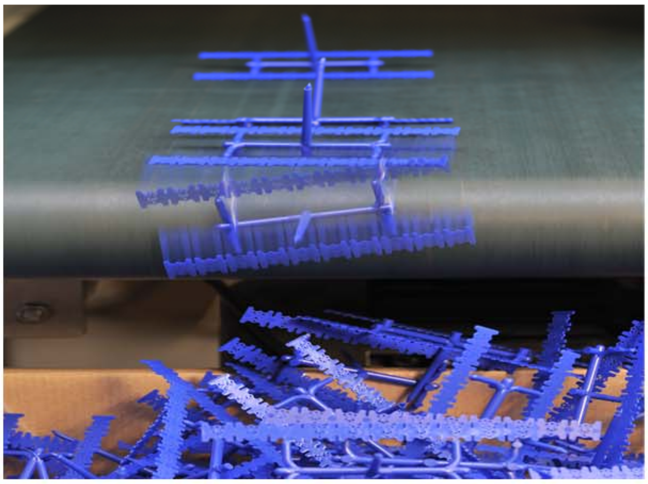
Plastberegner.dk - LCA tool for plastics converters in Denmark

Documentation of the tool and database

Plastindustrien. Brancheforeningen for danske plastvirksomheder

Produceret med støtte fra Life+

Life projektet "Green21" er et samarbejde mellem DI, Miljøministeriet, Green Cross Denmark og Aalborg Universitet

Om projektet FAQ Datasikkerhed

Miljøministeriet

AALBORG UNIVERSITET

Preface

Plastberegner.dk is developed by 2.-0 LCA consultants, and it is maintained and administrated by Plastindustrien (www.plast.dk) and 2.-0 LCA consultants (www.lca-net.com). Requests and comments can be sent to: info@plastberegner.dk

The project is financed by Plastindustrien with support from Life+. The partners of the The Life project "Green21" are: Confederation of Danish Industry (DI), The Danish Ministry of Environment, Green Cross Denmark and Aalborg University.

Jannick H Schmidt
2.-0 LCA consultants, Aalborg, Denmark

Aalborg, 8th October 2012

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1 Introduction

In 2010 the Danish Plastics Federation (Plastindustrien) initiated the development of a web-based tool that enables their members to produce life cycle environmental information on their products. The members of the Danish Plastics Federation are plastics processing companies in Denmark.

The tool is available via the webpage (http://plastberegner.dk). To access the tool, it is required to register and to create an account. This is required because the tool saves all information entered by the user.

In the tool it is possible to create own LCA activities and to link to activities in a database. The database contains pre-calculated life cycle emissions for a large number of LCA activities, e.g. electricity, transport, raw materials etc. It is not possible to modify the data in the database. These data are maintained by the tool administrator. The processes created by the user can link to other processes created by the user as well as to processes in the database.

The LCA activities in the database are stored as so-called terminated processes. This means that the database does not contain information on intermediate product transactions between processes – only the calculated life cycle emissions are stored in the database. The reason for this is that the calculation speed would become slow if the database contained more than e.g. 4000 linked activities that would have to be re-calculated (matrix inversion) for each calculation by the tool.

The current report documents all life cycle inventory data that are available in the database, and how the life cycle results are calculated, i.e. how the user specific linked LCA activities are combined with processes in the database.

The current report is structured as follows:

- **Chapter 2** describes and defines the applied data format and calculus in the tool for the LCI and LCIA. Further, the theoretical basis for switching between consequential and attributional modelling assumptions is also described.
- **Chapter 3** defines the goal and scope of the life cycle inventory behind the database in the tool. This chapter also describes the general methodology and necessary unit conversions used for switching on and off capital goods and services in the life cycle inventory.
- **Chapter 4** provides an overview of all data sets in the database including data source and metadata. For some data sets this is the only documentation provided. This is the case when the only modifications of the data sets are application of specific electricity data and enabling switches for capital goods and services. For data sets when more modelling and/or data collection has been required reference is given to the relevant sections in **chapter 5-9** where this is further documented.
- **Chapter 5-9** presents detailed life cycle inventories for all data sets where the documentation format in **chapter 4** does not allow for a fully transparent documentation. **Chapter 5-9** are organised so that each chapter represent one of the five main data categories in the tool, and the sub-sections of each chapter represent the same sub-categories as in the tool.
- **Chapter 10** briefly refers to the webpage plastberegner.dk where life cycle impact assessment (LCIA) results can be viewed for all building blocks and for all switch combinations.

- **Chapter 11** includes an evaluation of data quality and an evaluation of sensitivity, consistency and completeness of the data.

2 LCA calculus and methodology for CLCA-ALCA switch

Section 2.1 provides an alphabetical sorted list of definitions of terms used throughout the report, and **section 2.2** puts the main terms in a context, i.e. in a general framework for life cycle inventory. **Section 0** described the mathematical calculus of LCA results and the data format used in the tool. It should be noticed that the current chapter presents issues that are typically beyond what is described in a normal LCA-report. But the issues covered are necessary because:

- the current study involves the programming of a web-based LCA software, and
- the methodological foundation of distinguishing between attributional and consequential modelling is not well described in literature

2.1 Definition of terms

Activity	Part of technosphere. Activity refers to productive activities that aim at selling the resulting products to another activity. Synonym: process.
Attributional modelling	System modelling approach in which inputs and outputs are attributed to the functional unit of a product system by linking and/or partitioning the unit processes of the system according to a normative rule (Sonnemann and Vigon 2011, p 132). In the current study attributional modelling is modelled by assuming that the products are produced using existing production capacity (current or historical market average), and multiple-output activities are dealt with by applying allocation factors based on economic value.
By-product	Non-determining product that directly (i.e. without further processing) is used in place of other products.
Consequential modelling	System modelling approach in which activities in a product system are linked 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 functional unit (Sonnemann and Vigon 2011, p 133). Hence, in consequential modelling it is generally a change in demand of the product under study that is modelled. A cause-effect relationship between a change in demand and the related changes in supply is intended to be established. This implies that the product is produced by new capacity (if the market trend is increasing). Also it is taken into account that the affected production capacity must be the actual affected, i.e. it is not constrained. Multiple-output activities are dealt with using substitution.
Exchange	Exchanges with the environment, i.e. emissions, resource inputs, land use exchanges (occupation and transformation), and other such as radiation, noise, odour, vibrations, aesthetical effects on landscape etc.
Material for treatment	Output flow of a human activity that remains in the technosphere and cannot directly (i.e. without further processing in a treatment activity) displace a reference product.
Product	Output flow from a human activity with a positive either market or non-market value. Further distinction of the products can be made in terms of determining products and by-products.

Reference product | Product for which the production volume changes in response to changes in demand.

2.2 Modelling concepts and naming conventions

This section on general life cycle inventory theory is needed because the scope of the current project is wider than just following the ISO 14040/44 standards on LCA; life cycle results are calculated based on a common database, but different modelling assumptions are consistently applied throughout the database. Therefore, the inventory needs to be split into two parts:

- accounting part; where data are stored as they are, i.e. no assumptions on allocation are applied
- modelling part; where different modelling assumptions regarding allocation are applied

The ISO standards (or any guideline or methodology report on LCA) do not provide a framework that enables for this. Therefore, this theoretical chapter is needed in order to establish the required life cycle inventory framework. It should be noticed that the presented framework is closely related to the framework of ecoinvent v3 (Weidema et al. 2011).

It should be noticed that parts of this section are obtained from Schmidt and Dalgaard (2012b) which uses a similar approach to parameterised modelling with switches as the current study.

Product system, system boundary and flows

A life cycle inventory consists of a number of interconnected activities (also sometimes known as LCA processes), see **Figure 2.1**. The activities are connected via products or materials for treatment. An activity may have exchanges with the environment, i.e. emissions or other exchanges (radiation, noise, odour etc.) to the environment or resource inputs or other exchanges (occupation and transformation of land) from the environment. Activities are human, and they take place within the technosphere. Product transactions also always take place between activities in the technosphere. When calculating the inventory result, it is the sum of all exchanges that are calculated. The inventory result is used for calculating potential environmental impacts.

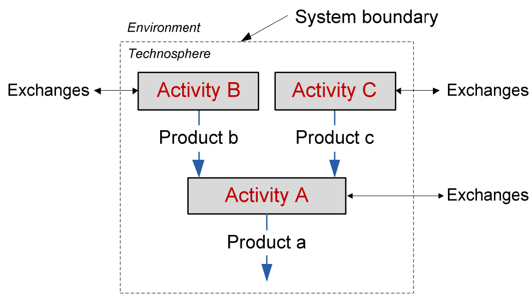

Figure 2.1: Product system with system boundary between environment and technosphere. Within the technosphere are activities which are linked via product and waste flows. Exchanges are flows that cross the system boundary. These are the ones recorded for the calculation of environmental impact indicators.

Different types of products and activities

Products can be differentiated based on the product characteristics relevant in an LCI context. Distinction is made between reference products and by-products. A reference product is characterised by determining the production volume of an activity, i.e. a change in demand for a reference product affects the production volume of the activity. An activity can have one or more reference products, but most often, there will only be one reference product. A by-product is a product of which a change in demand does not change the production volume of the supplying activity, i.e. by-product are all product outputs not being reference products. By-products can directly displace a reference product supplied by another activity

Materials for treatment are outputs from activities, not being a reference product that undergoes treatment. This treatment may turn the material into a by-product, material for treatment and/or emissions. An example of a material for treatment is waste.

Distinction is made between two types of activities:

- Activities
- Treatment activities

A treatment activity is characterised by receiving 'material for treatment', whereas other activities does not receive this. Treatment activities include waste treatment, recycling, reuse, and other processing of material outputs of activities into products that can displace reference products. **Figure 2.2** illustrates an activity A that supplies a reference product A, a material for treatment, and a by-product B. The by-product B from activity A can directly displace the reference product B from activity B. The material for treatment from activity A needs treatment in the treatment activity before the material can displace another product, here reference product B from activity B.

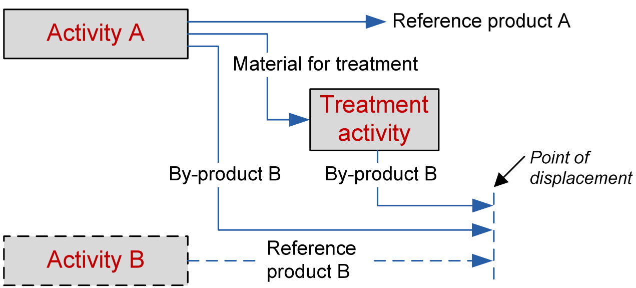

Figure 2.2: Naming conventions of different types of products and activities. The dotted line represents the displacement of product and activity B. The figure is based on Weidema et al. (2009, p 19)

Inputs and outputs of material for treatment (to treatment activity and from activities) are accounted for with a negative sign. I.e. the activity A in **Figure 2.2** uses minus quantity of material for treatment, and the treatment activity in **Figure 2.2** supplies minus quantity of material for treatment. This sign convention enables for establishing a mass balance of an activity while at the same time storing data in a format that can both handle system expansion (used in consequential modelling) and co-product allocation (used in attributional modelling).

Difference between substitution and allocation

Multiple-output activities are characterised by having more than one product output. When demanding only one of the co-products, we have a so-called allocation problem. In modelling terms, this problem can be solved either by system expansion or by allocation. In system expansion, it is determined which one(s) of the co-products that are determining, i.e. a change in demand for this/these products affects the production volume of the activity. The remaining co-products are dependant, i.e. the output of these products is not affected by a change in demand. Hence, a change in demand for determining products will also cause a change the output of the dependant co-products. The general assumption in LCA is that demand determines supply. Thus, a change in output of dependant co-products will cause a reduction in the alternative supply of these products (this is regulated through the markets for substitutable products). The modelling and system boundary for a change in demand for the determining product A, is illustrated in **Figure 2.3**. The technicalities and theory behind substitution are described in detail in Weidema et al. (2009).

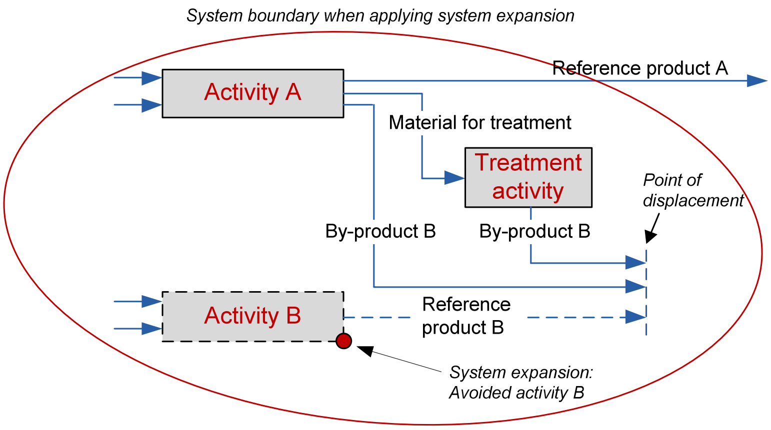

Figure 2.3: Multiple-output activities: Modelling of system expansion.

When the allocation problem is solved by allocation, each of the product outputs are converted to an allocation unit, e.g. EUR if economic allocation is applied, or MJ if energy allocation is applied. Then the relative outputs of the co-products measured in allocation unit determine the portion of the multiple-output system that is ascribed to each co-product. The interactions with other product systems supplying substitutable products to the same market (the avoided activities in system expansion) are not considered in allocation. The principle of allocation and system boundary are illustrated in **Figure 2.4**.

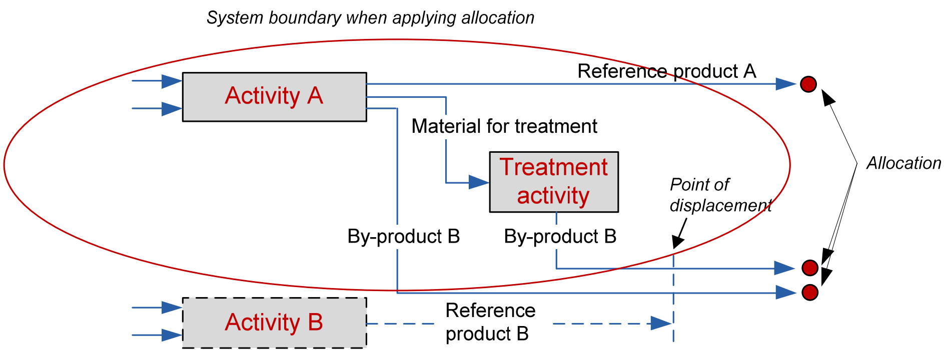

Figure 2.4: Multiple-output activities: Modelling of allocation.

2.3 LCA calculus and data format used in the tool

The tool consists of a background database with so-called building block that can be used to build the life cycle of a specific product, and a module where the user can create LCA activities. The intention of having these two components is that:

- data for activities within the premises of the user are entered in created user specific LCA activities, and
- data for activities outside the user's premises are obtained from the database

The types of data contained in the database are data for raw materials, auxiliary materials, electricity, heat, fuels, transport, capital goods, services etc. In the database, the building blocks are stored as pre-calculated LCIA-results. In the tool, it is possible to build any life cycle of a product; it is possible to create and link an unlimited number of LCA activities. If the user of the tool had unlimited time and access to generic LCI-data, the whole background database (the building blocks) could be constructed as linked LCA activities, e.g. the entire FORWAST database or ecoinvent database could in principle be entered in the tool. However, this is not desirable because the calculation time would become very long. Further, no existing databases fulfil the requirements to switches between modelling assumptions and on/off switches for capital goods and services for the tool. Therefore, the building blocks are stored as pre-calculated LCIA results. The full transparent background database links to the ecoinvent v2 database and the FORWAST database in the LCA software SimaPro where the LCIA results of the building blocks are calculated. For each of the switch combinations (m), the database with building blocks is created. In **Figure 2.5** the database is illustrated as a grey box in the top left corner.

The user can then establish a detailed and linked product system for the product understudy. Whenever, the user needs LCA data for which data are not immediately available, then links to the building blocks can be used. The user specified LCA activities contains the following information:

- Reference flow
- Inputs of reference flows from other user specified activities
- Inputs of building blocks from the database
- Direct emissions from the activity (notice that combustion related emissions shall not be included because there are included in the building blocks for fuels)

In **Figure 2.5** the module for user specified LCA activities is illustrated as the frame containing user specified LCA activities in the top right corner.

When the user wants to calculate LCA results, a calculation set-up is created. Here the functional unit and switch is specified, and some descriptive text is entered for the report generator. In the calculation set-up, the functional unit is specified as a quantity of one of the reference products of the LCA activities created in the 'User specified LCA activities'. The direct emissions from the user specified LCA activities are characterised to impact indicators using the life cycle impact assessment method (**Q**). The LCIA method (**Q**) is illustrated in the figure.

The overall data flow and procedure for calculating LCA results is presented in **Figure 2.5**. The user is involved in creating:

- User specified LCA activities
- User specified calculation set-up

The remaining parts of the data flow and procedure is carried out by the tool. The overall calculation procedure as presented in **Figure 2.5** is mathematically documented in detail below the figure.

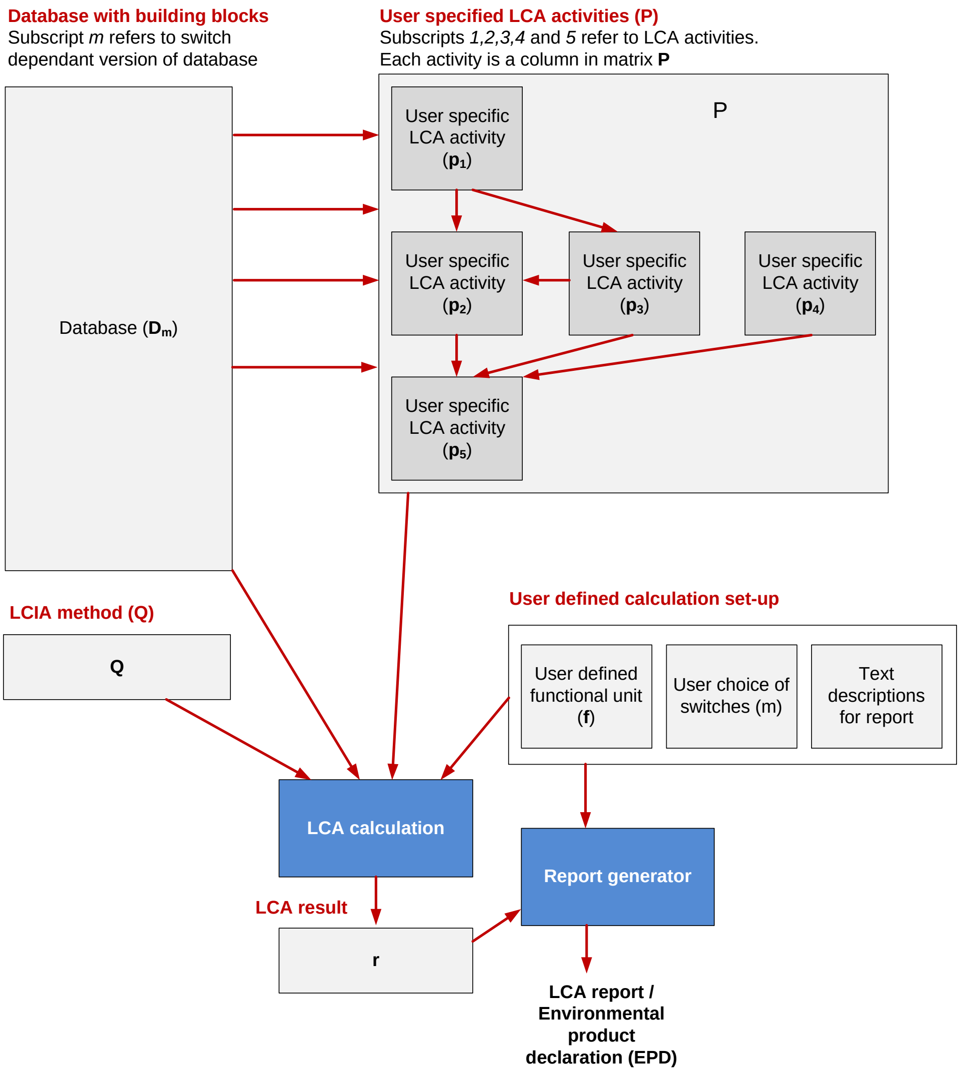

Figure 2.5: Overall data flow and procedure for calculating LCA results in plastberegner.dk. Grey boxes represent data sets/data tables and the two blue boxes represent operations or calculations carried out by the tool.

The user specific activities **P** are stored as three separate matrices. Each column represents an LCA activity. $\mathbf{Z}_{user}$ is a square matrix with format input of own products by own activities. $\mathbf{Z}_{building\_blocks}$ is a rectangular matrix with format input of building blocks by own activities. $\mathbf{B}_{direct}$ is a rectangular matrix with format emissions by own activities. **Figure 2.6** and **formula (1)** illustrate **P**.

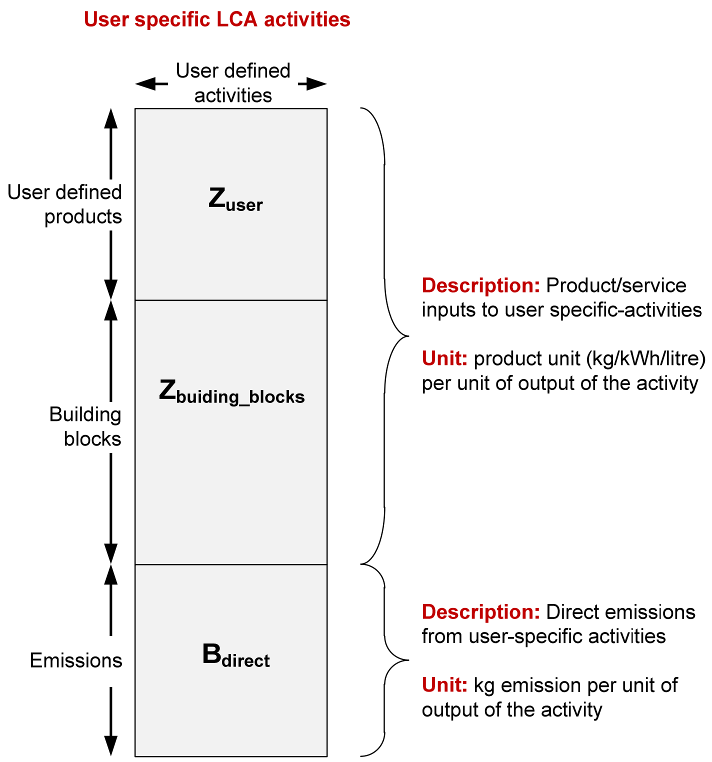

Figure 2.6: User-specific activities.

$$\mathbf{P} = \begin{bmatrix} \mathbf{Z}_{\text{user}} \\ \mathbf{Z}_{\text{building\_blocks}} \\ \mathbf{B}_{\text{direct}} \end{bmatrix} \qquad (1)$$

In the calculation set-up in the tool, the functional unit **f** of a calculation is defined. The functional unit specifies the desired output of any one of the user specified LCA activities (columns) in **P**. **f** has format user defined products (=reference flows of user specified LCA activities) by one (column vector).

LCIA results **r** are stored as six separate stacked column vectors where each column vector represents a data category. Distinction between data categories is made in order to show the final LCA result divided into different categories, see example in **Figure 2.10**. The format of **r** is (6 x impact categories) by 1, see **formula (2)**.

$$\mathbf{r}_{\text{total}} = \begin{bmatrix} \mathbf{r}_{\text{direct}} \\ \mathbf{r}_{\text{materials}} \\ \mathbf{r}_{\text{energy\_fuels}} \\ \mathbf{r}_{\text{capital}} \\ \mathbf{r}_{\text{transp\_services}} \\ \mathbf{r}_{\text{waste}} \end{bmatrix} \qquad (2)$$

Scaling factors **s** specify the quantity of each of the user specific LCA activities that are needed to produce the specified output in the functional unit **f**. **s** has format user specific products by one (column vector).

$$\mathbf{s} = (\mathbf{I} - \mathbf{Z}_{\text{user}})^{-1} \cdot \mathbf{f} \qquad (3)$$

where **I** is the identity matrix.

Direct emissions (from own activities) **b** are calculates as given in **formula (4)**. The scaling factors **s** are given in **formula (3)** and $\mathbf{B}_{\text{direct}}$ is part of **P**, see **formula (1)** and **Figure 2.6**.

$$\mathbf{b} = \mathbf{s} \cdot \mathbf{B}_{\text{direct}} = \left[(\mathbf{I} - \mathbf{Z}_{\text{user}})^{-1} \cdot \mathbf{f}\right] \cdot \mathbf{B}_{\text{direct}} \qquad (4)$$

The LCIA-method **Q** is a matrix with format impact categories by emissions, see **Figure 2.7**.

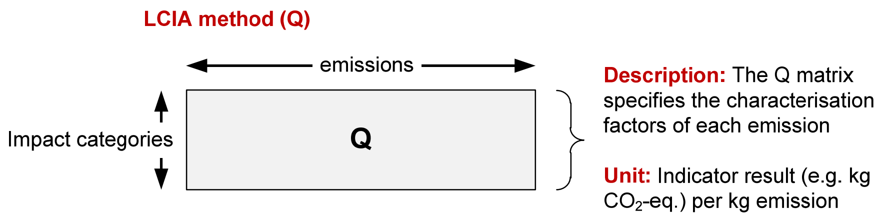

Figure 2.7: Matrix for LCIA matrix.

The LCIA-result $\mathbf{r}_{\text{direct}}$ for direct emissions **b** is calculated as of **formula (5)**. The calculation of the total LCA result $\mathbf{r}_{\text{total}}$ is illustrated in **Figure 2.9**.

$$\mathbf{r}_{\text{direct}} = \mathbf{Q} \cdot \mathbf{b} = \mathbf{Q} \cdot (\mathbf{s} \cdot \mathbf{B}_{\text{direct}}) = \mathbf{Q} \cdot \left(\left((\mathbf{I} - \mathbf{Z}_{\text{user}})^{-1} \cdot \mathbf{f}\right) \cdot \mathbf{B}_{\text{direct}}\right) \qquad (5)$$

The LCIA result above in **formula (5)** only concerns the direct emissions from the user specified LCA activities. The other part of the LCIA result concerns to the impact related to the inputs of building blocks to the user specified LCA activities. To calculate this, the building block database is needed. The building block database ($\mathbf{D}_{\mathbf{m}}$) has format (impact categories x 5) by building blocks, see **Figure 2.8**. Each of the five stabled parts represents the results belonging to the data categories shown in **Figure 2.8**. Distinction between data categories is made in order to show the final LCA result divided into different categories, see example in **Figure 2.10**.

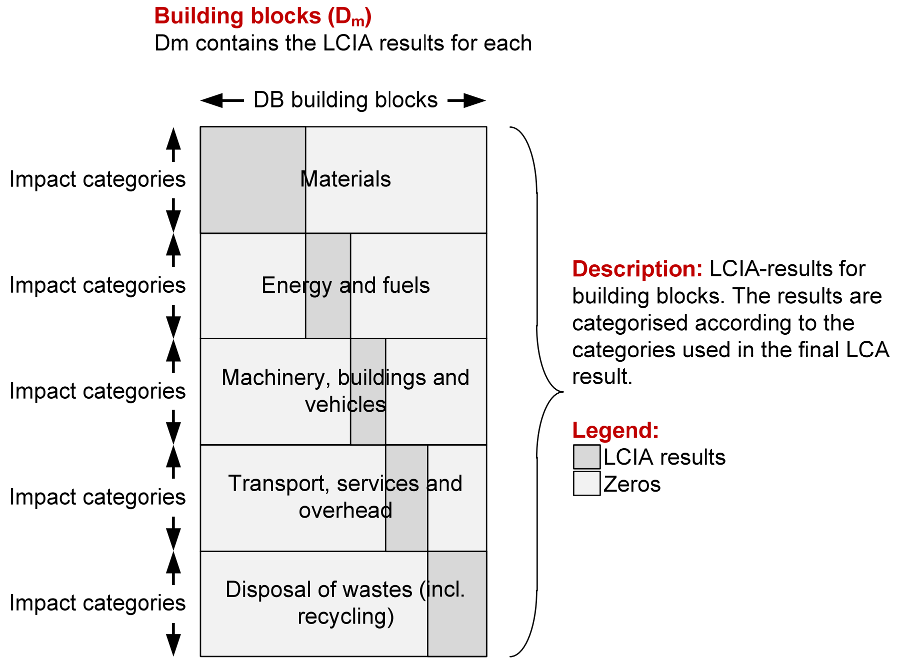

Figure 2.8: Data format of the building block database $\mathbf{D_m}$. The subscript m refers to a combination of switch settings, i.e. the database as shown above is present as many times as there are combinations of switches.

LCIA-result for [$\mathbf{r}_{materials}$ $\mathbf{r}_{energy\_fuels}$ $\mathbf{r}_{capital}$ $\mathbf{r}_{transp\_services}$ $\mathbf{r}_{waste}$] is calculated as of **formula (6)**. The calculation of the total LCA result $\mathbf{r}_{total}$ is illustrated in **Figure 2.9**.

$$[\mathbf{r}_{direct} \quad \mathbf{r}_{energy\_fuels} \quad \mathbf{r}_{capital} \quad \mathbf{r}_{transp\_services} \quad \mathbf{r}_{waste}] = \mathbf{D}_m \cdot [\mathbf{Z}_{building\_blocks} \cdot \mathbf{s}] = \mathbf{D}_m \cdot [\mathbf{Z}_{building\_blocks} \cdot ((\mathbf{I}-\mathbf{Z}_{user})^{-1} \cdot \mathbf{f})] \qquad (6)$$

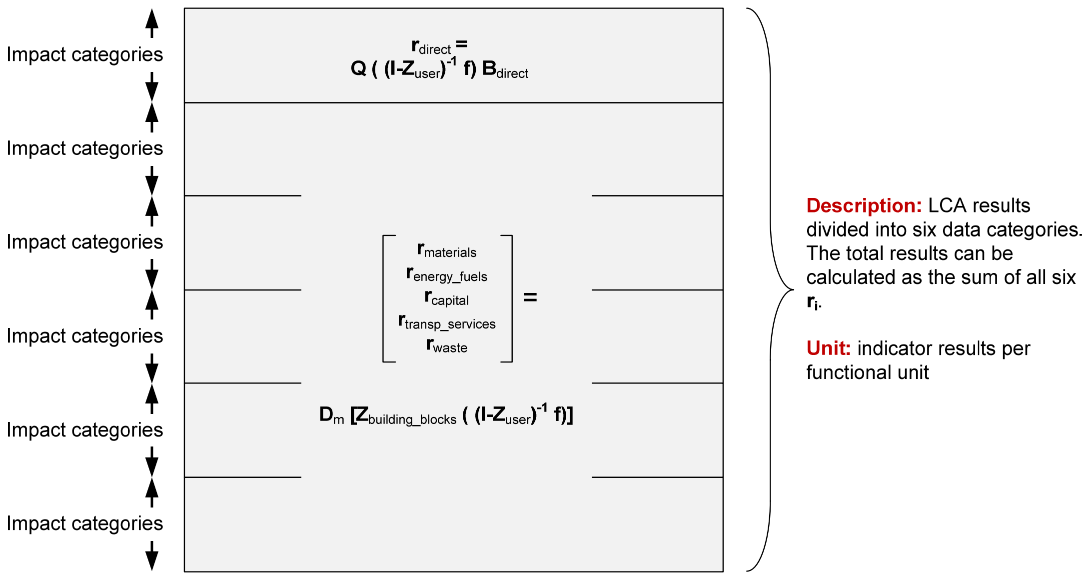

Figure 2.9: Calculation of LCIA result.

Based on the total LCIA result as in **formula (6)** and **Figure 2.9**, the final LCIA result can be shown as in **Figure 2.10** below – this is an example of a result graph (relative impacts) from plastberegner.dk.

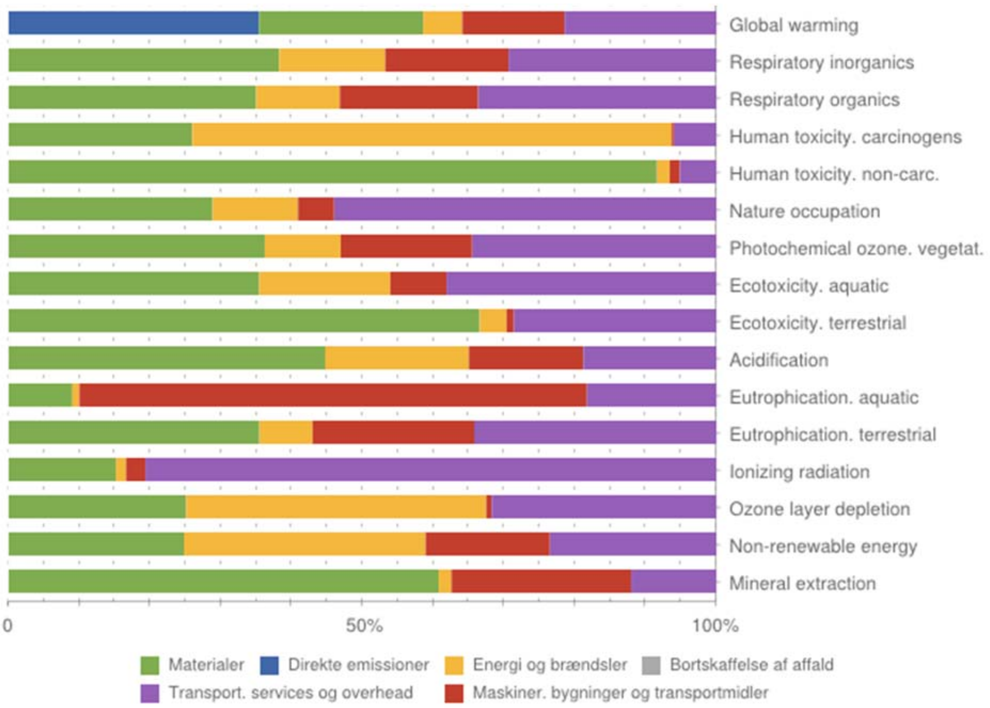

Figure 2.10: Example of final result output from the tool (data categories are in Danish).

3 Goal and scope definition

3.1 Standard and switches

The LCA-tool is carried out in accordance with three sets of modelling assumptions:

- ISO 14040 (2006) and ISO 14044 (2006): consequential modelling
- Attributional modelling (average/allocation): Some deviations from ISO 14040/44
- PAS2050 (2008)

The LCA results of the tool can be calculated in compliance with each of the three above mentioned standards by use of a switch. This is further described in **section 3.5**.

In addition to the feature to switch between different modelling assumptions, the tool also enables for switching on and off capital goods (machinery, buildings and infrastructure) and services (marketing, business travelling, post and telecommunication etc.). Below is an overview of the switch options in plastberegner.dk.

Table 3.1: Overview of included switch combinations in plastberegner.dk.

Modelling assumption	Capital goods	Services	
		Included	Excluded
ISO 14040/44 (consequential)	Included	✓	✓
	Excluded	✓	✓
Average/allocation (attributional)	Included	✓	✓
	Excluded	✓	✓
PAS2050	Included		
	Excluded	✓	

Recommendation regarding switch settings

The recommended modelling assumption switch is 'ISO 14040/44 (consequential)' with included capital goods and services. By using this switch the results represent the likely effect on the environment relating to a change in demand for the product under study.

The following two switch modes available in plastberegner.dk are related to some methodological problems which are briefly described in the following:

- Average/allocation (attributional)
- PAS2050

The methodological problems for these switches include:

- Lack of cause-effect relationships
  - When constrained suppliers are included in the inventoried system, something that cannot be affected is modelled. See more thorough elaboration in Schmidt (2010c) and Weidema et al (2009).
  - When multiple-output activities are allocated, something that does not exist in reality is modelled. No allocated activities which supplies only one product exists in reality.

- Allocated activities do not fulfil the mass balance principle (when inputs are allocated in another unit than their mass, the mass balance will be lost). See more thorough elaboration in Weidema and Schmidt (2010).

The exclusion of capital goods or services leads to incomplete results. Incomplete results represent under-estimated impacts which. This is seldom desirable. Further, the exclusion of capital goods and services may potentially lead to misleading results when different products are compared. This is relevant when the impacts from capital goods and services are different for the compared products.

3.2 ISO 14040/44 critical review

Is critical review according to ISO 14040/44 has been carried out. The critical review is carried out by Ole Dall.

The following material was provided to Ole Dall 25th July 2012:

- The final draft version of the current LCA-report
- The final draft version of the user manual (Schmidt and Dalgaard 2012a)
- the web tool Plastberegner.dk (version 1.2)

On 9th of August a review report was received from Ole Dall. Each of the comments raised in the review report has been addressed and is available in '**Appendix 2: Critical review report including author's response**'.

On 17th September the revised versions of the current LCA-report and the user manual as well as the review report including the author's comments were sent to Ole Dall.

On 21st September a final review statement was received from Ole Dall. This is also available in '**Appendix 2: Critical review report including author's response**'.

3.3 Functional unit and purpose of the study

Purpose of the study

The present report documents an LCA tool for Danish plastics processing companies. The purpose of the tool is to enable plastics processing companies to produce life cycle environmental information on their products. The tool is web-based and it is available at: plastberegner.dk.

The tool is characterised by being easy accessible, it can be used by non-LCA-experts, and the tool enables for applying different standards (ISO14044, average/allocation and PAS2050). The ISO 14040/44 (consequential) standard is included in order to enable the users of the tool to calculate LCA results that represent the likely effects on the environment related to a change in demand for the product under study. The two latter sets of modelling assumptions are included in order to enable the users of the tool to produce LCA results which are compatible with other LCAs/carbon footprints based on these standards.

Though the tool is made easy accessible for non-LCA experts, some basic knowledge on LCA is a precondition for using the tool. Especially for more complex product systems, where many user-specific

LCA-activities need to be created and linked, and were these activities are associated with co-production of by-products, more experience is required.

Further, it should be noticed, that guidance on how to carry out an LCA-study is not provided as part of the current product. For this existing LCA-literature should be used. Examples of recommended LCA-literature are:

- **Thrane and Schmidt (2007)**, Life Cycle Assessment. In: Kørnøv L, Thrane M, Remmen A and Lund H (eds.), Tools for Sustainable Development, pp 204-239, ISBN 978-87-7307-797-9, Aalborg Universitetsforlag, Aalborg
- **Weidema et al. (2009)**, Guidelines for applications of deepened and broadened LCA. Deliverable D18 of work package 5 of the CALCAS project. http://fr1.estis.net/includes/file.asp?site=calcas&file=7F2938F9-09CD-409F-9D70-767169EC8AA9

Functional unit

The functional unit is defined by the user. The tool is flexible and can handle any unit. It is possible to carry out partial (e.g. cradle to gate) and full life cycle assessments including the use and disposal stages.

The functional unit/reference flow of each of the entities in the database in plastberegner.dk is 1 kg/piece/kWh/EUR etc.

3.4 Included building blocks in the database

As described in the introduction, the tool enables the user to create own LCA activities as well as linking to LCA activities in a database. The LCA activities in the database are categorised in the following product categories:

- Materials
- Energy and fuels
- Capital goods (machinery, buildings and vehicles)
- Transport and services
- Overhead
- Waste disposal incl. recycling

The scope of the list of included activities is based on two workshops with plastics processing companies in Denmark in November 2010 and May 2011. These workshops resulted in a draft list of relevant building blocks in the database. The draft list was reviewed by a broad range of plastics processing companies in Denmark from September to December 2011. The improved draft list was then implemented in a beta version of the tool (web), and this was reviewed by a several plastics processing companies in April 2012. After that the final list was consolidated.

It should be noticed that the list is meant to be exhaustive so that the database enables the target industries to calculate LCA result with a cut-off criteria at 0%. Obviously, some minor product flows are not modelled in detail, but the database provides default standard data for some very broad product categories.

The full list of building blocks including meta-data is presented in **chapter 4**.

3.5 Modelling in life cycle inventory and parameter switches

This section described the implementation of the concepts described in **section 2.2**. Generally there exist two different approaches to modelling in life cycle inventory:

- consequential modelling
- attributional modelling

It should be noticed that parts of this section are obtained from Schmidt and Dalgaard (2012b) which uses a similar approach to parameterised modelling with switches as the current study.

According to Sonnemann and Vigon (2011, p 132), attributional modelling is defined as: "*System modelling approach in which inputs and outputs are attributed to the functional unit of a product system by linking and/or partitioning the unit processes of the system according to a normative rule.*" In the current study attributional modelling is modelled by assuming that the products are produced using existing production capacity (current or historical market average), and multiple-output activities are dealt with by applying allocation factors based on economic value.

According to Sonnemann and Vigon (2011, p 133), consequential modelling is defined as: "*System modelling approach in which activities in a product system are linked 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 functional unit.*" Hence, in consequential modelling it is generally a change in demand of the product under study that is modelled. A cause-effect relationship between a change in demand and the related changes in supply is intended to be established. This implies that the product is produced by new capacity (if the market trend is increasing). Also it is taken into account that the affected production capacity must be the actual affected, i.e. it is not constrained. Multiple-output activities are dealt with using substitution. The modelling principles are comprehensively described in Weidema et al. (2009) and Weidema (2003).

Included modelling approaches and standards

The modelling approaches/standards are included in the model are listed and described in **Table 3.2**.

Table 3.2: Description of the key elements of the modelling in LCI in the applied modelling approaches/standards.

Elements in modelling	Description
ISO 14040/44: Consequential modelling	
Included suppliers	The included suppliers represent the actual production mix (ISO14044, section 4.3.3.1). This is interpreted as the actual affected suppliers by a change in demand. As default, the actual production mix is regarded as the average product mix where constrained suppliers are excluded (Weidema et al. 2009). Whenever, more detailed data are available these data have been used.
Multiple-output activities	Whenever possible, allocation should be avoided (ISO 14044, section 4.3.4.2). The reference product(s), i.e. the determining co-product(s) is determined, and the remaining co-products are regarded as by-products which can directly substitute other products or as material to treatment. All exchanges are ascribed to the reference product(s) including the avoided exchanges related to the displaced activities due to by-products.
Completeness	The applied cut-off criterion is 0%, i.e. all transactions in the product system including **capital goods** and **services** are included (but can be switched off
Average/allocation: Attributional modelling	
Included suppliers	The included suppliers represent the average market mix including constrained suppliers.
Multiple-output activities	Allocation is carried out for all co-products. It should be noted that allocation is only carried out for products for which there exist a market, i.e. allocation is not carried out between co-products and material to treatment. In such cases the allocation is carried out between the products at the point of substitution; this is further explained in **section 2.2**.
Completeness	The applied cut-off criterion is 0%, i.e. all transactions in the product system including **capital goods** and **services** are included (but can be switched off).
PAS 2050: Mixed consequential and attributional	
Included suppliers	The included suppliers represent the average market mix, excluding by-products. This is not directly stated in the PAS 2050, but In PAS 2050 (2011, section 4.1) it is stated that attributional modelling shall be applied unless otherwise specified.
Multiple-output activities	Whenever possible, allocation shall be avoided when practicable (PAS 2050, 2011, section 8.1). **Special for waste incineration with energy recovery:** All burdens are allocated to the energy **Special for waste recycling:** When the recycled material maintains the same properties the avoided burden is fully allocated to the activity that sent waste to recycling. When the material does not maintain the same properties, then the avoided burden is fully allocated to the activity that receives the waste for recycling (this is called the 'recycled content method or the 100-0 method).
Completeness	The applied cut-off criterion is 0%, except the fact that capital goods are excluded (PAS 2050, 2011, section 6.4). I.e. all transactions in the product system excluding **capital goods** and including **services** (no options to switch on and off).

Modelling and switch between included modelling approaches/standards

The model enables the calculation of LCA results using all the modelling approaches/standards described in **Table 3.2**. This is done by use of parameters which switch between modelling assumptions and completeness of data. The differentiation between the modelling approaches by use of parameters is described in the following.

In order to enable switching between the standards/guidelines in **Table 3.2**, a parameter (M) is defined where $M \in [1;2;3]$. The meaning of the allowed parameter values of M is described in **Table 3.3**. The value of M determines the values of four parameters m_i used in the LCI calculations.

Table 3.3: Modelling approach switch (M) and the meaning of its values. The calculated parameters m_i are used in the actual calculations. When a calculated parameter is 0, then it is turned off, and when it is 1, then it is turned on.

Value M	Applied standard/guideline	Calculated parameter m_i used in LCI calculations
1	ISO14040/44	if(M=1, m_1 = 1 AND m_2=m_3=0), else
2	Average/allocation: attributional	if(M=2, m_2 = 1 AND m_1=m_3=0), else
3	PAS2050	if(M=3, m_3 = 1 AND m_1=m_2=0), else

Included suppliers: It is relevant to distinguish between suppliers when products are purchased on a market. If a product is purchased directly from a specific flexible supplier, then this is the affected one, and there is no difference between consequential and attributional modelling. When products are purchased on a market, a so-called market activity is inserted between the suppliers and the activity having the purchased product as input. In this market activity, the parameters controlling which suppliers are included are implemented.

It appears from **Table 3.2** that the applied modelling approaches/standards apply different rules regarding included suppliers. Generally, the included modelling approaches/standards only operate with two different sets of included suppliers for products purchased on the market:

- Actual affected suppliers, e.g. a market mix without constrained suppliers (M=1)
- Market average mix including constrained suppliers ($M \in [2;3;4]$)

Figure 3.1 illustrates that the above mentioned two different market mixes can be applied depending on which modelling approach is used. The switch between attributional and consequential changes the applied market mix for product A. In attributional modelling, the market shares of each supply of product (msa) correspond to the average market mix of product A. In consequential modelling, the market share of each supply of product (msc) represents the expected proportion of suppliers to respond to a change in demand for product A. In cases where supplies of product A are dependant co-products (as of supplier 3 in the figure), the market share is zero (as msc3 in the figure) because these products are constrained by the demand for the determining product of the multiple-output activity (demand for product B in the figure).

For each market activity, the msa and msc market shares must be defined. The suppliers of a certain product (A) are: supplier 1, supplier 2, supplier 3 etc. For each supplier, the market share of product A is specified both for attributional modelling and for consequential modelling. This is illustrated in **Table 3.4**. It should be noted, that data for msc and msa as in **Table 3.4** must be present for all products purchased from the market in the model.

Table 3.4: Market shares of suppliers for a product A. msc specifies the market shares in consequential modelling and msa specifies the market shares in attributional modelling.

Suppliers of product A	Market share, consequential (msc)	Market share, attributional (msa)
Supplier 1	msc1	msa1
Supplier 2	msc2	msa2
Supplier 3	msc3	msa3
etc.	etc.	etc.

The implementation of the parameters controlling the included suppliers is shown in **Figure 3.1**. When the switch (M) is M=1, then the msc marked share is applied, and when the switch m is having the value 2 or 3, then the msa market share is applied.

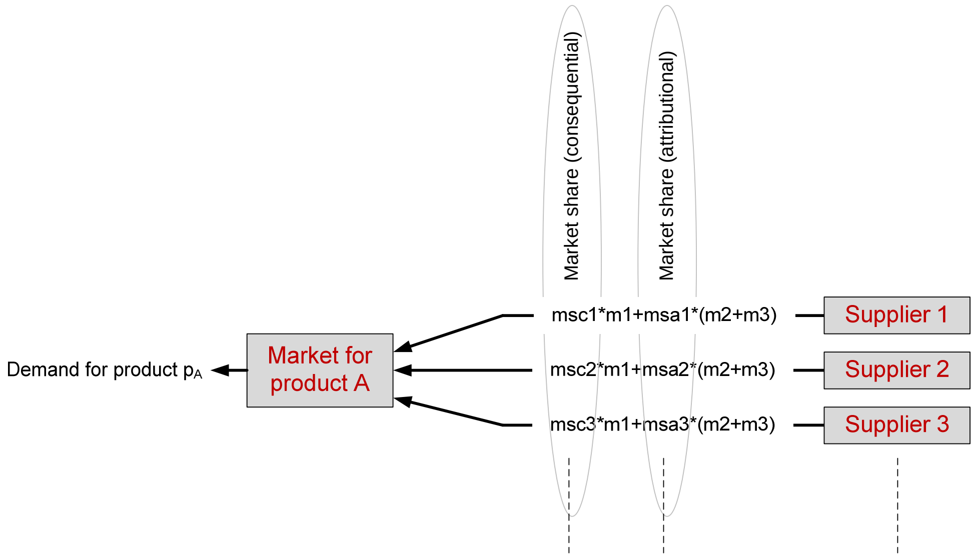

Figure 3.1: Market activities: modelling of average market mix (in attributional modelling) and marginal marked mix (in consequential modelling).

Multiple-output activities: According to **Table 3.2**, the standards/guidelines operate with the following types of modelling choices for multiple-output activities:

- System expansion (ISO 14040/44), M=1
- Economical allocation (attributional), M=2
- Mix of system expansion and allocation (PAS2050): specified in which cases allocated shall be applied and which allocation unit; other cases, use substitution, M=3

In order to enable the three modelling switches as specified above, the following data are needed for each multiple-output activity:

- the quantity, q, of each co-product
- the co-products are divided into determining co-products and dependant co-products
- for each of the three modelling switches, the allocation value (av) of each co-product must be specified. The allocation value converts a product quantity, q, into allocation unit; e.g. kg product is converted into EUR product if economical allocation is considered

The conceptual difference between substitution and allocation is illustrated in **Figure 2.3** and **Figure 2.4** in **section 2.1**.

Completeness: Completeness of product inputs to activities is handled through two parameters:

- capital goods: parameter 'cap', parameter values ∈ [0,1], where 0 means not included, and 1 means included
- services: parameter 'ser', parameter values ∈ [0,1], where 0 means not included, and 1 means included

The parameter 'cap' is multiplied with all inputs of capital goods throughout the product system, and the parameter 'ser' is multiplied with all inputs of services throughout the product system.

3.6 System boundaries

Building blocks in the database

The system boundaries for the building blocks in the database generally represent a cradle to gate perspective. For products and services (excluding electricity, heat and treatment services) the cradle is at the point of raw material acquisition and the gate is when the product leaves the supplier's manufacturing site. For services, such as consultancy and transport the gate is equal to the point where the user of the service receives the service. For physical products, transportation and possibly storage, retail and losses through distribution represent the difference between the manufacturer's gate and the user.

The system boundary for electricity and electricity represents a cradle to grave perspective, i.e. all stages of the life cycle of electricity and heat is included. However, the use and disposal stages are not relevant because this only involves heat losses and diffuse discharge of water from district heating.

The system boundaries for waste treatment activities represent a gate to grave perspective, i.e. the beginning of the life cycle of material for treatment is regarded at the point where the waste is being disposed of/recycled, and the grave is regarded at the point where the material for treatment has:

- been reprocessed into a new product (recycling)
- become emissions
- been deposited in landfill as inert material (after close down of the landfill site)

User specified LCA activities

For the user specified LCA activities, the system boundaries are fully defined by the user.

3.7 Cut-off criteria

The life cycle inventory of the building blocks in the database generally uses a cut-off criterion at 0%. Further the categories of available building blocks also enables the user for operating with the same cut-off criterion for the user specified LCA activities.

The life cycle inventory of the building blocks in the database is organised in a way so that each dataset can be purely divided into:

- Capital goods
- Services
- The rest (this is what is typically always included in life cycle inventories)

This enables for the use of the switches 'cap' and 'ser' (see **section 3.5**) so that capital goods and services can be switched on and off.

It should be noticed that care should be taken when inputs of capital goods and services are entered in user specified LCA activities. All products and services in the database can be present as an input to a user specified LCA activity – also if this can be regarded as capital goods or a service. E.g. inputs of 'Hotels and restaurents' can be entered as an input in the user specified LCA activities. 'Hotels and restaurents' is categoried as a service product. When the switch for services is set to 'exclude services', then only the service inputs to the 'Hotel and restaurents' are excluded in the inventory. A complete exclusion of capital goods inputs and service inputs require that there is no input of this entered in the user specified LCA activities.

3.8 Parameter modelling and relation to background data: ecoinvent, FORWAST database and iLUC

The data for building blocks are to a large extent based on information in the ecoinvent database (ecoinvent 2010). Service inputs and some of the capital goods inputs are generally based on the FORWAST hybrid IO-database (Schmidt 2010a, Schmidt 2010b, and Schmidt et al. 2010). These two databases do not include switches like the ones in the plastberegner.dk tool. Hence the scope of the current study is not compatible with the used databases. This problem is not fully overcome because this would require a full parameterisation of and a significant amount of additional data for the two databases. However, a large number of the activities in ecoinvent have been re-modelled and the electricity input in the entire ecoinvent dataset as well as the FORWAST database is parameterised in order to enable for the switching between marginal electricity mix (used in consequential modelling) versus average electricity mix (used in attributional modelling and PAS2050). This means that the database wide electricity mixes in ecoinvent and FORWAST depend on the switch value m.

The method for incorporating iLUC in the results is based on Schmidt et al. (2012). This model is implemented and linked to the ecoinvent database and the FORWAST hybrid IO database. The model is prepared for applying both attributional and consequential modelling assumptions – so this follows the switch value m. However, it should be noticed that the contribution from iLUC is generally insignificant for the types of products included in the building block database in the plastberegner.dk tool. This is because these products are not related to inputs of biogenic materials which are related to occupation of land.

3.9 Recycling and waste treatment in the different modelling switches

The modelling of waste treatment and hereunder recycling vary significantly among different modelling assumptions. The focus on modelling assumptions for treatment activities become relevant when the activities are associated with material recovery or recovery of other properties of the waste, e.g. energy recovery or volume recovery (i.e. material is used as filler).

In the following the applied modelling assumptions in the three different modelling switches for recycling, incineration and landfill are explained.

ISO 14040/44: The material for treatment (i.e. the waste or scrap) is assumed to be the determining flow of all treatment activities (i.e. recycling, incineration, landfill etc. activities), and any possible recovered material or other by-products are regarded as dependant co-products.

Attributional: The treatment activities are allocated between the service to treat waste and the recovered materials/other recovered by-products. Since it is very difficult to identify a price of the treatment service for recycling, 100% allocation to the recovered material have been applied for all recycling activities. For incineration, economic allocation between waste treatment service and the recovered heat and electricity is applied. For landfill, 100% allocation to the waste treatment service is applied because the economic value of possible recovered landfill biogas is regarded as being insignificant (especially for the waste fractions considered in this study).

PAS2050: Recycling activities are modelled as in the ISO 14040/44 switch mode because the inherent properties of the recycled material are regarded as being not changed – because recovered plastics waste can substitute primary plastics, recovered steel scrap can substitute primary steel etc. This is in accordance with the requirements in PAS2050 (2011, section 8.3). For incineration with energy recovery the full burden of waste treatment and benefits of recovered energy are allocated to the energy output (PAS2005, 2011, section 8.2). For incineration without energy recovery the burden is allocated to the waste being incinerated. For landfill, 100% allocation to the waste treatment service is applied. Recovered landfill biogas is regarded as being insignificant for the waste fractions considered in this study.

Table 3.5: Overview of applied modelling assumptions in the three different modelling switches for recycling, incineration and landfill.

Fuel	ISO 14040/44	Attributional	PAS2050
Recycling	Treatment of waste/scrap is the determining product. By-products are modelled via substitution	0% allocated to treatment of waste/scrap 100% allocated to recovered materials and other by-products	Treatment of waste/scrap is the determining product. By-products are modelled via substitution
Incineration	Treatment of waste/scrap is the determining product. By-products (recovered energy) are modelled via substitution	Economic allocation between treatment of waste/scrap and by-products (recovered energy)	With energy recovery: 100% allocation to energy Without energy recovery: 100% allocation to treatment of waste
Landfill	no or insignificant co-products	no or insignificant co-products	no or insignificant co-products

3.10 Data sources and data quality – special focus on plastics

Generally, the building block database in plastberegner.dk is based on data in the ecoinvent database (ecoinvent 2010) and in the EU27 FORWAST hybrid input-output database (Schmidt 2010a, Schmidt 2010b, and Schmidt et al. 2010). The ecoinvent as well as the FORWAST databases are fully linked and can be transparently viewed in LCA software such as SimaPro.

The most important data quality criterion for life cycle inventory data is that the data are transparently linked so that the modelling switches (consequential, attributional and PAS2050) as well the switches for capital goods and services can be implemented. Further, transparent data are preferred because the data quality can be assessed via sanity checks, cross checks and explorative impact analysis in LCA software that can show all the underlying contributing activities.

The starting point of the data collection is the list of building blocks, see **section 3.4**. For each building block, available data have been searched for in ecoinvent. In cases where sufficient data are not available, an inventory is established based on literature and on ecoinvent for upstream activities. Here the term 'sufficient data' refers to data that meet the quality criterion described above. When sufficient data are identified neither in ecoinvent nor in literature, data are either obtained from the FORWAST database or from 'insufficient' blackbox databases. Data from FORWAST, which is a hybrid input-output database with products at a relatively high degree of aggregation, are only used when a high level of aggregation is in accordance with the nature of the data input. The latter is the case when only little information on the production process is known and when no other more detailed data are available. Examples are inputs such as maintenance of buildings, industrial cleaning, accountants, lawyers, consultancy, business travelling etc.

When applying the approach as described above, it appears that no sufficient data are available for most types of primary plastics and related materials such as resins. Most of the data for primary plastics in ecoinvent, as well as in literature and other LCI databases, are based on Eco-profiles from PlasticsEurope (plasticseurope.org). These data sets are all blackbox data sets, where links between LCA activities and modelling assumptions are not visible in the database. These links and modelling assumptions are only described qualitatively. The consequences of this are:

- the switches regarding modelling assumptions have no effect on the plastics data,
- the product system of the plastics products is inconsistent with the product system of all other products in the database. I.e. the upstream activities in the plastics system (e.g. electricity, oil and gas extraction, refinery products, transportation etc.) are based on different data, modelling assumptions, years, technologies and regions than the other parts of the database, and
- data quality cannot be assessed

This is obviously a problem for a database for plastics products, and it is problematic for the switch on modelling assumption that does not have any effect for the modelling. However, no data on primary plastics that fulfil the data quality criterion have been identified. It is out of the scope of the current study to undertake a detailed life cycle inventory of the production of primary plastics. Hence, the blackbox data from PlasticsEurope are a major source of limited data and modelling quality of the building blocks database in plastberegner.dk.

About ecoinvent

Ecoinvent v2 is the most comprehensive transparent LCA database on the market. The database is fully linked (no black box processes) in LCA software (SimaPro), and the full documentation of all data in ecoinvent are publically available at http://ecoinvent.org/.

About the FORWAST database

FORWAST is a hybrid input-output model. The original FORWAST database includes the following emissions and resource inputs: Emissions to air: ammonia, carbon dioxide, carbon monoxide, methane, nitrogen dioxide, nitrous oxide, NMVOC, sulfer dioxide. Resources: carbon dioxide in air, coal, oil (crude), gas (natural gas), iron, aluminium, copper, nickel, zinc, lead, sand and clay, other minerals (extracted for use), other minerals (related to unused extraction).

The applied FORWAST database is an updated version compared to the original one available in SimaPro and described in the FORWAST reports. Compared to the original version, the updated version also includes iLUC for all activities, it distinguish production outside Denmark between Europe and rest of the world (RoW), and the following emissions have been added to the inventory in the database:

- Particulates, to air

- Nitrate, to water
- Phosphate, to water

The updates of the original FORWAST model are described in Mikkelsen et al. (2011).

It appears that the FORWAST database does not include all relevant emissions. All important greenhouse gas emissions are included, but emissions of toxic substances are generally not included. It should be noticed that the data from the FORWAST database generally account for a minor share of the total transactions/emissions relating to an LCA of plastics products. This is because the FORWAST database is only used to account for services and some capital goods. Therefore, the lack of completeness in terms of included emissions in the FORWAST database is regarded as being of minor importance.

3.11 Conversions between hybrid units

All life cycle inventory data in the building block database are partly based on the existing LCI databases (ecoinvent and FORWAST). In some cases there are differences in the unit of a product flow as entered in the tool, in the ecoinvent database and in the FORWAST database. Therefore, in order to flows that are entered with flows in ecoinvent and FORWAST, it has been necessary to convert between different units.

For fuels, it has been necessary to convert between mass, volume and calorific value. In **Table 3.6** the used conversion factors for this are shown.

Table 3.6: Flow properties used for converting between units.

Fuel	Density	Calorific value (lower)	Reference
Petrol	0.75 kg/litre	42.5 MJ/kg	Jungbluth (2007, p 16)
Diesel	0.84 kg/litre	42.8 MJ/kg	Jungbluth (2007, p 16)
Lubricating oil	0.84 kg/litre	42.8 MJ/kg	Assumed same as diesel
Fuel oil	0.86 kg/litre	42.6 MJ/kg	Jungbluth (2007, p 18)
Natural gas	0.80 kg/Nm^3	36.8 MJ/Nm3	Faist Emmegger et al (2007, p 8)
Coal	-	24.4 MJ/kg	Nielsen et al. (2012, p 840)
Waste (mixed municipal waste for incineration)	-	14.1 MJ/kg	Doka (2009)

For other products the unit of flows also imply monetary units. One example where conversion between units is necessary is when the use of machinery in plastberegner.dk is entered in Danish Kroner (DKK2011). This first has to be corrected for inflation via price indexes to reflect the same prices for which the FORWAST database is valid, i.e. year 2003. Second, the inflation corrected price has to be converted to basic prices[1]. Industry and product specific factors for converting to basic prices are derived from the background data of the FORWAST database. Finally, the basic price needs to be converted from DKK2003 to EUR 2003. This is done by applying the currency exchange rate between DKK and EUR in year 2003. The factors for converting from current purchasers prices in DKK to basic prices in EUR2003 are shown in **Table 3.7** to **Table 3.8**.

The FORWAST database accounts for product flows in EUR2003, kg dry matter or kWh (depending on the nature of the product). In the background data for the FORWAST database price information on the use of products in different industries are available as EUR2003 basic price per kg. Hence, all flows in the FORWAST database can be converted to EUR2003 in basic prices.

In **Table 3.7**, the price indexes are shown for the relevant categories for year 2003 (the year of the FORWAST database) and for 2011 (the most recent year for which data are available). Price indexes for goods are better covered in statistics than services. Price indexes on the general supply (domestic supply and imported products) of products are preferred over consumer price indexes. This is because the latter is special for end-users where taxes and trade margins may deviate from the general use of a product. Therefore, when price indexes on general supply are not available, then consumer price indexes are used. The latter is available for more product categories (i.e. also services) than the first.

[1] When products are purchased, only part of the price goes to the producer of the product. The rest is taxes and trade and transport margins. Purchaser's price minus taxes minus trade and transport margins is equal to basic prices.

Table 3.7:.Price indexes used for correcting for inflation between year 2011 (most recent year) and 2003 (the base year of the FORWAST database). The price indexes are obtained from Danmarks Statistik (2012).

Product	Type of price index	Price index 2003	Price index 2011	Factor to convert from 2011 to 2003 prices
Buildings (purchase, rent, maintenance)	Consumer price index (2000=100)	108	130	0.829
Machinery (purchase, rent, maintenance)	Price index on goods supply (2005=100)	104	93.3	1.12
Vehicles (purchase, rent, maintenance)	Price index on goods supply (2005=100)	97.7	108	0.904
Travel, taxi, bus, train	Consumer price index (2000=100)	111	137	0.811
Travel, ship	Consumer price index (2000=100)	111	137	0.811
Travel, flight	Consumer price index (2000=100)	111	137	0.811
Hotel and restaurants	Consumer price index (2000=100)	108	133	0.811
Post, telecommunication, internet	Consumer price index (2000=100)	94.4	84.6	1.12
Financial intermediation, insurance and pension	Consumer price index (2000=100)	121	131	0.925
Other services (consultants, marketing, IT, accounting etc.)	Consumer price index (2000=100)	109	141	0.772
Paper and paper products	Price index on goods supply (2005=100)	104	108	0.957
Printed and recorded media	Price index on goods supply (2005=100)	104	108	0.957
Office machinery (computers, printers, copy-machines etc.)	Price index on goods supply (2005=100)	103	99.3	1.04
Phones, television etc.	Price index on goods supply (2005=100)	103	99.3	1.04
Furniture and other (office equipment, tables, chairs, lighting etc.)	Price index on goods supply (2005=100)	97.9	111	0.883

In **Table 3.8**, the factors to convert from purchaser's price DKK2011 to basic price EUR2003 are shown. The first factor is from **Table 3.7**, the second factor is obtained from detailed supply use tables provided by Statistics Denmark as background data for the Danish part of the FORWAST database, and the third factor is the currency exchange rate between DKK2003 and EUR2003 which is obtained from Nationalbanken (2012).

Table 3.8:.Factors to convert from purchaser's price DKK2011 to basic price EUR2003.

Product	Factor to convert from 2011 to 2003 prices	Factor to convert from purchasers to basic prices	Factor to convert from DKK2003 to EUR2003	Resulting factor to convert from purchaser's price DKK2011 to basic price EUR2003
Buildings (purchase, rent, maintenance)	0.829	0.979		0.109
Machinery (purchase, rent, maintenance)	1.118	0.899		0.135
Vehicles (purchase, rent, maintenance)	0.904	0.791		0.0962
Travel, taxi, bus, train	0.811	1.03		0.113
Travel, ship	0.811	1.00		0.110
Travel, flight	0.811	0.951		0.104
Hotel and restaurants	0.811	0.803	0.135	0.0877
Post, telecommunication, internet	1.115	1.00		0.150
Financial intermediation, insurance and pension	0.925	0.990		0.123
Other services (consultants, marketing, IT, accounting etc.)	0.772	0.963		0.100
Paper and paper products	0.957	0.911		0.117
Printed and recorded media	0.957	0.981		0.126
Office machinery (computers, printers, copy-machines etc.)	1.039	0.828		0.116
Phones, television etc.	1.039	0.787		0.110
Furniture and other (office equipment, tables, chairs, lighting etc.)	0.883	0.917		0.109

3.12 Life cycle impact assessment (LCIA) method

The method used for LCIA is the Stepwise 2006 method, version 1.3. The method is described and documented in Annex II in Weidema et al. (2008) and in Weidema (2009). This method is developed by picking the best principles of the Danish EDIP 2003 method (Hauschild and Potting 2005) and the Impact 2002+ method (Jolliet et al. 2003).

Generally, inputs and outputs of biogenic CO_2 are considered as having no effect on global warming. The only exception is CO_2 emissions related to indirect land use changes. However, this contribution is generally insignificant for the types of products included in the building block database in the plastberegner.dk tool. This is because these products are not related to inputs of biogenic materials which are related to occupation of land.

4 Building blocks in the plastberegner.dk database

The list of building blocks including meta-data is presented in **chapter 4**. The tables provide information on the product category (see list below), name of building block, unit of reference flow as well as metadata for the data used to model the LCA activities.

The metadata contain data source, information on the year, geographical location and technology the data sets represent. Further the modelling of co-products is described if applicable, and the electricity model used in the upstream system is specified. Generally, two different electricity models are appear in the upstream system; the switch dependant electricity model described in Schmidt et al. (2011), see **section 6.1**, and a blackbox European electricity model adopted from the Eco-profiles from PlasticsEurope when these data are used. The metadata also contain information on the data source and approach for including capital goods and services. Capital goods are obtained either from ecoinvent or from the EU27 FORWAST hybrid input-output database. This is described further in **section 7.2**. For data sets where services are not originally included, services are generally obtained from the EU27 FORWAST hybrid input-output database. This is described further in **section 8.3**. For data sets which are based on the EU27 FORWAST hybrid input-output database, the inputs are divided into capital goods related, service related and other inputs.

Categories of building blocks:

- Materials
  - \Plastics, thermo-
  - \Plastics, foil
  - \Plastics, hardened-
  - \Plastics waste as raw material
  - \Synthetic rubber
  - \Resins
  - \Fiber for composite materials
  - \Hardeners
  - \Solvents
  - \Flame retardants
  - \Metal, non-processed sheets/rods/profiles
  - \Metal, processed cast/extruded/cut/turned
  - \Other materials
- Energy and fuels (incl. combustion)
- Machinery, buildings and vehicles
- Transport, services and overhead
- Waste disposal
  - \Recycling
  - \Incineration
  - \Landfill

Table 4.1: List of included building blocks in the database. The list is supplemented with meta information of the applied data.

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Plastics – thermoplasts									
Polyethylene, HDPE, granulate	Kg	Eco-profile from PlasticsEurope in ecoinvent: Polyethylene, HDPE, granulate, at plant/RER	1999	Europe	Average	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Polyethylene, LDPE, granulate	Kg	Eco-profile from PlasticsEurope in ecoinvent: Polyethylene, LDPE, granulate, at plant/RER U	1999	Europe	Average	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Polyethylene, LLDPE, granulate	Kg	Eco-profile from PlasticsEurope in ecoinvent: Polyethylene, LLDPE, granulate, at plant/RER U	1999	Europe	Average	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Fleece, polyethylene	Kg	ecoinvent: fleece, polyethylene, at plant	1993-1995	Europe	Average	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European mix, **switch** dependant inventory (Schmidt et al. 2011). Electricity in raw material is blackbox from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Polyethylene terephthalate, amorphous	Kg	Eco-profile from PlasticsEurope in ecoinvent: polyethylene terephthalate, granulate, amorphous, at plant	1999	Europe	Average; PET production out of PTA and ethylene gylcol	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Polyethylene terephthalate, bottle grade	Kg	Eco-profile from PlasticsEurope in ecoinvent: polyethylene terephthalate, granulate, bottle grade, at plant	1999	Europe	Average; PET production out of PTA and ethylene glycol	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Polypropylene	Kg	Eco-profile from PlasticsEurope in ecoinvent: polypropylene, granulate, at plant	1999	Europe	Average; polymerization out of propylene	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Plastics – thermoplasts									
Polystyrene, expandable	Kg	Eco-profile from PlasticsEurope in ecoinvent: polystyrene, expandable, at plant	2001-2003	Europe	Average; production by suspension polymerization out of benezene and ethylene	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Polystyrene, general purpose, GPPS	kg	Eco-profile from PlasticsEurope in ecoinvent: polystyrene, general purpose, GPPS, at plant	2001	Europe	Average; polymerization out of ethylene and benzene by free radical processes	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Polystyrene, high impact, HIPS	kg	Eco-profile from PlasticsEurope in ecoinvent: polystyrene, high impact, HIPS, at plant	2001	Europe	Average; polymerization out of ethylene and benzene by free radical processes	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Polyvinylchloride, emulsion polymerised	kg	Eco-profile from PlasticsEurope in ecoinvent: polyvinylchloride, emulsion polymerised, at plant	1998-2001	Europe	Average; production by emulsion polymerization of vinylchloride	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Polyvinylchloride, suspension polymerised	kg	Eco-profile from PlasticsEurope in ecoinvent: polyvinylchloride, suspension polymerised, at plant	1998-2001	Europe	Average; production by suspension of vinylchloride	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Acrylonitrile-butadiene-styrene copolymer, ABS	kg	Eco-profile from PlasticsEurope in ecoinvent: acrylonitrile-butadiene-styrene copolymer, ABS, at plant	1996-2001	Europe	Average; production by emulsion polymerization out of its three monomers	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Plastics – thermoplasts									
Styrene-acrylonitrile copolymer, SAN	kg	Eco-profile from PlasticsEurope in ecoinvent: styrene-acrylonitrile copolymer, SAN, at plant	1996-2001	Europe	Average (2 European production sites); production by different polymerization processes out of its different monomers	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Nylon 6	kg	Eco-profile from PlasticsEurope in ecoinvent: nylon 6, at plant	1993-2001	Europe	Average (3 European production sites); production out of hexamethylene diamine and adipic acid	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Nylon 66	kg	Eco-profile from PlasticsEurope in ecoinvent: nylon 66, at plant	1996-2001	Europe	Average (4 European production sites); production out of hexamethylene diamine and adipic acid	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Polycarbonate	kg	Eco-profile from PlasticsEurope in ecoinvent: polycarbonate, at plant	1996-2001	Europe	Average (3 European production sites); production by interfacial and polycondensatio n out of phosgene and bisphenol A	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Plastics – thermoplasts									
Polymethyl methacrylate, beads	kg	Eco-profile from PlasticsEurope in ecoinvent: polymethyl methacrylate, beads, at plant	1996-2001	Europe	Average (5 European production sites); production by different types of polymerization out of MMA	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Polymethyl methacrylate, sheet	kg	Eco-profile from PlasticsEurope in ecoinvent: polymethyl methacrylate, sheet, at plant	1996-2001	Europe	Average; production by different types of polymerization out of MM	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Polyphenylene sulfide	kg	ecoinvent: polyphenylene sulfide, at plant	1995-2005	GLO	Average; Production from sodium sulfide nonahydrate.	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Tetrafluoroethylene	kg	ecoinvent: tetrafluoroethylene, at plant	1999	Europe	Average	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Ethylene vinyl acetate copolymer	kg	ecoinvent: ethylene vinyl acetate copolymer, at plant	2000	Europe	Average; Production from ethylene and vinyl acetate.	None	European mix, **switch** dependant inventory (Schmidt et al. 2011). Electricity in raw material is blackbox from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Representative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Plastics – foil									
Packaging film, LDPE	kg	ecoinvent: packaging film, LDPE, at plant	1993-1997	Europe	Average European extrusion process; present technologies	Raw materials: Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Tetrafluoroethylene film, on glass	kg	ecoinvent: tetrafluoroethylene film, on glass	2002	Europe	Average European extrusion process; present technologies	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Ethylvinylacetate, foil, at plant	kg	ecoinvent: ethylvinylacetate, foil, at plant	1993-1997	Europe	Average European extrusion process; present technologies	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Materials\Plastics – hardened									
Polyurethane, flexible foam	kg	ecoinvent: polyurethane, flexible foam, at plant	1997	Europe	Average	Raw materials: Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European mix, **switch** dependant inventory (Schmidt et al. 2011). Electricity in raw material is blackbox from Eco-profile from PlasticsEurope	ecoinvent, capital goods in production of raw materials not included	EU27 IO-database
Polyurethane, rigid foam	kg	ecoinvent: polyurethane, rigid foam, at plant	1997	Europe	Average	Raw materials: Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European mix, **switch** dependant inventory (Schmidt et al. 2011). Electricity in raw material is blackbox from Eco-profile from PlasticsEurope	ecoinvent, capital goods in production of raw materials not included	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Representative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Plastics waste as raw material									
Scrap, polyethylene (PE)	kg	Specifically modelled, see **section 5.4**	2000-2010	Denmark	Average	CLCA and PAS2050: allocation avoided, ALCA: 0% allocation to waste	European mix, **switch** dependant inventory (Schmidt et al. 2011)	EU27 IO-database	EU27 IO-database
Scrap, polypropylene (PP)	kg	Specifically modelled, see **section 5.4**	2000-2010	Denmark	Average	CLCA and PAS2050: allocation avoided, ALCA: 0% allocation to waste	Danish mix, **switch** dependant inventory (Schmidt et al. 2011). Electricity in raw material is blackbox from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Scrap, polystyrene (PS)	kg	Specifically modelled, see **section 5.4**	2000-2010	Denmark	Average	CLCA and PAS2050: allocation avoided, ALCA: 0% allocation to waste	Danish mix, **switch** dependant inventory (Schmidt et al. 2011). Electricity in raw material is blackbox from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Scrap, polyethylene terephthalate (PET)	kg	Specifically modelled, see **section 5.4**	2000-2010	Denmark	Average	CLCA and PAS2050: allocation avoided, ALCA: 0% allocation to waste	Danish mix, **switch** dependant inventory (Schmidt et al. 2011). Electricity in raw material is blackbox from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Representative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Plastics waste as raw material									
Scrap, acrylonitrile-butadiene-styrene copolymer (ABS)	kg	Specifically modelled, see **section 5.4**	2000-2010	Denmark	Average	CLCA and PAS2050: allocation avoided, ALCA: 0% allocation to waste	Danish mix, **switch** dependant inventory (Schmidt et al. 2011). Electricity in raw material is blackbox from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Scrap, styrene-acrylonitrile copolymer (SAN)	kg	Specifically modelled, see **section 5.4**	2000-2010	Denmark	Average	CLCA and PAS2050: allocation avoided, ALCA: 0% allocation to waste	Danish mix, **switch** dependant inventory (Schmidt et al. 2011). Electricity in raw material is blackbox from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Scrap, polyvinylchloride (PVC)	kg	Specifically modelled, see **section 5.4**	2000-2010	Denmark	Average	CLCA and PAS2050: allocation avoided, ALCA: 0% allocation to waste	Danish mix, **switch** dependant inventory (Schmidt et al. 2011). Electricity in raw material is blackbox from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Scrap, other plastics	kg	Specifically modelled, see **section 5.4**	2000-2010	Denmark	Average	CLCA and PAS2050: allocation avoided, ALCA: 0% allocation to waste	Danish mix, **switch** dependant inventory (Schmidt et al. 2011). Electricity in raw material is blackbox from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Synthetic rubber									
Ethylene Propylene Diene Monomer, EPDM	kg	ecoinvent: synthetic rubber, at plant	1995-2003	Europe	This module refers to the EPDM elastomer as it is used in technical products. Ziegler-Natter solution polymerisation of EPDM.	Raw materials: Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European mix, **switch** dependant inventory (Schmidt et al. 2011). Electricity in raw material is blackbox from Eco-profile from PlasticsEurope	ecoinvent	EU27 IO-database
Polybutadiene	kg	Eco-profile from PlasticsEurope in ecoinvent: polybutadiene, at plant	2001	Europe	Average (2 European production sites); graft-based polybutadiene - produced out of butadiene	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Resins									
Unsaturated Polyester	kg	ecoinvent: polyester resin, unsaturated, at plant	1995-2002	Europe	Average; data represents a mix of most often used substances for the production of polyester resin	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Vinylester	kg	Eco-profile from PlasticsEurope in ecoinvent: Epoxy resin, liquid, at plant/RER	1994	Europe	Represented by data for Epoxy resin.	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
MMA - Methylmetacrylate	kg	Eco-profile from PlasticsEurope in ecoinvent: methyl methacrylate, at plant	1996-2001	Europe	Average (5 European production sites); product out of hydrogen cyanide and acetone	None	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Bisphenol-A epichlorhydrine	kg	ecoinvent: bisphenol A, powder, at plant	2000	Europe	Average; Production by catalysed condensation of phenol and acetone	none	European mix, swich dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Phenolic resins	kg	ecoinvent: phenolic resin, at plant	2000	Europe	Average; Production from phenol and formaldehyde.	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Epoxy resin	kg	Eco-profile from PlasticsEurope in ecoinvent: Epoxy resin, liquid, at plant/RER	1994	Europe	Average (3 European production sites); production by interfacial and polycondensation	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Fiber for composite materials									
Glass and glass rovings	kg	ecoinvent: glass fibre, at plant	2000	Europe	Average	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Carbon fiber and carbon fiber rovings	kg	Specificly modelled, see **section 5.7**	2000-2010	Global	Average	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Materials\Hardeners									
Anhydride hardener	kg	ecoinvent: phthalic anhydride, at plant	1995	Europe	Average; Data used are based on a Dutch and US study.	Raw materials: Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European mix, **switch** dependant inventory (Schmidt et al. 2011). Electricity in raw material is blackbox from Eco-profile from PlasticsEurope	ecoinvent	EU27 IO-database
Polyetherpolyol	kg	Eco-profile from PlasticsEurope in ecoinvent: polyols, at plant	1995-2001	Europe	Average; production out of alcohols and epoxides by alkoxylation	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Isocyanate - toluene diisocyanate	kg	Eco-profile from PlasticsEurope in ecoinvent: toluene diisocyanate, at plant	1995-2001	Europe	Average (3 European production sites, D,F, I); production out of phosgene, toluene and hydrogen	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Hardeners									
Isocyanate - methylene diphenyl diisocyanate	kg	Eco-profile from PlasticsEurope in ecoinvent: methylene diphenyl diisocyanate, at plant	1995-2001	Europe	Average (5 European production sites B,D,I, NL); production out of phosgene, aniline and formaldehyde	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Amine hardener (TETA)	kg	ecoinvent: trimethylamine, at plant	unknown	Europe	Average; Production from vaporised methanol and ammonia.	100% allocation to trimethylamine. Co-produced with di-methylamine and mono-methylamine.	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Hardener for fenol system (hexamine)	kg	No specific LCI data have been identified. LCI data on methylene diphenyl diisocyanate (Isocyanate) are assumed to be representative for hardener for phenol resin (hexamine). ecoinvent: methylene diphenyl diisocyanate, at plant	1995-2001	Europe	Average (5 European production sites B,D,I, NL); production out of phosgene, aniline and formaldehyde	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Materials\Solvents									
Acetone	kg	Eco-profile from PlasticsEurope in ecoinvent: acetone, liquid, at plant	1992-2002	Europe	Average (3 European plants - NL, D); production of oxidation of cumene	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database
Styrene	kg	Eco-profile from PlasticsEurope in ecoinvent: styrene, at plant	1995-2002	Europe	Average; mixture of process od dehydrogenation of ethyl benzene and oxirane process	Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European average (blackbox) adopted from Eco-profile from PlasticsEurope	EU27 IO-database	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Flame retardants									
ATO – antimony trioxide	kg	No specific LCI data have been identified. LCI data on antimony are assumed to be representative for antimony trioxide. ecoinvent: Antimony, at refinery/CN	unknown	China	Mixture of blast furnace, rotry kiln and electrowinning process.	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Chloro paraffin	kg	Based on Back et al. (1994, p 19) it has be estimated that chloro paraffin is composed of 50% paraffin and 50% chlorine. The LCI data are obtained from ecoinvent as 'Paraffin, at plant/RER' and 'Chlorine, gaseous, membrane cell, at plant/RER'.	1995	Europe	The chlorine production route (membrane) represents modern technology. Paraffin is produced with average technology.	Multiple outputs from the production of choride (co-produced with sodium hydroxide and hydrogen) and paraffin are allocated by mass in the ecoinvent data sets.	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
ATH – aluminiumtrihydroxide	kg	ecoinvent: aluminium hydroxide, at plant	1995-2002	Europe	Average; Some Swiss datasets are used for European processes.	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Metal, non-processed sheets/rods/profiles									
Steel, non-alloyed	kg	Based on modified LCA data from ecoinvent: Steel, converter, unalloyed, at plant/RER. The modifications are described in **section 5.11**	2001-2002	Europe	CLCA & PAS2050: Blast furnace technology, ALCA: Mix of blast furnace and electric arc furnace (reprocessing of iron scrap)	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Steel, low-alloyed	kg	Based on modified LCA data from ecoinvent: Steel, converter, low-alloyed, at plant/RER. The modifications are described in **section 5.11**	2001-2002	Europe	CLCA & PAS2050: Blast furnace technology, ALCA: Mix of blast furnace and electric arc furnace (reprocessing of iron scrap)	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Steel, stainless	kg	ecoinvent: Steel, converter, chromium steel 18/8, at plant/RER	2001-2002	Europe	Primary stainless steel using blast furnace technology	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Metal, non-processed sheets/rods/profiles									
Cast iron	kg	Based on modified LCA data from ecoinvent: Cast iron, at plant/RER. The modifications are described in **section 5.11**	2001-2002	Europe	CLCA & PAS2050: Blast furnace technology, ALCA: Mix of blast furnace and electric arc furnace (reprocessing of iron scrap)	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Aluminium	kg	Based on modified LCA data from ecoinvent: Aluminium, production mix, at plant/RER and Aluminium, primary, liquid, at plant/RER. The modifications are described in **section 5.11**	1995-2002	Europe	CLCA & PAS2050: Hall-Herould cells & Pre-bake carbon anodes, ALCA: mix of Hall-Herould cells & Pre-bake carbon anodes and re-processing of alu scrap	None	Aluminium industry mix, **switch** dependant inventory. See **section 5.11**	ecoinvent	EU27 IO-database
Copper	kg	Based on modified LCA data from ecoinvent: Copper concentrate, at beneficiation/GLO and Copper, secondary, at refinery/RER. The modifications are described in **section 5.11**	1994	Global	CLCA & PAS2050: primary copper, ALCA: mix of primary copper and re-processing of copper scrap	Primary copper: Copper ore contains molybdenite. Economic based allocation	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Metal, non-processed sheets/rods/profiles									
Lead	kg	Based on modified LCA data from ecoinvent: Lead, at regional storage/RER. The modifications are described in **section 5.11**	1990-2000	Global	CLCA & PAS2050: primary copper, ALCA: mix of primary copper and re-processing of copper scrap	Primary lead: lead ore contains silver. Economic based allocation	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Zinc	kg	ecoinvent: Zinc, primary, at regional storage/RER	1990-2000	Europe	Primary zinc	Zinc ore contains inidium and cadmium. Economic based allocation	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Nickel	kg	ecoinvent: Nickel, 99.5%, at plant/GLO	1994	Global	Primary nickel	Coupled production with copper. Economic based allocation.	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Metal, processed cast/extruded/cut/turned									
Steel, processed	kg	Based on modified LCA data from ecoinvent: Steel product manufacturing, average metal working/RER. The modifications are described in **section 5.12**	2002-2005	Europe	Average	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Steel, stainless, processed	kg	Based on modified LCA data from ecoinvent: Chromium steel product manufacturing, average metal working/RER. The modifications are described in **section 5.12**	2002-2005	Europe	Average	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Aluminium, processed	kg	Based on modified LCA data from ecoinvent: Aluminium product manufacturing, average metal working/RER. The modifications are described in **section 5.12**	2002-2005	Europe	Average	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Materials\Other materials									
Epoxy adhesive	kg	ecoinvent: adhesive for metals, at plant	1996-2001	Germany	Average; Data retrieved from a safety data sheet by a German producer.	Raw materials: Mass allocation (blackbox) adopted from Eco-profile from PlasticsEurope	European mix, **switch** dependant inventory (Schmidt et al. 2011). Electricity in raw material is blackbox from Eco-profile from PlasticsEurope	ecoinvent	EU27 IO-database
Varnish, acrylic	kg	ecoinvent: acrylic varnish, 87.5% in H2O, at plant	2012; indicates a literature source von Däniken et al. 1995	Europe	Unknown	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Other materials									
Get-coat	kg	Composition based on Throne (1996, p 391). The LCI data set is described in **section 5.13**	1990s	Not specified	Typical gel-coat recipe	None	European average (blackbox) adopted from ecoinvent.	EU27 IO-database	EU27 IO-database
Pigment, titanium dioxide	kg	ecoinvent: Titanium dioxide, production mix, at plant/RER	1995-2000	Europe	Various plants in Europe	None	European average (blackbox) adopted from ecoinvent.	ecoinvent	EU27 IO-database
Pigment, carbon black	kg	ecoinvent: Carbon black, at plant/GLO	1995-2006	Global	Average	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Filler (chalc) (calcium carbonate)	kg	ecoinvent: limestone, milled, packed, at plant	2000-2002	Switzerland	Data are from only one company in Switzerland.	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Bitumen	kg	ecoinvent: bitumen, at refinery/RER	2000	Europe	Average	Raw material: Energy allocation between refinery products	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Oxidised bitumen	kg	Based on Eurobitume (2011) and the ecoinvent activity: bitumen, at refinery/RER. The LCI data set is described in **section 5.13**	2010	Europe	Average	Raw material: Energy allocation between refinery products	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Materials\Other materials									
Paper and cardboard (packaging)	kg	Based on modified LCA data from ecoinvent: Packaging, corrugated board, mixed fibre, single wall, at plant/RER. The modifications are described in **section 5.13**	1995-2005	Europe	Average of primary paper	Co-produced with minor electricity and heat. 100% allocation to paper	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
EUR pallet	units	ecoinvent: EUR-flat pallet/RER U	unknown	Europe	Average	Raw material (wood) is allocated between timber qualities	Danish mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	DK IO-database
Water, tap	liter	ecoinvent: Tap water, at user/RER	2007	Infrastructure: Switzerland, Energy use: Germany	Average: 45% river, 18% lake, and 36% ground water as in Switzerland.	None	Danish mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	DK IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Energy and fuels (incl. combustion)									
Electricity	kWh	Based on Schmidt et al. (2011)	2008-2020 depending on switch	Denmark	Average and marginal depending on switch	None	Danish mix, switch dependant inventory (Schmidt et al. 2011)	ecoinvent	DK IO-database
District heating	MJ	Same methodology as for electricity. The inventory is described in **section 6.2**	2008-2020 depending on switch	Denmark	Average and marginal depending on switch	The major co-product is electricity. Co-products are modelled as substitution and allocation depending on switch.	Danish mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	DK IO-database
Fuel oil	MJ	ecoinvent: light fuel oil, burned in industrial furnace 1MW, non-modulating/RER	1990s	Europe	Average; Average non-modulating, non-condensing furnace used in 2000.	Raw material: Energy allocation between refinery products	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Natural gas	MJ	ecoinvent: Natural gas, burned in industrial furnace >100kW/RER	2000	Europe	Average; Extrapolation from Switzerland to Europe (RER); Fan burners on market (modulating or non-modulating, non-condensing)	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Coal	MJ	ecoinvent: hard coal, burned in industrial furnace 1-10MW/RER	1988-1992	Europe	Average; Stoker boiler used as reference technology	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Energy and fuels (incl. combustion)									
Petrol	litre	Fuel is obtained from ecoinvent: petrol, unleaded, at regional storage/RER. Converted to litre (see **Table 3.6**). Combustion of fuel is based on ecoinvent: Operation, passenger car, petrol, fleet average 2010/RER	2000; Split up of NMVOC emissions published 1989.	Europe	Average; Surveys mainly for DE and CH; Distribution of petroleum products.	Raw material: Energy allocation between refinery products	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Diesel	litre	Fuel is obtained from ecoinvent: diesel, at regional storage/RER. Converted to litre (see **Table 3.6**). Combustion of fuel is based on ecoinvent: Operation, lorry 3.5-16t, fleet average/RER	2000; Split up of NMVOC emissions published 1989.	Europe	Average; Surveys mainly for DE and CH; Distribution of petroleum products.	Raw material: Energy allocation between refinery products	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Lubricants	litre	Lubricant is obtained from ecoinvent: lubricating oil, at plant/RER. Converted to litre (see **Table 3.6**). Combustion/degradation of lubricant is assumed to similar as to combustion of diesel.	2000; date of published literature	Europe	Average; Production out of diesel by hydrocracking, followed by distillation and dewaxing.	Raw material: Energy allocation between refinery products	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Machinery, buildings and vehicles									
Buildings	DKK	FORWAST hybrid IO. Purchasers price in DKK2011 is corrected for inflation, taxes, trade and transport margins, and currency to reflect EUR2003 in basic prices	2003	Danish market	Average	Substitution for any by-products	Schmidt et al. (2011) is implemented in the FORWAST hybrid IO database	FORWAST hybrid IO capital goods product categories	FORWAST hybrid IO Service product categories
Machinery	DKK	FORWAST hybrid IO. Purchasers price in DKK2011 is corrected for inflation, taxes, trade and transport margins, currency to reflect EUR2003 in basic prices. This is converted to kg by use of price.	2003	Danish market	Average	Substitution for any by-products	Schmidt et al. (2011) is implemented in the FORWAST hybrid IO database	FORWAST hybrid IO capital goods product categories	FORWAST hybrid IO Service product categories
Vehicles (cars/vans/lorries)	DKK	FORWAST hybrid IO. Purchasers price in DKK2011 is corrected for inflation, taxes, trade and transport margins, and currency to reflect EUR2003 in basic prices	2003	Danish market	Average	Substitution for any by-products	Schmidt et al. (2011) is implemented in the FORWAST hybrid IO database	FORWAST hybrid IO capital goods product categories	FORWAST hybrid IO Service product categories

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Transport, services and overhead									
Transport, van	tkm	ecoinvent: transport, van <3.5t	2005	Europe	Average; vehicle operation and road infrastructure reflect Swiss conditions. Vehicle manufacturing and maintenance represents European data.	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Transport, lorry (3,5-16 t)	tkm	ecoinvent: transport, lorry 3.5-16t, fleet average	2005	Europe	Average; vehicle operation and road infrastructure reflect Swiss conditions. Vehicle manufacturing and maintenance represents European data.	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Transport, lorry (16-32 t)	tkm	ecoinvent: transport, lorry 16-32t, EURO5	2005	Europe	Average; vehicle operation and road infrastructure reflect Swiss conditions. Vehicle manufacturing and maintenance represents European data.	None	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Transport, services and overhead									
Travel, taxi	DKK	FORWAST hybrid IO. Purchasers price in DKK2011 is corrected for inflation, taxes, trade and transport margins, and currency to reflect EUR2003 in basic prices	2003	Danish market	Average	Substitution for any by-products	Schmidt et al. (2011) is implemented in the FORWAST hybrid IO database	FORWAST hybrid IO capital goods product categories	FORWAST hybrid IO Service product categories
Travel, train	DKK	FORWAST hybrid IO. Purchasers price in DKK2011 is corrected for inflation, taxes, trade and transport margins, and currency to reflect EUR2003 in basic prices	2003	Danish market	Average	Substitution for any by-products	Schmidt et al. (2011) is implemented in the FORWAST hybrid IO database	FORWAST hybrid IO capital goods product categories	FORWAST hybrid IO Service product categories
Travel, air transportation	DKK	FORWAST hybrid IO. Purchasers price in DKK2011 is corrected for inflation, taxes, trade and transport margins, and currency to reflect EUR2003 in basic prices	2003	Danish market	Average	Substitution for any by-products	Schmidt et al. (2011) is implemented in the FORWAST hybrid IO database	FORWAST hybrid IO capital goods product categories	FORWAST hybrid IO Service product categories
Hotel and restaurent	DKK	FORWAST hybrid IO. Purchasers price in DKK2011 is corrected for inflation, taxes, trade and transport margins, and currency to reflect EUR2003 in basic prices	2003	Danish market	Average	Substitution for any by-products	Schmidt et al. (2011) is implemented in the FORWAST hybrid IO database	FORWAST hybrid IO capital goods product categories	FORWAST hybrid IO Service product categories
Post, telecommunication, internet	DKK	FORWAST hybrid IO. Purchasers price in DKK2011 is corrected for inflation, taxes, trade and transport margins, and currency to reflect EUR2003 in basic prices	2003	Danish market	Average	Substitution for any by-products	Schmidt et al. (2011) is implemented in the FORWAST hybrid IO database	FORWAST hybrid IO capital goods product categories	FORWAST hybrid IO Service product categories

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Transport, services and overhead									
Financial and other intermediation	DKK	FORWAST hybrid IO. Purchasers price in DKK2011 is corrected for inflation, taxes, trade and transport margins, and currency to reflect EUR2003 in basic prices	2003	Danish market	Average	Substitution for any by-products	Schmidt et al. (2011) is implemented in the FORWAST hybrid IO database	FORWAST hybrid IO capital goods product categories	FORWAST hybrid IO Service product categories
Business services (accounting, marketing, consultants etc.)	DKK	FORWAST hybrid IO. Purchasers price in DKK2011 is corrected for inflation, taxes, trade and transport margins, and currency to reflect EUR2003 in basic prices	2003	Danish market	Average	Substitution for any by-products	Schmidt et al. (2011) is implemented in the FORWAST hybrid IO database	FORWAST hybrid IO capital goods product categories	FORWAST hybrid IO Service product categories
Paper and paper products	DKK	FORWAST hybrid IO. Purchasers price in DKK2011 is corrected for inflation, taxes, trade and transport margins, currency to reflect EUR2003 in basic prices. This is converted to kg by use of price.	2003	Danish market	Average	Substitution for any by-products	Schmidt et al. (2011) is implemented in the FORWAST hybrid IO database	FORWAST hybrid IO capital goods product categories	FORWAST hybrid IO Service product categories
Printed matter and recorded media	DKK	FORWAST hybrid IO. Purchasers price in DKK2011 is corrected for inflation, taxes, trade and transport margins, currency to reflect EUR2003 in basic prices. This is converted to kg by use of price.	2003	Danish market	Average	Substitution for any by-products	Schmidt et al. (2011) is implemented in the FORWAST hybrid IO database	FORWAST hybrid IO capital goods product categories	FORWAST hybrid IO Service product categories
Office machinery (computers, printers, copy machines etc.)	DKK	FORWAST hybrid IO. Purchasers price in DKK2011 is corrected for inflation, taxes, trade and transport margins, currency to reflect EUR2003 in basic prices. This is converted to kg by use of price.	2003	Danish market	Average	Substitution for any by-products	Schmidt et al. (2011) is implemented in the FORWAST hybrid IO database	FORWAST hybrid IO capital goods product categories	FORWAST hybrid IO Service product categories

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Transport, services and overhead									
Phones, televisions, projectors etc.	DKK	FORWAST hybrid IO. Purchasers price in DKK2011 is corrected for inflation, taxes, trade and transport margins, currency to reflect EUR2003 in basic prices. This is converted to kg by use of price.	2003	Danish market	Average	Substitution for any by-products	Schmidt et al. (2011) is implemented in the FORWAST hybrid IO database	FORWAST hybrid IO capital goods product categories	FORWAST hybrid IO Service product categories
Furniture and other overhead articles	DKK	FORWAST hybrid IO. Purchasers price in DKK2011 is corrected for inflation, taxes, trade and transport margins, currency to reflect EUR2003 in basic prices. This is converted to kg by use of price.	2003	Danish market	Average	Substitution for any by-products	Schmidt et al. (2011) is implemented in the FORWAST hybrid IO database	FORWAST hybrid IO capital goods product categories	FORWAST hybrid IO Service product categories

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Waste disposal\recycling									
Scrap, polyethylen (PE) to recycling	kg	Based on Schmidt (2005, p 105). See **section 9.1**	1995-2008	50% Denmark and 50% China	Average	CLCA & PAS2050: 100% allocation to treatment of waste including substituted primary materials, ALCA: 0% allocated to treatment.	European mix, **switch** dependant inventory (Schmidt et al. 2011)	EU27 IO-database	EU27 IO-database
Scrap, polypropylen (PP) to recycling	kg	Based on Schmidt (2005, p 105). See **section 9.1**	1995-2008	50% Denmark and 50% China	Average	CLCA & PAS2050: 100% allocation to treatment of waste including substituted primary materials, ALCA: 0% allocated to treatment.	European mix, **switch** dependant inventory (Schmidt et al. 2011)	EU27 IO-database	EU27 IO-database
Scrap, polystyren (PS) to recycling	kg	Based on Schmidt (2005, p 105). See **section 9.1**	1995-2008	50% Denmark and 50% China	Average	CLCA & PAS2050: 100% allocation to treatment of waste including substituted primary materials, ALCA: 0% allocated to treatment.	European mix, **switch** dependant inventory (Schmidt et al. 2011)	EU27 IO-database	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Waste disposal\recycling									
Scrap, polyethylen terephthalat (PET) to recycling	kg	Based on Schmidt (2005, p 105). See **section 9.1**	1995-2008	50% Denmark and 50% China	Average	CLCA & PAS2050: 100% allocation to treatment of waste including substituted primary materials, ALCA: 0% allocated to treatment.	European mix, **switch** dependant inventory (Schmidt et al. 2011)	EU27 IO-database	EU27 IO-database
Scrap, acrylonitrile-butadiene-styren copolymer (ABS) to recycling	kg	Based on Schmidt (2005, p 105). See **section 9.1**	1995-2008	50% Denmark and 50% China	Average	CLCA & PAS2050: 100% allocation to treatment of waste including substituted primary materials, ALCA: 0% allocated to treatment.	European mix, **switch** dependant inventory (Schmidt et al. 2011)	EU27 IO-database	EU27 IO-database
Scrap, styrene-acrylonitril copolymer (SAN) to recycling	kg	Based on Schmidt (2005, p 105). See **section 9.1**	1995-2008	50% Denmark and 50% China	Average	CLCA & PAS2050: 100% allocation to treatment of waste including substituted primary materials, ALCA: 0% allocated to treatment.	European mix, **switch** dependant inventory (Schmidt et al. 2011)	EU27 IO-database	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Waste disposal\recycling									
Scrap, polyvinylchlorid (PVC) to recycling	kg	Based on Schmidt (2005, p 105). See **section 9.1**	1995-2008	50% Denmark and 50% China	Average	CLCA & PAS2050: 100% allocation to treatment of waste including substituted primary materials, ALCA: 0% allocated to treatment.	European mix, **switch** dependant inventory (Schmidt et al. 2011)	EU27 IO-database	EU27 IO-database
Scrap, other plastics to recycling	kg	Based on Schmidt (2005, p 105). See **section 9.1**	1995-2008	50% Denmark and 50% China	Average	CLCA & PAS2050: 100% allocation to treatment of waste including substituted primary materials, ALCA: 0% allocated to treatment.	European mix, **switch** dependant inventory (Schmidt et al. 2011)	EU27 IO-database	EU27 IO-database
Paper waste to recycling	kg	Based on ecoinvent: Corrugated board base paper, testliner, at plant/RER. Original ecoinvent activity modified, see **section 9.1**	2005	Europe	Average	CLCA & PAS2050: 100% allocation to treatment of waste including substituted primary materials, ALCA: 0% allocated to treatment.	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Waste disposal\recycling									
Iron and steel waste to recycling	kg	Based on ecoinvent: Steel, electric, un- and low-alloyed, at plant/RER. Original ecoinvent activity modified, see **section 9.1**	2002-2005	Europe	Average	CLCA & PAS2050: 100% allocation to treatment of waste including substituted primary materials, ALCA: 0% allocated to treatment.	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Aluminium waste to recycling	kg	Based on ecoinvent: Aluminium, secondary, from old scrap, at plant/RER. Original ecoinvent activity modified, see **section 9.1**	2002-2005	Europe	Average	CLCA & PAS2050: 100% allocation to treatment of waste including substituted primary materials, ALCA: 0% allocated to treatment.	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Other metal waste to recycling	kg	Based one coinvent: Copper, secondary, at refinery/RER. Original ecoinvent activity modified, see **section 9.1**	1990-2000	Germany	Average: One large plant	CLCA & PAS2050: 100% allocation to treatment of waste including substituted primary materials, ALCA: 0% allocated to treatment.	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Waste disposal\recycling									
Inert waste to recycling (used as filler material)	kg	Based on parts of ecoinvent activity: Gravel, crushed, at mine/CH. Only the parts of the activity that relates to the crushing is included. See **section 9.1**	1997-2001	Switzerland	Average	CLCA & PAS2050: 100% allocation to treatment of waste including substituted primary materials, ALCA: 0% allocated to treatment.	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Waste disposal\incineration									
Plastics waste, exclusive PVC, to incineration	kg	Based on ecoinvent: Disposal, polyethylene, 0.4% water, to municipal incineration/CH. Modified to include co-generation of electricity and heat, see **section 9.2**	1995-2008	Switzerland (incineration process) and Denmark (energy recovery efficiencies)	Average: Electrostatic precipitator and wet flue gas scrubber.	CLCA: 100% allocation to treatment of waste including substituted electricity and heat, ALCA: economic allocation between treatment, electricity and heat, PAS2050: 0% allocation to waste treatment.	Danish mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Plastics waste, PVC, to incineration	kg	Based on ecoinvent: Disposal, polyvinylchloride, 0.2% water, to municipal incineration/CH. Modified to include co-generation of electricity and heat, see **section 9.2**	1995-2008	Switzerland (incineration process) and Denmark (energy recovery efficiencies)	Average: Electrostatic precipitator and wet flue gas scrubber.		Danish mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Waste disposal\incineration									
Paper waste to incineration	kg	Based on ecoinvent: ecoinvent: Disposal, paper, 11.2% water, to municipal incineration/CH. Modified to include co-generation of electricity and heat, see **section 9.2**	1995-2008	Switzerland (incineration process) and Denmark (energy recovery efficiencies)	Average: Electrostatic precipitator and wet flue gas scrubber.	CLCA: 100% allocation to treatment of waste including substituted electricity and heat, ALCA: economic allocation between treatment, electricity and heat, PAS2050: 0% allocation to waste treatment.	Danish mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Iron and steel waste to incineration	kg	ecoinvent: Disposal, steel, 0% water, to municipal incineration/CH	1995-2005	Switzerland	Average: Electrostatic precipitator and wet flue gas scrubber.	none	Danish mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Aluminium waste to incineration	kg	ecoinvent: Disposal, aluminium, 0% water, to municipal incineration/CH	1995-2005	Switzerland	Average: Electrostatic precipitator and wet flue gas scrubber.	none	Danish mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Other metal waste to incineration	kg	ecoinvent: Disposal, copper, 0% water, to municipal incineration/CH	1995-2005	Switzerland	Average: Electrostatic precipitator and wet flue gas scrubber.	none	Danish mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Inert waste to incineration	kg	ecoinvent: Disposal, glass, 0% water, to municipal incineration/CH	1995-2005	Switzerland	Average: Electrostatic precipitator and wet flue gas scrubber.	none	Danish mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database

Products in Database	Unit	Main data sources	Represen-tative year	Represen-tative region	Represen-tative technology	Modelling of multiple product outputs	Electricity model	Capital goods	Services
Waste disposal\landfill									
Plastics, metal and other inert waste to landfill	kg	ecoinvent: Disposal, inert waste, 5% water, to inert material landfill/CH	2000	Switzerland	Sanitary landfill with base seal, and collection and treatment of leachate.	none	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database
Paper waste to landfill	kg	ecoinvent: Disposal, paper, 11.2% water, to sanitary landfill/CH	2000	Switzerland	Sanitary landfill with base seal, and collection and treatment of leachate.	none	European mix, **switch** dependant inventory (Schmidt et al. 2011)	ecoinvent	EU27 IO-database

5 Life cycle inventory of materials

This chapter describes the life cycle inventory of materials in the building block database in plastberegner.dk. LCI data are only described if **chapter 4** does not provide a full transparent documentation, i.e. when new life cycle inventories have been constructed based on literature etc.

5.1 Materials\Plastics, thermo-

Full documentation in **chapter 4**.

5.2 Materials\Plastics, foil

Full documentation in **chapter 4**.

5.3 Materials\Plastics, hardened-

Full documentation in **chapter 4**.

5.4 Materials\Plastics waste as raw material

Building blocks belonging to the 'Plastics waste as raw material' are relevant for recycling/reprocessing industries only, i.e. industries that treat waste/scrap into new products. The building blocks cover the environmental impacts related to the use of plastic scrap.

When plastics waste is used as a raw material, i.e. when it is reprocessed into new plastics, the modelling is highly affected by the modelling switch. Generally, the market for reprocessed plastics waste and virgin plastics is not considered as two different markets because the products are substitutable. Further, it is assumed that the amount of plastics waste collected for recycling is determined by the end-of-life fate of products and not by the demand for reprocessed plastics waste.

In the ISO 14040/44 switch the default assumption is that the use of collected plastics waste will not affected the amount of plastics waste collected for recycling. Hence, the marginal effect will be that virgin plastics are affected. This is because if one actor in the market uses the collected plastics waste, then less collected plastics waste is available for other actors in the market. It should be noticed, that the 1 kg plastic scrap is not equivalent to 1 kg virgin plastics. This is because impurities etc. cause that the reprocessing is associated with losses. Material recovery efficiencies for different plastic scrap types have been review in Schmidt (2005), Arena et al. (2003) and Shonfield (2010). Based on the review a recycling efficiency at 88% as of Shonfield (2010) is applied for all scrap types. A material recovery efficiency of 88% means that 1 kg scrap is reprocessed into 0.88 kg new plastics and 0.12 kg processing waste. Hence the LCA activity for 1 kg plastics scrap also includes -0.12 kg disposal of plastics waste. As described in **chapter 9.1**, it is assumed that a change in the use of collected plastic scrap in Denmark will affect the 50% domestic recycling and 50% export of recyclable scrap. It is assumed that the waste disposal of process waste from the substituted domestic recycling is incineration with energy recovery and that the process waste from substituted abroad recycling is landfill. It should be noticed that the industry that uses plastic scrap, i.e. where inputs of the building blocks described in this section are entered, shall enter data on the actual amounts of process waste (wastes in the reprocessing activity) that is sent to disposal. The inventory data used for the ISO 14040/44 modelling switch are presented in **Table 5.1**.

In the attributional switch mode, constraints on the collected and sorted plastics waste are not considered. Hence, the effects of using collected and sorted plastics waste are the inputs of fuels etc. required for the sorting, collection and transport to a scrap dealer. Data on this are based on the ecoinvent activity: 'Polystyrene scrap, old, at plant/CH' which includes fuels, vehicles, maintenance of vehicles and infrastructure related to transport, see **section 3.9**.

In the PAS2050 switch mode, modelling is equal to ISO 14040/44, see **section 3.9**.

Table 5.1: Applied LCI-data for the use of 1 kg plastic scrap as a raw material. Where more than one input of virgin plastics are specified, the average of the ones shown is applied.

Plastics waste used as raw material	Virgin plastics	Incineration and landfill
Polyethylen (PE)	0.88 kg average of: Polyetylen, HDPE, granulat Polyethylen, LDPE, granulat Polyethylen, LLDPE, granulat	-0.06 kg incineration of plastics waste -0.06 kg landfill of plastics waste LCI data see **chapter 9.2** and **9.3**
Polypropylene (PP)	0.88 kg Polypropylene, granulate, at plant	-0.06 kg incineration of plastics waste -0.06 kg landfill of plastics waste LCI data see **chapter 9.2** and **9.3**
Polystyrene (PS)	0.88 kg Polystyrene, general purpose, GPPS, at plant	-0.06 kg incineration of plastics waste -0.06 kg landfill of plastics waste LCI data see **chapter 9.2** and **9.3**
Polyethylene terephthalate (PET)	0.88 kg Polyethylene terephthalate, granulate, amorphous, at plant	-0.06 kg incineration of plastics waste -0.06 kg landfill of plastics waste LCI data see **chapter 9.2** and **9.3**
Acrylonitrile-butadiene-styrene copolymer (ABS)	0.88 kg Acrylonitrile-butadiene-styrene copolymer, ABS, at plant	-0.06 kg incineration of plastics waste -0.06 kg landfill of plastics waste LCI data see **chapter 9.2** and **9.3**
Styrene-acrylonitrile copolymer (SAN)	0.88 kg Styrene-acrylonitrile copolymer, SAN, at plant	-0.06 kg incineration of plastics waste -0.06 kg landfill of plastics waste LCI data see **chapter 9.2** and **9.3**
Polyvinylchloride (PVC)	0.88 kg average of: Polyvinylchloride, emulsion polymerised, at plant Polyvinylchloride, suspension polymerised, at plant	-0.06 kg incineration of plastics waste -0.06 kg landfill of plastics waste LCI data see **chapter 9.2** and **9.3**
Other plastics	0.88 kg Average of all above	-0.06 kg incineration of plastics waste -0.06 kg landfill of plastics waste LCI data see **chapter 9.2** and **9.3**

All data sets and all switches for the use of 1 kg plastics scrap include input of 0.01 tkm transport based on the ecoinvent 'Polystyrene scrap, old, at plant/CH'.

5.5 Materials\Synthetic rubber

Full documentation in **chapter 4**.

5.6 Materials\Resins

Full documentation in **chapter 4**.

5.7 Materials\Fiber for composite materials

Glass fiber is fully documented in **chapter 4**. No data on carbon fiber is available in ecoinvent. Therefore, a specific life cycle inventory based on literature data is carried out. See below.

Table 5.2: Applied LCI-data for the production of carbon fiber. The LCI data (process data) are obtained from Griffing and Overcash (2010). Data on capital goods and services are estimated based on glass fiber production.

Carbon fiber	Amount	Unit:	LCI data
Output of products			
Carbon fiber	1.00	kg	Reference product
Material inputs			
Polyacrylonitrile (PAN precursor fiber)	1.82	kg	Polyacrylonitrile fibres (PAN), from acrylonitrile and methacrylate, prod. mix, PAN w/o additives EU-27 S; (ELCD 2008)
Nitrogen	10.0	kg	Nitrogen, liquid, at plant/RER (ecoinvent 2010)
Water	2.88	kg	Tap water, at user/RER (ecoinvent 2010)
Sizing solids	0.0100	kg	Epoxy resin, see **chapter 5.6**.
Sulfuric acid	0.0200	kg	Sulphuric acid, liquid, at plant/RER (ecoinvent 2010)
Energy Use			
Electricity, EU27	6.99	MJ	See **chapter 6.1**.
Heating steam	3.10	MJ	Natural gas, burned in industrial furnace >100kW/RER (ecoinvent 2010)
Transport			
Transport, lorry 16-32 t	2.37	tkm	Transport, lorry 16-32t, EURO5/RER U. Assumed distance at 200 km for all material inputs (except water).
Capital goods and services			
Capital goods	4E-10	P	Flat glass plant/RER/I U (ecoinvent 2010)
Services	1.00	kg	Service inputs to glass manufacturing industries. Based on the FORWAST EU27 IO-database. See **chapter 8.3**
Process Emissions			
Sulfuric acid	0.0199	kg	Emission to water
Ethane	0.0000101	kg	Emission to air
Ammonia	0.00116	kg	Emission to air
Hydrogen cyanide	0.0157	kg	Emission to air
Carbon monoxide	0.00324	kg	Emission to air
Carbon dioxide	1.013	kg	Emission to air

5.8 Materials\Hardeners

Full documentation in **chapter 4**.

5.9 Materials\Solvents

Full documentation in **chapter 4**.

5.10 Materials\Flame retardants

Chloro paraffin

Based on Back et al. (1994, p 19) it has be estimated that chloro paraffin is composed of 50% paraffin and 50% chlorine. According to Back et al. (1994), the production of chloro paraffin does not involve other raw materials (except from minor inputs of solvents in some cases) and it does not require significant energy inputs, i.e. it is produced at 80-100 °C. Hence, the LCI data for 1 kg cholo paraffin are obtained from ecoinvent as 0.5 kg 'Paraffin, at plant/RER' and 0.5 kg 'Chlorine, gaseous, membrane cell, at plant/RER' without any further inputs of materials and energy and emission outputs.

5.11 Materials\Metal, non-processed

The inventories in the current section follow the methodology described in **section 3.9** on recycling and waste treatment in different switch modes.

Steel

The LCA activities for unalloyed, low-alloyed and stainless steel and cast iron are all based on ecoinvent processes. In the following it is documented how these ecoinvent activities have been modified in order to comply with the three modelling switches.

Table 5.3: Modification of the ecoinvent activity for unalloyed steel 'Steel, converter, unalloyed, at plant/RER'. The table only shows the modified flows in the original ecoinvent activity.

Unalloyed steel	Original ecoinvent activity	Switch		
		ISO 14040/44	Attributional	PAS2050
Supply				
Unalloyed steel	1 kg	0.788 kg	1 kg	0.788 kg
Use				
Iron scrap, at plant/RER	0.212 kg	0 kg	0.212 kg	0 kg
Steel, electric, un- and low-alloyed, at plant/RER	0 kg	-0.212 kg	0 kg	-0.212 kg

Table 5.4: Modification of the ecoinvent activity for low-alloyed steel 'Steel, converter, low-alloyed, at plant/RER'. The table only shows the modified flows in the original ecoinvent activity.

Low-alloyed steel	Original ecoinvent activity	Switch		
		ISO 14040/44	Attributional	PAS2050
Supply				
Low-alloyed steel	1 kg	0.875 kg	1 kg	0.875 kg
Use				
Iron scrap, at plant/RER	0.125 kg	0 kg	0.125 kg	0 kg
Steel, electric, un- and low-alloyed, at plant/RER	0 kg	-0.125 kg	0 kg	-0.125 kg

The ecoinvent process for stainless steel 'Steel, converter, chromium steel 18/8, at plant/RER' is not modified.

Table 5.5: Modification of the ecoinvent activity for cast iron 'Cast iron, at plant/RER'. The table only shows the modified flows in the original ecoinvent activity.

Cast iron	Original ecoinvent activity	Switch		
		ISO 14040/44	Attributional	PAS2050
Use				
Iron scrap, at plant/RER	0.387 kg	0 kg	0.387 kg	0 kg
Pig iron, at plant/GLO	0.718 kg	1.11 kg	0.718 kg	1.11 kg

Aluminium

The European market for aluminium is represented by the ecoinvent activity 'Aluminium, production mix, at plant/RER'. According to this activity the European aluminium mix consists of a mix of primary aluminium and secondary aluminium from new and old scrap.

The activity is modified to reflect the three modelling switches.

Table 5.6: Modification of the ecoinvent market activity 'Aluminium, production mix, at plant/RER'. The table only shows the modified flows in the original ecoinvent activity.

Market for aluminium in Europe	Original ecoinvent activity	Switch		
		ISO 14040/44	Attributional	PAS2050
Primary aluminium	68%	100%	68%	100%
Secondary aluminium, from new scrap	22%	0%	22%	0%
Secondary aluminium, from old scrap	10%	0%	10%	0%

The three inputs to the market activity described above are inventoried in the following.

Table 5.7: Modification of the ecoinvent activity 'Aluminium, primary, at plant/RER'. The table only shows the modified flows in the original ecoinvent activity.

Primary aluminium	Original ecoinvent activity	Switch		
		ISO 14040/44	Attributional	PAS2050
Electricity use	15.6 kWh	13.3 kWh	15.3 kWh	15.3 kWh
Electricity mix				
Electricity mix – coal	19%	62%	19%	19%
Electricity mix – lignite	4.5%	-	4.5%	4.5%
Electricity mix – oil	3.3%	-	3.3%	3.3%
Electricity mix – natural gas	6.5%	9%	6.5%	6.5%
Electricity mix – nuclear	14%	-	14%	14%
Electricity mix – hydro power	53%	29%	53%	53%
Electricity mix – total	**100%**	**100%**	**100%**	**100%**

The electricity use for ISO-switch is the electricity use associated with the marginal supply of aluminium. This is identified in Schmidt and Thrane (2009, p 124). The electricity use in the original ecoinvent activity represents European average in 1998. This has been corrected to represent the global average in 2005 (Schmidt and Thrane 2009, p 124).

The electricity mix in the original ecoinvent activity has been applied on the switches for attributional and PAS2050 modelling. The electricity mix for the ISO 14040/44 switch represents the marginal supply of aluminium. This electricity mix is obtained from Schmidt and Thrane (2009, p 80).

The ecoinvent activities for the reprocessing of aluminium scrap into new aluminium have not been modified.

Copper

Data on the European copper market are obtained from ecoinvent (Classen et al. 2009). The data are shown in the table below.

Table 5.8: Parameterisation of market activity for copper.

Market for copper in Europe	Original ecoinvent activity (Classen et al. 2009, part III, p 16)	Switch		
		ISO 14040/44	Attributional	PAS2050
Primary copper	56%	100%	56%	100%
Secondary copper	44%	0%	44%	0%

The two copper inputs to the copper market in the table above are based on the following ecoinvent processes: Copper, primary, at refinery/GLO and Copper, secondary, at refinery/RER.

Copper mining is joint production with other metal ores, e.g. molybdenum. In ecoinvent the mining activities are allocated. Due to the limited importance of the material copper in the plastics product calculator, no further efforts in obtaining a more accurate modelling of the mining stage has been undertaken.

Lead

The European market for lead is represented by the ecoinvent activity 'Lead, at regional storage/RER'. According to this activity the European lead mix consists of a mix of primary lead and secondary lead from scrap.

The activity is modified to reflect the three modelling switches.

Table 5.9: Modification of the ecoinvent market activity 'Lead, at regional storage/RER'. The table only shows the modified flows in the original ecoinvent activity.

Market for lead in Europe	Original ecoinvent activity	Switch		
		ISO 14040/44	Attributional	PAS2050
Primary lead	25%	100%	25%	100%
Secondary lead	75%	0%	75%	0%

The two lead inputs to the lead market in the table above are based on the following ecoinvent processes: Lead, primary, at plant/GLO and Lead, secondary, at plant/RER U.

Lead mining is joint production with other metal ores, e.g. zinc, silver and cadmium. In ecoinvent the mining activities are allocated. Due to the limited importance of the material lead in the plastics product calculator, no further efforts in obtaining a more accurate modelling of the mining stage has been undertaken.

Zinc and Nickel

Zink and nickel are modelled as 100% primary metals. This limitation is introduced because the purpose of plastberegner.dk is to facilitate Danish plastics converters, and because the use of zinc and nickel as raw materials is very limited in this sector.

5.12 Materials\Metal, processed

There exist several different types of products which can be characterised as processed metal. This involves casting, turning, extruding, drawing, drilling, welding etc. The purpose of plastberegner.dk is to facilitate Danish plastics converters. It is assessed that metal products constitutes a very limited share of raw materials in this sector. Therefore, it has been decided only to include the following generalised product categories for processed metal products.

- Steel, processed
- Steel, stainless, processed
- Aluminium, processed

The LCI data are based on ecoinvent: 'Steel product manufacturing, average metal working/RER', 'Chromium steel product manufacturing, average metal working/RER' and 'Aluminium product manufacturing, average metal working/RER'. These general LCA activities for metal processing include working machines and other capital goods as well as energy for the operations. Approximately 23% loss of raw material is also included.

Raw materials and losses in the processing are based on the data described in **section 5.11**, and recycling of the processing waste (scrap) is based on the data described in **section 9.1**.

5.13 Materials\Other materials

Gel-coat

No good life cycle inventory data have been identified for gel-coat. The recipe for typical polyester resin gel-coat has been identified in Throne (1996, p 391). This is used for the establishment of the data set in **Table 5.10**. No data for process energy have been identified, and therefore this is not included. Capital goods and services are included based on generic industry averages. The data in Throne (1996) includes 20% white pigment (titanium dioxide). The data set for gel-coat in **Table 5.10** is for non-coloured gel-coat. Therefore titanium dioxide is not included. Data for pigments are described in **chapter 4**.

Table 5.10: Applied LCI-data for the production of polyester resin gel-coat. The recipe is based on Throne (1996, p 391).

Carbon fiber	Amount	Unit:	LCI data
Output of products			
Gel-coat	1.00	kg	Reference product
Material inputs			
Polyester	0.60	kg	Polyester resin, unsaturated, at plant/RER (ecoinvent 2010)
Titanium dioxide (TiO_2) pigment	0.20	kg	Titanium dioxide, production mix, at plant/RER (ecoinvent 2010)
Styrene diluent	0.40	kg	Styrene, at plant/RER (ecoinvent 2010)
Fumed silica	0.015	kg	Not included
Cobalt octoate promoter	0.003-0.006	kg	Not included
Methyl ethyl ketone peroxide catalyst	0.003-0.006	kg	Not included
Transport			
Transport, lorry 16-32 t	0.204	tkm	Transport, lorry 16-32t, EURO5/RER U. Assumed distance at 200 km for all material inputs.
Capital goods and services			
Capital goods	1.00	kg	Service inputs to chemical industries. Based on the FORWAST EU27 IO-database. See **chapter 7.2.**
Services	1.00	kg	Service inputs to chemical industries. Based on the FORWAST EU27 IO-database. See **chapter 8.3.**

Oxidised bitumen

According to Eurobitume (2011, p 22) the energy use to oxidise bitumen is approximately 0.033 MJ/kg. It is presumed that this energy is produced from the combustion of light fuel oil. The data set used for this is based on the ecoinvent activity 'Light fuel oil, burned in industrial furnace 1MW, non-modulating/RER' (ecoinvent 2010).

The oxidation process generates gases, i.e. CO_2, CO, vapor, light hydrocarbons and sulphur compounds. These off-gases are burned to CO_2, water and SO_2. The emissions from that are (Eurobitume 2011, p 22):

- CO_2: 0.00300 kg/kg oxidised bitumen
- SO_2: 1.30E-5 kg/kg oxidised bitumen

Paper and cardboard (packaging)

The LCA activity for paper and board (packing) is based on ecoinvent. However, the ecoinvent activities for paper are a mix of virgin and recycled production. Therefore, the activities are modified in the same way as the steel activities in **section 5.11** to be able to switch between different modelling assumptions.

The LCA activity for paper and board (packing) is based on the ecoinvent activity: 'Packaging, corrugated board, mixed fibre, single wall, at plant/RER'. No changes are made to this activity.

The activity for paper and board (packing) has inputs of 'Corrugated board, mixed fibre, single wall, at plant/RER' as its main raw material. The modifications of this activity are shown in the table below.

Table 5.11: Modification of the ecoinvent activity 'Corrugated board, mixed fibre, single wall, at plant/RER'. The table only shows the modified flows in the original ecoinvent activity.

Unalloyed steel	Original ecoinvent activity	Switch		
		ISO 14040/44	Attributional	PAS2050
Supply				
Corrugated board	1 kg	1 kg	1 kg	1 kg
Use				
Virgin paper: Corrugated board base paper, kraftliner, at plant/RER	0.299 kg	1.03 kg	0.299 kg	0.299 kg
Recycled paper: Corrugated board base paper, wellenstoff, at plant/RER, and Corrugated board base paper, testliner, at plant/RER	0.731 kg	0 kg	0.731 kg	0.731 kg

It should be noticed that the wood LCA activities in ecoinvent are allocated between forest product outputs. This has not been corrected for in the current study because the upstream forest activities related to the use of packing paper in the production of typical plastics products are relatively insignificant. The purpose of the plastberegner.dk is to be able to carry out LCAs on plastics products.

Tap water

LCA data for water are based on the ecoinvent activity: ‘Tap water, at user/RER’. The input of electricity to the activity is modified to Danish electricity. The inventory data for electricity are described in **section 6.1**.

6 Life cycle inventory of energy and fuels

6.1 Energy and fuels\Electricity

Electricity is modelled using the inventory project 'Inventory of country specific electricity in LCA - consequential and attributional scenarios v2' (Schmidt et al. 2011). The electricity project enables for using different modelling switches to comply with the switches in the current study.

When modelling according to ISO 14040/44, the affected electricity mix is identified as the proportion between the relative predicted changes in domestic generation from 2008 to 2020. When modelling according to attributional and PAS2050, the electricity mix is applied as the average of domestic generation in 2008.

The above mentioned electricity project is linked to activities in the ecoinvent database in two ways;

1. Upstream activities in the electricity product system are modelled using data from ecoinvent
2. The ecoinvent activity for European electricity is replaced with the one for European electricity from the above mentioned electricity project. Hence, when ecoinvent activities use electricity from Europe (this the case for most ecoinvent activities since the database generally considers European production) this is affected by the modelling switches in plastberegner.dk

Table 6.1: Applied electricity mix for Denmark in the different modelling switch modes. The data are from Merciai et al. (2011a).

Denmark	**Electricity mix**		
Source of electricity	**ISO 14040/44**	**Attributional**	**PAS2050**
Coal	0	0.482	0.482
Oil	0.004	0.030	0.030
Gas	0.197	0.190	0.190
Biomass	0.403	0.107	0.107
Nuclear	0	0	0
Hydro	0.003	0	0
Wind	0.393	0.190	0.190
Geothermal	0	0	0
Solar	0	0	0
Marine	0	0	0
Import from other countries	0	0	0
Total	**1.000**	**1.000**	**1.000**

Table 6.2: Applied electricity mix for Europe in the different modelling switch modes. The data are from Merciai et al. (2011b).

Europe	Electricity mix		
Source of electricity	**ISO 14040/44**	**Attributional**	**PAS2050**
Coal	0	0.257	0.257
Oil	0	0.029	0.029
Gas	0.127	0.239	0.239
Biomass	0.121	0.031	0.031
Nuclear	0	0.254	0.254
Hydro	0.067	0.153	0.153
Wind	0.580	0.033	0.033
Geothermal	0.011	0.003	0.003
Solar	0.093	0.002	0.002
Marine	0.003	0	0
Import from other countries	0	0	0
Total	**1.000**	**1.000**	**1.000**

6.2 Energy and fuels\District heating

The modelling of district heating using different modelling assumptions is not straight forward. First of all the affected technologies (different fuels and plant types) must be identified and then co-products (electricity) needs to be handled.

When modelling heat, the following types of plants are considered:

- Combined heat and power (CHP) where the heat is the determining product and electricity is a dependant co-product
- Standalone heat production
- Heat from waste generation; the amount of waste to incineration is the determining "product" and heat and electricity are dependant co-product

A large share of district heating in Denmark is produced on central power plants which are extraction plants. This means that the output of heat and electricity can be independently varied by switching between condensation mode (only electricity production) and back-pressure mode (heat and electricity production). These plants can be considered as two separate plants; a condensation plant and a back-pressure plant. Any change in demand will only affect the back-pressure plant. This type of plant is included in the list above.

Another significant supplier category of district heating in Denmark is secondary sources, i.e. industries which can benefit from utilising excess heat and sell it as district heating. An example is Aalborg Portland. In the list of relevant plant types above, these industries are modelled as if they belonged to the two first categories.

Switches

In the ISO 1040/44 switch, the affected technologies are identified as the fuels which are predicted to increase their production volume from 2008-2020. Further, the affected plant technology (CHP or only heat) is assumed to be CHP only since these plants in general are more competitive and they are being encouraged by energy planning authorities in Denmark. The electricity (by-product) from CHPs is modelled using substitution, i.e. marginal electricity is substituted.

In the average/allocation switch, the included technologies represent the market average in 2008. Co-products of electricity are modelled by using economical allocation. When allocating using prices average prices of Danish production prices of district heating and electricity for year 2008 are used. Production prices are obtained from Danmarks Statistik (2012) where data on the total monetary (DKK) and physical (MJ) supply of district heating and electricity in Denmark in 2008 are obtained. Based on these data, the prices can be determined as 0.11 DKK per MJ heat and 0.19 DKK per MJ electricity. Economic allocation of waste incineration requires that also the price of waste incineration is known. According to 3.6 million tonne of waste was incinerated in 2008. Correspondingly, the total costs associated with waste incineration around 2008 were 2000 million DKK (Incentive Partners 2010). Hence, the price for waste incineration can be estimated as 0.556 DKK per kg waste. Based on the total amount of incinerated waste (3.6 million tonne) and on electricity and heat supply data from Energistyrelsen (2011) it can be determined that the average energy generation in waste incineration in Denmark in 2008 is 7.29 MJ heat/kg waste and 1.90 MJ electricity/kg waste. Knowing the prices of heat and electricity, the allocation factors for waste incineration can be calculated. This is shown in **Table 6.5**.

In the PAS2050 switch, the included technologies represent the market average in 2008. Co-products of electricity are modelled by using energy allocation (PAS2050 2011, p 23).

Characteristics of the Danish district heating system

The sources (fuels) for district heating in Denmark in 2008 are shown in **Table 6.2**, see second column. Most of the district heating production in Denmark is co-produced with electricity.

The third column shows the estimated heat and electricity efficiencies for co-generation of electricity with heat. The energy efficiencies for coal, oil and gas are based on figures for back-pressure mode at Studstrupværket (Holm-Nielsen et al. 2011). Biomass efficiencies are based on figures for Herningværket (Dong Energy 2012). Waste incineration efficiencies are obtained from Schmidt (2005).

In the fourth column the projected development of the fuel consumption (for al purposes) in Denmark from 2008 to 2020 is shown. These projections are based on Energistyrelsen (2011). The projections are used to identify which fuels that can be expected to be affected as a consequence of changes in demand in the long term. The fuels that are predicted to decrease in the future are regarded as being constrained (either because they are phased out by regulation or because they are the least competitive fuels).

Table 6.3: Characteristics of the Danish district heating system

Sources of heating	Share 2008	Estimated heat and elec eff	Projection of general energy consumption per fuel type 2008-2010
Coal	26%	59% / 30%	-64%
Oil	3%	59% / 30%	-10%
Gas	29%	59% / 30%	-35%
Biomass	18%	59% / 28%	64%
Waste	21%	71% / 14%	no data
Other	3%	-	no data
Total	**100%**		

In **Table 6.4**, the shares of all considered technologies (fuels and plant types) are shown. The share of each fuel in **Table 6.3** has been subdivided into heat only and CHP. This sub-division is based on the fact that 78.2% of all district-heating is co-produced with electricity (Energistyrelsen 2011). This share has been assumed for all fuels. The applied shares in the three modelling switches are specified; ISO 14040/44 applies the most likely technology to be affected as a consequence of a long term change in demand, and the attributional and PAS2050 switches apply market averages.

Table 6.4: Shares of modelled district heating technologies in the different modelling switch modes.

Technology	Heat share, DK 2008	Share in switch		
		ISO 14040/44	Attributional	PAS2050
Coal, heat only	6%	0%	6%	6%
Coal, CHP	21%	0%	21%	21%
Oil, heat only	1%	0%	1%	1%
Oil, CHP	2%	0%	2%	2%
Gas, heat only	7%	0%	7%	7%
Gas, CHP	23%	0%	23%	23%
Biomass, heat only	4%	0%	4%	4%
Biomass, CHP	15%	100%	15%	15%
Waste, heat only	5%	0%	5%	5%
Waste, CHP	17%	0%	17%	17%
Total	**100%**	**100%**	**100%**	**100%**

Based on the information in **Table 6.3** and on price information given in the section above, **Table 6.5** specifies the modelling of co-product, i.e. substitution for the ISO 14040/44 switch and allocation factors for the attributional and PAS2050 switches.

Table 6.5: Modelling of co-products in the three modelling switch modes. * indicates that this product is the determining co-product.

Technology	Product	Energy efficiency	Allocation		
		Energy efficiency	ISO 14040/44	Attributional	PAS2050
Coal, heat only	Heat*	90%	-	-	-
Coal, CHP	Heat*	59%	-	52%	66%
	Electricity	30%	-	48%	34%
Oil, heat only	Heat*	90%	-	-	-
Oil, CHP	Heat*	59%	-	52%	66%
	Electricity	30%	-	48%	34%
Gas, heat only	Heat*	90%	-	-	-
Gas, CHP	Heat*	59%	-	52%	66%
	Electricity	30%	-	48%	34%
Biomass, heat only	Heat*	90%	-	-	-
Biomass, CHP	Heat*	59%	100%	54%	68%
	Electricity	28%	substitution	46%	32%
Waste, heat only	Waste disposal*	-	-	36%	100%
	Heat	90%	-	64%	0%
Waste, CHP	Waste disposal*	-	-	33%	100%
	Heat	71%	-	45%	0%
	Electricity	14%	-	22%	0%

Table 6.6: LCI data used to model the burning of fuels for heat production.

Fuel	Applied LCI data
Coal	ecoinvent: Hard coal, burned in power plant/NORDEL
Oil	ecoinvent: Heavy fuel oil, burned in power plant/DK
Gas	ecoinvent: Natural gas, burned in power plant/NORDEL
Biomass	Wood pellets burned in power plant (Schmidt et al. 2011)
Waste	ecoinvent: Disposal, municipal solid waste, 22.9% water, to municipal incineration/CH. It should be noticed that, according to the data set, the lower heating value of mixed waste is 11.7 MJ/kg

6.3 Energy and fuels\Fuels

The production of fuels is based on ecoinvent data. In order to avoid that the user of the plastberegner.dk tool needs to manually enter combustion emissions every time some fuels are used, combustion related emissions are added to the fuels. Data on combustion of petrol, diesel and lubricants are based on the following ecoinvent activities:

- Combustion of petrol: Operation, passenger car, petrol, fleet average 2010/RER
- Combustion of diesel: Operation, lorry 3.5-16t, fleet average/RER
- Combustion/degradation of lubricants is assumed to be related to similar emissions per litre as for diesel

7 Life cycle inventory of capital goods

7.1 Capital goods used by plastics converters

Full documentation in **chapter 4**.

7.2 Capital goods (general)

This section described the inventory data used for switching on and off capital goods for the building blocks in the database in plastberegner.dk.

Capital goods include the production of machinery, buildings and infrastructure. In general, the GHG-emissions related to capital goods are obtained from the ecoinvent database v2.2 (ecoinvent 2010). SimaPro 7.3 enables for analysing products with and without capital goods. The difference between the two results represents the GHG-emissions related to capital goods.

In cases where no ecoinvent data are available, some the capital goods are estimated by use of the EU27 IO-database. Each activity in the EU27 IO-database has inputs of 132 products. The life cycle emissions related to 16 of these products are defined as the emissions related to capital goods. The 16 products are:

- Sand, gravel and stone from quarry
- Clay and soil from quarry
- Concrete, asphalt and other mineral products
- Bricks
- Fabricated metal products, except machinery
- Machinery and equipment n.e.c.
- Office machinery and computers
- Electrical machinery n.e.c.
- Radio, television and communication equipment
- Instruments, medical, precision, optical, clocks
- Motor vehicles and trailers
- Transport equipment n.e.c.
- Furniture and other manufactured goods n.e.c.
- Buildings, residential
- Buildings, non-residential
- Infrastructure, excluding buildings

When industries have inputs of the 16 above mentioned products, this can typically be characterised as belonging to purchases of durable goods that will not become part of their supply of products, i.e. capital goods. However, for some industries there are exceptions. This is the case when the inputs of one or some of the 16 'capital goods products' are used as feedstock, i.e. the input of the 'capital goods product' becomes part of the supply of products from the industrial activity. An example is the chemical industry that uses 'Sand, gravel and stone from quarry' and 'Clay and soil from quarry'. These products are often used as feedstocks in the production of different chemicals. The exceptions relevant for the current study are listed in **Table 7.1**. The identification of industries where the 16 'capital goods products' are used as feedstocks is based on data sets for feedstock specification from the FORWAST project (available at http://forwast.brgm.fr/).

Table 7.1: List of which of the 16 typical capital goods products that are not regarded as capital goods for the relevant included activities that represent building blocks in the tool.

Industry activities included in the tool	Exceptions: Which of the 16 capital goods products are not capital goods
Chemicals	Sand, gravel and stone from quarry Clay and soil from quarry
Machinery and equipment n.e.c.	Fabricated metal products, except machinery Machinery and equipment n.e.c. Electrical machinery n.e.c.
Office machinery and computers	Fabricated metal products, except machinery Machinery and equipment n.e.c. Office machinery and computers Electrical machinery n.e.c. Radio, television and communication equipment
Electrical machinery n.e.c.	Fabricated metal products, except machinery Machinery and equipment n.e.c. Electrical machinery n.e.c.
Radio, television and communication equipment	Fabricated metal products, except machinery Machinery and equipment n.e.c. Office machinery and computers Electrical machinery n.e.c. Radio, television and communication equipment Instruments, medical, precision, optical, clocks
Instruments, medical, precision, optical, clocks	Fabricated metal products, except machinery Machinery and equipment n.e.c. Electrical machinery n.e.c. Radio, television and communication equipment Instruments, medical, precision, optical, clocks
Motor vehicles and trailers	Fabricated metal products, except machinery Machinery and equipment n.e.c. Electrical machinery n.e.c. Motor vehicles and trailers
Transport equipment n.e.c.	Fabricated metal products, except machinery Machinery and equipment n.e.c. Electrical machinery n.e.c. Transport equipment n.e.c.
Furniture and other manufactured goods n.e.c.	Fabricated metal products, except machinery Furniture and other manufactured goods n.e.c.
Buildings	Concrete, asphalt and other mineral products Bricks Fabricated metal products, except machinery Buildings, residential Buildings, non-residential

8 Life cycle inventory of transport, services and overhead

8.1 Transport

Full documentation in **chapter 4**.

8.2 Service inputs to plastics converters

Full documentation in **chapter 4**.

8.3 Services (general)

This section described the inventory data used for switching on and off services for the building blocks in the database in plastberegner.dk.

Services includes inputs to the product system which are often excluded from life cycle assessments, such as retail, wholesale, accounting, marketing, consultancy etc. Inventory data for services are obtained from the EU27 input-output hybrid input-output database (Schmidt 2010a, Schmidt 2010b, and Schmidt et al. 2010). This database is publically available in SimaPro 7.3 (it can be freely accessed in the demo version): www.pre-sustainability.com.

Each activity in the EU27 IO-database has inputs of 132 products. The life cycle emissions related to 21 of these products is defined as the emissions related to services. The 21 products are:

- Agricultural services n.e.c.
- Recycling services
- Trade and repair of motor vehicles and service stations
- Wholesale trade
- Retail trade and repair services
- Hotels and restaurants
- Post and telecommunication
- Financial intermediation
- Insurance and pension funding
- Services auxiliary to financial intermediation
- Real estate services
- Renting of machinery and equipment etc.
- Computer and related services
- Research and development
- Business services n.e.c.
- Public service and security
- Education services
- Health and social work
- Membership organisations
- Recreational and cultural services
- Services n.e.c.

For some products the unit in plastberegner.dk is different from the unit in the FORWAST database. Below, the relevant conversion factors are provided:

- Water: Price is estimated 0.007 DKK2003 per litre (Danva 2004)
- Transport: Price is estimated 0.210 EUR2003 per tkm. Europen average price is calculated based on total road freight transport given in tkm divided by total supply in EUR2003 by this sector. Total freight in tkm (1625 billion tkm in 2003) is obtained from Eurostat (2009) and total supply in EUR2003 (69% of 495503 MEUR) is obtained from the EU27 input-output database (Schmidt 2010a, Schmidt 2010b, and Schmidt et al. 2010). No distinction between different size of vehicles.

9 Life cycle inventory of waste disposal

9.1 Disposal\Recycling

The modelling assumptions for recycling in the different switches are described in **chapter 3.9**. From **Table 3.5** it appears that inventory data are only relevant for the ISO 14040/44 switch and the PAS2050 switch. This is because all exchanges related to recycling are allocated to the recovered material in the attributional switch mode.

Recycling activities in plastberegner.dk includes recycling of the waste/scrap fractions as shown in **Table 9.1**. The LCI data have their cradle at the gate of a scrap dealer in Denmark. The LCI data includes transport from scrap dealer to recycling plant.

Table 9.1: LCI data for recycling of different waste fractions. The data are further described below the table.

Waste/scrap fraction to recycling	Material recovery rate	Data source for recycling activity	Data source for the displaced virgin material
Scrap, polyethylene (PE) to recycling	88%	Schmidt (2005, p 105), see detailed description in **Table 9.2**.	See **chapter 5.4**.
Scrap, polypropylene (PP) to recycling			
Scrap, polystyrene (PS) to recycling			
Scrap, polyethylene terephthalat (PET) to recycling			
Scrap, acrylonitrile-butadiene-styrene copolymer (ABS) to recycling			
Scrap, styrene-acrylonitril copolymer (SAN) to recycling			
Scrap, polyvinylchloride (PVC) to recycling			
Scrap, other plastics to recycling			
Paper waste to recycling	90%	ecoinvent: Corrugated board base paper, testliner, at plant/RER. Original ecoinvent activity modified, see text below table.	ecoinvent: Corrugated board base paper, kraftliner, at plant/RER
Iron and steel waste to recycling	90%	ecoinvent: Steel, electric, un- and low-alloyed, at plant/RER. Original ecoinvent activity modified, see text below table.	See **chapter 5.11**: low alloyed steel
Aluminium waste to recycling	97%	ecoinvent: Aluminium, secondary, from old scrap, at plant/RER. Original ecoinvent activity modified, see text below table.	See **chapter 5.11**
Other metal waste to recycling	76%	ecoinvent: Copper, secondary, at refinery/RER. Original ecoinvent activity modified, see text below table.	ecoinvent: Copper, primary, at refinery/GLO
Inert waste to recycling (used as filler material)	100%	Based on parts of ecoinvent activity: Gravel, crushed, at mine/CH. Only the parts of the activity that relates to the crushing is included.	ecoinvent: Sand, at mine/CH

Material recovery efficiencies for different plastic scrap types have been reviewed in literature: Schmidt (2005), Arena et al. (2003) and Shonfield (2010). Based on the review, a recycling efficiency at 88% as of

Shonfield (2010) is applied for all plastics scrap types. A material recovery efficiency of 88% means that 1 kg plastics waste/scrap which is sent to recycling is reprocessed into 0.88 kg new plastics and 0.12 kg processing waste. The material recovery efficiency for paper waste is 90% (based on Hischier 2007). The efficiencies of recycling of iron/steel scrap and aluminium scrap are 90% and 97% respectively (based on Classen et al. 2009). Recycling of other metals is modelled as recycling of copper. According to Classen et al. (2009), material recovery efficiency of copper is 76%. When inert material is used as filler material no loss is considered, i.e. the efficiency is 100%.

Recycling of plastics scrap/waste

The inventory data used for the modelling of recycling of plastics scrap in **Table 9.1** are described in detail in **Table 9.2**.

Table 9.2: LCI data for recycling of 1 kg plastics scrap – the shown data are applicable to all included plastic types. Data are obtained from Schmidt (2005, p 105).

Recycling of plastics scrap	Amount	Description of LCI data
Reference flow		
Recycling of plastics scrap	1 kg	
Substituted production		
Recovered material, plastics	-0.88 kg	The specific LCI data depends on the type of plastic being recycled. See LCI data in **chapter 5.1**
Electricity inputs		
Electricity, DK	0.29 kWh	See **chapter 6.1**
Electricity, CN	0.29 kWh	Schmidt et al. (2011) and Merciai et al. (2011c), also see **chapter 6.1**
Transport		
Transport, lorry	0.150 tkm	Transport from scrap dealer to recycling plant in Denmark (transport of process waste included). ecoinvent: Transport, lorry 16-32t, EURO5/RER
Transport, lorry	0.300 tkm	Transport from scrap dealer in DK to harbour for shipment and from harbour in China to recycling plant (transport of process waste included). ecoinvent: Transport, lorry 16-32t, EURO5/RER
Transport, ship	10.0 tkm	Transport from harbour in DK/DE to China. ecoinvent: Transport, transoceanic freight ship/OCE
Process waste to treatment		
Plastics waste to incineration	0.06 kg	See **chapter 9.2**
Plastics waste to landfill	0.06 kg	See **chapter 9.3**

Schmidt (2005) assumes that 50% of all plastic waste that is collected for recycling, is recycled in Denmark and that the remaining is recycled in China. Process waste in Denmark is assumed to be incinerated and in China it is assumed that process waste is landfilled.

Notice, that for the attributional switch, all inputs to the recycling activities have been multiplied with zero, because 0% is allocated to the waste treatment service; see **section 3.9** and **Table 3.5**.

Recycling of other materials

The ecoinvent activities which are used for the modelling of the recycling activities in **Table 9.1** are modified. All the ecoinvent activities have the recovered material as the determining product output. This is changed to be the incoming scrap instead. In order to do so, the reference flows of the original ecoinvent activities are renamed to be '*Recycling of…*' instead of '*Secondary…*'. Further the reference flows are calculated as one divided by the material recovery efficiencies as of **Table 9.1**. For the attributional switch, all inputs to the activity have been multiplied with zero, because 0% is allocated to the waste treatment service; see **section 3.9** and **Table 3.5**.

9.2 Disposal\Incineration

The modelling assumptions for incineration in the different switches are described in **chapter 3.9**.

For waste incineration, direct emissions data as well as upstream activities (the inputs of capital goods and auxiliary materials/fuels) are based on data for incineration plants in Switzerland.

For incineration with energy recovery it appears from **Table 3.5** that inventory data are only relevant for the ISO 14040/44 and the attributional switches. This is because all exchanges related to incineration with energy recovery are allocated to the recovered energy in PAS2050 (2011). For incineration without energy recovery, i.e. incineration of metals and inert materials, there are no difference in the LCI data (except database wide parameterisation of electricity and switches for capital goods and services).

Life cycle inventory data on the direct emissions and upstream activities for waste incineration is based on ecoinvent (2010). The ecoinvent activities do not include energy recovery. Therefore, this is added to the relevant ecoinvent activities. According to Rambøll (2008, p 111), the total calorific value (lower) of all incinerated waste in 2005 in Denmark is 9.87 TJ, and the total sold district heating and electricity in 2005 are 6.41 TJ and 1.59 TJ respectively. Hence, the energy recovery rates for heat and electricity are 64.9% and 16.1% respectively.

Incineration activities in plastberegner.dk include incineration of the waste fractions as shown in **Table 9.3**. The LCI data have their cradle at the gate of the incineration plant.

Table 9.3: LCI data for incineration of different waste fractions. The recovered energy is calculated based on the calorific values and the energy efficiencies described above the table.

	Used in all switches		Used in ISO 14040/44				Used in attribu-tional
Waste fraction to incineration	**Data source for incineration activity, excl. energy recovery**	**Calorific value (lower), MJ/kg**	**Electricity recovery, kWh/kg**	**Heat recovery, MJ/kg**	**Price waste treatment, DKK2008/ kg**	**Price energy, DKK2008/ kg**	**Allocation incineratio n**
Plastics waste, exclusive PVC, to incineration	ecoinvent: Disposal, polyethylene, 0.4% water, to municipal incineration/CH	40	1.79	26.0	0.556	4.08	12%
Plastics waste, PVC, to incineration	ecoinvent: Disposal, polyvinylchloride, 0.2% water, to municipal incineration/CH	23	1.03	14.9	0.556	2.35	19%
Paper waste to incineration	ecoinvent: Disposal, paper, 11.2% water, to municipal incineration/CH	18	0.805	11.7	0.556	1.84	23%
Iron and steel waste to incineration	ecoinvent: Disposal, steel, 0% water, to municipal incineration/CH	0	0	0	0.556	0	100%
Aluminium waste to incineration	ecoinvent: Disposal, aluminium, 0% water, to municipal incineration/CH	0	0	0	0.556	0	100%
Other metal waste to incineration	ecoinvent: Disposal, copper, 0% water, to municipal incineration/CH	0	0	0	0.556	0	100%
Inert waste to incineration	ecoinvent: Disposal, glass, 0% water, to municipal incineration/CH	0	0	0	0.556	0	100%

All electricity inputs of the ecoinvent incineration activities are modified to Danish switch dependant electricity mix (see **section 6.1**).

The calorific value (lower) of plastics is generally around 40 MJ/kg (dry plastics waste). For PVC, the calorific value is 23 MJ/kg. The calorific values are determined based on information in C-Tech Innovation (2003) and Christensen (Christensen 1998, p 48). The calorific value (lower) of paper is 18 MJ/kg (Christensen 1998, p 48).

When substitution is carried out in the ISO 14040/44 switch, the substituted heat and electricity is modelled using the LCI data as described in **chapters 6.1** and **6.2**.

9.3 Disposal\Landfill

Life cycle inventory data on the direct emissions and upstream activities for landfill of waste is based on ecoinvent (2010). Landfill activities in plastberegner.dk include landfilling of the waste fractions as shown below. The used LCI data are also indicated. The activities have their cradle at the gate of the landfill site.

- Plastics, metal and other inert waste to landfill, LCI data from ecoinvent: Disposal, inert waste, 5% water, to inert material landfill/CH
- Paper waste to landfill, LCI data from ecoinvent: Disposal, paper, 11.2% water, to sanitary landfill/CH U

10 Life cycle impact assessment

The current study can be characterised as a life cycle inventory, and not a full life cycle assessment. Therefore, no life cycle impact assessment is included. However, all the LCA results including all switch combinations can easily be accessed for each building block in the database on the web-page: plastberegner.dk.

11 Evaluation of data quality, sensitivity, consistency and completeness

According to ISO 14044 (2006) an evaluation in the interpretation phase including sensitivity, completeness and consistency check must be carried out in order to establish confidence in the results of the LCA. This is presented in the current chapter. Further, this chapter includes an evaluation of the data quality of the data used for the inventory of the building blocks in plastberegner.dk.

11.1 Evaluation of data quality

As described in **section 3.10**, the data for primary plastics from PlasticsEurope are related to a number of problems relating to data quality. This is mainly because these data sets are not affected by the modelling switches and because the data are not transparent. Also, for some building blocks no LCI data have been identified and other data have been assumed to represent the missing data. Further, some data sets do not represent the correct/presumed likely technology or geography. In order to have an overview of the data quality, all data sets are evaluated with respect to:

- Is the data set sensitive to switches:
    - Substitution vs. allocation?
    - Electricity model (marginal/actual vs. average)?
    - Capital goods (included vs. excluded)?
    - Services (included vs. excluded)?
- Does the data set represent the actual technology?
- Does the data set represent the actual geographical location?
- Is the data set documented transparently?

The questions above are inspired by Weidema and Wesnæs (1996). In principle the data quality requirement used in the current study involves the answer ‘yes’ to all above mentioned questions. However, as described in **section 3.10**, LCI data that fulfil these requirements are not available, and it is out of the scope of the current study to carry out detailed new life cycle inventories of the included building blocks. Therefore, the data quality of each building block is evaluated in order to obtain an overview of strengths and limitations of the data used for plastberegner.dk. This is presented in **Table 11.2**, where each of the above mentioned questions are addressed for each building block. Each question is evaluated using four different colour codes. The meaning of the colour codes is explained in **Table 11.1**. The evaluation of data quality is summarised in **Table 11.3**.

Table 11.1: Description of the colour codes used in **Table 11.2**. The column headings refer to the bullets above.

colour code	Switch:				Actual tech.	Actual geo.	Transparent data source
	Subst vs. alloc.	Elec. model	Cap. Goods	Services			
Green	Yes, incl. upstream activities	Yes, incl. upstream activities	Yes, incl. upstream activities	Yes, incl. upstream activities	Actual technology	Actual geo (this is most often global for bulk materials)	Yes, incl. upstream activities
Yellow	Yes, but not for significant part of upstream	Yes, but not for significant part of upstream	Yes, but not for significant part of upstream	Yes, but not for significant part of upstream	Some deviations / average of highly aggregated data	Data for large region, but not the actual	Yes, but not for significant part of upstream
Red	No	No	No	No	Data for other technology is used	Data for a single country and not actual country	No
White	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant

Table 11.2: Evaluation of data quality of the included building blocks. The colour codes are explained in **Table 11.1**. The headings are described above **Table 11.1**.

Data set / Building block	Switch:				Actual tech.	Actual geo.	Transpa-rent data source
	Subst vs. alloc.	Elec. model	Cap. goods	Services			
Materials\Plastics – thermo-							
Polyethylene, HDPE, granulate							
Polyethylene, LDPE, granulate							
Polyethylene, LLDPE, granulate							
Fleece, polyethylene							
Polyethylene terephthalate, amorphous							
Polyethylene terephthalate, bottle grade							
Polypropylene							
Polystyrene, expandable							
Polystyrene, general purpose, GPPS							
Polystyrene, high impact, HIPS							
Polyvinylchloride, emulsion polymerised							
Polyvinylchloride, suspension polymerised							
Acrylonitrile-butadiene-styrene copolymer, ABS							
Styrene-acrylonitrile copolymer, SAN							
Nylon 6							
Nylon 66							
Polycarbonate							
Polymethyl methacrylate, beads							
Polymethyl methacrylate, sheet							
Polyphenylene sulphide						Global	
Tetrafluoroethylene							
Ethylene vinyl acetate copolymer							
Materials\Plastics, foil							
Packaging film, LDPE							
Tetrafluoroethylene film, on glass							
Ethylvinylacetate, foil, at plant							
Materials\Plastics, hardened-							
Polyurethane, flexible foam							
Polyurethane, rigid foam							
Materials\Plastics waste as raw material							
Scrap, polyethylene (PE)							
Scrap, polypropylene (PP)							
Scrap, polystyrene (PS)							
Scrap, polyethylene terephthalate (PET)							
Scrap, acrylonitrile-butadiene-styrene copolymer (ABS)							
Scrap, styrene-acrylonitrile copolymer (SAN)							
Scrap, polyvinylchloride (PVC)							
Scrap, other plastics							
Materials\Synthetic rubber							
Ethylene Propylene Diene Monomer, EPDM							
Polybutadiene							
Materials\Resins							
Unsaturated Polyester							
Vinylester							
MMA - Methylmetacrylate							
Bisphenol-A epichlorhydrine							
Phenolic resins							
Epoxy resin							
Data set / Building block	**Switch:**				**Actual**	**Actual geo.**	**Transpa-**

	Subst vs. alloc.	Elec. model	Cap. goods	Services	tech.		rent data source
Materials\Fiber for composite materials							
Glass and glass rovings							
Carbon fiber and carbon fiber rovings						Global	
Materials\Hardeners							
Anhydride hardener							
Polyetherpolyol							
Isocyanate - toluene diisocyanate							
Isocyanate - methylene diphenyl diisocyanate							
Amine hardener (TETA)							
Hardener for fenol system (hexamine)							
Materials\Solvents							
Acetone							
Styrene							
Materials\Flame retardants							
ATO – antimony trioxide						China	
Chloro paraffin							
ATH – aluminiumtrihydroxide							
Materials\Metal, non-processed							
Steel, non-alloyed							
Steel, low-alloyed							
Steel, stainless							
Cast iron							
Aluminium							
Copper						Global	
Lead						Global	
Zinc							
Nickel						Global	
Materials\Metal, processed							
Steel, processed						Europe	
Steel, stainless, processed						Europe	
Aluminium, processed						Europe	
Materials\Other materials							
Epoxy adhesive						Germany	
Varnish, acrylic							
Gel-coat						Not spec.	
Pigment, titanium dioxide						Europe	
Carbon black						Global	
Filler (chalk) (calcium carbonate)						Switzerland	
Bitumen						Europe	
Oxidised bitumen						Europe	
Paper and cardboard (packaging)						Europe	
EUR pallet						Europe	
Water, tap						Denmark	
Energy and fuels (incl. combustion)							
Electricity						Denmark	
District heating						Denmark	
Fuel oil							
Natural gas							
Coal							
Petrol							
Diesel							
Lubricants							

Data set / Building block	Switch:				Actual tech.	Actual geo.	Transpa-rent data source
	Subst vs. alloc.	Elec. model	Cap. goods	Services			
Machinery, buildings and vehicles							
Buildings						DK market	
Machinery						DK market	
Vehicles (cars/vans/lorries)						DK market	
Transport, services and overhead							
Transport, van							
Transport, lorry (3,5-16 t)							
Transport, lorry (16-32 t)							
Travel, taxi						DK market	
Travel, train						DK market	
Travel, air transportation						DK market	
Hotel and restaurant						DK market	
Post, telecommunication, internet						DK market	
Financial and other intermediation						DK market	
Business services (accounting, marketing, consultants etc.)						DK market	
Paper and paper products						DK market	
Printed matter and recorded media						DK market	
Office machinery (computers, printers, copy machines etc.)						DK market	
Phones, televisions, projectors etc.						DK market	
Furniture and other overhead articles						DK market	
Waste disposal\Recycling							
Scrap, polyethylene (PE) to recycling							
Scrap, polypropylene (PP) to recycling							
Scrap, polystyrene (PS) to recycling							
Scrap, polyethylene terephthalate (PET) to recycling							
Scrap, acrylonitrile-butadiene-styrene copolymer (ABS) to recycling							
Scrap, styrene-acrylonitrile copolymer (SAN) to recycling							
Scrap, polyvinylchloride (PVC) to recycling							
Scrap, other plastics to recycling							
Paper waste to recycling						Denmark	
Iron and steel waste to recycling							
Aluminium waste to recycling							
Other metal waste to recycling							
Inert waste to recycling (used as filler material)						Switzerland	
Waste disposal\Incineration							
Plastics waste, exclusive PVC, to incineration							
Plastics waste, PVC, to incineration							
Paper waste to incineration							
Iron and steel waste to incineration							
Aluminium waste to incineration							
Other metal waste to incineration							
Inert waste to incineration							
Waste disposal\Landfill							
Plastics, metal and other inert waste to landfill							
Paper waste to landfill							

Table 11.3: Summary of the evaluation of data quality.

Data category	Overall assessment of data quality
Materials\Plastics – thermo-	Most of the data are based on Eco-profiles from PlasticsEurope. Hence, the building blocks are not sensitive to allocation and electricity switches, and only partly sensitive to capital goods switches (only first tier – upstream is not). All data represent Europe, whereas global average would be more representative. Data documentation is blackbox.
Materials\Plastics, foil	One of three data sets is based on PlasticsEurope's Eco-profiles; same data quality as indicated for thermo plastics above. The two other data sets fulfil the requirements except with respect to geographical coverage.
Materials\Plastics, hardened-	Same as for thermo plastics.
Materials\Plastics waste as raw material	For foreground activities the data quality requirements are all met, but since the data sets link to the data sets for primary plastics (thermo plastics), the data quality requirements for these upstream activities are not met.
Materials\Synthetic rubber	One of the two data sets generally meets the data quality requirement for the foreground activity, but not for upstream activities which are Eco-profiles from PlasticsEurope. The other data set is directly obtained from PlasticsEurope (see text for thermo plastics).
Materials\Resins	Two out of six data sets are based on Eco-profiles from PlasticsEurope and do not meet the data quality requirements (see text for thermo plastics). The remaining data generally meet the requirements, except for geographical coverage.
Materials\Fiber for composite materials	The data quality requirements are generally met. Only for one of the two data sets, the requirement for geographical coverage is not global which is regarded as being more representative than data for Europe only.
Materials\Hardeners	Most of the data are based on Eco-profiles from PlasticsEurope. Hence, the building blocks are not sensitive to allocation and electricity switches, and only partly sensitive to capital goods switches (only first tier – upstream is not). All data represent Europe, whereas global average would be more representative. Data documentation is blackbox.
Materials\Solvents	Most of the data are based on Eco-profiles from PlasticsEurope. Hence, the data quality is generally similar as of the thermo plastics.
Materials\Flame retardants	Two of three data sets generally meet the data quality requirements, except for geographically coverage and some upstream allocation issues for one of the building blocks. The third data set is based on data for a technology for another (but expected similar) material.
Materials\Metal, non-processed	The data quality requirements are generally met. A few data sets are associated with multiple output activities upstream in their product system that are not sensitive to the switches, and some of the data sets do not meet the requirement for geographical coverage.
Materials\Metal, processed	Same as for non-processed metals above.
Materials\Other materials	The data quality requirements are generally met – with some exceptions regarding geographical coverage. Three data sets are associated with upstream activities that are not sensitive to the switches, and two data sets (gel-coat and titanium dioxide) only meet the data quality requirements to a low degree.
Energy and fuels (incl. combustion)	The data quality requirements are generally met – with some exceptions regarding geographical coverage.
Machinery, buildings and vehicles	The data quality requirements are met.
Transport, services and overhead	The data quality requirements are generally met – with some exceptions regarding geographical coverage and technology coverage where the data represents broader aggregated product categories than what they should represent.
Waste disposal\Recycling	The data quality requirements are generally met – exceptions are upstream activities for the recycling of plastics scrap because these activities link to data from PlasticsEurope.
Waste disposal\Incineration	The data quality requirements are generally met – with some exceptions regarding geographical coverage for upstream activities.
Waste disposal\Landfill	Same as for incineration.

11.2 Evaluation of sensitivity

The objective of the sensitivity check is to assess the reliability of the results and how they are affected by system boundaries, uncertainties in data, assumptions and LCIA-methods (ISO 14044 2006).

System boundaries/the model: The approach to system delimitation (different switch modes) significantly affects the LCIA results for the building blocks. This is because the different modelling assumptions affect the database wide approach to allocation and electricity system.

The included switches enables for using system wide different ways of modelling co-producing activities, market mixes (including or excluding constrained suppliers), and applying different levels of completeness (including/excluding capital goods and services).

Uncertainty in data

In **section 11.1** the most critical issues with respect to data quality are identified as LCI data for primary plastics. Since the data on primary plastics from PlasticsEurope are not available in a transparent form, it has not been possible to quantitatively evaluate the sensitivity related to uncertainties of these data. However, based on the evaluation of data quality in **section 11.1**, it may be expected that significant uncertainties are potentially present for these data.

Another significant source of uncertainty is associated with the data on electricity used in the inventory. The data for electricity are based on Schmidt et al. (2011) which enables for switching between average and marginal electricity mixes. The average electricity mix used in the attributional and the PAS2050 modelling switches is related to a relatively high degree of precision (based on energy statistics): The electricity mix used in the consequential modelling switch is associated with a lower degree of precision because data are based on comparison of current electricity mix and outlook data for future electricity mix. Obviously, such outlook data are associated with significant uncertainties, e.g. the realisation of policy goals. However, it should be noticed that the electricity mix in the consequential modelling switch has a high degree of accuracy because it is consistently sought to identify the actual affected sources of electricity when changing the demand. This accuracy is absent for the attributional and PAS2050 switches.

Similar uncertainties exist for district heating as for electricity (see text above).

A less significant issue related to uncertainties in data is the issue of prices of products which are measured in monetary units. The reason why the issue is less significant is that the contributions from inputs which are measured in monetary units are generally expected to account for a minor share of the total LCA-result for a product. LCA data for inputs which are measured in monetary units are based on the FORWAST database which is for 2003. These prices are adjusted to represent 2011 prices via price indexes. This is associated with minor uncertainties because prices may vary from industry to industry and because the price indexes are for very broad product groups which may cover large variations. Further, the prices are adjusted to account for taxes and transport and trade margins. The uncertainty will grow as time goes because the current data represents 2011 prices.

LCIA-method

The Stepwise v1.3 LCIA method has been used to transform/translate the inventory data to a number of impact indicator results in the tool. No other LCIA-methods are available in the tool and LCIA calculations have not been carried out by use of other LCIA methods. Based on comparisons of different LCIA-methods in other studies (Schmidt and Thrane 2009; Schmidt 2007) the most significant uncertainties are expected to be present for toxicities where large differences among LCIA methods are identified. A higher level of agreement with other LCIA methods is expected for the other impact categories.

The uncertainty in results obviously differs from building block to building block. Therefore, the overall uncertainty in results of LCAs carried by use of plastberegner.dk depends on which building blocks are used in the study.

11.3 Evaluation of consistency

The objective of the consistency check is to verify that assumptions, methods and data are consistent with the goal and scope. Especially the consistency regarding data quality along the product chain, regional/temporal differences, allocation rules/system boundaries and LCIA are important (ISO 14044).

In general the inventory of the building blocks is based on a very consistent and well defined methodological framework as presented in **chapter 2** and **3**. This framework and data enables for consistently and system wide applying different modelling assumptions and levels of completeness in the inventory. However, as identified in **section 11.1** the evaluation of data quality shows that there are several building blocks where limited access to transparent LCI data has led to no or limited effect of the modelling switches. Therefore, better (i.e. transparent) data sets on especially primary plastics would have been desirable.

Inventory data are partly based on ecoinvent (2010), which also contain data sets from PlasticsEurope, and on the DK/EU27 IO-database (available in SimaPro 7.3). The modelling assumptions (allocation and included suppliers) in ecoinvent, Eco-profiles from PlasticsEurope and the DK/EU27 IO-database are different. In the current study this has been compensated for by including switches for the major differences in completeness of the three databases (i.e. for capital goods and services) and by implementing the same and database wide electricity model in ecoinvent and the DK/EU27 IO-database. Despite these modifications, the three databases are not identical with respect to modelling assumptions and completeness. Therefore, some inconsistencies are introduced when mixing the databases in the same study.

In general, the study is regarded as having a relatively high degree of consistency.

11.4 Evaluation of completeness

The objective of a completeness check is to ensure that the information provided in the difference phases of the LCA are sufficient in order to interpret the results (ISO 14044 2006).

The life cycle inventory consistently operates with a cut-off criterion at 0%, and the switches enables for turning capital goods and services off.

12 References

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Appendix 1: Emissions included in the tool

Emission	Compartment
Acetaldehyd	Air
Acetone	Air
Acetophenon	Air
Acrolein	Air
Acrylonitril	Air
Acrylsyre	Air
Ammoniak	Air
Benzen	Air
Bisphenol A	Air
Bly	Air
Butylaldehyd	Air
Cadmium	Air
Caprolactam	Air
Carbondioxid, fossil	Air
Carbonmonooxid	Air
Carbonmonooxid, fossil	Air
Carbontetrachlorid	Air
Chrom	Air
Chrom VI	Air
Di(2 –Ethylhexyl)phtatalat	Air
Dinitrogen monoxid	Air
Eddikesyre	Air
Ethan, 1,1,1,2-tetrafluoro-, HFC-134a	Air
Ethylbenzen	Air
Formaldehyd	Air
Hydrogencyanid	Air
Isopropylbenzen	Air
Kobber	Air
Kulbrinter (C3-C14)	Air
Kulbrinter (C4-C16)	Air
Kulbrinter uden CH4	Air
Kviksølv	Air
Maleinanhydrid	Air
Metan, fossil	Air
Methyl ethyl keton	Air
Methylenchlorid	Air
Methylmethacrylat	Air
Monochlorbenzen	Air
Nikkel	Air
Nitrogen oxider	Air
NMVOC (ikke metanholdige flygtige organiske forbindelser (uspecificeret oprindelse))	Air
o-xylen	Air
p,m-xylen	Air
PAH, polycyclic aromatic hydrocarbons	Air
Partikler, < 2.5 um	Air
Partikler, > 2.5 um, and < 10um	Air
Partikler, > 10 um	Air
Pentan	Air
Phenol	Air
Propionaldehyd	Air
Selen	Air
Styren	Air
Svovldioxid	Air

Toluen	Air
Total VOC	Air
Total VOC (GC/FID)	Air
Tunge hydrocarboner	Air
Vinylacetat	Air
Xylen	Air
Zink	Air
Bly	Soil
Cadmium	Soil
Chrom	Soil
Kobber	Soil
Nikkel	Soil
Zink	Soil
Bly	Water
Cadmium, ion	Water
Chrom, ion	Water
Kobber, ion	Water
Nikkel, ion	Water
Zink, ion	Water

Appendix 2: Critical review report including author's response

In the following, the critical review report from Ole Dall is shown. In the report, each of the issues raised are commented by the author of the current LCA report. The author's responses are marked with grey.

Final review statement, September 21st. 2012

I have received and read the authors comments to my review dated August 9th, and hereby approve that the review is performed according to the ISO 14044 standard. In general I can also accept the changes and comments from the author, and I can recommend the program for the expected use. To my knowledge the LCA calculator at plastberegner.dk including the guidelines and the background report is a suitable tool to help non LCA experts with providing relevant and reliable environmental information about products mainly based on plastic materials.

If the results for a specific product made using the tool are meant for public purposes, each specific study must be verified by a critical review according to the ISO 14044 standards. This is correctly stated in the guidelines for the program.

My comments as mentioned in the review note on the next pages (including the authors comments), could be used as a checklist if a specific LCA-study made using plastberegner.dk is undergoing a review process. Some of my comments are not relevant for all types of products as they are related to inclusion/exclusion of biogenic C which is not relevant for most plastic products.

In my opinion the most important issues to consider in a verification process for a specific product LCA (made by plastberegner.dk) is the interpretation of the results where the importance of each potential environmental impact must be evaluated, and the performance of a sensitivity analysis related to the use of energy in the material production stage and the use of marginal electricity and heat in the manufacturing stage. Especially the latter is a subject of continual discussion among LCA-experts.

Review note: plastberegner.dk
By Ole Dall, August 9th. 2012

Content:

Recommendations in short

Input
- Help to scope of study depending on goal of study
- Include guidelines to use of switches
- Guidelines to find correct economic input data
- Guidelines for recycling of plastic products

Data
- More specific evaluation for some datasets
- Free access to all documentation

Results
- Include biogenic C in GWP or as separate impact
- Help to interpretation of results by introducing Graphs based on PE (person-equivalents)
- Help selecting data for sensitivity analysis (present color codes as graphic shares of results)
- Electricity and district heating short sight marginal (EPD) as sensitivity analysis
- Guideline to improve data if use is ISO-verified reports (Use of specific geographic oriented data, own data or marginal plastic production data)

Purpose of reviewing the tool "plastberegner.dk" and the data "documentation" report.
A critical review according to the ISO 14040/44 standard aims to review a specific LCA-study, and is not meant to review a LCA-tool to perform LCA-studies. So the aim with the review of plastberegner.dk is to evaluate if plastberegner.dk is a suitable tool to use as a basis for performing ISO-certified LCA-studies for specific products, mainly plastic based, in Denmark. This means that the expected users are provided the needed information and data to produce a LCA-study for most plastic based products, including reporting according to the ISO-14040/44 standard and with the possibility for an external review of every specific study (if relevant for the purpose). Whether the program provides results which can be used to meet the British PAS2050 standard is not examined in this review.

[Author's comment #1]: It is made clear that the critical review does not mean that the tool produces ISO 14040/44 compliant LCA-results (LCA report). The user of the tool is responsible for defining the purpose of a study and the functional unit, entering data, creating and linking user-specific LCA-processes, documenting user-specific data and for interpreting the results. In order to claim that a study is ISO 1400/44 compliant, the specific study must undergo a critical review.

It is stated in the documentation report that "The current study can be characterized as a life cycle inventory, and not a full life cycle assessment. Therefore, no life cycle impact assessment is included". This means that if the user wants to assess the result, he must do an interpretation of the results, either based directly on the LCI-data or by using normalization and/or weighting method (see EcoInvent background report on methods). Included in the interpretation should be a validation of the results by testing the sensitivity to important assumptions and data inputs, regarding the goal and scope of the study.

Hence one of the most important things the tool and documentation should provide is information and references that help the user to validate the results and data sources, and this review will have its main focus here.

The user of plastberegner.dk

In the documentation report is stated "The tool is characterized by being easy accessible, it does not require special skills in terms of LCA-modeling, and the tool enables for applying different standards (ISO14044, average/allocation and PAS2050)". Online is a 13 page user manual (version may 9$^{th.}$) which focus on the actual input of data including some exercises. The program gives different options for selection switches to meet different LCA-standards including the ISO 14040/44 using consequential LCA-modeling, but guidelines to use the different options is given in the documentation report and only in the English language.

[Author's comment #2]: It is specified in the LCA-report and user manual that a minimum level of LCA knowledge is a precondition for using the tool. In the user manual, reference to some recommended LCA literature/guidance is made. Guidelines on switches are included in the user manual.

The built in functions allows printout and download of results for every product, but included in the user manual is only a brief help to understand the 16 impact categories. In neither the program nor the result printout is there any help given to interpret the results. The focus on the relative contribution from 6 process groups in different impact categories by showing the graphics as relative results will tempt unskilled users to overestimate unimportant impact Categories since they all are represented as 100% emission output.

[Author's comment #3]: Guidelines on interpretation and a specification of impact categories those are typically important for plastics products are included in the user manual.

In the result presentation there are no links to the actual data used for the calculations – this has to be found in the documentation report (see comments in later section) which is provided in English (the program and user manual is in the Danish language).

To meet the aim of the tool being "easy accessible, not requiring special skills in LCA-modeling" will at least require some advice directly in the program to help the user to understand and make the right choice of calculation switches according to the goal and scope of the actual study. Also more help to understand the *output graphics should be included (showing relative impacts) – maybe by including normalized result as another graphic output (shown as person equivalents but not as relative impacts).*

[Author's comment #4]: The above mentioned items (see comment #3 from author above) are included in the user manual. Normalization/weighting is not included. Such information is typically not included in EPD's, and normalization/ weighting are optional items of ISO 14044 and not included in PAS2050. If normalization/weighting is desired, it is recommended that the user uses an LCA-software.

Purposes to use the plastberegner.dk

In the documentation report it is stated that "The purpose of the tool is to enable plastics processing companies to produce life cycle environmental information on their products". This means that the tool aims to provide relevant basic data and help the companies to set up well defined LCA-systems for their own products.

"It is possible to carry out partial (e.g. cradle to gate) and full life cycle assessments including the use and disposal stages", the report states, which means that the user defines the functional unit and the scope of their study. The program leaves space to define this (which will also be included in the result presentations), but does not provide any help to define the functional unit.

[Author's comment #5]: In the guidelines reference to good basic LCA manuals is made, e.g. "Håndbog I miljøvurdering – en enkel metode", http://www2.mst.dk/udgiv/publikationer/2001/87-7944-349-4/pdf/87-7944-350-8.pdf.

Advice about relevant system borders of a LCA-study could be relevant to include~~,~~ since some users are expected to be "unskilled". This could take offset in life cycle stages in relation to the company's activities and the goal and scope of the LCA-study. If the purpose solely is internal improvements, one scope and more narrow system borders could be relevant compared to what need to be included if the purpose is to join eco-labeling schemes. Such advice is closely related to the lack of advice~~s~~ about the use of switches as mentioned in the section above.

[Author's comment #6]: In the guidelines it is made clear that if the product system is associated with by-products, this will require more LCA skills. This will also be made clearer in the section of the purpose and intended audience in the LCA report. Further, the section on purpose will also make it clear that general LCA guidelines on how to carry out an LCA is out of the scope of the current study, and appropriate references to existing guidelines will be made.

The program and basic data aims to provide the user with data that makes implementation of the consequential LCA-approach easy and possible. Especially the electricity and heat supply, waste management and indirect changes in land use can turn results upside down if they are modeled in the consequential LCA compared to the attributional LCA, which is excellent that the program will help documenting. The consequential approach is a part of the ISO 14040/44 standard, but still not implemented globally.

But since the consequential approach has not been used in many former LCA-studies, many existing LCA-databases provide average data sets. This means that it can be hard to actually find data based on the consequential approach and if the databases are not disaggregated enough to manually select relevant data as the market marginal, one must often start from scratch. This is the case for some of the data used in the project (see later section about data quality), the question is actually if the tool in general is able to provide data that lives up to the ISO 14040/44 standards which should be based on consequential datasets – at least this can be a very sensitive matter, and the results should be interpreted with this in mind.

[Author's comment #7]: The LCA report clearly states where data deviate from the data quality requirements, and it is clearly acknowledged that data on primary plastics from PlasticsEurope are related to problems especially regarding allocation and transparency.

Interpretation of LCI-results

The first step in the interpretation of data collected in a life cycle study, is to aggregate several hundred input and outputs into 10-20 impact groups. This is done by conversion into the most typical representative for each impact group using a conversion factor for each substance (e.g. for GWP impacts CO2 is the main contributor, and 1 kg NH3 (methane) is contributing to this with 25 times as much as 1 kg CO2. The GWP for 1 kg NH3 is calculated as 25 kg CO2 eq. According to the ISO 14040/44 – standard there is a range of internationally accepted impact groups and the 16 impact categories as used in plastberegner.dk (listed in the results) is state of the art, but is still under development i.e. for water use and other resources. Since the units for each group represents very different impact types, the actual numbers are very different, and very often in LCA-studies the actual numbers are related to the annual emission for each group. A common method is to calculate the total annual emissions per affected person for each impact group in the common unit PE (person equivalent) and convert all LCI results for a LCA-study into PE for each impact group. By doing so the share of the contribution to each impact group is made comparable. This step is widely used and also accepted in the ISO-standard, but it is not mandatory to do. The interpretation of the results based on PE-results still have to consider which impact is the most important (and emissions with insignificant contribution to an impact group might not be relevant to prioritize).

By leaving this step out of the result presentation generated from plastberegner.dk does not help unskilled LCA-users to understand the results, and their focus for improvements might easily be mistaken as mentioned earlier. This is especially important since the tool is intended to be used for several studies.

[Author's comment #8]: See author's comments #3 and #4.

But one issue this review has investigated is how CO2 originating from Biogenic sources is calculated. Some methods to define impact groups only include fossil CO2, since the Biogenic CO2 is expected to be GWP neutral due to the CO2 uptake during growth of biogenic matters. The concept is that the output and input evens out during a short time span, and that calculating the impact of this is not relevant, which can easily be proven to be true (Weidema and Christensen, 2008).

[argument 1 which is addressed below]: But since the world according to IPCC could be close to a climate tipping point, even a short delay in emissions could help improve the situation, it is necessary to keep track of all emissions no matter the origin. **[argument 2 which is addressed below]:** Another reason is that the combustion of any biogenic matter that is used for energy supply replaces some fossil fuels emitting CO2, and implementation of inefficient energy systems based on biogenic sources can be avoided by keeping track of biogenic emissions in the same way as fossil C. **[argument 3 which is addressed below]:** A third argument is that a biogenic fuel source that is not combusted but degraded or stored in soil, both emits

GHG and store GHG for a period. Calculating this in the ILUC models should help to keep track of CO_2 both as input and output (which might not be done in all studies). Later emissions by combustion should therefore also be included on the output side. **[argument 4 which is addressed below]:** A final argument is that projects aiming to delay climate effects by new forest projects are given too low credits if the CO_2 binding in wood is not counted (because it is seen as climate neutral by later release).

[Author's comment 9]:
Re argument 1: The LCI data in plastberegner.dk which involves combustion of biomass and emissions of biogenic CO_2 do not take into account that the uptake of CO_2 from regrowth after harvest of biomass, takes place a number of years after the emission (this may be up to around 80 years for wood based biomass). This will be made clear in the documentation of the electricity LCI data where this issue is most relevant. It should be noticed that research is on-going in this field, e.g. Levasseur et al. (2010): "Considering Time in LCA - Dynamic LCA and Its Application to Global Warming Impact Assessments". In addition 2.-0 LCA is also involved in research project in this field (http://www.lca-net.com/projects/iluc_model/). Future updates of the electricity data in plastberegner.dk should address this issue.

Re argument 2: The efficiency of combustion of fossil fuels versus biogenic fuels is addressed in the life cycle inventory data – not in a subdivision of the contribution to global warming in fossil and biogenic CO_2.

Re argument 3: Indirect land use changes are specifically modelled in the study. This includes the change in carbon stock from one type of land to another, including soil carbon. But as mentioned under argument 1 above, the current modelling does not take into account the manipulation of biomass in the cultivation activity and hereunder soil carbon. The current modelling only addresses change in stored carbon as a consequence of the upstream changes in land use (iLUC) and not carbon balance manipulation in the specific cultivation activity.

Re argument 4: I don't see how re-forestation initiatives can be relevant for the current project.

The documentation (shown in a table in the user manual) does not tell if biogenic CO_2 is included – at least there is no specific impact group for this. A test calculation for marginal electricity based on natural gas, biofuel, wind and solar sources indicates that the CO_2 emission for biogenic sources is set to zero as also done in the stepwise model in SimaPro. If this is so, then emissions of biogenic C should be added (maybe as a separate impact category) in plastberegner.dk since it is part of a complete inventory. In the later interpretation the user can then decide if this GHG emission will contribute to the GWP depending on the timespan between CO_2 uptake and emission.

[Author's comment #10]: Biogenic CO_2 will not be included as a separate impact category. Firstly, indirect land use changes related to land occupation of biomass cultivation is included. The emissions of biogenic CO_2 from deforestation caused by iLUC are included with characterization factors different from zero. Secondly, a separate specification of biogenic CO_2 will not help the interpretation because the impact of delayed emissions or uptake is highly dependent on the time of regrowth of harvested biomass – and this is not known/specified in the current data set. Thirdly, the tool already operates with a number of different switch opportunities. Hence by bringing in further options for inclusion/exclusion of items will not make the tool more user-friendly and easy to interpret.

Data quality
The database included in plastberegner.dk is based on several studies with very different data origin, and thereof the evaluation of data reliability needs to be done for every single dataset provided. In the report is stated "Therefore, some inconsistencies are introduced when mixing the databases in the same study. In general, the study is regarded as having a relatively high degree of consistency."

A solution to the potential problem is addressed in the report where every data set is evaluated (table 11.2) to what extent the 4 switches can be implemented properly (with/without allocation, with/without change of electricity model, with/without capital goods, with/without service) and evaluated against the 3 issues: technological stage, geographical coverage and data transparency. The evaluation is done by categorizing each dataset with 4 colours (green good, yellow not sufficient, red for data gaps or white for not relevant). This approach is very useful to evaluate the sensibility of an actual LCA-study made by users of plastberegner.dk. But this will need a few more options for the output format from plastberegner.dk where each impact group for a product is presented in normalized values, should be split up in the different color codes as mentioned above. The user would then be able to see if an important share of an impact is based on good or insufficient datasets. If insufficient data are important this is where the sensibility analysis should focus. The colour codes should also be a part of the input in plastberegner.dk so the user is aware of the data quality already when modelling the LCA-system.

[Author's comment #11]: The requested feature of how to show results in plastberegner.dk goes well beyond what is supported in advanced LCA software. If the data quality was to be included in the calculation and presentation of results, it would be recommended to implement this by use of pedigree data on uncertainty and then quantify these uncertainties via Monte Carlo analysis – instead of showing the results divided into different colour codes. Such analyses are supported in advanced LCA software. If the user finds it necessary to quantify the uncertainties, it is recommended that an advanced LCA tool is used instead of plastberegner.dk.

In the user manual, reference is made to the data quality assessment in the LCA-report.

In this review I have not gone through all datasets, but checked out specifically electricity, heat and waste handling processes to see if these match ISO 14040/44 quality standards (see next section). But some general comments to the data quality are concerning the transparency, the completeness and consistency of data from the different sources, which is addressed in the documentation report chapter 11.

Transparency
Transparency is about the users possibilities to access every detail in the background information of the datasets. Ideally it should be visible which company has provided information about a specific process, but according to the ISO standard, generic data can be used, based on statistical representatives collected and presented in a way that ensures that the sources are well defined i.e. information about technological state must be very precise. To obtain this the data must also be very transparent about each partial contribution from different sub contributors i.e. energy suppliers. This level the EcoInvent database lives up to by publishing background reports for free at the internet and along with commercial databases based on the

reports. But one crucial point is that the background reports are accessible for free for everyone, even though that the easy access and overview demands use of a professional data tool. The access to the EcoInvent background reports should be mentioned in the reference section in the documentation report.

[Author's comment #12]: This is included.

The most important database in plastbregner.dk is the LCA-database from PlasticsEurope – the Association of Plastic Manufactures. As mentioned in the documentation report the format of the information from this source does not allow to investigate which type of energy input is used in the data sets, which is due to lack of transparency. Without having looked deeply into the background report from PlasticsEurope, it could be expected that also other issues as precise technological state which is needed to exclude constrained technologies for definition of marked marginal is not possible. Also system expansions for co-productions are impossible to implement due to lack of transparency. Lack of geographic information makes definitions of regional averages impossible for use in attributional data sets, which is also stated in the documentation report for several plastic types.

For data origination from the FORWAST project, which in general Is concerning buildings and other capital goods, as service, transport and overhead (administration) the source is well documented if one has access to a database tool as SimaPro even in a free Demoverion. But the transparency is not total, since the documentation report mention that new electricity supplies has been implemented, which is not included in my SimpPro version. The completeness and uncertainties and completeness in FORWAST will be commented in the section below.

[Author's comment #13]: The applied electricity mix is documented in the LCA report, and the FORWAST-database is publically available in the free demo version of SimaPro. Further, reference is made to all background information of the FORWAST database.

For the Electricity production scenarios, the reference is very transparent and well documented. The only problem for transparency is the issue of access that is not for free, which should be easy to solve.

[Author's comment #14]: The applied electricity mix is documented in the LCA report, and the background data for the electricity model are publically available in: Schmidt J H, Merciai S, Thrane M and Dalgaard R (2011), Inventory of country specific electricity in LCA – Consequential and attributional scenarios. Methodology report v2. 2.-0 LCA consultants, Aalborg, http://www.lca-net.com/projects/electricity_in_lca/

Consistency and completeness of data

An overall consideration is if the selected data sets are relevant for the potential users of plastberegner.dk. The project has ensured this by involving the user target group which is plastic producers in Denmark, which must be an optimal approach. In addition users are given an option to include own data sets as well, which ensures all in principle can use the tool.

In terms of data consistency and completeness, the weak point is the use of different studies based on very different sources of information and differences in the presentation. The main database from

PlasticsEurope is not transparent enough to actually evaluate the completeness in the collected data sets, and major inconsistencies with the 3 other databases (EcoInvent, FORWAST and ILUC) are mentioned in the report. The most important difference between PlasticsEurope is the lack of switches for consequential data sets, and the consequence is in fact that data originating from this source does not live up to the ISO-14040/44 standards.

[Author's comment #15]: The issue of inconsistency between EcoInvent, FORWAST and EcoProfiles from PlasticsEurope is addressed and included in the data quality assessment in the LCA report. It should be noticed, that the FORWAST and ecoinvent databases have been modified (switch dependant electricity mix) in order to be more consistent.

The FORWAST database is based on Economic data from production and trade statistics, which means that the annual total economic turn over in principle is included for each country. The FORWAST project aims to relate the economic statics to known environmental emissions by a matrix distribution of total emissions to relevant service and product groups. Nothing is in principle left out in this way. On the other hand the price is paid by lost precision of the emission data, caused by loss of product transaction data since they are related to relative broad statistic groups (133 products and services). The emissions data includes 8 emission types, where 7 contribute to GWP and SO2 to acidification. The number of impact categories is limited due to the methodology where distribution of energy use is about the only possible thing to do. So in terms of completeness the data are lacking accuracy towards specific products, and lacking most other emissions than GHG. In the report the completeness of the calculation are stated to be close to 0%, which is only partly correct for GHG-emissions, but it seems as if other emissions are missing as stated in the documentation for the EU27 FORWAST database in SimaPro.

[Author's comment #16]:
The original FORWAST database includes the following emissions and resource inputs: Emissions to air: ammonia, carbon dioxide, carbon monoxide, methane, nitrogen dioxide, nitrous oxide, NMVOC, sulfer dioxide. Resources: carbon dioxide in air, coal, oil (crude), gas (natural gas), iron, aluminium, copper, nickel, zinc, lead, sand and clay, other minerals (extracted for use), other minerals (related to unused extraction).

The applied FORWAST database is an updated version compared to the original one available in SimaPro and described in the FORWAST reports. Compared to the original version, the updated version also includes iLUC for all activities, it distinguish production outside Denmark between Europe and rest of the world (RoW), and the following emissions have been added to the inventory in the database:

- Particulates, to air
- Nitrate, to water
- Phosphate, to water

The above mentioned information will be included in the LCA report. Also a reference to the description of the most important elements of the update: **Mikkelsen K D, Høst-Madsen N K, Kjær L L, Kreilgaard L, Müller J, Schmidt J H, Madsen B og Zhang J (2011)**, Klimafodaftryk fra borgere og virksomheder i Region Hovedstaden, Bilag 2 - metoderapport. Region Hovedstaden, http://www.lca-net.com/files/Region_Hovedstaden_Bilag%202_Metoderapport_ver1.pdf

It should be noticed that the data from the FORWAST database generally account for a minor share of the total transactions/emissions relating to an LCA of plastics products. This is because the FORWAST database is only used to account for services and some capital goods. Therefore, the lack of completeness in terms of included emissions in the FORWAST database is regarded as being of minor importance.

The conclusion is that by using the “service categories as transportation and overhead” (an important exception is made for road transportation of goods – see next section) and “production good and building categories” based on FORWAST data, some relative uncertain data are introduced in the system. This is in opposition to the data quality statement in the documentation report in table 11.3:
“- Machinery, buildings and vehicles: The data quality requirements are met.
- Transport, services and overhead: The data quality requirements are generally met – with some exceptions regarding geographical coverage”.
This evaluation should be specified more since road transportation of goods has higher quality – see next section.

[Author’s comment #17]: A short note regarding completeness of included emissions is introduced in the LCA report.

The uncertainty is amplified by the input method for the service data, which are supposed to be done as economic value. The economic value for a company of service cost can be very much affected by taxes in the actual country where the service is paid. At least there must be guides in the plastberegner.dk about how to find correct values.

[Author’s comment #18]: Guidance will be included in the user manual. Generally, the FORWAST model takes into account taxes etc. However, these data are based on 2003 – so uncertainties related to development in taxes are present. Changes of prices from 2003 to 2011 are accounted for by adjusting prices via user price indexes. A short note regarding uncertainties in prices is included in the LCA report.

The ILUC (Indirect Land Use Change) database introduces an important impact in terms of land use changes and GHG-emissions. This area is scientifically developing rapidly in these years, and no doubt that it is relevant to include, even though some changes in methodology probably will be introduced in the near future (see also comment in previous section on biogenic C). The completeness and consistency is hard to estimate because of such new developments. For the plastberegner.dk the ILUC data are mostly relevant because of the electricity marginal introduces major use of biofuels.

The guidelines to use of plastperegner.dk could advise users that depending on the purpose of the LCA-study production goods and buildings could preferably be left out (if the purpose is comparing similar products), or use own datasets instead.

[Author’s comment #19]: I see no reason for leaving items out of an LCI because they are anticipated being insignificant – especially not when all data are available.

Data evaluation

Transportation

In plastberegner.dk an important exception for the use of FORWAST data is made for the road transportation or goods, where data are based on actual market responders to transportation services as average/new trucks in different sizes including relevant empty return driving based on EcoInvent data for these types of transportation. The input for road transportation is also done by tkm instead of value, which reduces the above mentioned uncertainty of using value as input. By doing so the completeness of a LCA-study of the impact categories i.e. toxic compounds originating from transportation are possibly improved much over the FORWAST data.

[Author's comment #20]: I am not sure that the uncertainty by use of tkm instead of DKK for transport services will reduce uncertainties. The use of tkm may not be appropriate in many cases; if the volume of goods determine when the truck is loaded or if the truck is not loaded as of the market average. It is correct that ecoinvent includes more toxic emissions than FORWAST, but the most significant emissions relating to transportation are often referred to as CO2, particulates, NOx and SO2. These emissions are included in FORWAST. Therefore the difference in completeness of included emissions is not regarded as being significant.

Electricity

Most important for the switch between the ISO 14040/44 and the attributional LCA/PAS2050 is the use of electricity, where the ISO standard should be based on the market marginal depending on the time and scope, where the attribution and PAS2050 uses the actual production average. This is implemented in all datasets except those originating from PlasticsEurope, which means that to some extent it is not possible to produce ISO-certified results for most plastic products using the tool.

For the 3 databases (EcoInvent, FORWAST and ILUC) the marginal electricity supply is defined in a separate study (Schmidt et al, 2011). In this study the so called build marginal is defined according to the expected and political accepted electricity supply plans for Europe27 and Denmark. The time scope for these datasets is 2008-2020 according to the documentation report. In the same study is defined a coal marginal which is suggested to be used for sensitivity analysis. This coal marginal is recommended to be used as marginal in the Danish EPD-program (www.epd.dk), if the time scope for a product is a few years.

[Author's comment #21]: If the user finds it necessary to operate with sensitivity analysis on coal based electricity, it is recommended to use advanced LCA software. It is out of the scope of the current study to facilitate sensitivity analysis on LCI data in the building blocks (except what the switches offer).

The Danish build marginal is to a high degree based on biomass and wind energy, which is a possible scenario if the political goals in EU are realized. The latest negotiations about the CO2 quota regulation could be interpreted as this might not happen. Together with stagnation in prices for fossil fuels i.e. natural gas could indicate the marginal to a high degree should be based on expected development in marked prices instead of political goals. A political constraint is only a constraint as long it pays of could be an argument. This in fact also goes for the high build out share for biofuels, which also could be constrained by increasing market prices as also expected for food production.

[Author's comment #22]: Yes, the data on marginal electricity are related to uncertainties. This is addressed in the LCA report.

Since a high share of plastic products is sold for once use, and has a lifetime of less than a year. This could justify the use of the short sight electricity marginal for such products, or at least as sensitivity calculation. This should be implemented in plastberegner.dk.

[Author's comment #23]: LCA generally supports the long term effects of decisions – and not the short term effect of the purchase of an isolated single product, see Weidema (2003) and Weidema et al. (2009). Hence, it is not regarded as being relevant for plastberegner.dk to support short-term changes of decisions.

District heating
As for electricity production also the marginal production supply is used for district heating in Denmark. And the project only considers Denmark since use of district heating and heat use from waste incineration is related to Danish conditions. For production of district heating, the major part in Denmark is produced as coproduction with electricity, and is expected to be build out in the next years.

The expectations for more use of biomass in CHP-plants then means that new heat demands in a consequential LCA-study will demand more biomass as increased production of heat from waste incineration will reduce use of other biomass with 100%, as described in the documentation report chapter 6. For the 2 attributional approaches the share of avoided productions (electricity and heat) are dependent on allocation rules which either are economical or based on European averages for heat utilization.

As for the expected built out marginal for electricity the huge increase in use of biofuels, and reduction of fossils might not be realized, especially because the price ratio between biomass and natural gas can rapidly change in a world of economic crises and lack of political decisions in EU. This could indicate that the marginal in the near future could be natural gas, and therefore I suggest this as a optional choice for sensibility analysis in a LCA-study using heat or producing waste for incineration.

[Author's comment #24]: It is correct that the identification of the marginal source of district heating is associated with uncertainties (though the used outlook data on district heating indicate quite significantly that biomass is the marginal source of heat). The uncertainties are addressed in the LCA report, section 11.2. Regarding the request for additional sensitivity analysis, see comment #21.

For general use of fuels the documentation report states; "Energy and fuels (incl. combustion): The data quality requirements are generally met – with some exceptions regarding geographical coverage". I agree to this, but would like a more explicit evaluation of electricity, district heating and other fuels, mentioning especially the sensibility of marginal to realization of EU energy policy goals.

[Author's comment #25]: The uncertainties related to data on marginal electricity and heat are specifically addressed in the LCA report section 11.2.

Waste incineration

Incineration of plastic waste in plastberegner.dk is supposed to happen in Denmark, since export of plastic today is only done for recycling purposes. The share of energy from incineration used as heat (65%) and electricity (16%) is found for 2005 – which is the same level as I found in a study for the Danish EPA in 2003. The energy recovery is related to switch dependent electricity and district heating production, and sensible to the choice hereof.

The documentation report states "Waste disposal\Incineration: The data quality requirements are generally met – with some exceptions regarding geographical coverage for upstream activities". I agree in this, but would like the latest comment be more explicit – what is actually missing for different types of products?

[Author's comment #26]: It is added in the LCA report (section 9.2) that for waste incineration, direct emissions data as well as upstream activities (the inputs of capital goods and auxiliary materials/fuels) are based on data for incineration plants in Switzerland.

Recycling

An important assumption is the actual recycling rate of plastic products collected for recycling. This is set to 88% out of the total collected for recycling, and recycling is supposed to be done with equal share in Denmark and by export to China (chapter 9 in the documentation report).

But more important is in fact the actual collection rate for recycling of different plastic products. For household products the plastic recycling is as low as 12% for most types of plastic products (Kaysen and Petersen, Miljøprojekt Nr. 1328, 2010). In p lastberegner.dk some guidelines about relevant recycling rates could be relevant to implement.

[Author's comment #26]: The 88% is not a recycling rate. A material recovery efficiency of 88% means that 1 kg plastics waste/scrap which is sent to recycling is reprocessed into 0.88 kg new plastics and 0.12 kg processing waste. I see no reason why a larger share should be discarded as waste in the reprocessing process in China?

The study contains no data on typical collection rates because this varies significantly from product to product.