be its negative reference product, moving also the original reference product to be a by-product (when an alternative production route exists, for which this product is a reference output) or an elementary exchange, thus quantifying the resulting reduction in consumption. The market demand for the specific

[9] Unconstrained suppliers to a constrained market is possible when the constraint, e.g. a quota, is enforced at the level of the market only, or when supplying activities have more than one reference product, see Chapter 14.4.2.

input from the consumption activity thus translates into a reduction in the negative reference product output of the consumption activity. Note that the reduction in a negative output is a positive input, namely the input required by the constrained market. The technology level of the consumption activity is at the same time changed to “current”, to reflect that the consumption activity is now constrained by its constrained input.

The above rules – together with the rule for linking transforming activities to their local markets – results in a database which is fully linked upstream, i.e. all inputs to all datasets are directly linked to their specific supplying activities.

14.4 Modelling principles for joint production

The linked, multi-product datasets are converted to single-product datasets with the help of database-wide modelling rules, either by partitioning (allocation) or through substitution (system expansion).

14.4.1 Models with partitioning

For use in partitioning (allocation), the ecoSpold format allows recommended allocation factors to be separately recorded as properties of the outputs of a multi-output activity. Each multi-output dataset may include information about the recommended allocation factors. This information can be recorded per individual input and output. Each pollutant, each intermediate or resource input may therefore have its individual recommended allocation factor, if necessary.

The ecoinvent software system tests whether 100% of all exchanges of the unallocated activity are attributed to its outputs. This guarantees that no elementary exchanges are lost or counted twice.

The ecoinvent database can be supplied with different models with different partitioning rules applied. These models may use the same allocation property for all multi-output datasets (e.g. price), or may use a combination of allocation properties depending on the nature of the multi-output dataset.

For each partitioned model, as many single-product datasets are created from each multi-product dataset as the dataset have products with the specified allocation property. For each of the single-product datasets, the original inputs and elementary outputs without the allocation property are multiplied by the ratio of the specified allocation property for the product (when multiplied by the amount of the product) relative to the sum of this (multiplied) property for all outputs. This procedure is called co-product “allocation”.

While mass inputs and outputs are balanced for each multi-product activity, the derived single-product datasets are only balanced for the applied allocation property, and only if the partitioning is applied to all outputs. In general, mass balances are therefore not relevant for partitioned system models.

The choice of allocation property depends on the purpose of the analysis. Allocation by revenue (price * product volume) is often applied with the argument that the (expected) revenue is the reason for the activity to operate. On the other hand, since an economically allocated model does not provide a correct mass or elemental balance for a product, it can therefore not be used to say anything about how much mass of a specific material or from a specific activity is part of the studied product. For this purpose, a model allocated by the mass of all outputs is more relevant. However, a mass allocated system model will not include electricity and services, and will therefore have limited relevance for assessing the total environmental impacts of a product.

The inability of system models with economic allocation to correctly reflect the elemental balances has led to the suggestion to add allocation corrections for the most environmentally important elements. An allocation correction for e.g. carbon is an additional dataset with a carbon input or output that is added to one allocated dataset of an activity and subtracted from the other allocated dataset of the same activity to correct the mis-allocation made by the economic allocation. The two allocation correction datasets cancel each other out, and the result is a model that gives correct mass balances for carbon. This exercise can be repeated for any other element. If this were implemented for all elements, the result would be a completely mass allocated model with elemental specification, which would then no longer have any economic rationale.

For a particular application, it may therefore be a question of finding an appropriate balance between these two incompatible rationales of economic causality and balanced mass flows. The ecoinvent database provides one such “compromise” implementation, which uses “true value” (a modified form of revenue) as general allocation property [**Feature considered for implementation later:**, but includes corrections to re-establish the mass balance for carbon. The rationale for this is that for carbon, in contrast to most other elements, the same substance as both input (capture of carbon dioxide from air) and output (carbon dioxide to air) has the same significant environmental impact pathway (change in the atmospheric concentration). For most other elements, the lack of an exact mass balance is a less obvious flaw, since the most significant environmental impact pathways are usually different for the inputs of resources and the emissions to the environment.]

For the partitioning, activities which have a material for treatment as input, i.e. treatment markets, treatment activities and speciality productions, are seen in combination with the activity that supplies the material for treatment. It is this combined system of activities that needs to be allocated, which can also be understood as an allocation at the point of substitution, as illustrated in Figures 14.1 to 14.2.

Thus, activities which have a material for treatment as an input are not allocated separately, and consequently, allocation properties are not relevant for materials for treatment but only for the materials *after* the recycling activity or speciality production; see Figures 14.1 to 14.2.

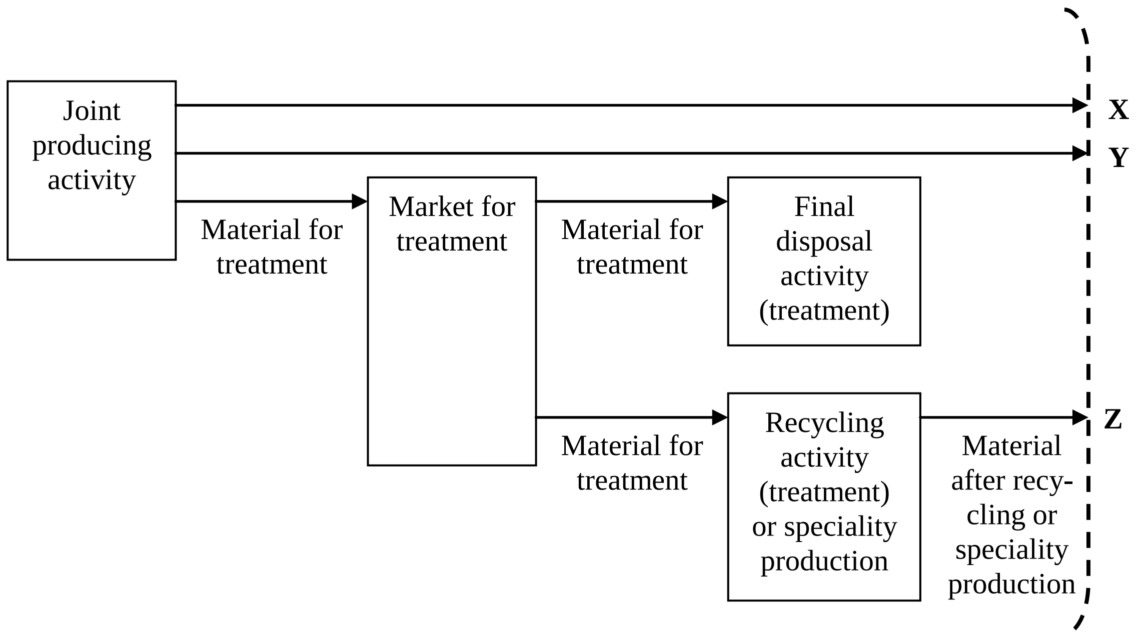
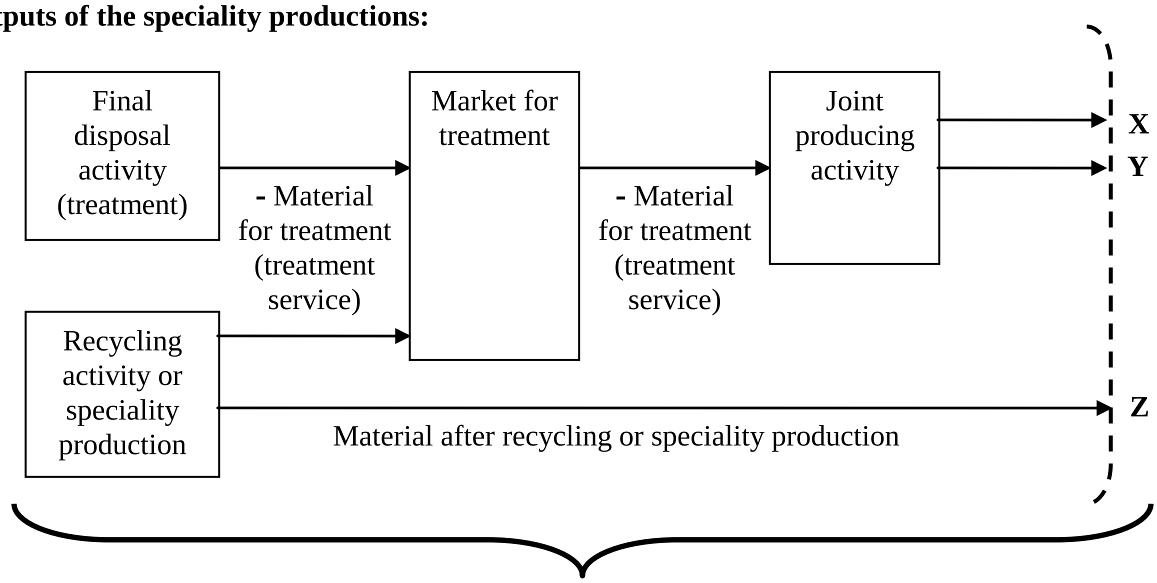
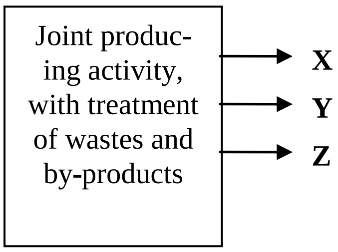


Figure 14.1. A joint production activity with outputs of two products (X and Y) and a material for treatment, with its treatment activities and or speciality productions, of which one has a by-product Z. The dotted line indicates the system boundary at which allocation between X, Y and Z is performed. For the material for recycling, this is also the point of substitution, where the material can – without further treatment - substitute a reference product as an input to an activity.

Database representation after moving materials for treatment cf. Chapter 14.1, and moving inputs of materials for treatment into speciality productions to be negative outputs of the speciality productions:



Before allocation, either:



or:

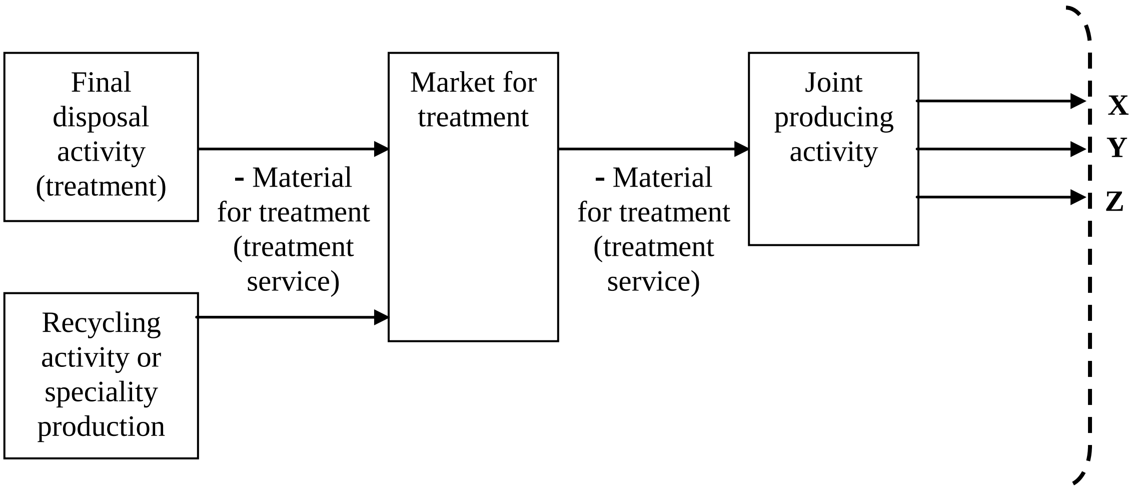


Figure 14.2. Top: The database representation of the system of activities in Figure 14.1 after the moving of materials for treatment to be negative inputs as described in Chapter 14.1, and moving inputs of materials for treatment into speciality productions to be negative outputs of the speciality productions (compare to figure 11.8). Middle: The same activities, aggregated into one activity dataset. Bottom: The same activities, now with the material after recycling or speciality production moved to be an output of the co-producing activity, which is now ready for allocation.

Mathematically, allocation at the point of substitution can be performed either by first creating an aggregated activity dataset including the treatment of wastes and by-products, and then allocating this aggregated activity, or – mathematically equivalent, but simpler and more transparent – by moving the material after treatment to be an output of the activity that supplies the material for treatment, before allocating this activity alone. In the latter approach, the treatment markets, treatment activities and speciality productions are inputs to the activity that supplies the material for treatment, see Figure 14.2, and these inputs are therefore indirectly allocated with the same allocation key as used for the activity that supplies the material for treatment.

By performing the allocation at the point of substitution, it is ensured that all treatment activities are attributed to the activities that produce the materials that need treatment, disregarding whether these are defined as wastes or by-products. The result of the allocation will be the same as if the treatment activities take place within the joint production activity. Thereby it is ensured that the results of the allocation is unaffected by any choices of the degree of detail in modelling the activities, and that a result cannot be manipulated by moving a treatment activity inside or outside the joint production activity.

Performing the allocation at the point of substitution furthermore ensures that the full value of the by-products is attributed to the product system that gives rise to these by-products, and that any value-correction therefore becomes unnecessary. Furthermore, the price of the by-product is always available at the point of substitution, since this is the point at which the product is exchanged and substituted with other products, while the price of a waste or by-product before or during treatment often can only be estimated, because it is not available as a market price, and if available may often be influenced by irrelevant properties of other wastes or by regulatory conditions.

When a treatment activity or speciality production treats materials from many different activities, as e.g. a waste incineration plant that recycles wastes into energy, the recycled product will become an output of each of the systems that supplies the material for treatment. This means that the partitioning will generate as many datasets for the recycled product as there are suppliers of the specific material for treatment.

In real life, the supplier-specific recycled products cannot be distinguished, since the recycled products as inputs to other activities are always obtained as uniform products from the treatment activities or speciality productions. To reduce the number of irrelevant datasets, the database service layer therefore aggregates all partitioned datasets for each recycled product from each treatment activity or speciality production, so that each original output from each treatment activity or speciality production is only represented by one dataset, see the illustration in Figure 14.3.

These aggregated, partitioned datasets for recycled products are given the same activity name as the treatment activity or speciality production that originally produced the recycled product, even though their exchanges will be those of the different datasets that supplied the original material for treatment, and the amounts of these exchanges will depend on the allocation factors of each of these supplying datasets.

The theoretical example in Figure 14.3 begins with the datasets before allocation (row 1&2), in parallel to the bottom representation in Figure 14.2, but now with two joint production datasets with the same material for treatment. To simplify the example, both joint production datasets here have the same amount of by-product output **Z**. The allocation factors in the example are 0.8:0.2 for X:Z and 0.9:0.1 for Y:Z, as can be seen in row 3-6 of Figure 14.3, where each row is multiplied with the respective allocation factor. The aggregation at the bottom of Figure 14.3 aggregates row 4 and 6 into the aggregated result in row 9. Note that row 9 is normalised to the output of one unit of Z. Note also the name change of the aggregated activity, which now takes its name after the original activity that produced the recycled product. The aggregation does not affect rows 3 and 5, which remain unaltered as row 7&8. The aggregation also does not affect the original treatment activity or speciality product, which remains with its own original inputs, reference product and emissions. Only the recycled product is now the output of the new aggregated activity.

[**Feature considered for implementation later:** Feature to view the contribution of each supplying dataset to each exchange in the aggregated, partitioned dataset.]

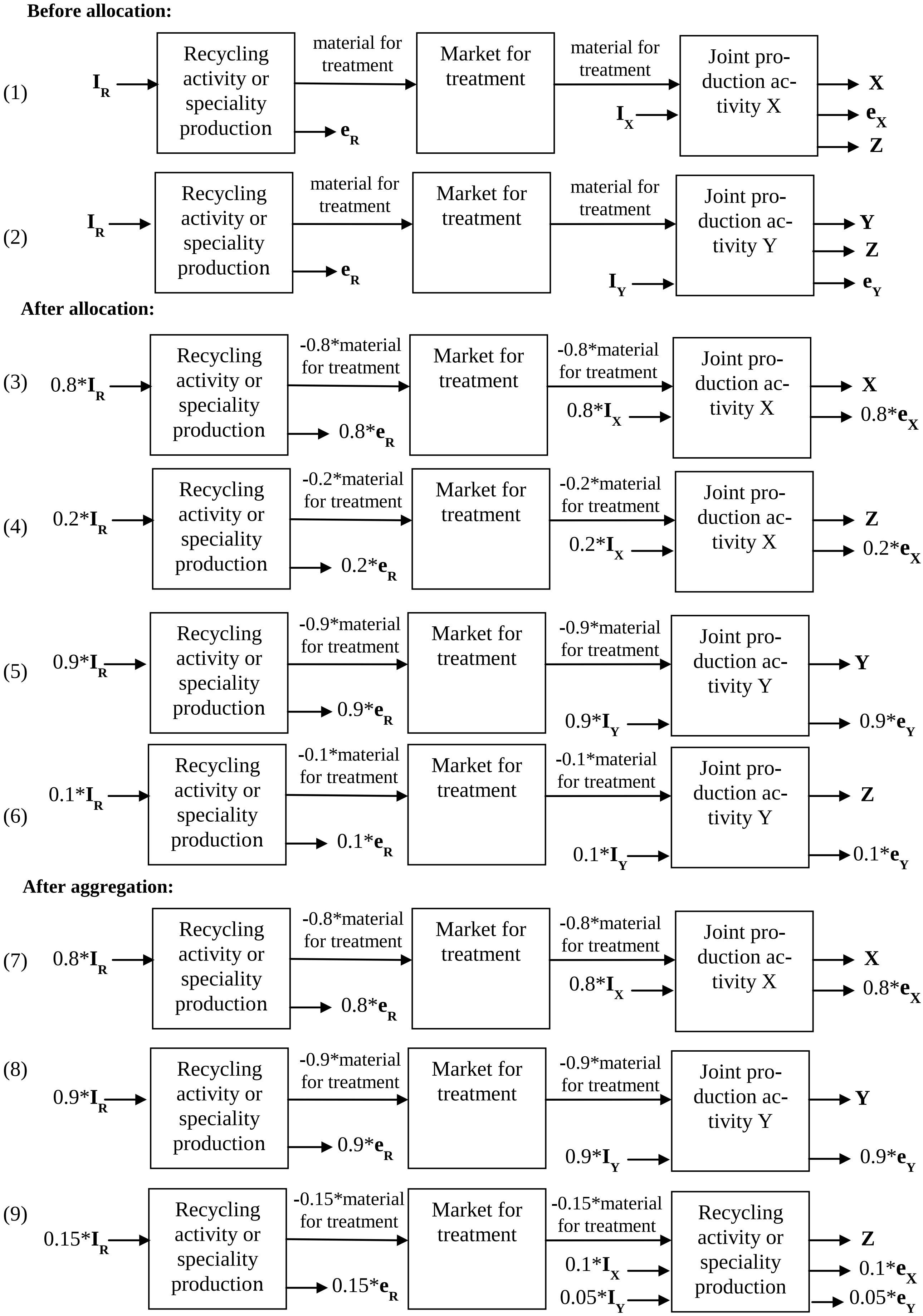


Figure 14.3. Aggregation of partitioned products from recycling. See text on previous page for explanation.

14.4.2 Models with substitution

In the ecoinvent database, the substitution (system expansion) is implemented by moving the non-reference products (also known as dependent co-products or by-products) from being outputs of the multi-product activity to be negative inputs of this activity, see Figure 14.4. This procedure for dealing with multi-product activities was originally presented by Stone (1984) for use in input-output analysis, where it has become known as the *by-product technology model*. For practical purposes the results of the by-product technology model is strictly identical to the more well-known, more widely used, but less transparent *commodity technology model* (Suh et al. 2010).

This operation is performed automatically by the ecoinvent database service layer. Links to the by-product from other activities via activityLinkId will be ignored, which effectively means that the supply is shifted to the market for the by-product (B in Figure 14.4). Note that by-products and wastes for which substitutes are *not* available have already been placed as materials for treatment by the procedure in Chapter 14.1. This implies that for the remaining by-products there will always be an activity that supplies the by-product as its reference product, and which will therefore be displaced when an additional amount of the by-product from the joint production activity is supplied to the market. The database service layer links the negative input to its local market, in the same way as described for all other intermediate inputs in Chapter 14.1.

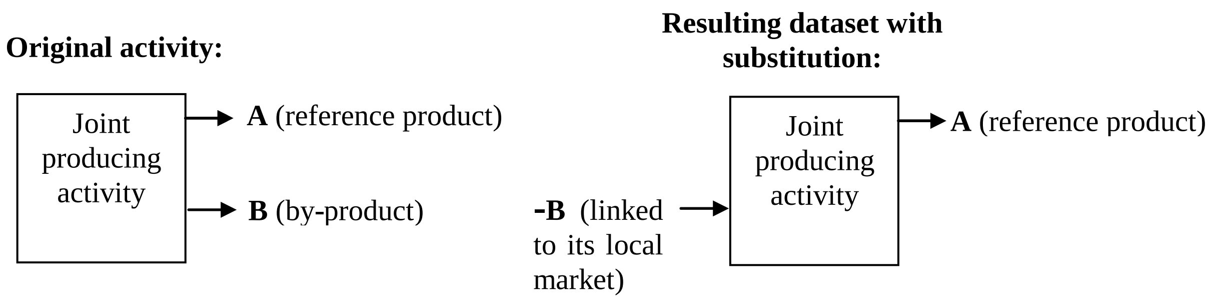


Figure 14.4. Original multi-product activity and the resulting database-generated dataset with substitution.

When there is more than one reference product for an activity, which can happen when there is more than one product output without an alternative production route, the multi-product dataset is duplicated into the same number of activities as there are reference products, since the described procedures are performed for each of the reference products separately, reflecting the consequences of an increased demand for each product separately. The following additional operations are performed to deal with this situation:

First, each new dataset is multiplied by the ratio of the revenue of its reference product relative to the revenue from all products of the multi-product activity. This is equivalent to the result of a revenue partitioning (allocation) of the multi-product activity, and is justified by the necessity for the prices of the joint products (that do not have any relevant alternative production routes) to adjust so that the market is cleared, i.e. so that all the products produced will also be sold. In this situation, a change in demand for one of the joint products will influence the production volume of the joint production in proportion to its share in the revenue of the joint production.

Since the change in the multi-product activity only partly satisfies the demand that gave rise to the change in its output, the missing supply to the market activity must be obtained by a reduction in use of the product in its marginal application (the application that has the least alternative costs from not using the product in question, and is therefore the most sensitive to changes in price). Such reductions in marginal use are therefore added as inputs to the market activities supplied by the multi-product activity to compensate for the missing supply from the multi-product activity.

Since the multi-product activity is not partitioned, but only scaled to the change in demand, it is still a multi-product activity, and the output of the other joint products thus increases proportionally to the induced change in the multi-product activity, and must therefore be dealt with as for the simple situation above. However, since the other reference products have no alternative production route, the additional output cannot displace any other production, and therefore specifically influences their marginal consumption activities and further downstream lifecycles, and thus require the inclusion of these specific activities. This is achieved by linking the negative input of the other reference products directly (with the activityLinkId specified in the original multi-product activity) to the marginal consumption activities.

An example is provided in Figure 14.5 where the multi-product activity has two outputs with the revenue 75 for product A and 25 for product B. For ease of explanation we can assume that the output in mass units follows the revenue. The modelling now distinguishes between the two separate situations of an increase in demand for 100 units of A and an increase in demand for 100 units of B. The following text focuses on the situation of an increase in demand for 100 units of A. The modelling for an increase in demand for 100 units of B follows in complete parallel.

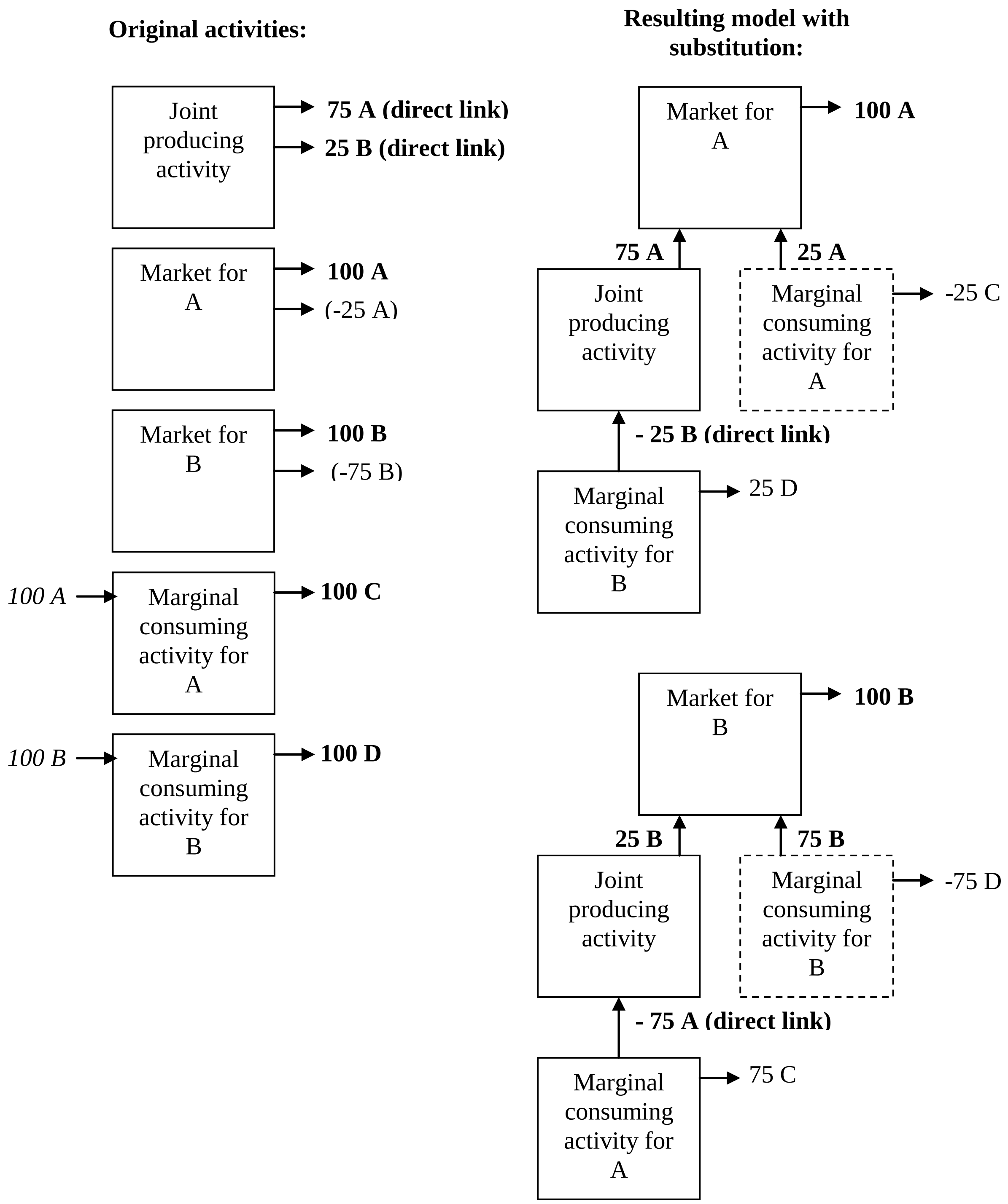


Figure 14.5. A joint production activity with two reference products (A and B), and the resulting substitution model of an additional demand of 100 units of product A and B, respectively. Exchanges in bold are reference products. Exchanges in brackets are conditional market constraints that are not actually part of the original data but are auto-generated by the database. Activities with dotted lines represent activities that are reduced in volume.

The increase in demand for A of 100 units leads to an increase in supply from the multi-product activity of 75 units of A and 25 units of B (the 75 being the percentage of the revenue of A out of the revenue from A+B). Thus, we miss 25 units of A and have 25 units of B too much, compared to the initial demand. The missing 25 units of A are supplied from reduced consumption in its marginal application, while the surplus 25 units of B are additionally consumed in its marginal application. The two consumption adjustments are added to the constrained market for A and to the joint production activity, respectively.

The database service layer automatically performs all the described linking; only the direct activityLinkIds for the reference products and conditional exchanges must be supplied in the original data[10].

The datasets for the joint production activity, each with only one reference product, all have the same activityID as the original joint production dataset, which implies that the name of the reference product is required to distinguish the datasets from each other.

Any implementation of the above-described substitution (system expansion, by-product technology model) can be validated numerically by checking any of the mass, material and/or economic balances, since all of these balances shall be preserved during the transformations. As a positive output equals a negative input, the simple moving of the dependent co-products from positive outputs to negative inputs obviously preserves the balances. Since all the originally balanced unit processes are maintained intact (no partitioning), and simply scaled to accommodate the required change in product output, there is no way these unit processes can become unbalanced, except by error. Since the product system is a simple aggregate of these balanced unit processes, the same applies for the resulting product system. In this context it is important to note that treatment services for wastes, while possibly having a positive economic product flow, the mass of this flow must negative (the mass of the treated waste) to maintain mass balances correct. The same is true for the inputs to the multi-product activities representing changes in downstream activities caused by the other co-products. In general, any corrections made are always balanced by similar counter-corrections, to maintain balances intact.

14.5 Interlinked datasets

The differences between the original, manually generated, stand-alone datasets and the derived, database-generated, interlinked datasets are illustrated in Figure 14.6 and 14.7. Note that Figure 14.6 takes as a starting point the situation where *inputs* of materials for treatment (identified by the database service layer as by-products/wastes that are not positive reference products of any activity in the same geographical area; see Chapter 4.8) to a treatment activity or to a speciality production (see Chapter 4.8) have already been moved to be negative outputs of these activities, so outputs A or C in Figure 14.6 and 14.7 may in this situation already have a negative amount.

The initial operations common to the generation of datasets for all system models are illustrated in this way:

- By-products/wastes that are identified as outputs of materials for treatment (outputs C, D and E in Figure 14.6) are moved to be negative inputs of the same activity, in order to include the treatment activities for the material into the product system. Since a negative input is the same as a positive output, this operation does not affect the mass, energy and monetary balances of the activity. For the system models with partitioning, any outputs of by-products from the treatment activities are moved to the multi-product activity before this activity is partitioned. This is required to ensure an allocation at the point of substitution, as explained in Chapter 14.4.1 and illustrated in Figures 14.1 to 14.2.
- Intermediate inputs to an activity, which do not already have activityLinkIds (inputs G and J in Figure 14.6), are always linked directly to the local markets that supply the inputs as reference products. The database service layer identifies the local market based on the geographical location of the activity, matching this with the available market for this location. This linking algorithm was described in detail in Chapter 14.1.

[10] *Outlook:* This will also be the case for conditional reference products, when this potential feature is applied, see Chapter 11.4.

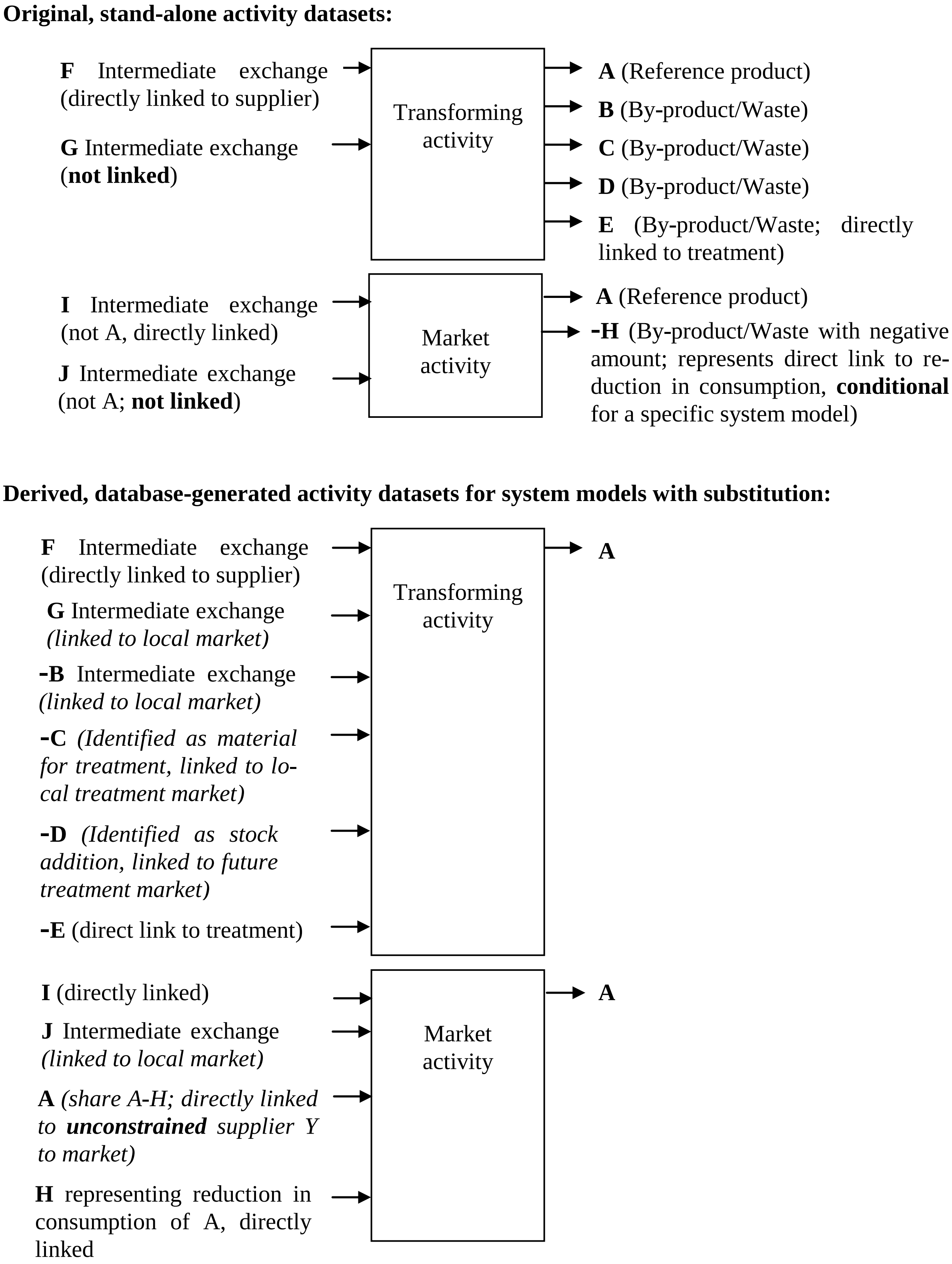


Figure 14.6. The intermediate exchanges in the original, stand-alone transforming and market activity datasets and the database-generated, linked implementations of the same datasets for the system models with substitution. To avoid unnecessary detail, two specific situations are not included: The situation of loss of product from market activities (Chapter 4.3) and the situation with more than one reference product (Chapter 14.4.2, Figure 14.5). Text in *italics* represents database-generated changes, in addition to the moving of some outputs to be inputs with a sign reversal.

Derived, database-generated activity datasets for system models with partitioning:

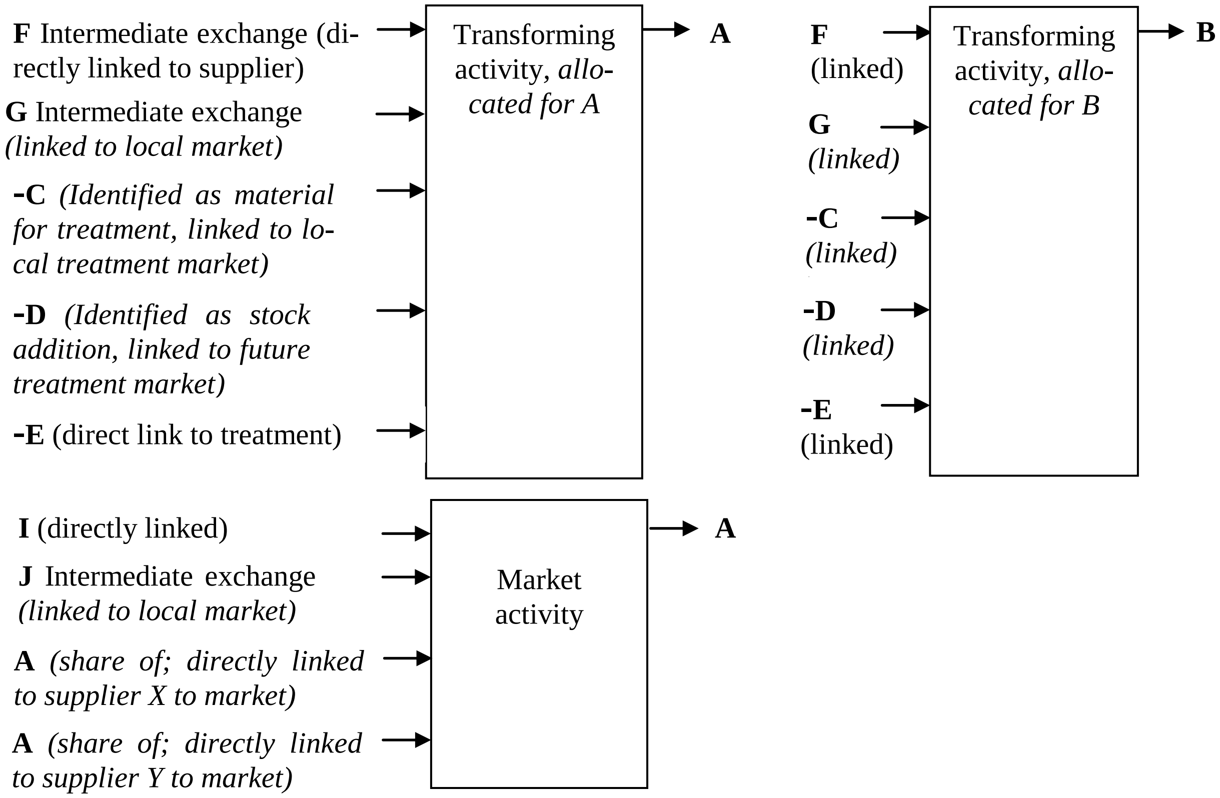


Figure 14.7. The database-generated, linked, allocated implementations, derived from the original, stand-alone transforming and market activity datasets shown in Figure 14.6. To avoid unnecessary detail, the situation of loss of product from market activities (Chapter 4.3) is not included. Also not shown, are any additional by-products from treatment activities, which would imply additional allocated instances of the transforming activity. Text in *italics* represents database-generated changes, in addition to the moving of some outputs to be inputs with a sign reversal.

In system models with substitution, by-products that can immediately – without further treatment – substitute a reference product as an input to an activity (output B in Figure 14.6; identified by the database service layer as a non-reference output which is the reference product of another activity in the same geographical area) are moved to be negative inputs of the same activity and linked to the local markets in the same way as described in the preceding paragraph for any other intermediate input. A negative input implies a reduction in output from the market and therefore a reduction in (displacement of) the other activities that supply the by-product to the market.

In system models with partitioning, a new allocated dataset is generated for each such by-product B (by-product/waste C, D and E are identified as materials for treatment). The allocation procedure is described in Chapter 14.4.1. The cumulative LCI results (see Chapter 4.15) of the multi-product activity (before allocation) are not available as ecoinvent LCI results. The allocated datasets have the same activityID as the original dataset, which implies that the product name is required to distinguish the allocated datasets from each other. For recycled products (by-products from treatment activities and speciality productions), cumulative LCI results are not available for the allocated results before aggregation, but only for the aggregated, partitioned activities. These aggregated, partitioned activities have the same activityID as the original treatment activity or speciality production, which implies that the product name is required to distinguish the allocated datasets from each other.

In the original market activities, the inputs of the reference product (product A in figure 14.6) are not specified. These inputs are added by the database service layer: Based on the geographical area specified for each market activity, the database service layer first identifies the transforming activities that are located within this geographical area. For the system models with linking to average current suppliers, an input to the market is then added for each transforming activity (links to suppliers X and Y in Figure 14.7). For system models with linking to unconstrained suppliers, an input is added only for those transforming activities that are unconstrained (supplier Y in Figure 14.6), which are those for which the product is a reference output (i.e. not a by-product, since the amount of a by-product is per definition constrained by the corresponding reference products), and which has a technology level (see Chapter 5.5) corresponding to the specific rule for the particular system model, see Chapter 14.6. For both types of models, the amounts of inputs are added in proportion to the available production volumes of the transforming activities included.

In system models that take into account constrained markets, any conditional exchanges (negative output -H in Figure 14.6), representing reductions in consumption of the specific market output (see Chapter 11.4), are moved to be positive inputs to the market activity, and are subtracted from the amount of the reference product A before the remaining amount of market output is distributed over the unconstrained suppliers, as described in the preceding paragraph. The market output, which stays the same, is thus balanced by an input represented by that of the conditional exchange and the remainder from any unconstrained suppliers.

[**Changes relative to ecoinvent version 2:** In version 2, all links between activity datasets were hard links, added by the data providers. The new feature of database-generated links allows a more flexible updating of the database, since all links can be automatically updated after the addition of new datasets, and the data provider does not need to consider linking datasets specifically. The modelling of materials for treatment is now more consistent. The option to produce implementations of the database with system models with substitution is new.]

14.6 Models with substitution in the ecoinvent database

14.6.1 The "Substitution, consequential, long-term" model

The 'Substitution, consequential, long-term' model (short name: 'Consequential') is a system model intended to reflect the consequences of small-scale, long-term decisions, by taking into account the constraints that are applicable at this scale and time horizon. The scale and time horizon are relevant because they delimit what suppliers, markets, products and technologies can be affected by the decision, and which should therefore be included in the system model.

A *small-scale* decision is defined as a decision that does not affect the determining parameters of the overall market situation, i.e., the direction of the trend in market volume and the constraints on and production costs of the involved products and technologies. The consequences of the decision can thus be assumed linearly related to the size of the change and both an increase and a decrease in production volume will affect the same processes. As shown by Mattsson et al. (2001), even a change in the annual electricity demand by 1 TWh can still be regarded as small (marginal), since it affects the same technologies as a change of 1 kWh, which means that the effects are linearly related to the size of the change. The typical decisions studied by LCA can therefore be said to be small-scale.

The time horizon of a decision is defined as *long-term* if it affects capital investment (installation of new machinery or phasing out of old machinery) as opposed to short-term decisions that affect only capacity utilisation, but not capacity itself. However, even the effect of small, short-term decision can seldom be limited to the short-term perspective, since each individual short-term purchase decision will contribute to the accumulated trend in the market volume, which is the basis for decisions on capital investment (long term changes). This is obvious in free market situations (where market signals play a major role when planning capacity adjustments) with a short capital cycle (fast turnover of capital equipment, as for example, in the electronics and polymer industries), but it is also true for markets with a long capital cycle (as for example, in the building and paper industries).

If a long-term investment is planned and announced well in advance of its implementation (as for example, the installation of a new pipeline), it may involve only long-term effects, namely the effects from installation and production on newly installed capacity. But such planned decisions are the exception. Most decisions will also lead to some immediate short-term effects, affecting the existing capacity, while at the same time affecting investments decisions and in the long run affecting the production from this newly installed technology. Since the technology affected in the short term will often be old technology (the least competitive technology which typically has a low capacity utilisation compared to newly installed technology) while the technology affected in the long term will often be modern technology, long-term product substitutions may often be seen to affect a mix of technologies (Mattsson et al. 2001). However, the short-term effect will typically be negligible compared to the long-term effect, simply because the long-term effect is typically more permanent, while the short-term effect only lasts until the next capacity change.

Consider a factory in which several production lines exist, some using an older technology, which is more polluting and more expensive to run, and some with a new technology (less polluting, less costly to run). Small, short-term fluctuations in demand will affect the capacity utilisation of the production line with the older technology (since this is the most costly to run), while the line with the new technology will be utilised as much as possible, and will therefore not be affected. If the demand increases beyond what can be covered by the current capacity, new machinery will be installed, and here the factory may choose to install the newest technology even though it is more costly to acquire, or it may decide to buy a cheaper, but more polluting technology. Whatever the choice, this can be said to be the long-term result of the change in demand and the additional environmental exchanges from the factory are now those coming from the newly installed machinery. It is therefore reasonable to ascribe these exchanges to the change in demand. Once the new machinery has been installed, further changes in short-term demand will still affect the older technology (since this is still the most costly to run). It is important to understand that even though the short-term fluctuation constantly will affect the older technology in the short-term, it is the accumulated changes in the short-term demands that make up the long-term changes, which eventually lead to the installation of the new machinery. The long-term effect of the demand is therefore the additional exchanges from the newly installed technology, and the short-term effects can be seen as a mere background variation for this long-term effect. Thus, the long-term effect should also be guiding for decisions that at first sight appear short-term, such as individual purchase decisions, and the product declarations that support such decisions.

The ‘Substitution, consequential, long-term’ model generally assumes full elasticity of supply, just like the models with linking to average current suppliers. This means that if the demand increases with one unit, the producers will react by increasing their supply with one unit, and conversely when the demand decreases. This makes it straightforward to trace the changes in the product system upstream, simply by following the increases in outputs of the upstream activities required to satisfy the increases in demand of the downstream activities.

The assumption of full elasticity of supply is in accordance with the theoretically expected long-term result of a change in demand on a unconstrained, competitive market, where there are no market imperfections and no absolute shortages or obligations with respect to supply of production factors, so that production factors are fully elastic in the long term, and individual suppliers are price-takers (which means that they cannot influence the market price), so that the long-term market prices are determined by the long-term marginal production costs (implying that long-term market prices, as opposed to short-term prices, are *not* affected by demand).

When suppliers are constrained or markets are imperfect (so that producers can influence the market prices), the assumption of full elasticity of supply should be modified.

Because the ‘Substitution, consequential, long-term’ model considers long-term changes, the rule for the technology level of unconstrained suppliers depends on the market trend. If the market is generally increasing, stable, or slowly decreasing (at a rate *less* than the average replacement rate for the capital equipment), new capacity must be installed, typically involving a modern, competitive technology, and any change will affect the decision on this capacity adjustment. In a market that decreases rapidly (at a higher pace than what can be covered by the decrease from regular, planned phasing out of capital equipment) the affected suppliers will typically be the least competitive (often using an older technology).

The replacement rate for production equipment is determined as the inverse of the estimated lifetime of the equipment. For the 'Substitution, consequential, long-term' model of the ecoinvent database, a general lifetime of 30 years and a consequent rate of replacement of 3.33% annually is applied. The market trend is automatically identified by the ecoinvent database service layer using the market datasets with current average suppliers to compare the production volume for the current year with the same dataset covering a period 3 years later. If a dataset covering the period 3 years later does not exist, the following datasets are used for the comparison, in order of priority: 3 years into the past, 4 years into the past, most recent past year, assume stable market without comparing to any other year.

Thus, *when the production volume of the reference product is decreasing more than 3.33% annually, the activity is identified as unconstrained if its technology level is "Old", and when the production volume of the reference product is decreasing less than 3.33% annually, increasing, or stable, the activity is identified as unconstrained if its technology level is "Modern". If there are no supplying activities with the required technology setting, the requirement for "Modern" is replaced by "New", and "Old" is replaced by "Outdated", and if these do not exist, by the option "Current".*

In the ecoinvent database, market constraints are modelled by the use of conditional exchanges, see Chapter 11.4, i.e. exchanges that are only activated for a specified system model, and which represents the share of the demand that is not met by increased supply, but which instead is coming from a reduction in specified consumption activities. In general, the 'Substitution, consequential, long-term' model does not apply empirical elasticities, but only considers absolute constraints, as described in Chapter 11.4.

In the 'Substitution, consequential, long-term' model, a joint production activity can only have *one reference product*, except if there are more products from the activity that have no alternative production routes. This follows from the assumption that suppliers are price-takers (which means that they cannot influence the market price), so that the long-term marginal production costs of the alternative production routes for the respective products provides a constraint on the long-term market prices of the products, and thus on their contribution to the overall revenue of the joint production activity. Thus, a change in demand for a specific joint product with an alternative production route will not lead to a change in its (long-term) price and the change in demand will therefore not affect the overall (long-term) revenue of the joint production activity.

The products that are defined as reference products in the ecoinvent database *before* any system modelling (system model *undefined*) are also the reference products of the 'Substitution, consequential, long-term' model. Only for other consequential system models (not currently implemented, see Chapter 14.6.3) it may be relevant to define additional *conditional* reference products.

The system model 'Substitution, consequential, long-term' corresponds to the model described as applicable for "goal situation B for meso/macro-level decision support" in the ILCD Handbook (EC 2010), and is the one recommended by the ecoinvent Centre for consequential LCA modelling. As argued above, this model is also applicable to study the effect of small, short-term decisions, since each individual short-term decision contributes to the accumulated trend in the market volume, which is the basis for decisions on capital investment.

14.6.2 Substitution, constrained by-products

The 'substitution, constrained by-products' model (short name: 'substitution, ILCD A') is a system model **[Not available at the time of release of version 3.0 of the ecoinvent database]** where the only constraint taken into account is that the volume of a by-product per definition is constrained by the corresponding reference product. Technology constraints are not taken into account. The inputs to each market activity are therefore modelled as the market mix, excluding the by-products. This implies that the inputs are coming from all those transforming activities within the geographical area of the market activity, which have the market product *as a reference product*, in proportion to their available production volume. Constrained markets are only applied for situations of more than one reference product, as described in Chapter 14.4.2, and in case of markets where all inputs are by-products.

Thereby, this system model corresponds to the model described as applicable for “goal situation A for micro-level decision support” in the ILCD Handbook (EC 2010).

14.6.3 Outlook: Other models with substitution

The ecoinvent database does not currently provide other models with substitution than the above described. However, the flexibility of the database structure allows the creation of other such models if desired. Some reflections on other possible models are provided here.

Large-scale decisions affect the overall market situation, and therefore may bring into play new suppliers, new markets, or even new products and technologies. Different large-scale decisions may affect different markets, and it is therefore impossible to provide a generally applicable background database for large-scale decisions. However, the datasets in the ecoinvent database may be modified by the users to model specific large-scale changes, involving changes in market trends etc.

A system model for pure short-term effects of small, short-term changes could be constructed. As the short term per definition does not involve capacity changes, many more production factors would be constrained in such as system model. Only effects within the existing production capacity, including reduction in current capacity would be included, and “old” technology would be the rule for the technology level of unconstrained suppliers, without any relation to the market trend. However, the results of such a model would only be of interest in markets where no capital investment is planned (for example, industries in decline), or where the market situation has little influence on capacity adjustments (monopolised or highly regulated markets, which may also be characterised by surplus capacity). An example of a substitution with a short-term effect only would be an isolated decision to remove heavy metals from the components of a product, which – all other things equal – would not involve capital investment in the metal industry, since heavy metals are already being phased out.

It would also be possible to construct a system model that introduced additional market elasticities via the conditional exchanges, see Chapter 11.4. Thus, the inclusion of more elements from equilibrium modelling would be possible. Research is ongoing at the ecoinvent Centre to investigate these options. Both for such system models and for the modelling of large-scale changes the option to add more conditional reference products is of interest.

14.7 Models with partitioning in the ecoinvent database

14.7.1 Revenue allocation

In the revenue allocated system model, the property "price" is used as allocation property. When multiplied by the amount of the outputs, the resulting values represent the revenues to the activity from each output. When expressed relative to the total revenue, these values are the allocation factors, representing the share of the other exchanges of the activity to be allocated to each output. Figure 14.8 provides an example of an allocation by revenue, with the allocation factors 9 and 1, based on the amounts 1 kg and 0.5 unit, and the prices 9 EUR/kg and 2 EUR/unit, respectively.

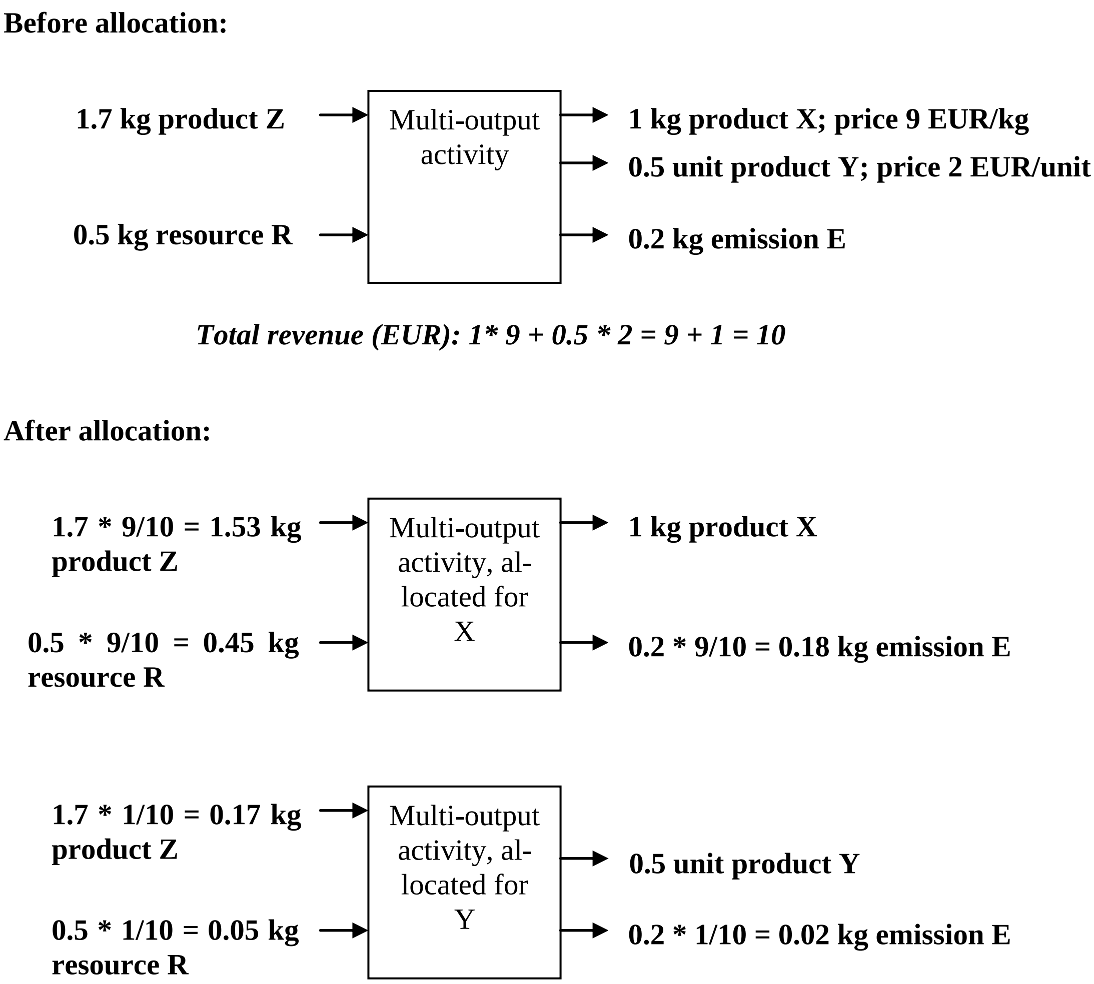


Figure 14.8. Numerical example of an allocation by revenue.

14.7.2 Dry mass allocation (for mass flow analysis; not for LCA)

In the dry mass allocated system model **[Not available at the time of release of version 3.0 of the ecoinvent database]**, the property "dry mass" (DM) is used as allocation property. When multiplied by the amount of the outputs, the resulting values represent the dry mass of each output. When expressed relative to the total dry mass balance of the activity, these values are the allocation factors, representing the share of the other exchanges of the activity to be allocated to each output.

Note that this allocation is performed to all outputs with mass, including exchanges to the environment, in order to achieve a complete allocation that can be applied for mass flow analysis. It is *not* a mass allocation to the products alone, as described in older LCA literature. The model is relevant for investigating the origin of the mass included in a specific product, but not the mass of individual elements. It is not appropriate for investigating the total mass required to produce a specific product. For such an investigation, we recommend the model 'Substitution, consequential, long-term' (Chapter 14.6.1) or the 'Allocation, ecoinvent default' model (14.7.4).

Figure 14.9 provides an example of the dry mass allocation, using the same example as for revenue allocation.

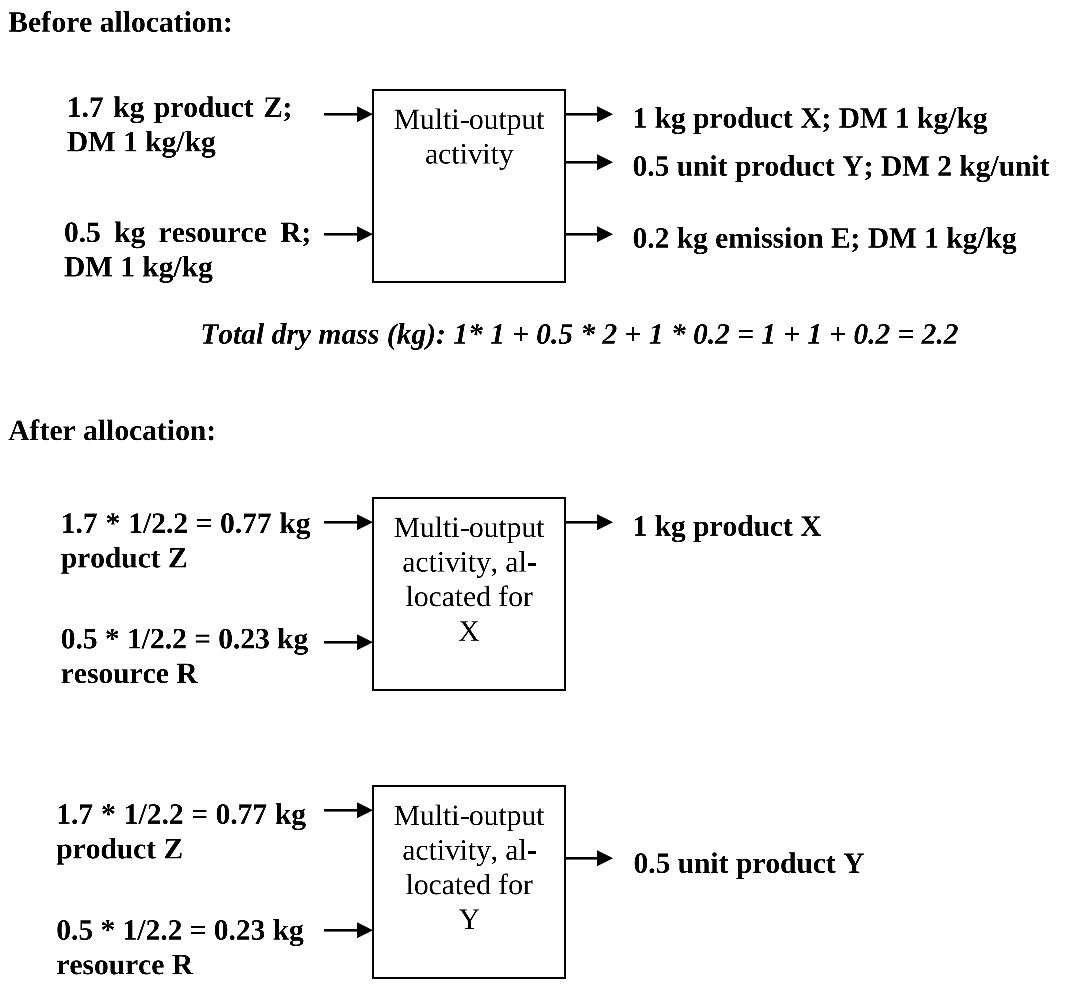


Figure 14.9. Numerical example of an allocation by dry mass. Note that in order to achieve a complete allocation that can be applied for mass flow analysis, allocation is made to all outputs with dry mass. The mass balance is maintained for each activity, also after allocation. Allocation to emission E is not shown in the Figure. This is *not* a mass allocation to be applied for LCA.

It should be noted that in a mass allocated system, no exchanges will be allocated to products without mass, such as electricity and services. In the ecoinvent database, this also affects infrastructure products, since these are modelled as services providing production capacity.

14.7.3 Carbon allocation (not for LCA)

In the carbon allocated system model **[Not available at the time of release of version 3.0 of the ecoinvent database]**, the property "carbon allocation" (C_allocation) is used as allocation property. This property is derived by multiplying the property "dry mass" by the property "carbon content" (C_content), which is carbon per dry mass (itself the sum of the properties "carbon content, non-fossil" and "carbon content, fossil"). When the property "carbon allocation" is multiplied by the amount of the outputs, the resulting values represent the carbon in each output. When expressed relative to the total carbon balance of the activity, these values are the allocation factors representing the share of the other exchanges of the activity to be allocated to each output.

Note that in order to achieve a complete allocation that can be applied for carbon flow analysis, this allocation is performed to all outputs with carbon content, including exchanges to the environment. It is *not* an allocation to be applied for LCA. The model is relevant for investigating the origin of the carbon included in a specific product. It is not appropriate for investigating the total carbon required to produce a specific product. For such an investigation, we recommend the system model 'Substitution, consequential, long-term' (Chapter 14.6.1) or the 'Allocation, ecoinvent default' system model (14.7.4).

Figure 14.10 provides an example of this allocation, using the same example as for revenue and dry mass allocation.

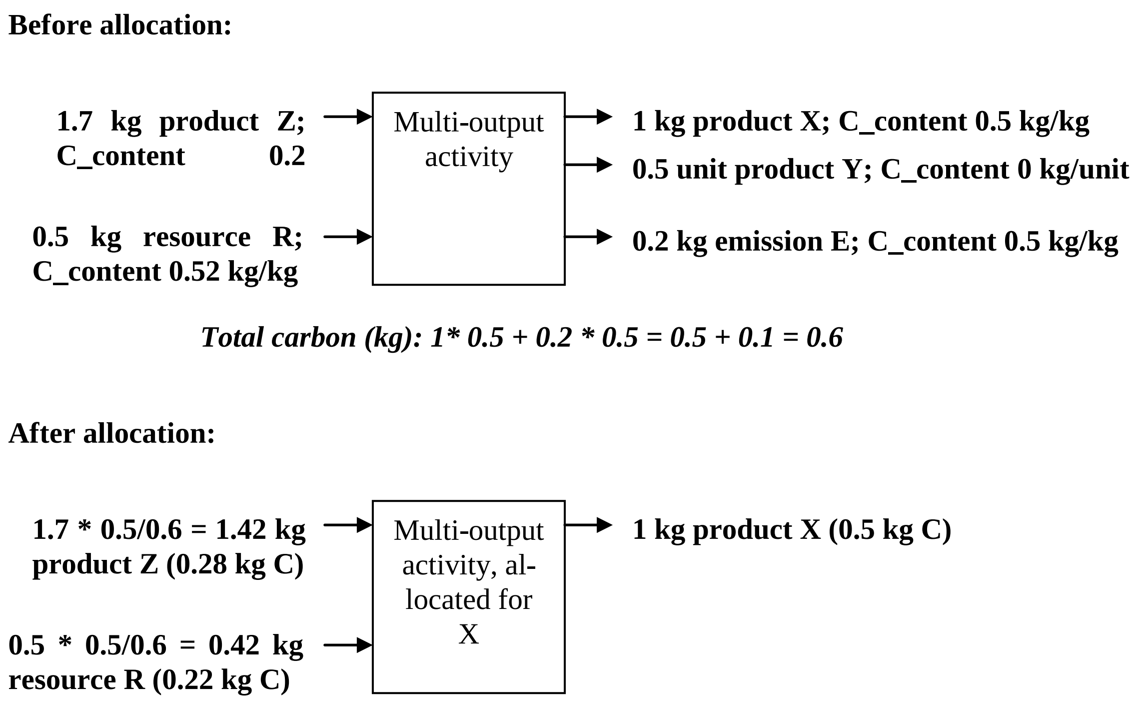


Figure 14.10. Numerical example of an allocation by carbon. Note that in order to achieve a complete allocation that can be applied for carbon flow analysis, allocation is made to all outputs with carbon content, including the emissions. Since only one product had carbon content, there is only one allocated product. The carbon balance is maintained for each activity, also after allocation. Allocation of the 0.1 kg C to emission E is not shown in the Figure. This is *not* an allocation to be applied for LCA.

No exchanges will be allocated to products without carbon content, such as electricity and services, including infrastructure products, see also under mass allocation. Special care must be taken when using these results.

14.7.4 "True value" allocation (ecoinvent default)

The system model with "true value" allocation ('Allocation, ecoinvent default'; short name: 'Allocation, default') is a variant of the revenue allocated system model, introduced to correct for some problems identified in the latter approach.

One problem in revenue allocation is that prices may be influenced by market imperfections or regulation that distorts markets, resulting in relative prices that have very little to do with the true, functional value of the products. An example of this is the price of heat as a joint product from electricity production. Here, it is possible to argue that exergy, i.e. the ability of the products to perform work, is a shared property of the two products that reflects the true, functional value of the products, and that in a perfect market this would be reflected in the price of the products.

Another problem in revenue allocation is that applying average prices for one single year may result in a very high annual variation in the allocation factors for some multi-product datasets. To correct for this, the ecoinvent default allocation instead applies three-year, historical average prices in such situations.

In the ecoinvent default allocation, the allocation property is identical to the price, unless the property "true value relation" (true_value_relation) is specifically provided in the original dataset (the dataset with system model *undefined*). See Chapter 5.6.6 for examples of situations where the "true value" has been applied. One important example is the use of exergy to allocate between electricity and useful heat.

When the property "true value relation" (true_value_relation) is specifically provided, the "*true value"* of the output is calculated as the "true value relation" property * amount * sum of revenues for all products, divided by the sum of "true value relation" property * amount for all products. In this way, the total "true value" of an activity (i.e. the "true value" summed over all products) is always identical to the total revenue of the activity (price * amount, summed over all products). Thus, the "true value" allocation only re-distributes the overall revenue, but does not change it.

When expressed relative to the total revenue, the "true values" are the allocation factors, representing the share of the other exchanges of the activity to be allocated to each output.

[**Feature considered for implementation later:** The system model 'allocation, ecoinvent default' includes also corrections of carbon balances (see next sub-Chapter).]

The system model 'allocation, ecoinvent default' is the system model recommended by the ecoinvent Centre for attributional LCA modelling. It is intended as a consistent implementation of the approach used for ecoinvent versions 1 and 2.

14.7.5 Allocation corrections

An allocation correction is two datasets that counterbalance each other, re-allocating one or more environmental exchanges, so that the resulting allocated product systems have correct mass balances for the re-allocated exchanges.

[**Feature considered for implementation later:** Allocation corrections are currently only considered for the system model 'Allocation, ecoinvent default', and for one exchange only, namely "carbon dioxide, from air". The rationale for applying the corrections to carbon only is that for carbon, in contrast to most other elements, the same substance as both input (capture of carbon dioxide from air) and output (carbon dioxide to air) has the same significant environmental impact pathway (change in the atmospheric concentration).] Figure 14.11 illustrates how the allocation correction for carbon works on the example from Figure 14.8 and 14.10.

All allocation corrections are added automatically by the database service layer.

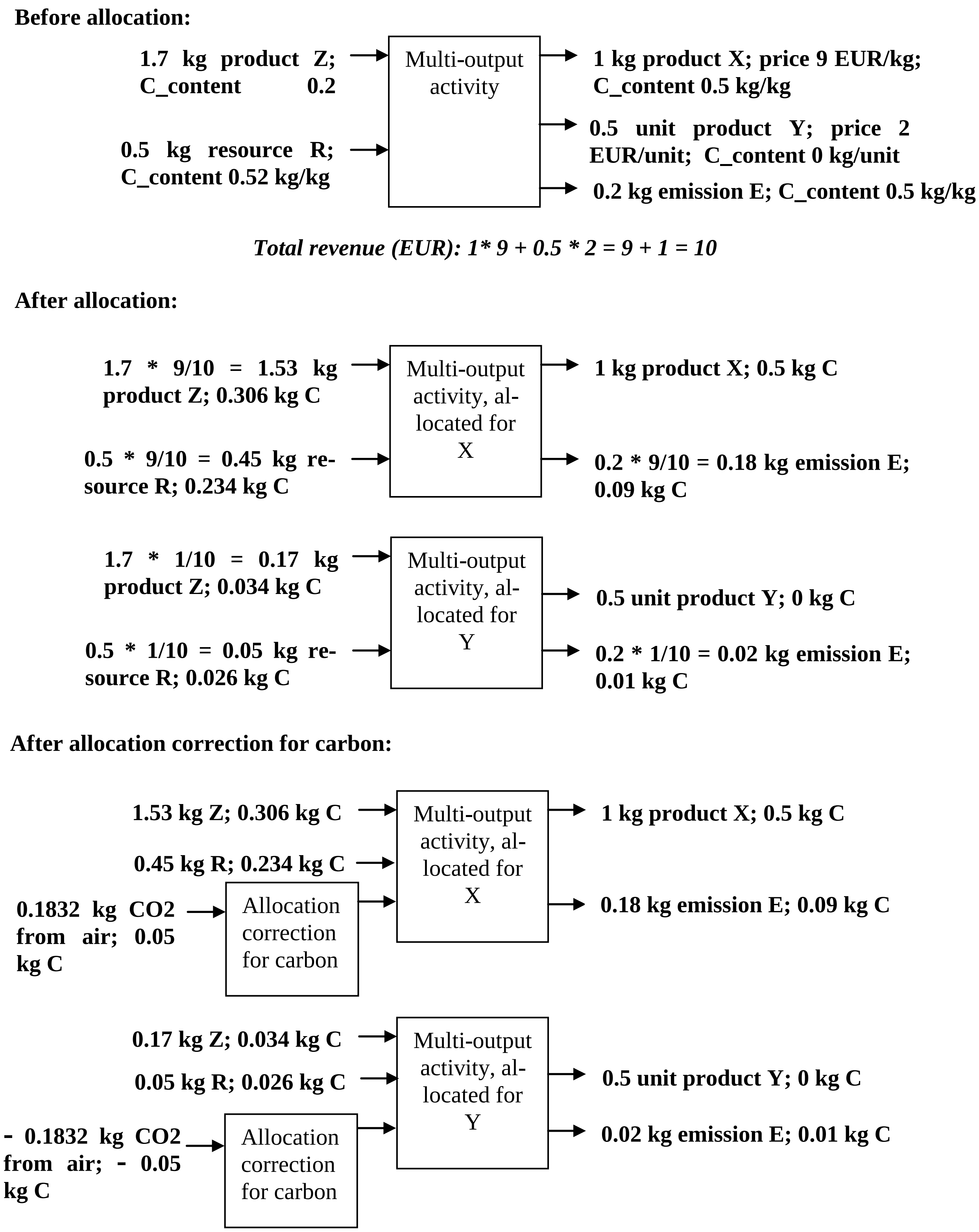


Figure 14.11. The numerical example of an allocation by revenue from Figure 14.8, with the carbon contents from Figure 14.10. After allocation, the activity allocated for X misses an input of 0.05 kg of C, while the activity allocated for Y has a surplus input of 0.05 kg of C. The allocation correction datasets remove the surplus input from the activity allocated for Y and add it to the activity allocated for X, so that both allocated activities balance for both revenue and carbon.

14.7.6 Outlook: Other models with partitioning

The ecoinvent database currently only provides partitioned models with average current suppliers. It is possible to generate partitioned models with e.g. average modern suppliers or using rules for excluding specific constrained suppliers, while still maintaining allocation as the procedure for dealing with joint production.

A system model with 100% allocation to the reference product is currently considered for implementation, since comparing this to the system models with substitution would allow to identify and quantify the accumulated effect of the substitutions.

Since allocation is by definition a normative exercise, the number of thinkable allocation properties and allocation corrections is unlimited. The ecoinvent Centre can provide specific system model implementations on demand.

14.8 Computing of LCI results

The ecoinvent database system uses matrix inversion to calculate accumulated system datasets (LCI results), separately for each combination of time period, macro-economic scenario and system model for which datasets are present in the database. Calculations are only made for full calendar years or a number of calendar years. Calculations are made for the current year and any full calendar year thereafter for which both start date (01-01) and end date (12-31) are present in any dataset. Beyond the years for which individual calculations are made, calculations are also made for longer time periods of calendar years for which the start date (01-01) and end date (12-31) are present in a dataset. Calculations for historical time periods, i.e. prior to the current year, are only performed on demand. For the basic database result presentation, only the calculation results for the current year are displayed, using the most recent data available for each activity and geography.

The calculation of the cumulative LCI results uses only the linked, single-product datasets derived from the unlinked, multi-product datasets, as described above.

A dataset for an activity can be represented using vector notation. A dataset vector consists of an upper part which specifies the links to other activity datasets (intermediate input to the activity per unit of output of the activity, see **a** in the vector below) and a lower part which specifies the elementary exchanges per unit of output of the activity, see **b** in the vector below. The vector includes *m* intermediate exchanges a_i (inputs of products supplied by other activities) and *n* elementary exchanges b_j (resources, emissions, and other inventory entries).

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

All datasets in the ecoinvent database can be arranged so that each activity is represented by a column in a matrix. Each row in the upper part of the matrix (the **a** part of each vector) then represents the intermediate inputs per unit of output of each activity, and the lower part of the matrix (the **b** part of each vector) represents the elementary exchanges per unit of output of the activities.

All activity column vectors together form a matrix with a square intermediate transaction part **A** and an elementary part **B**. The matrix includes *m* columns (*l*), i.e. one column per activity whereas the number of activities is the same as the number of products (*m* intermediate exchanges).

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

Since all the datasets are directly linked, and all datasets have only one product output, the intermediate transaction part **A** of the matrix above is square. The inverse of the matrix can therefore be calculated to provide the matrix of cumulative demand **C** of the intermediate products required to produce each product:

$$\mathbf{C} = (\mathbf{I} - \mathbf{A})^{-1}$$

C includes *m* rows and *m* columns. Each column in **C** represents the cumulative demand of intermediate products (rows) per unit of supply of the activity.

The matrix of cumulative elementary exchanges **D** for each product is calculated as

$$\mathbf{D} = \mathbf{B}(\mathbf{I} - \mathbf{A})^{-1}$$

D includes *n* rows (each row represents an elementary exchange) and *m* columns. Each column in **D** represents the cumulative elementary exchanges per unit of supply of the activity.

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 **A** 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.

Nevertheless, computational capacity may make it necessary to place certain restrictions on the number of datasets included in the matrix calculations. If such restrictions on the matrix size become necessary, the limitations will be applied to the geographical detail. First, transforming activities that supply to the same market will be pre-aggregated before matrix calculation, and secondly markets may be pre-aggregated, starting with products that have many small geographical markets.

15 User advice on the results

15.1 LCI, LCIA and LCA results

The ecoinvent database does not aim at providing full LCA information (i.e., including a complete goal and scope, and interpretation phase) of all investigated products. In general the discussion of results is kept quite short or even missing.

The ecoinvent database also contains life cycle impact assessment (LCIA) results to facilitate the interpretation of LCI results. Assumptions and interpretations were necessary to match current LCIA methods with the ecoinvent inventory results. They are described in Frischknecht *et al.* (2007a). It is strongly advised to read the respective chapters of the implementation report and the original reports describing the LCIA methods before applying LCIA results. Impact assessment results are reported on the basis of a final indicator (e.g. “eco-indicator 99, hierarchist/average, total”) as well as on the basis of safeguard subjects (e.g. “human health”) and environmental topics (e.g. “ionising radiation”).

The data collected and compiled in the ecoinvent database are not primarily suited for direct comparisons. Waste management datasets for instance shall not directly be used for waste management policy assessments (landfilling versus incineration), transport service datasets shall not directly be used for transport systems comparison and farming systems (integrated, extensive or organic production) shall not directly and solely be compared based on ecoinvent data. In all cases the systems for comparison have to be thoroughly defined beforehand. Then it has to be checked which adaptation to the average data investigated would be necessary to appropriately describe these systems according to the goals of the study.

15.2 Legal disclaimer

The ecoinvent Centre shall not be liable for any material defects/damages, including consequential damages, loss of income, business or profit, special, indirect or incidental damages due to the use of ecoinvent database or any ecoinvent dataset. The ecoinvent Centre disclaims all warranties, expressed or implied, including, but without limitation, the warranties of merchantability and of fitness for any purpose of ecoinvent Database or any ecoinvent Dataset. The database user must assume the entire risk of using the ecoinvent database or any ecoinvent dataset.

15.3 Choice of system model

The ecoinvent data are available in different implementations representing different system models.

The original stand-alone activity datasets, each representing a specific human activity as it can be observed “in real life”, are represented by the system model:

- *Undefined*

These are the unlinked, multi-product activity datasets that form the basis for all the other system models. This is the way the datasets are obtained and entered by the data providers. These activity datasets are useful for investigating the environmental impacts of a specific activity (gate-to-gate), without regard to its upstream or downstream impacts.

When the activity datasets are linked into product systems, a choice of a system model has to be made, providing the rules for linking the activity datasets into contiguous product systems, each one isolated from the datasets of all other product systems.

Two classes of system models can be distinguished: System models with substitution (system expansion) and system models with partitioning (allocation). Within each of these two classes, several instances can be defined.

For use in consequential LCA studies that investigates the long-term consequences (i.e. the consequences including changes in production capacity) of small-scale decisions (i.e. decisions that do not change the overall market conditions), the ecoinvent Centre recommends the system model:

Substitution, consequential, long-term (short name: 'Consequential')

This use situation corresponds to the one described as "goal situation B for meso/macro-level decision support" in the ILCD Handbook (EC 2010), as long as this is restricted to small-scale decisions, not affecting the market trends. This system model uses substitution (also known as 'system expansion') to substitute by-product outputs. It includes only activities to the extent that they are expected to change in the long-term as a consequence of small-scale changes in demand, taking into account both constrained markets and technology constraints.

Consequential system modelling can be defined as a linking of activities in a product system so that activities are included in the product system to the extent that they are expected to change as a consequence of a change in demand for the product. Most LCA studies are aimed at decision support involving a choice or substitution between two product systems. Even studies of a single product are typically later used in a comparative context. For example, in LCA studies for hot-spot-identification and product declarations, what appears to be stand-alone assessments of single products have the ultimate goal to improve the studied systems, thus supporting decisions that involve comparisons:

If a hot-spot-identification of a current product identifies a number of improvement options, it is still necessary to assess the environmental impact of implementing the improvements, namely the difference in impact between the improved and the current product, obtained as a result of adding the improved product and removing the current product.

Product declarations are used by the customer to make a choice between several products, and the (intended) effect of this choice is that more of the chosen product will be produced at the expense of the competing products. Thus, the impact of the choice is obtained as a result of adding one unit of the chosen product and removing the corresponding amount of the current average product.

However, there are application areas where consequential modelling is less relevant, and an attributional model may be more appropriate. For these applications, the ecoinvent Centre recommends the system model:

Allocation, ecoinvent default (short name: 'Allocation, default')

This system model subdivides multi-product activities by allocating all flows relative to their 'true value', which is the economic revenue corrected for some market imperfections and fluctuations. It includes activities in proportion to their current production volume. [**Feature considered for implementation later:** This system model also applies corrections to maintain mass balances for carbon, while other mass and monetary balances are not corrected for.]

Examples of application areas are:

- Studies at a societal level, where the entire environmental impact of all human activities is studied, with the aim of identifying areas for improvement, disregarding whether such improvements shall be sought through product-oriented policies or through direct regulation of the individual activities. In such a situation, it would not be reasonable to limit the study to those activities that can be affected by changes in demands, but to include all activities, also those that are not linked to any consequential product system, and for which a policy-driven improvement can only be achieved through direct regulation. One can argue that since the objective of such a study is not product-oriented, LCA is simply not the (only) relevant assessment technique. An attributional model, where all activities in society are included in proportion to a specific attributional rule, such as "true value", would better reflect the objective of such a study. Once improvement options are identified by such a model, those improvement options that have upstream or downstream consequences can then afterwards be studied with a consequential model. The IMPRO study on meat and dairy products (Weidema et al. 2008) is an example of such an attributional study at the level of EU-27, where the identified improvement options were analysed with a consequential model.

- Studies on environmental taxation, where the focus is less on the consequences of the tax, but rather on who is to carry the burden. Often, studies on taxes or quota systems are performed for a specific administrative area, and any consequences outside this administrative area are discounted. Although the consequences of a tax on a product or an activity can be studied by a consequential model, this model cannot say anything about the attribution of the tax and its fairness. An attributional model, where all activities in society are included in proportion to their perceived contribution to the taxed activity variable, whether or not this changes as a consequence of the tax, would better reflect the objective of such a study.
- Studies that seek to avoid blame or to praise or reward for past good behaviour, for example avoiding blame that a specific controversial activity, such as nuclear power, occurs in the product system, or rewarding producers that have invested in a praiseworthy technology such as solar power. While a consequential model can answer the question whether the controversial or praiseworthy activity changes as a consequence of buying the product, it cannot tell how much of the controversial or praiseworthy activity *exist* in the product system. An attributional model, where activities are included in proportion to a specific attributional rule, for example "true value", would better reflect the objectives of such studies.

Outlook: In addition to the above database implementations recommended respectively for consequential and attributional LCA studies, the ecoinvent database will also be available in separate implementations for very specific application areas:

Substitution, constrained by-products (short name: 'Substitution, ILCD A')

This implementation is specifically provided for users that need to fulfil the requirements of the ILCD Handbook (EC 2010) for the "goal situation A for micro-level decision support". It consistently applies substitution (system expansion) for by-products, but substitutes with the market mix, excluding the substituted by-products.

Allocation by revenue (short name: 'Allocation, revenue')

This system model includes activities in proportion to their current production volume and subdivides multi-product activities by allocating all flows relative to the revenue generated by the outputs, using annual prices as basis. The allocations may therefore fluctuate more than in the 'ecoinvent default' implementation where "true value" is used. However, this is the same modelling principle as applied in many input-output analyses, and this system model is therefore the most appropriate implementation to compare with national direct requirement tables ("input-output" tables) using the industry-technology model, and for creation of corresponding hybrid models.

Allocation by dry mass (short name: 'Allocation, dry mass')

This system model subdivides multi-product activities by allocating all flows relative to the dry mass of the outputs. It includes activities in proportion to their current production volume. This implementation is applicable for mass flow analysis, since the dry mass balances are preserved, including the mass leaving the product systems as emissions. This model can therefore be used to investigate exactly how much of a specific mass input is contained in any product. It is *not* a mass allocation to the products alone, as described in older LCA literature, and should *not* be used for Life Cycle Assessments.

Allocation by carbon (short name: 'Allocation, carbon)

This system model subdivides multi-product activities by allocating all flows relative to the carbon content of the outputs. It includes activities in proportion to their current production volume. It is intended for carbon tracing along supply chains, since the carbon balances are preserved, including the carbon leaving the product systems as emissions. This model can be used to investigate exactly how much of a specific carbon input is contained in any product. It is *not* an allocation to be applied for LCA.

15.4 Uncertainty information

[**Feature considered for implementation later:** Resuming the display of uncertainty information for the accumulated LCI results.]

The ecoinvent inventory result files contain quantitative and qualitative information about the uncertainty of each individual elementary exchange. In many cases a simplified pedigree approach has been used.

Uncertainty information is valuable to judge the overall variability of LCI results. Care must be taken when using the uncertainty values in comparative assertions on the basis of LCI results because most underlying uncertainty values are estimated.

The uncertainty values presented in the cumulative LCI results should not be used directly for LCA case studies, since the uncertainty values of the individual exchanges and datasets are not independent. For a correct uncertainty assessment for the modelled LCA case study, the uncertainty information on a unit process level is required. A simulation (e.g. Monte Carlo) based on the case study's LCI raw data is required to correctly assess the uncertainty in the LCI results. Some of the commercially available LCA software are able to perform such project-specific simulations.

The minimum and maximum values of elementary exchanges reported in the LCI results of the ecoinvent database shall not be added to total emissions into a compartment because the sum of all minimum and maximum values, respectively, does not correspond to the minimum and maximum values determined with a Monte Carlo simulation.

15.5 How to reproduce and quote ecoinvent data in case studies

The ecoinvent terms of use state that:

"Licensee is not entitled to use the ecoinvent Database or the ecoinvent Dataset by preparing extracts, or for any further commercial purposes.

Licensee is not entitled to reproduce, disseminate or publicly display any significant portions of the ecoinvent Database or the ecoinvent Datasets.

Licensee is not entitled to sell, rent, lease, loan, distribute, export, import, act as an intermediary or provider, or grant any kind of licence rights to third parties with regard to the ecoinvent Database, the ecoinvent Dataset or any portions thereof.

Licensee is not entitled to undertake, cause, permit or authorize the modification, creation of derivative works, translation, reverse engineering, decompiling, disassembling or hacking of the ecoinvent Database the ecoinvent Dataset or any part thereof except to the extent permitted by law."

It means that ecoinvent LCI raw data and results and LCIA results (either directly downloaded from the ecoinvent database or calculated with ecoinvent LCI results and the factors downloaded from the ecoinvent database) shall not be reproduced in other LCA case studies. Contribution analyses may include graphical representation of the share of ecoinvent activities on the total LCA results (e.g., the contribution of energy supply to the total burdens of manufacturing a mobile phone). Hereby the possibilities to recalculate the exact LCI and LCIA results of an ecoinvent dataset shall be prevented as much as possible.

The ecoinvent data shall generally be quoted by including the exact version number and system model of the database applied. Additional reference may be made to the respective location of the datasets if specific datasets have been used. If the ecoinvent database and its contents are cited as a whole the following format is recommended:

ecoinvent Centre 2013	ecoinvent Centre (2013) ecoinvent data v3.0. Swiss Centre for Life Cycle Inventories, St. Gallen, retrieved from: www.ecoinvent.org.

16 Contributing to the ecoinvent database

16.1 Individual data providers

Anyone can contribute to the ecoinvent database. To supply new data or to make larger changes to existing datasets, prospective data providers should download (from www.ecoinvent.org) the ecoEditor software that supports the editing process.

The dataset(s) that you wish to edit can be downloaded to your harddisk from the production version of the ecoinvent database. From the dataset it can be seen if the dataset has an active author assigned, see Chapter 16.3. If you intend to edit or update an existing dataset with an active author, it may be a good idea to inform the active author of your intentions/suggestions, e.g. by using the dataset talk page, see Chapter 16.4.

Once you have finished editing your dataset(s), you can upload it/them for pre-validation and/or for review directly from the ecoEditor, when on-line.

Outlook: If you have restrictions on allowing the ecoEditor on-line access (e.g. a firewall), it is considered that you may submit your dataset(s) via the ecoinvent web-site, using your web-browser. This feature has not yet been implemented.

When submitting a dataset, the data provider confirms ownership to the data, and transfers the right to use to the ecoinvent Centre.

We particularly encourage LCA practitioners to share their data though the ecoinvent database. The new data collected for a specific LCA could very well be useful for others. An added benefit is that both you and others will be able to reuse the supplied data in other contexts, fully embedded in the richness of the ecoinvent database.

We also encourage industry associations, individual enterprises and public and private organisations to provide data for their own activities. For larger data collection projects, the ecoinvent Centre offers support for planning and fundraising.

16.2 National data collection initiatives

The ecoinvent Centre cooperates with national data collection initiatives (NDIs) to provide national versions of the ecoinvent database, fully integrated with the rest of the World.

The ecoinvent Centre provides free of charge the necessary infrastructure for validation and publishing of the national data as part of the ecoinvent database. The ecoinvent Centre provides an in-kind payment of free ecoinvent licenses to all active in the NDIs, and supports the NDIs with annual financial contributions.

The NDI proposes one or more editors to be responsible for reviewing datasets for geographical consistency before uploading to the ecoinvent database, irrespective of whether the datasets result from the national data collection programme or is provided by a third party. The ecoinvent Centre has the final responsibility for appointing and supervising editors. Editors are paid directly by the ecoinvent Centre in accordance with the ecoinvent procedures for such payments.

The NDI retains copyright and the right to license the collected data to third parties, while providing the collected data for publication in the ecoinvent database. Data provided to the ecoinvent Centre are provided with the permission to the ecoinvent Centre to publish these data.

16.3 Active and passive authorship

The ecoinvent Centre regards data providers as authors of the supplied datasets. Thus, editors cannot make corrections to the datasets, but only comment back to the data provider, asking the data provider to make corrections. This is also the case after publication of the dataset, if the editor or a third party discovers an error in a dataset, or suggests improvements.

When submitting a dataset, the data provider (author) chooses to be either an *active author,* i.e. responsible for future modifications of the dataset, or a *passive author*, i.e. recognised as author of the submitted version, but not involved in any further maintenance or modifications of the dataset.

If a dataset has an active author, prospective data providers are recommend to submit comments to the active author via the discussion boards on the Editor's pages before submitting changes or updates as full datasets.

Active authors are automatically informed when there are news on the talk page related to the dataset and if another data provider submits a modified version of the dataset. In the latter situation, the active author is given 14 days to comment on the suggested modifications, and to indicate whether she/he wishes to maintain authorship of the dataset, before the dataset is passed on to the activity editor. Failure to react is interpreted as acceptance that authorship and responsibility for the modified dataset is transferred to the modifying data provider. The original author is informed of this, and has the option to resume responsibility as long as the modified dataset is not yet published. This does of course not affect the authorship of the original, unmodified dataset, which remains accessible in the older versions of the database.

An author can always decide to withdraw from this active role, in which case the responsibility for responding to questions and suggestions for modifications of the dataset lies exclusively with the editor. If modifications are to be made in a dataset where the author has withdrawn from active participation, the person who modifies the dataset becomes the author of the new modified dataset. Appropriate credits to the previous author(s) are included in the new dataset.

An author of a dataset cannot at any time be editor for the same dataset. Instead, a co-editor will be the editor for this dataset. This applies to the situation where an editor contributes datasets within his own editorial area, and also when an editor is forced to make corrections to a dataset for which the active author has withdrawn. In the latter situation, the editor may ask another author to make the required changes and remain as editor, or – when this is not possible or appropriate – perform the changes and thus resign as editor for this particular dataset.

In the situation that an active author refuses to make changes that are seen by the editor as essential for the scientific validity of a dataset, the editor may allow a new version of the dataset with another author. As always, the old dataset remains in the old version of the database. Such cases, where an editor suggests dismissing an active author, will always be handled by the ecoinvent database management, which will express its view on the matter. Both the editor and the author will also have the possibility to consult the ecoinvent database management before the decision is made to transfer the responsibility to a new author.

16.4 Reporting errors / suggesting improvements

If you discover an error in an ecoinvent dataset, or wish to suggest an improvement, but are not interested in supplying the corrected or improved dataset yourself, you may submit your observations via the ecoinvent discussion boards for the dataset in question on the Editor's pages at www.ecoinvent.org. The ecoinvent discussion boards on the Editor's pages are also open for placing questions, which may be answered by the authors, the editors or any other interested party.

Active authors and the editor of an ecoinvent talk page are responsible for ensuring a response to reported errors, suggestions and questions within a reasonable time (typically 14 days).

Discovered errors will be corrected in a next intermediate version of the database. Until then, known errors are reported on the ecoinvent web-site, both on the relevant talk page and in the aggregated "Known errors" page.

17 History of the ecoinvent database

17.1 The origin

Up to the late nineties, several public Life Cycle Assessment (LCA) databases existed in Switzerland, partly covering the same economic sectors (Frischknecht et al. 1994, 1996; Gaillard et al. 1997; Habersatter et al. 1996, 1998; Künniger & Richter 1995). These databases were developed by different institutes and organisations. Life cycle inventory data for a particular material or activity available from these databases often did not coincide and therefore the outcome of an LCA were (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 received more and more attention by industry and authorities as one important tool for e.g., Integrated Product Policy, Technology Assessment, or Design for the Environment. In parallel with this increasing trend in LCA applications, the demand for high quality, reliable, transparent, independent and consistent LCA data increased as well.

17.2 ecoinvent data v1.01 to v1.3

The first steps for the ecoinvent project were taken during the late 1990ties. 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.

After the successful launch of ecoinvent data v1.01 in 2003, the work concentrated on an extension and revision of the contents resulting in the release of version 2.0 in 2007.

17.3 ecoinvent data v2.0 to 2.2

The 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.

By 2007, the ecoinvent database had become 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.

In 2008, the management of the ecoinvent Centre was taken over by Bo Weidema, with Roland Hischier as deputy manager, and the planning of version 3 was initiated, while at the same time publishing additional data and corrections in the versions 2.1 and 2.2.

17.4 ecoinvent data v3.0

The cooperation of the ecoinvent institutes continued for the development of version 3, under the leadership of Gerard Gaillard from Agroscope Reckenholz-Tänikon Research Station (ART). The scientific management was performed by Bo Weidema, while the business management from 2012 was passed on to Gregor Wernet. The staff of the ecoinvent Centre had in the meantime grown from one full-time person to five. The cooperation with ifu Hamburg GmbH for software development and support was continued.

The development of version 3 of the ecoinvent database was possible exclusively from the funds obtained from sales of licenses and substantial in-kind contributions of the above-mentioned LCA-institutes in the ETH domain. We furthermore received funding for data collection from TetraPak.

Annex A. The boundary to the environment

To distinguish human activities from their environment, two principles are followed in combination:

1) “The natural background”, i.e. to include everything that would not have occurred without the activity, and to exclude anything that would have occurred even without the activity. The exclusion of the natural background may be done implicitly, by simply ignoring it, but for transparency it may be preferable to include the natural background phenomena in the activity description (or in a separate description) and *explicitly* subtract them. This principle delimits the subject of LCA from the study of natural phenomena, but does not in itself provide a delimitation between life cycle inventory (LCI) and life cycle impact assessment (LCIA). Examples of application of this principle are:

- Forest residues, such as branches and stubs left after harvesting, are excluded, because they would anyway have decomposed, *in situ*, on the forest floor (although possibly at a different time). This implies that only the wood actually harvested (and the management activities required to achieve this) is seen as included in the forest activity and in the mass and carbon balance for this activity.
- If the forest activity has an effect after the harvest, e.g. CO_2 emissions from the soil after a clear-cut, additional to those that would have occurred without the clear-cut, these are to be included in the LCA.
- The heavy metals and nutrients brought into an agricultural system by the management are to be included, while the deposition from precipitation (whether from natural or human sources) are excluded. Likewise, the natural background leaching that would have occurred from the area, had it been under natural climax vegetation, is excluded.
- Indoor emissions from an activity are to be included, since they would not have occurred without the activity.
- Deposition of waste in a landfill, as well as littering, is included as an activity, since it would not have occurred without human presence.

2) “Human management”, i.e. to include everything that takes place under human management and exclude anything that takes place after human management has terminated. This principle is mainly aimed at delimiting LCI (the human activity) from LCIA (the fate and exposure modelling and assessment of e.g. the emissions from the activity). While this principle may at first appear simple, it does not in practice provide a clear and practicable boundary between LCI and LCIA:

- The CO_2 emissions from the soil after a forest clear-cut do not take place under human management. The human management leaves a disturbed soil (this could be seen as the “exchange to the environment”), which then has these emissions. Nevertheless, it appears more practical to include the CO_2 emissions as emissions from the forestry activity (or a separate after-forestry activity), rather than to introduce disturbed soil as an environmental exchange.
- Many fate models for pesticides take their starting point in the amount of pesticide applied to the agricultural soil, although this clearly is within the sphere of human management and only the amount of pesticide that reaches the surrounding environment (and possibly the soil after human management terminates) are included in the final impact assessment (i.e. excluding the effect on the flora and fauna of the agricultural soil while under human management).
- Landfill emissions are included as elemental emissions also after the human management of the landfill has terminated. If the principle of management was followed strictly, the landfill content at the time of termination of human management should be reported as an exchange to the environment, and the rest treated as part of the LCIA fate modelling. Since the fate models used would not be different from those applied during human management, this would be a very unpractical division.

- Following the principle of management, each individual type of litter (PET bottles, alu cans, etc.) should be treated as an exchange to the environment. Although specific issues of littering (e.g. direct harm to wildlife) may still need special treatment, a more practical solution would be to apply a surface landfill model resulting in the traditional elemental emissions.

As it appears difficult to determine an unambiguous and practicable boundary between LCI and LCIA, the ecoinvent database applies a pragmatic, exemplary approach, where the centrally managed master list of elementary exchanges (available via www.ecoinvent.org and via the ecoEditor software) provides the definition of the borderline between LCI and LCIA. This implies that all activities up to the point where the listed emissions first occur are regarded as included as human activities, while the remaining fate modelling is regarded as belonging to the LCIA. The ecoinvent Editor for Exchanges with the environment is thus responsible for the smooth linking to the available LCIA methods, ensuring that no gaps or overlaps occur between the LCI and the LCIA phases.

Annex B. Parent/child datasets (inheritance)

[Note: In the context of the ecoinvent database version 3, inheritance is restricted to geographical inheritance, i.e. the creation of local child datasets from a global parent dataset. The ecoinvent Centre will perform experiments with temporal and scenario child datasets to investigate the options for expanding the use of inheritance in future versions of the database.]

B.1 Reference datasets

A reference activity dataset is intended as a dataset that provides data close to the global average for the activity for the most recent year for which data is available.

The reference settings applied in the ecoinvent database version 3 are:

- Geography: Global
- Time period: The most recent year (current year or earlier) for which a global dataset covering a full calendar year is available (individually for each activity)
- Macro-economic scenario: Business-as-Usual

Reference datasets are only defined for transforming and market activities, and are not available for other special activity types.

B.2 Inheritance rules

The ecoSpold 2 data format is in itself not very restrictive in terms of which datasets are allowed to inherit from which. In order to ensure consistency of the ecoinvent database, a number of further restrictions are therefore applied:

- A child dataset always refers to a parent dataset with the same activity name as the child, using the “parentActivityId” field of the ecoSpold format. Also the system model, activity type (unit process or aggregated system, see Chapter 4.15) and special activity type (see Chapter 4.3) cannot be changed from parent to child.
- A child dataset differs from the parent dataset on one (and only one) of the settings for geography, time period and macro-economic scenario.
- Temporal child datasets (i.e. datasets with a time period setting different from the parent) and macro-economic scenario child datasets (i.e. datasets with a macro-economic scenario setting different from the parent) are only allowed for time periods after the current calendar year, and can only be created by the use of database-wide algorithms that are not dependent on a fixed reference year. The addition of temporal and macro-economic child datasets can therefore only be added in cooperation with the ecoinvent database administration, and not as individual datasets.

The inheritance is furthermore limited to the fixed sequence: Reference activity → Geography child → Temporal child → Macro-economic scenario child, with the exception that a Geography child may keep its original parent (the corresponding global dataset) even after a more recent dataset has become the reference activity dataset for this activity. This means that:

- A geography child (i.e. a dataset with a geographical location setting different from the parent) can only refer to a global dataset for the same time period as its parent and geography child datasets can only be available for the reference year or earlier. Geographically specific datasets for future years can be constructed from the most recent geographical child datasets as temporal child datasets.

- A temporal child (i.e. a dataset with a time period setting different from the parent) can only refer to a reference activity or the most recent geography child as its parent. Temporal child datasets are only available for the reference scenario (Business-as-Usual). Temporal specific datasets for other macro-economic scenarios are constructed from the temporal child datasets as macro-economic scenario child datasets. This allows the construction of time series of datasets for any activity, location and macro-economic scenario.
- A macro-economic scenario child (i.e. a dataset with a macro-economic scenario setting different from the parent) can only refer to a reference activity, the most recent geography child, or a temporal child as its parent.

The fixed sequence implies that different geographies are allowed to have different temporal resolution and different developments over time, while all macro-economic scenarios using inheritance must have the same geographical and temporal resolution, but can still have different developments over geography and time.

This also means that inheritance is *not* used to model technologically similar datasets (e.g. lorries with different capacities) outside the context of a geography child. Technologically similar datasets are instead modelled with the use of variables, see Chapter 5.7. Ideally, the reference activity dataset is parameterised with the use of variables, before it is applied for inheritance.

In the ecoSpold 2 format, inheritance is implemented through the use of *delta datasets* that contain only data on the inheritance and difference of the child as compared to a parent dataset, so that the actual *child dataset* only occurs when the delta dataset is combined with the inherited content from the parent dataset.

The ecoSpold format distinguishes 5 ways in which data in a delta dataset is interpreted:

1. A blank field: The value from the parent activity dataset applies.
2. Filled-in content: The filled-in value applies, and the value from the parent activity dataset is ignored.
3. In text fields of the string type, content may include the text {{PARENTTEXT}}, in which case the field content from the parent activity dataset is included at this place in the filled-in text in the child dataset.
4. In fields of the type TTextAndImage, content may include both {{PARENTTEXT}} and {{text_variables}}. The latter represents a text variable defined in the parent dataset, which may be redefined by the delta dataset while keeping the rest of the parent text intact. This allows easy changes of text parts in child datasets.
5. In amount fields with corresponding mathematical relation fields, the latter may include the reserved variable PARENTVALUE referring to the value of the parent dataset. For example, the formula PARENTVALUE*0.5 halves the value of the parent amount field.

Additional advice for data providers:
When expressing an amount in a delta dataset, it is important to consider whether it is most relevant to enter the child value as a fixed value (i.e. not relative to the parent), or whether the PARENTVALUE variable should be used. When the PARENTVALUE relationship is used, it is important to consider whether the relationship is additive or multiplicative. For example, a child value of 50 relative to a parent value of 100 can be expressed as PARENTVALUE-50 or PARENTVALUE*0.5. It is important to consider what will happen to the child value if the parent amount is changed. If there is no specific reason to assume an additive relation, the multiplicative relation should always be preferred. If the child value is believed to be more correct than any relative amount, e.g. because it is a measured value, the child value should be entered as a fixed value that will *not* change with the parent value. If the parent field is a mathematical relationship, it is often relevant to re-use this mathematical rela-

tionship in the child dataset. It is important to use the comment fields to explain the rationale behind any entered relationships.

When data for a specific local activity is available, it is recommended simultaneously to consider the global and the local dataset for this activity and which specific data are most relevant to add to each of these datasets. It may be most simple at first to create a stand-alone local dataset with the available data and in a second step split it up in the global parent and the local child, which will then supersede the stand-alone dataset.

When submitting an edited version of a parent dataset, the consequences for the child datasets will be reviewed at the same time as the edited parent dataset.

Abbreviations

AOX	Adsorbable Organic Halogen Compounds
BOD_5	Biological oxygen demand in five days
CED	Cumulative Energy Demand
CIF	Cost Insurance and Freight
COD	Chemical oxygen demand
CPC	Central Product Classification
CV	Coefficient of Variance
DM	Dry matter
DOC	Dissolved organic carbon
FOB	Free On Board
GDP	Gross Domestic Product
GLO	Global
ID	Identifier
IO	Input Output (economic model)
ISO	International Organization of Standardization
ISIC	International Standard Industrial Classification
KML	Keyhole Markup Language
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NAICS	North American Industry Classification System
NDI	National Data collection Initiative
NPP	Net Primary Productivity (NPP-C: Net Primary Productivity Carbon)
NMVOC	Non-methane Volatile Organic Compound
PM10	Particulate matter with a diameter of less than 10 µm
PM2.5	Particulate matter with a diameter of less than 2.5 µm
ROW	Rest-Of-World
SPOLD	Society for the Promotion of Lifecycle Development (www.spold.org)
TCDD	Tetra-chlor-dibenzo-dioxin
TOC	Total Organic Carbon
TPM	Total Particulate Matter
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
UN	United Nations
UUID	Universally Unique Identifier
XML	Extended Markup Language

Standard terminology used in the ecoinvent network (glossary)

Accumulated system dataset: An activity dataset showing the aggregated environmental exchanges and impacts of the product system related to one specific product from the activity.

Activity: The doing or making something. Example: "International Standard Industrial Classification of All Economic Activities". Etymology: Latin: actio ("'doing or making'")

Activity class: Group of activities classified together under a heading in a statistical classification of activities, such as ISIC.

Addition to stock: By-product or waste with a lifetime in excess of one year. See also under Infrastructure.

Branded dataset: Dataset for a specific brand or a specific company, where the company or brand name is specifically mentioned as part of the activity and/or product name.

By-product/Waste: Any activity output that is neither a reference product nor an exchange to the environment. The ecoinvent database does not discriminate between by-products and wastes.

Child dataset: Dataset that occurs when a parent dataset is combined with a delta dataset.

Conditional exchange: Exchange that is only activated for a specified system model.

Constrained activity: An activity that is limited in its ability to change its production volume in response to a change in demand for its product.

Consumption mix: The output from a market activity.

Cost: The expenditure necessary to acquire a product or production factor.

Delta dataset: Dataset that contains information on the inheritance and difference of a child dataset as compared to a parent dataset.

Determining product: See reference product.

Direct requirements table: A transformed supply-use table representing a linear, homogeneous steady-state model of the economy. In a "product-by-product" direct requirements table, each column represents a single-product, interlinked implementation of an activity dataset.

Elementary exchange: Exchange with the natural, social or economic environment. Examples: Unprocessed inputs from nature, emissions to air, water and soil, physical impacts, working hours under specified conditions.

Environment: Surroundings. Etymology: French: environ ("around").

Exchange: Relationship between a human activity and another human activity or the natural, social or economic environment. Synonym: Input or output.

Good: Product with mass.

Human activity: Activity performed by humans, machines or animals in human care.

Infrastructure: Product not intended for consumption, with a lifetime exceeding one year. In the ecoinvent database typically modelled as a service, and identified by the property "capacity" or "lifetime_capacity". Synonyms: Capital goods, Investments.

Inheritance: Passing on of field contents from a parent dataset to a child dataset.

Intermediate exchange: Product, material or energy flow occurring between unit processes. Synonym: Product or waste.

IO activity dataset: A dataset corresponding to a column in a supply-use or direct requirements table, typically representing the production function of an industry class.

Lifetime of a product: The period between the time of production and the time of initiating waste treatment of the product.

Make-use table: See Supply-use table.

Material for treatment: A by-product/waste that no other activity in the same geographical area has as its *positive* reference product, and which therefore cannot substitute a reference product as an input to an activity.

Market activity: An activity representing a market for a specific product, mixing similar intermediate outputs from the supplying transforming activities and providing the resulting consumption mix to the transforming activities that consume this product as an input.

System model: A model describing how activity datasets are linked to form product systems. Synonym (input-output economics): Technology model.

Parent dataset: A dataset referred to by a delta and child dataset as the dataset from which field values in the child dataset are to be inherited to the extent defined by the delta dataset.

Process: Set of interrelated or interacting activities that transforms inputs into outputs. ISO 9000:2005, definition 3.4.1.

Product: Good or service output of a human activity with a positive either market or non-market value. Example of a product with a non-market value: Household childcare.

Product system: Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product. ISO 14040:2006, definition 3.28.

Production mix: The production-volume-weighted average of the suppliers of a specific product within a geographical area.

Reference activity dataset: A dataset representing a default description of an activity intended to be close to the global average for the most recent year for which data is available, when applied as parent dataset for other datasets for the same activity but with other specific geographical location and/or temporal and/or scenario settings.

Reference product: Product of an activity for which a change in demand will affect the production volume of the activity (also known as the determining products in consequential modelling).

Residual activity: Resulting activity when subtracting all available unit processes within an activity class from the supply-use data of the same activity class, for the same year and geographical area.

Revenue: The income from the sale of a product.

Service: Product without mass.

Supply mix: A production mix with the addition of the import of the specified product to the geographical area.

Supply-use table: A combination of a supply table and a use table, each with activities on one axis and products on the other. The supply table stores data on the supply of products from each activity, and the use table stores data on the use of products by each activity. Together, the two tables can be interpreted as providing the production function of an activity, i.e. what production factors (inputs) are required to produce the outputs of an activity. The transpose of the supply table is sometimes referred to as a make table.

Transforming activity: A human activity that transforms inputs, so that the intermediate output of the activity is different from the intermediate inputs, e.g. a hard coal mine that transforms hard coal in ground to the marketable product hard coal, as opposed to a market activity. Including extraction, production, transport, consumption and waste treatment.

Treatment activity: Transforming activity with a reference product with a negative sign, which means that the activity is supplying the service of treating or disposing of the reference product.

Unit process: Smallest element considered in the life cycle inventory for which input and output data are quantified. ISO 14040:2006, definition 3.34.

Variable: A placeholder for a value for use in mathematical formulas.

Variable property: A property of an exchange which is included as a variable in a mathematical relation of another exchange of the same dataset.

Waste: See By-product/waste.

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