



# Methodology Report



## Pilot Study Diesel

Contribution to the Brazilian National  
Life Cycle Inventory (LCI) Database

Commissioned by  
**IBICT**



University of Stuttgart  
Chair of Building Physics (LBP)  
Life Cycle Engineering (GaBi)



**PE INTERNATIONAL**  
EXPERTS IN SUSTAINABILITY

**Methodology Report – Pilot Study Diesel  
Contribution to the Brazilian National Life Cycle Inventory (LCI) Database**

**Commissioned by IBICT**

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## List of Abbreviations

AP	Acidification Potential
BAT	Best Available Technology
ELCD	European Reference Life Cycle Data System
EP	Eutrophication Potential
EPS	Environmental Priority Strategies
FAETP	Freshwater Aquatic Ecotoxicity Potential
GWP	Global Warming Potential
HTP	Human Toxicity Potential
IS	International System of Units
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory analysis
LCIA	Life Cycle Impact Assessment
MAETP	Marine Aquatic Ecotoxicity Potential
ODP	Ozone Depletion Potential
POCP	Photochemical Oxidant Creation Potential
TETP	Terrestrial Ecotoxicity Potential
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
UBP	Umweltbelastungspunkten (“Environmental Impact Points”)

# 1. General specification and definition of the LCI database

This document is a result of the team work between PE INTERNATIONAL GmbH and LBP-GaBi – University of Stuttgart. It aims to highlight the most important aspects that should be taken into consideration, when planning and creating a national database concept. The points discussed here are based on the more than 15-year-experience of these groups on the field of LCA.

## 1.1 Introduction

In the following arguments are listed and described which have been discussed with the project expert group to be clearly defined to set-up a national LCI database. This paper represents some of the experience made by PE INTERNATIONAL and University of Stuttgart within past being an active player in the field of providing the LCA software GaBi and related databases for industrial and academic application. PE and LBP-GaBi have worked constantly over this period together with industry to:

- understand the applied technologies;
- identify the related environmental impacts;
- emphasis the sensitive situation of industry and within data collection;
- understand the needs from industry on LCI databases for a day to day application of LCA in industry.

This report should be understood as a listing of important tasks for such an effort which might be also necessary for the creation and continuous development of a national LCI database in Brazil. Also it should be mentioned that the following listing might be able to raise important questions for the creation of LCI database, nevertheless an intensive discussion as well as an analysis of the specific situation in Brazil was and must be performed to define the final approach and workflow for a successful creation of a Brazilian LCI database. Therefore PE and LBP-GaBi offer to support with their experience gained in the past within this cooperation.

The creation of a LCI database must be understood as a multiple step procedure, whereas this first section of the report will cover the essential underlying aspects. The covered aspects are:

- General definition and specification of the LCI database which includes aspects like
  - Content of the database;
  - Definition of the application of the LCI database content;
  - Definition of the type of LCI database “production mix versus consumption mix”;
  - Level of disclosure of LCI data within the database;
  - Data sources and relation/involvement to industry ;
  - Requirements on the team performing the LCI database creation procedure;

- Overall description of the necessary workflow of the database creation procedure;
- Methodological guidelines for LCI database creation covering topics like (chapter 2 and chapter 3)
  - System boundaries;
  - Cut-off rules;
  - Allocation methods;
  - Modelling principles;
  - Documentation.

Further steps will than define and describe all single aspects and work task for the successful creation of the LCI database..

## 1.2 National LCI database – Who will be involved?

As a first essential step the objective of the project must be clearly stated. Probably the most important question is – Why is there the need for a national database? – or with other words said – **What will be the expected application of the created Brazilian LCI database?**

Apart from this question to be answered also the involved parties within this project must have a clear and common understanding why this database will be created and what possible applications are foreseen (benefits). Also all parties have to understand what their contribution to the project should be and all parties must understand everybody's position and tasks within such an activity. The following listing of bullet points includes aspects to be discussed within the project group or at least must be taken into account during the layout and definition of the project planning.

- inquiry about Life Cycle Assessment strengthen forces of industry and politics in Brazil, leading to better environmental protection and quality of life;
- preparation of the Brazilian industry for the increasing international environmental requirements;
- data sources and relation/involvement to/of industry;
- performance of research projects and further development of the LCA methodology;
- Capacity creating aspects within academy, research organisations and industry
- since the LCI database will represent the activities of industry in Brazil, it is obvious that industry must be involved in this project. Also the support from industry is necessary in order to get information / data for the analysed processes needed for the LCI database. From experience PE/LBP-GaBi can state that an involvement of industry at an early stage offers a lot advantages to a project like this:
- early and open communication with industry can create a positive situation;

- understanding of the position and thinking of industry in respect to the creation of a LCI database;
- knowledge of important aspects which might exist at industry referring the database creation process as well as an active feedback on the possibilities (expected quality) of data support by industry (important for a realistic planning of the project duration);
- information on willingness of industry to provide the LCI database project with data / information (this includes level of detail for data support, necessity of secrecy agreements,...);
- identification how industry is currently using LCA in existing activities and in the future as well as the chance to have a discussion with industry on their expectations and needs regarding a Brazilian LCI database.

This discussion with industry offers the chance to create a clear understanding of the position and thinking of every party included in the project to ensure an overall common understanding and an accepted outcome (win-win situation).

On the one hand, the industry can make use of the project results for their own purposes, e.g. better knowledge of their processes and their environmental impact, sustainability reports, etc. On the other hand, the project executing organizations have the opportunity for gaining more technical know-how as well as strengthen their contact with the industrial parties by supporting them with the sustainability issues.

Also the point of view from researcher and academics on this project needs to be involved and it must be focussed that their might be the potential to run into a conflict of interest within industry and research defining such a LCA database, especially in the field of defining the level of disclosure.

Finally it should be realized that such a project also will require contributions from official authorities which will also benefit from a Brazilian LCI database as well as all parties mentioned before.

### 1.3 Description of the intended application of the LCI database content – What it will be used for?

This task includes the definition of:

- Who will be users of the database (industry, academy, politics,...);
- Which applications will be addressed – supported, data handling and decision support concerning:
  - Life Cycle Assessment (LCA);
  - Design for Environment (DfE);
  - Integrated Product Policy (IPP, mostly European driven);

- Environmental Product Declaration (EPD);
- Energy Using Products (EUP, mostly European driven);
- Carbon footprinting and Green House Gas Accounting
- ISO 14001 (Environmental management systems -- Requirements with guidance for use);
- Green Purchasing Programs;
- Decision support;
- Others.

## 1.4 Content of the LCI database – What will be included?

Within the description of the project proposal it was stated that the following major areas of Brazilian industry should be covered by the national LCI database. These will be:

- Energy → country specific situation in Brazil
- Transport → general task
- Plastic → country specific situation in Brazil
- Paper → country specific situation in Brazil
- Metals → country specific situation in Brazil
- Others

For sure a more defined description of the specific commodities within the listed sectors need to be prepared to define and create the content of the national LCI database more complete. In terms of creating the LCI database it is obvious that at the starting point more basic commodities should be analysed which will be important input to the more downstream commodities. This is reason why for example the first activities within the project will focus on the analysis of fuels, energy and transportation.

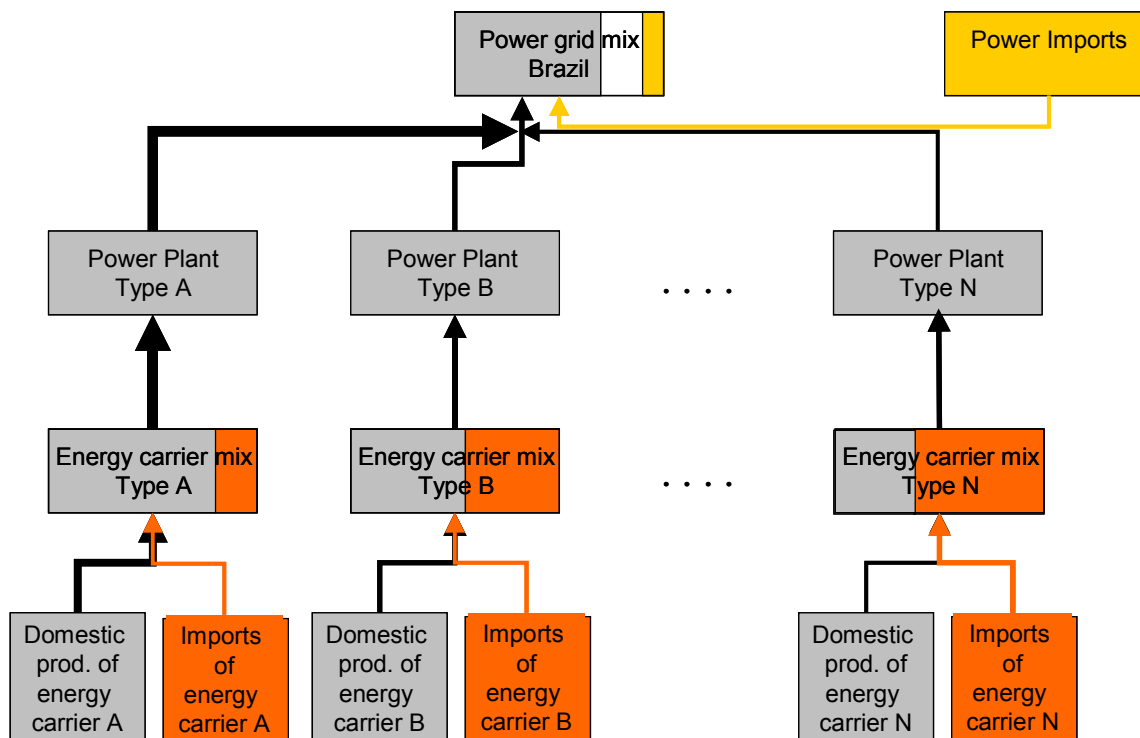
Another essential question to be answered is: What will be represented by the LCI inventories included in the Brazilian database?

In general two different levels of information can be understood as:

- a) “**production mix**”: this approach focuses on the domestic production routes and technologies applied in Brazil
- b) “**consumption mix**”: this approach focus on the domestic production and imports taken place. This approach represents the situation which exists for every commodity in Brazil in a day to day situation.

Figure 1 shows the differences between the two principle approaches. To explain the two approaches examples focusing the generation of electric power is selected. The example is set-up on the thinking that electric power available within Brazil is generated by running different

types of power plants. The supplies on energy carriers necessary for the operation of the power plant will be supplied by domestic resources as well as by imports from different countries. Also it is likely that besides the supplies for the power generation also electric power might be imported as well. (This illustrated scenario must be understood as principle approach not necessarily representing the current situation in Brazil).



**Figure 1: Difference between “production mix” and “consumption mix” demonstrated at the example of power generation**

The part of the Figure 1 which is coloured in grey represents the domestic part of the production which represents the “production mix” approach.

All parts of the supply chain of the power generation process coloured in orange represent the imports of supplies for the power generation (imports on energy carriers). Imports on end consumer level (imported power) are illustrated by yellow colour. The “consumption mix” includes the “production mix” as well as all information regarding the imports. The inclusion of the imports in the LCI data requires that country specific information about the generation of supplies and final products are available or will be gathered during a data collection. Not included in this example are exports.

It is obvious that for every commodity of the planned LCI database a screening of the existing situation focusing the relation on domestic production and imports have to be done, since this will be different for every commodity. This approach will lead to a clear understanding which data / information will be necessary to create the Brazilian database.

The decision which approach will be selected for the creation of a Brazilian LCI database will have significant effect on amount of effort, time and money needed. So this is a question that

must be answered on an early stage, having always in mind who are the users of this database and for which purpose they plan to use it. Nevertheless these questions cannot fully answer by focusing only on the mentioned parameters moreover the following tasks must be included into the considerations.

## 1.1 Level of disclosure of the National LCI database – “What is needed?” versus “What is possible?”

One task which will for sure require intensive discussion as well as a clear agreement with industry as well as with research, academia and politicians will be on the provided level of detail within the LCI database. There are several options available for the publication of the data within a LCI database:

- **Unit process level**

This level allows every user to get an insight to all analysed processes and technologies on the most detailed level which will be than defined by the level required within the procedure of data collection. Based on the experience of PE and LBP-GaBi it will be very difficult to get data / information support from industry if this level will be selected to be the level of disclosure of the LCI database. A release of unit processes within a national database might create problems for industry regarding:

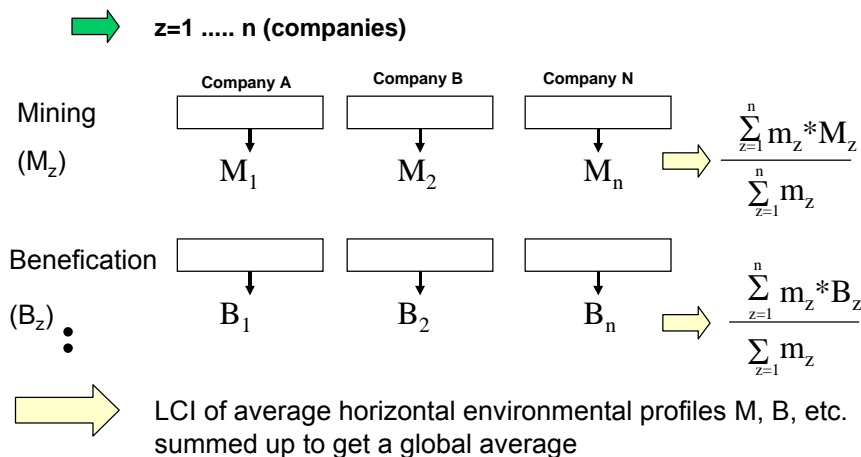
- Competitive situation;
- Challenging situation regarding the relations with the supply chain (cost calculations are possible using the information on material and energy on unit process level);
- Problems with general communication (compare e.g. activities of associations like IISI, PlasticsEurope,...);

Besides these aspects focusing the position from industry a database on unit process level also is challenging for users as well because:

- They must have the knowledge on all the details of process technologies applied and therefore represented with the collected unit processes to be able to handle all the details. A solution to this problem is software which automatically creates the up- and downstream supply chains which does not allow to build-up customer specific models and also will be most probably not as transparent.

- **Averaged unit process level**

This level can be reached if a so-called “**horizontal average**” is generated. Within this procedure two or more data sets on unit process exists which allow to come with an average for the analysed process step. This requires that at least three companies exist running the same process technology.

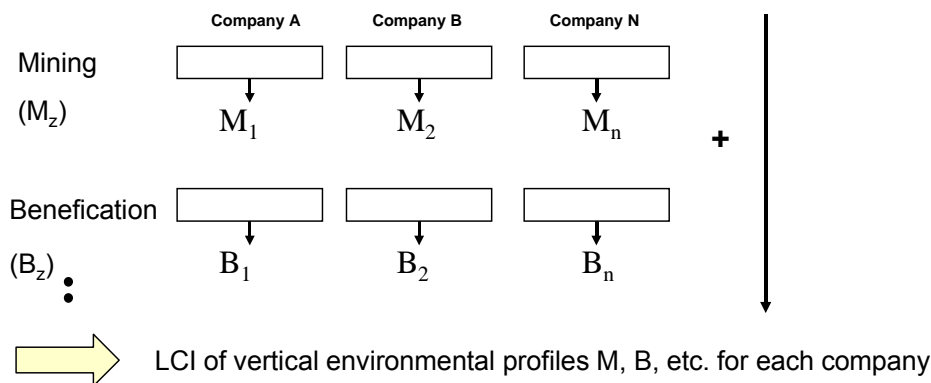


**Figure 2: Illustration for the process of horizontal average of unit process information**

This approach will overcome the problem of proprietary information on unit process level, but might be not inline with other strategies for data support.

- **Averaged unit process chains**

This level can be reached if a so-called “**vertical average**” is generated as illustrated in Figure 3. This requires that at least three companies are providing data / information for the production route. Within this approach the unit processes of every company will be aggregated along the material production process. This leads to an aggregated level of information unit process level (non-elementary inputs). In case very specific inputs are needed at the different unit process level secrecy of information is not protected completely. Therefore at least two producers per commodity are required running the same technology and the same range of manufacturing. This datasets can be first used to create a vertical average before a horizontal average is than calculated.



**Figure 3: Illustration for the process of vertical average of unit process information**

Providing a national database it is questions whether the level of information must be provided on level of aggregated unit process level (applying horizontal or vertical averages or combinations) since a transfer to other country specific settings by connecting country specific supplies is not correct because of eventually existing differences in production technology as well as performance of installed applications exist. So there is the chance of misuse of provided data by people not that familiar with the technologies represented by this unit process information. On the other hand for experts using these details advantages can be expected. These groups want to go on a detailed analysis and interpretation of inventory results. This type of analysis seeks to identify the contribution from single process steps as well as the effect of process energy and material usage to the overall inventory. Usually this is one argument to convince industry to participate to get all the detailed analysis of the production processes to increase the internal knowledge and allow providing most like more aggregated information generated on the single unit processes to be used within the national LCI database.

- **rolled up processes**

Rolled up process can be understood as “cradle to gate” process. This allows to understand the environmental impact of a material production, but do not allow having direct access to the unit process level, which guarantees to keep proprietary data information from data collection confidential. Depending on the level of “rolled-up” intermediates or products provided allows the detailed creation of results if needed.

The analysis and / or interpretation of the questions whether a specific intermediate or even process step has a good or bad environmental performance can not be made on the basis of existence of unit process information only. That kind of interpretation requires detailed expertise on the production technology applied and/ or existing or potentially available technologies (e.g. BAT information). This knowledge necessary usually exists within industry or very specialized experts at research and academia (typically these experts have already good relationships with the relevant industry anyway). Consumers of materials, focusing on their own production process, usually will not have this expertise because e.g. of an increasing outsourcing process of responsibilities and know-how. Universities and research institutes which have specialized on

a specific commodity might get or already have access to the unit process information or have cooperation with the specific industry in place to perform detailed analysis which is than basis for the identification of improvement potential.

This type of database content (rolled-up processes) in combination with a transparent documentation (providing information for each included single process step) will help to provide a substantial and comprehensive LCI database for several applications on end consumer products and allow cooperation with industry fulfilling secrecy agreements on unit process information. As an outcome capacity building in use of LCA is given by such a national LCI database but also the responsibility to avoid misuse of provided LCI information can be better fulfilled.

The discussion which level of disclosure will be the best one to be applied for a national LCI database is a rather difficult one. A general rule cannot be addressed; this question can just be solved by considering all interests and requirements of all involved parties.

Nevertheless, regardless of the disclosure level chosen, the possibility to produce parameterized models can ease the work done in terms of working time and the flexibility of the processes. Moreover, scenarios can be modelled in a short time without much effort.

These major questions should be discussed with all partners for the planned project to get a clear understanding of requirements, thinking, application and complications of interests which might exist. In the following some more task will be addressed focusing more practical steps for the process of creating a Brazilian LCI database.

## 1.2 Requirements on the team performing the LCI database creation procedure – What will be needed?

The process of creating a LCI database requires experts which have good background in the following fields:

- Performing LCAs and specifically having experience in analyzing technical production routes (background in engineering helps a lot to communicate within industry);
- Good understanding of the analysed production technologies applied for the material production and/ or power generation;
- Being sensitive for the situation of industry and having a appropriate understanding of the role of LCA within industry;
- Work self-directed and effective in cooperation with industry;
- Advising and orientating students to support the collection of the right and good quality data.

## 1.3 Overall description of the necessary workflow of the database creation procedure – How to organize such a project?

The necessary workflow of creating a LCI database covers the following major points:

- Definition and finalization of the major goals like:
  - Final content;
  - Contribution/ level of cooperation with industry;
  - Level of disclosure;
  - Intended application;
- Definition of clear responsibilities and guidelines;
- Setting up a procedure for data collection (including everything from identification of data needs, procedure of data collection, creation & communication of questionnaires, questionnaire evaluation and quality checks,...);
- Setting-up the model in a LCA software (defining rules for creation of new objects (naming, classification,...), documentation of used data and data origin,...);
  - Consistency and quality checks for created models and database content;
  - Quality checks of work performed within LCA software;
  - Verification if the applied methodology, format and documentation is in accordance with the ones applied in an international level.

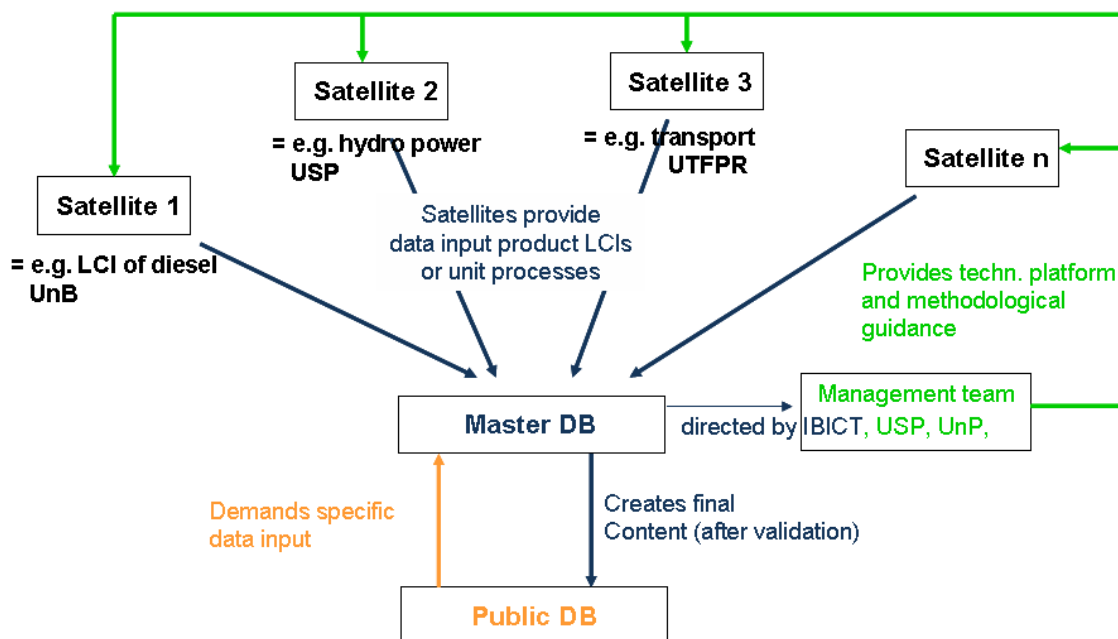
A listing of aspects which have to be defined in the methodological outline for such a project is given in chapter 2 of the report.

## 1.5 Other aspects related to a national database – What else needs to be considered?

### 1.5.1 Architecture, Handling, Interface to other software

To create a National database this also requires that a technical platform is defined. The following Figure 4 show how the general set-up for the National LIC database project can be understood. The definition of the technical platform creating such a LCI database includes the below listed tasks:

- Data format and guideline for nomenclature at all levels (public DB, master DB and satellite)
- Software technical platform (on master DB and public DB level, also requirements on what should be delivered by the satellites)



**Figure 4: Overview about project set-up**

The management team and experts from IBICT have been analysing applied standards and therefore have entered in cooperation with the European based activities of the Joint Research Centre of the European Commission located in Ispra, Italy. The sub chapter 1.6 will provide some more detailed information about this process of creating a LCI platform in Europe.

### 1.5.2 Long-term process

Besides these operational steps it is also necessary that the general thinking should already include aspects like:

- Support of the database (continuous information for users having a question);
- Maintenance of the database (ongoing checks and corrections of possible errors);
- Updates of the database (keeping the LCI database a-life and as updates as possible/necessary).

The above mentioned topics seems to be far away at this stage of the project but are the almost the most challenging questions to be answered with a solid approach addressing both technical understanding and required financial support. Here an analysis of other national database which have been already started or are even in place can give a good overview on challenges to be considered even during this early stage.

## 1.6 Technical platform – ELCD Format

The technical platform for the Brazilian National LCI database is given by the “European Platform on Life Cycle Assessment”, a project of the European Commission, which has two main goals:

- Support life cycle thinking in the development of goods and services
- Support life cycle thinking in a broad range of policies

With the deliverables of reference data and recommended methods, this project addresses the needs of:

- Private business and
- Public policy makers

in the European Commission and Member States for more reliable and cost-effective LCA studies towards improved environmental performance and increased competitiveness.

The project will deliver information an European Reference Life Cycle Data System (ELCD), this includes the following aspects

- Core Life Cycle Inventory (LCI) data sets from European business associations with emission and resource consumptions figures of key materials, energy carriers, transport, and waste management. Focus on data quality, consistency, and applicability.
- Life Cycle Impact Assessment (LCIA) factors for estimating potential impacts of resource consumption and pressures on the environment and human health. Focus on scientific robustness, relevance, and practicality.

To have the basis for such a LCI platform within the project a format for LCI data as well as a guideline for the need nomenclature of LCI parameters a developed. Coming along with these developments also a methodological handbook for a harmonized LCI modelling is part of the project as well as a guidance document on LCIA categories.

For the publication of the generated materials and tools has created a web based platform which can be found at <http://lca.jrc.ec.europa.eu/EPLCA/>. On the web page all content related to the ELCD format can be found. Most important information can be found at.

- Link to download package for format developers 1.0.1:  
<http://lca.jrc.ec.europa.eu/lcainfohub/developerPage.vm>
- Link to copyright and license conditions of the format and editor 1.0.1:  
[http://lca.jrc.ec.europa.eu/EPLCA/Doc/ELCD\\_format\\_and\\_editor\\_license\\_1.0.1.txt](http://lca.jrc.ec.europa.eu/EPLCA/Doc/ELCD_format_and_editor_license_1.0.1.txt)
- Link to the validity and conformity rules (i.e. which documentation extend has a well documented data set):  
[http://lca.jrc.ec.europa.eu/EPLCA/Doc/EP-LCA\\_ELCD-Format\\_validity-and-conformity\\_1\\_0\\_1.pdf](http://lca.jrc.ec.europa.eu/EPLCA/Doc/EP-LCA_ELCD-Format_validity-and-conformity_1_0_1.pdf)

## 2 Methodological Guidelines

This chapter give an overview of the most important methodological aspects during the complete process of creating a national database. This process covers the following steps:

- Phase 1: Definition of the database;
- Phase 2: Data collection and system modelling;
- Phase 3: Quality checks;
- Phase 4: Documentation;
- Phase 5: Critical Review.

The methodological guidelines represent an important basis for the consistent development of the database. They address the most important points but are not exhaustive. Since going from theory to practice always requires interpretation and experience, certain responsibility will be kept by the practitioner in any case.

### 2.1 Goal and scope definition

The results of a LCI study as a rule are related to a respective question or questions. Therefore, the goal and scope definition is of central importance. In simple terms – the efforts to find an answer and the quality of the answer must be balanced with the complexity and the importance of the research, study or project question.

In most cases the complexity of the answer or result interpretation is strongly depending on the degree of general validity of the answers. Systems and system behaviour of very special circumstances is much simpler to describe than systems of under general circumstances with possible variations of boundaries.

Defining this question is the task of the goal and scope definition phase. According to the ISO 14044 [7] the following points are documented in the goal definition:

- Intended application;
- Reasons for carrying out the study;
- Intended audience;
- Whether the results are intended to be used in comparative assertions.

### 2.2 Functional unit

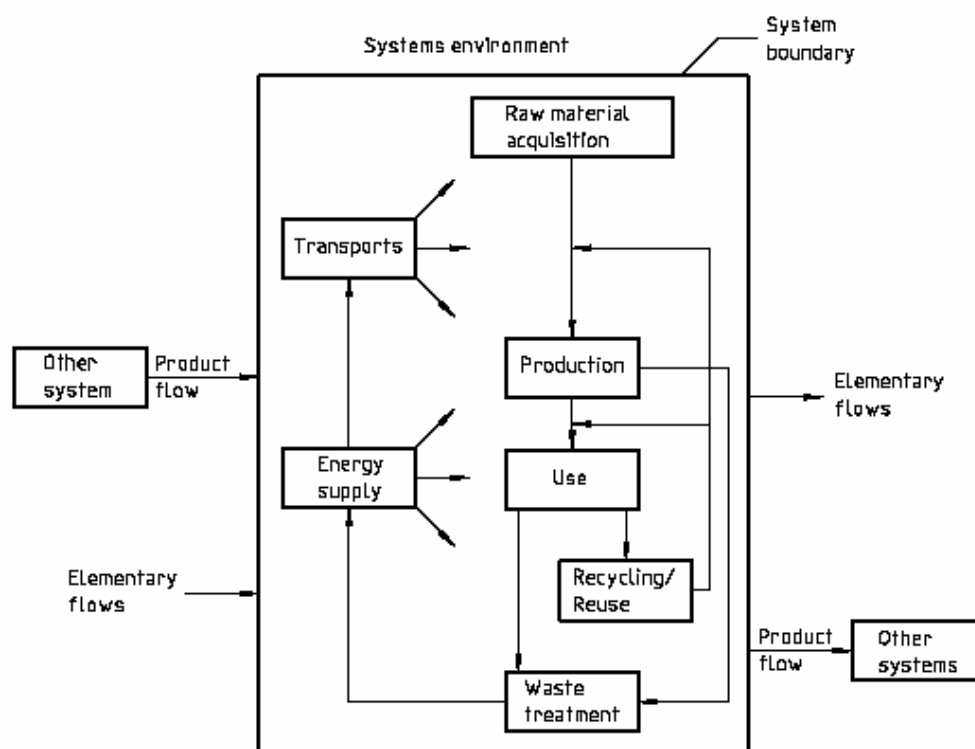
Following the goal definition, the functional unit has to be defined. The functional unit is a “quantified performance of a product system for use as a reference unit” in a life cycle assessment study (ISO 14044 [7]). It should be representative to the goal of the study and should allow the comparison of similar systems, processes or products, if needed.

Depending on the product used functional units in the GaBi databases 2006 [8] are basically physical SI-units related to the amount of product e.g.: 1 kg, 1 MJ, 1000 kg, 1 m<sup>3</sup>. The functional

unit of each process is defined within the process. The choice of the SI-unit does not influence the results of a comparison, if all compared systems can be described in the chosen SI-unit.

## 2.3 System boundaries

Within this subchapter the basis for the data collection as well as for the system modelling (building up the LCI database) is given. It defines what will be included in the study under investigation: a 'gate to gate', a 'cradle to gate' or a 'cradle to grave' analysis. The system boundaries can be a subject of adjustments due to the iterative process of conducting an LCA.



**Figure 5: Example for a product system for LCA purpose**

The basic terms and definitions have to be given which should cover at least the definition of the major terminology used to describe a basic product system covering objects like systems, processes and flows based on the finding in the ISO 14044 [7].

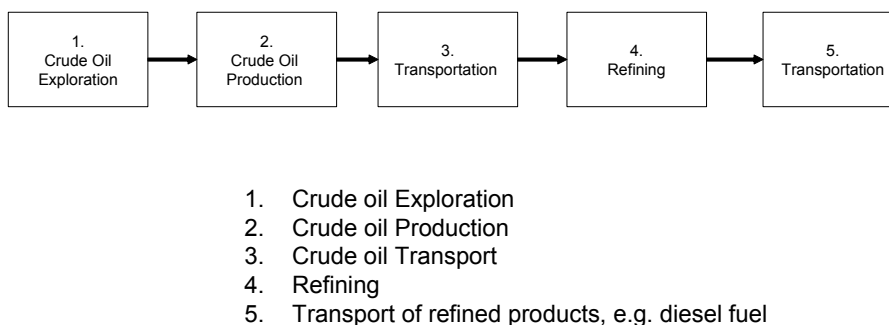
Definition for:

- **System boundaries:** defines the content of the life cycle assessment performed this focuses on the necessity to decide which process steps must be included
- **Unit process:** smallest element considered in the life cycle inventory analysis for which input and output data are quantified
- **Elementary flows:** material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation

- **Product flows:** this describes any good and service within a life cycle consideration

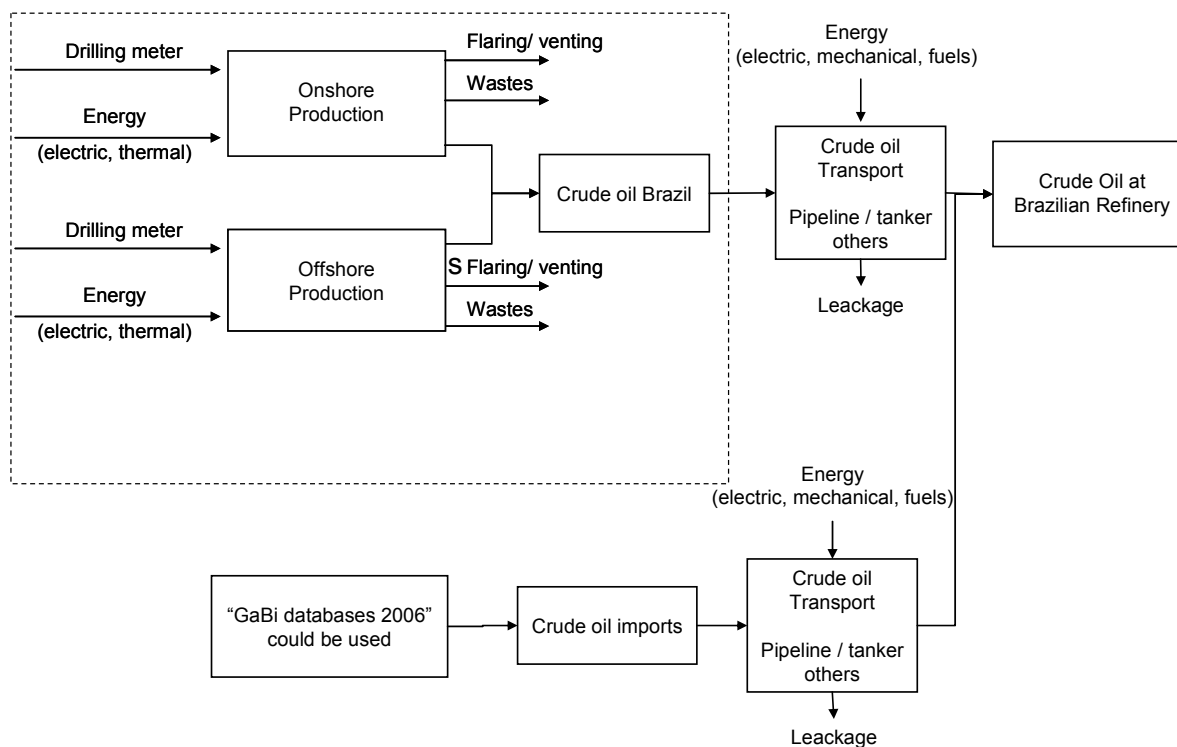
### 2.3.1 Definition of system boundaries for the creation of the LCI database

Within this section inclusions and exclusions of life cycle steps, investigated processes and relevant flows for the generation of a specific inventory are specified. Therefore an example is given focusing the production route for e.g. diesel fuel. Figure 6 shows a general overview of the system boundary to be considered.



**Figure 6: Overall system boundaries for the manufacturing phase of “diesel”**

Furthermore a more detailed breakdown of the identified major process is needed and could result in the following Figure 7, which are outlining the content of the crude oil production and exploration process steps.



**Figure 7: More detailed breakdown of the processes crude oil exploration and production**

In this manner all commodities are analysed and result in a transparent description of the system boundaries. Certainly, a set of general definitions and rules how to set the system

boundaries helps to minimize effort needed within this step and also give as good as possible guidance for this procedure. In practice “pre-modelled” cradle-to-gate datasets can be used for certain parts of the system to keep a balance of “sufficient system boundaries” and “sufficient time effort”. But it is to keep in mind that those “pre-modelled” cradle-to-gate datasets have initially to be set-up in detail and maintained as described, before those can be used in other product systems.

### 2.3.2 Cut-off Rules

Cut-off rules are defined to provide practical guidelines during the process of identifying the process chain under study in order to create a model of a specific product system. The ISO 14044 [7] mentions some criteria used to decide which inputs are to be included: a) mass, b) energy and c) environmental significance.

As a general rule the mass- and energy balances of unit processes should always be respected. Unit processes have should reflect actual physical and thermodynamic laws.

In the following description some frequently used cut-off criteria are listed and some examples are shown that a “straight forward” application of these rules can lead to problems within the definition of the system boundaries. Therefore the definition of the system boundaries using cut-off rules should essentially be done by experts:

- Knowing the respective process chain technically, and
- Knowing the field of environmental effects caused by the related material and energy flows.

Only this combined knowledge will lead to a meaningful definition of the system boundaries. Therefore system boundaries and cut-off rules are indeed essential elements preparing data collection. In the following, practical cases of cut-off rules are listed.

On the unit process level (input side) the following major rules are applied:

- Cut-off of any input 1 % according to mass and energy, and
- Expert-judgement according to ecological impact relevance of inputs less than 1 %.

This is especially important for processes with a high amount of different substances flows or large material flows, such as pesticide in agriculture or with concrete, as even small amounts (<1% mass) can be summed up in total, they are important due to their relative environmental relevancy in comparison to the main mass flows.

Therefore a technical and environmental understanding of the process is needed by the user. Otherwise suitable cut-off criteria are hard to define without uncertainty.

As a general principle of the unit processes, everything that is available or known, should be reported, even if it falls below the 1 %. Whether, the cut-off criterion is applied or not is then rather a matter on system level.

The suitable application of cut-off rules on the input side defines the amount of relevant included upstream process-chains.

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

On the output side, the procedure is as follows:

1. All known by-products are recorded (primary data is first choice);
2. All known emissions are recorded (primary data is first choice);
3. In case no data is available, emissions from similar processes or suitable literature data is used;
4. Alternatively with technological engineering know-how emission data can also be calculated over reaction equations and mass-energy balances;
5. Optionally, gaps in the data are identified and provided with a worst-case scenario (for example legal limit);
6. The ecological relevance of the individual emissions are calculated with the data categories described above (individually per category a sensitivity analysis is recommended. Sensitivity analyses are supported by actual software solutions and can therefore easily be done during this process). A check is carried out, as to whether temporarily entered literature values and estimated emissions produce important contributions;
7. If so the relevant emissions need to be investigated in detail (maybe iterative step of primary data acquisition needed as most representative values are the primary data sources of the actual process.

Hence the 7 points above may guide through possible steps of a data acquisition considering cut-off rules. But if the data of concern is not known but possibly unsuitable for cut-off an iterative step of primary data collection has to be applied or respective uncertainties are to be reported.

The fundamental problem is to establish the ecological relevance of emissions in order to assess the contribution of one particular emission, the total effect of all emissions must be known (and this has perhaps most often not even been measured completely; however the most contributing emissions are considered to be known). This criterion should therefore be seen as an indicator for which emissions are crucial according to the existing working-categories. The following sample calculation aims to develop a feeling for this, making the procedure easier.

#### **Sample Calculation from the Energy Sector for Diesel at refinery:**

As can be seen in Table 1, neither a cut-off below 1 % mass fraction, nor a cut-off below 1 % energy fraction makes sense in the example used, as most pollutants with significant effects on

the environment would then be excluded. To avoid this, every potentially occurring substance must be estimated (e.g. concerning substance contents in fuel or emission limit values for exhaust), so that its relevance to working-categories (incl. possible margins of variation) can be ascertained and finally assessed, as to whether detailed data research is useful.

**Table 1: Most important emissions of the average diesel at refinery in GaBi databases 2006 per kg diesel**

					AP	EP	GWP	POCP
	kg	%	MJ	%	%	%	%	%
Total emissions to air	5,95E-01	100,00	-	-	-	-	-	-
Exhaust	1,83E-01	30,78	-	-	-	-	-	-
Steam	1,06E-01	17,83	-	-	-	-	-	-
Carbon dioxide	3,02E-01	50,73	-	-	-	-	99,29	-
Nitrogen oxides	8,78E-04	0,15	-	-	25,86	97,52	-	5,61
Sulphur dioxide	1,76E-03	0,30	-	-	73,88	-	-	19,23
Carbon monoxide	4,16E-04	0,07	-	-	-	-	-	2,56
Nitrous oxide (laughing gas)	6,97E-06	0,00	-	-	-	-	0,71	-
Group NMVOC to air	8,74E-04	0,15	-	-	-	-	-	72,60
Ammonia	3,27E-06	0,00	-	-	0,26	0,98	-	-
Waste heat	-	-	1,29	100,00	-	-	-	-
Total emissions to fresh water	0,00834863	100,00	-	-	-	-	-	-
Chloride	5,82E-03	69,75	-	-	-	-	-	-
Chemical oxygen demand (COD)	8,00E-05	0,96	-	-	-	1,50	-	-
Particles to fresh water	2,13E-03	25,49	-	-	-	-	-	-
Sulphate	3,04E-04	3,65	-	-	-	-	-	-
Sulphide	1,26E-05	0,15	-	-	-	-	-	-
Waste heat	-	-	0,056	100,00	-	-	-	-

In summary a general rule can be stated: **“Only cut-off what can be quantified”** (see point 1 to 7).

This makes system boundary definition and the choice of cut-off criteria quite demanding for users that have limited knowledge or access to the relevant technical background data.

Therefore two principal requirements are needed to prevent rude or unsuitable cut-off.

1. Experience, as a comparable system has been modelled before and the important aspects are already known, approved and possibly even reviewed;
2. Time, as if no experience related to the system under study exists; this experience has to be built up.

### 2.3.3 Infrastructure

Infrastructure is a question of cut-off criterion: if relevant, the infrastructure is also taken into account. Since infrastructure in most cases is not relevant (assuming mass production and a long use phase) it can be excluded from the scope of the system boundaries in most of the cases, as the inclusion would not significantly change the result. This has been proven in many cases over the last 2 decades of LCA history.

Nevertheless these aspects need to be kept in mind if mass production is not taking place or the production system is rather exclusively described by the infrastructure (e.g. at the production of electricity by wind power converters). Therefore an estimation of the relevance of infrastructure should be checked (this can be done e.g. based on a worst case material composition of the infrastructure for example).

### 2.3.4 Transports

Whether transport must be considered or not is a question of cut-off criterion as well:

As a general rule the transportation processes are to be included due to consistency. However transportation processes, including fuel production and utilization, is in principle only to be included if the process in the considered system is known as to be relevant due to

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

If in doubt, it is recommended to include the transportation process in the model. In general the LCI database should be build up using the same source for transportation processes.

### 2.3.5 Waste

Waste treatment is integrated over the whole system during modelling, where the treatment is known. That means that e.g. for waste, which should be disposed, incinerated or landfilled related processes are integrated. In the case of GaBi databases 2006 [8] these aspects are prepared as models (inert matter landfill, domestic waste landfill, hazardous waste landfill underground/ above ground, waste incineration of domestic waste, waste incineration of hazardous waste). Hence the waste fractions of the processes must be identified by its composition.

There are many products which are considered legislatively a waste, but which have to be treated as products in life cycle assessment, as those are not leaving the system boundaries. Waste going to any kind of reuse or recycling is allocated or substituted, if a considerable positive market value (a product) exists. It should be noted that the same market value is applied at the point where the waste (or waste products) accumulates and at the point where the waste is recycled. For a suitable modelling feedback from the both side (producer of waste product and user or processor of waste product) is necessary. Waste to be recycled without a market value will stay (virtually) as waste in the producer process and is documented as such. The user of the waste product may process the waste without burden of the previous operation. All allocations must be documented.

In case that specific information is not available, a standard procedure is adopted at the GaBi databases 2006 [8]. Following the EU rules and goals on recycling and waste treatment

- Any secondary material that already has a recycling market is treated as recycled according to the market share (see examples in following table);
- All waste generated within the EU that has a calorific value is treated in an incineration plant (see selected examples);
- All other waste goes to landfill (see selected examples):

**Table 2: General procedure for material specific waste treatment process**

<b>Material</b>	<b>Waste treatment Process</b>
Mixture of plastics	Incineration
PVC waste	Incineration
Wood	Incineration
Aluminium waste	Recycling
Steel waste	Recycling
Coating and sealing	Recycling
Glass, concrete, stones	Inert landfill

The above description is a definition which was drawn for the GaBi databases 2006 [8]. Each case should be analysed separately in order to decide how to define the general integration/modelling of waste treatment.

In addition the treatment of waste water should be included in the modelling. As in the case of waste treatment (incineration and landfill) the composition of the waste water must be determined in order to make the individual adaptation of the waste water treatment process possible. Within the GaBi databases 2006 [8] waste water is modelled until release to river or sea. In case the water is treated with related consumption of energy and chemicals leading to lower emissions to nature; in case of untreated water with higher emissions respectively.

## 2.4 Types of data

### 2.4.1 Data selected for an LCA

It is really important to clearly define the data categories which should be covered by the national database. Therefore it is necessary to have a clear understanding of all material and energy flows connected to the commodities considered to be included in the national database. Also it is really helpful to have this definition done comprehensively to focus on the impact categories and evaluations methods which will be included in the database or will be in the focus of more downstream application of the LCI inventories provided with the national database. In this way, consistency among different data sets provided by different groups is also assured. Below a listing of some commonly used impact categories and evaluation methods is provided, nevertheless this list must be considered specifically under a Brazilian view.

- **Input-dependent quantities**
  - Abiotic Depletion;
  - Water use
  - Primary energy non-renewable (is entered as an additional quantity);

- Primary energy renewable (is entered as an additional quantity);
- Demands on natural space (surface).
- **Output-dependent quantities**
  - CML 2001 Categories (GWP 100, ODP, AP, EP, POCP, HTP, TETP, FAETP, MAETP);
  - TRACI categories;
  - EDIP 2003;
  - Disposal space (volume);
  - Others.

The database should of course also be usable for other assessments, such as

- Ecoindicator 99 or 95;
- Impact 2002+;
- UBPs;
- EPS;
- Others.

## 2.4.2 Land use (optional issue)

Land is necessary to produce goods and nutrition to guarantee our life on earth, to have space for housing and infrastructure. All these industrial processes and buildings are land consuming. Through anthropogenic land use damage to ecological functions can occur and can endanger ecosystems. Therefore the resource land shall be addressed in a sustainability assessment of products, product groups or services.

During the last ten years many approaches were made to address land use in the LCA framework; unfortunately there is no commonly accepted method so far.

At the University Stuttgart, Department of Life Cycle Engineering, an ecosystem function based classification of anthropogenic land use in process chains (effects of land use are quantified by looking at the effects of certain landscape functions and potentials) has been developed. A sophisticated tool calculates a set of key parameters for the ecosystem functions which can be entered as inventory data based on [3].

The following ecosystem key parameters are used in the tool to calculate the set of parameters:

1. **Erosion resistance:** That means the capability of soil to prevent soil loss.
2. **Physical and chemical filtration:** Physical and chemical filtration means the ability of soil to absorb dissolved substances from the soil solution to prevent pollutants entering the soil matrix (characteristic value: cation exchange capacity).
3. **Mechanical filtration:** Under mechanical filtration the mechanical ability of soils to clean a suspension through the binding of pollutants on soil particles is understood.
4. **Ground water regeneration rate:** This is the capacity to regenerate groundwater.

5. **Net primary biomass production:** Net primary biomass production is the ability of the ecosystem to produce biomass.
6. Indicator to express **the potential of an ecosystem to maintain and regenerate ecological** interactive structures through interdependencies between biotic and abiotic factors. This indicator is currently being reviewed.

All these parameters are calculated for the transformation phase (that means, land properties are modified during the use of the land; for example the change of the use of land from a natural forest to an open pit mine and after the use phase back into a secondary forest) and the occupation phase (that means that land properties are maintained; for example during the use phase of an open pit mine the land is occupied and the land cannot develop a natural succession, it can be assumed that the status of the land is constant during the occupation phase). So far an applicable land use method for generating LCI results is developed, based on [3].

The input background data for the tool is available for many countries. Also a set of key parameters as inventory data is calculated for several land consuming processes. Here the focus is set on mining.

When opting by using this method, the data requirements for the inventory consist of: Information on the size of the land, the time the land is used and the country in which the land using process takes places. Data like soil type, climate information etc. would deliver more precise results, but they are not absolutely necessary.

## 2.5 Data Quality Requirements

### 2.5.1 Reference Time and Reference Area

Reference time and Reference area have to be defined as one of the basis setting for the database creation process. Here the focus is to select the most up-to-date year possible keeping in mind that different industries have different reporting systems and innovation cycles. If data might come from governmental agencies also their delay in publishing data must be considered.

Regarding the reference area please compare with the section of chapter 2.3 discussing the definition of system boundaries.

### 2.5.2 Technology coverage

The intent is to develop industry average data for the range of technologies currently in use for specific unit processes. If more than one technology is used for the production of a certain product system in an industry, data should be collected for the full technology range and reported separately with the market proportion served by that technology. If it proves impossible to produce anonymous data by averaging from plants using similar technology or if there are

confidentiality agreements in force to prevent disclosure then results can be aggregated to produce weighted averages, with the relative contribution to the market by each technology type used as the weights. Data by technology type should also be separately reported unless confidentiality agreements with manufacturers prevent its disclosure.

Where distinctly different technology pathways are used to produce the same materials/products/commodities, then these may need to be kept distinct and not aggregated – the average values would not be representative of any of the technologies. Examples include:

- Electricity from different pathways
- Steel making: electric arc, basic oxygen furnace, HiSmelt
- Blast furnace or electro-refined metals
- Wet or dry process cement clinker production

There may also be a rationale for regional production models for commodities which are predominantly traded just within a local region.

- Electricity, gas and petroleum products
- Wood panels and timber products
- Cement, aggregates and sand
- Waste management services

For some low impact materials, transport is the dominant impact in their production and transport distances and modes may crucially affect the LCI results with sometimes counter-intuitive outcomes. For example:

- Aggregates shipped long distances by sea from coastal quarries may have lower net impacts than apparently more local sources travelling by road haul.

All technology or region specific models should document the following information where it is available:

- Location, Geography, Climate and Land use
- Environment issues and International Agreements
- Natural Resources and Hazards
- Economy and Industry Infrastructure and Logistics
- Fuel and energy, Infrastructure and Transportation

### 2.5.3 Precision, completeness, representativeness

These items provide specific details to the data used and should be included in the documentation. Precision determines the variance of data, e.g. whether measured, calculated or estimated. Completeness provides information regarding the percentage of flows that are measured, estimated or recorded as well as unreported emissions. Information about data

representativeness is assessed qualitatively and reflects to which extent the data set represents the reality, being data e.g. completely, partly or not representative.

## 2.5.4 Uncertainty

Uncertainties can be present in different ways in the inventory of a process:

- Uncertainties in the measurement, process or time variations, mean values from literature;
- Assumptions made based on missing data or process conditions;
- Approximations or estimations, e.g. use of a Bolivian process to estimate a Brazilian process;
- Completeness of the flows, e.g. in case not all relevant flows were captured;
- Errors in terms of modelling;
- Human errors.

Although it is not always easy to quantify this uncertainty, as in many cases just one value for each process step in the inventory is available, whenever possible, it should be quantified and documented. Methods for uncertainty estimations such as Monte-Carlo Simulation can be used. All references and assumptions must be documented.

As a general rule: Due to the extreme complexity of life-cycle-models and the high amount of measurements, calculations, estimations and external data sources a “real” difference in terms of “better” or “worse” option should only be interpreted, if results vary more than 5 %.

## 2.6 Data Categories

Data categories refer to the classification of the database content. Its main objective is to enable a better structure of the database as well as provide guidance on the datasets within the database. Within ELCD (European Reference Life Cycle Data System), the following types of categories are mentioned:

- Process categories (e.g. energy carriers, materials, etc.);
- LCIA method categories (e.g. human health, natural environment, etc.);
- Flow categories (e.g. emissions to air, resources, etc.);
- Flow property categories (e.g. technical flow properties, chemical composition, etc.);
- Unit group categories (e.g. technical unit group, impact unit group, etc.);
- Contact categories (e.g. organizations, working groups, etc.);
- Source categories (images, databases, general information sources, etc.).

Using diesel as an example for a process category, a possible classification could be: energy carriers (process top category) → crude oil based energy carriers (process sub-category) → Diesel at refinery (data set).

## 2.7 Data Collection

### 2.7.1 Team

Data collection is one of the most time consuming and important part of this process. In this way it is very important to have a very organized team formed by experts from each area, in which the data sets are to be created. They are the ones who should guide the work and prepare the questionnaires to be sent to industries or in case of no access to data, they should orientate the literature research. Having a good understanding of the processes, the experts can ‘talk’ the same language of the industry and provide a consistent questionnaire.

Once data is collected, they are also responsible for analysing the data in order to assure consistency and good quality.

### 2.7.2 Procedure

The data collection will be the basis for all following steps of analysing the gathered data and the use of this data for the set-up of the process models which will be the basis for the inventory calculation. So this means that the quality of the database will be dependent on the success and the level of quality resulting from data collection. Therefore a unique procedure should be defined how to do the data collection. Such a procedure should cover the following aspects:

- Try to understand firstly the core production technically;
- Identify the general situation on the manufacturing phase of the commodity to be analysed (e.g. how many producers exist, what are the applied technologies,...);
- Identify the essential single process steps which are dominating the manufacturing phase (this requires to be familiar with the technologies). In case that industry has given a commitment to provide data than this process should be done in cooperation;
- Create a questionnaire which explains the reason for data collection and also describes the data need on process level (Golden rule: the questionnaire should be as detailed as possible but not more than necessary and very objective → which means stay on a realistic level which can be supported by the data source but also fulfils the needs of the LCA project). A flow chart of the process also helps very much to have a good overview from where which data comes from. It also facilitates the understanding of the questions. Try to fill in as much as information you already know. That gives the data supplier the feeling that you have informed yourself and of having less work;
- Hand over the questionnaire to the data supplier, possibly this is taking place during a personal meeting to explain the procedure in detail and to make sure that the questionnaire is understood correctly, or by e-mail with a telephone conference;
- Check of the returned data applying general rules which focus on consistency and overall quality of the gathered data. This should include:
  - Mass and energy balance;

- Emission balances;
- Plausibility check focusing the general process characteristics;
- others ;
- Provide feedback to the data supplier and also use this additional conversation to clarify challenging things if any existing from analysing the provided data.

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

- Printed paper version;
- Electronically Word® or Excel® Document;
- Specific macros (e.g. GaBi 4 data process recording tool);
- Web based applications (e.g. GaBi 4 web questionnaire).

Within this section also aspects can be listed which give tips what to do if there is an inconsistent or even missing data set.

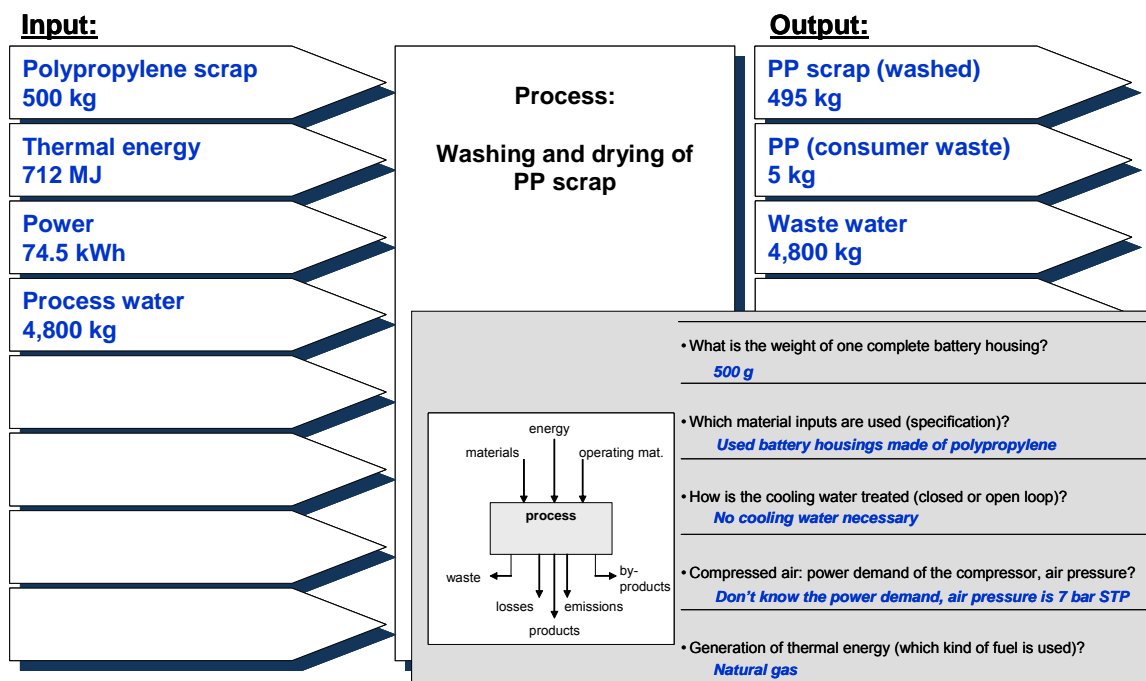


Figure 8: Example for a PowerPoint® based questionnaire

**Refinery - Questionnaire**

**1. Refinery - Black box**

Please fill in the following questions concerning the black box model for each refinery.  
reference unit: 1 kg crude oil input

**1.1. Refinery black box - Inputs**

Materials	Quantity	Unit	Notes
Crude oil	1 kg	kg/kg crude oil	
Intermediates		kg/kg crude oil	if you can specify the intermediates, please specify
Natural gas		kg/kg crude oil	
Add further items		kg/kg crude oil	
Auxiliary materials			
Portable water		kg/kg crude oil	
Surface water		kg/kg crude oil	
Chemicals		kg/kg crude oil	if you can specify the chemicals, please specify
Catalysts		kg/kg crude oil	if you can specify the catalysts please specify
Add further items		kg/kg crude oil	
Energy			Please only specify energy flows which cross the system boundaries of the black box model. (see flow chart above)
Power from grid		MJ/kg crude oil	
Power from heavy fuel oil		MJ/kg crude oil	Energy which is produced within the refinery (black box model) e.g. produced fuel oil is directly used for underfiring a distillation column, do not include here.
Thermal energy from natural gas		MJ/kg crude oil	Reason: Environmental burdens (emissions) of the energy internal energy should
Thermal energy from light fuel oil		MJ/kg crude oil	

Figure 9: Example for an Excel® based questionnaire

SoFi+  
Username: Fiscal period: 2007  
logout, change password, Online help

Site: LBP Site1  
back to sites

Stainless steel making and casting - Example

Positions	Value	Costs	Quality	Source	Year	rel.	unit/product	Mass [kg]	Net Calorific Val
Flows	overview								
Production residues in life cycle	overview								
Waste for recovery	overview								
Stainless scrap (external supply)	3152662830 kg	0,00 €	Calculated	Factory				0,65 3152662830	
Stainless scrap (home scrap)	485025050 kg	0,00 €	Measured	Factory				0,1 485025050	
Stainless scrap (internal scrap)	824542590 kg	0,00 €	Measured	Factory				0,17 824542590	
Valuable substances	overview								
Energy carrier	overview								
Electric power	overview								
Power	1164060120 MJ	0,00 €	Measured	Factory				2,4 - 11640	
Fuels	overview								
Hard coal products	overview								
Coal	97005010 kg	0,00 €	Calculated					0,02 97005010	2958
Materials	overview								

Figure 10: Example for a web-based questionnaire

### 2.7.3 Quality check and Validation of collected data

During the process of data collection, experts can prepare a check-list of general points that should give evidence if the data quality requirements are fulfilled. As mentioned above, this includes: mass and energy balance, emission balances, plausibility check, but also if all processes steps and inputs and outputs are included. In the presence of return flows inside the process and/ or waste, it must be checked the procedure adopted by the data provider. This is also part of the data collection.

In case of anomalies, problems should be checked with the data provider. It should be clarified whether this is a common problem with the specific process or any special case.

Once the quality level is achieved and all points are checked, data is validated and can go further for modelling.

### 2.7.4 Treatment of missing data

Data gap is a common problem of LCA practitioners. This can happen due to unavailability of data from data provider, no measurement performed for all emissions, no access to data due to confidentiality reasons, etc. In this case it is up to the expert team to decide which procedure to adopt.

The goal is just to close the gap as efficient as possible, without mistakes.

There is no standard rule for this problem as each case should be analysed separately, but the following measures can be taken:

- Literature: reports, papers, books, etc. can be checked;
- Average value from similar processes;
- In case of chemical reactions, often a good estimation can be provided by the stoichiometry and estimation of the reaction's yield;
- Estimation based on similar processes/ technologies or in the case of cross-boundary situation, consider the situation of countries with similar boundary conditions;
- Expert judgement (but this should be based on one or more aspects of the above).

In any case, according to the ISO 14044 [7] the procedure adopted for the treatment of data shall be documented.

## 2.8 System Modelling

The system modelling starts with editing gathered data to the selected software system. Therefore a clear defined nomenclature is necessary to specify new:

- Flows

Example: A flow needs to be specified by the following aspects:

- Name (most commonly used or according to existing systems);
- Case code;

- Abbreviation (e.g. polypropylene → PP);
- Chemical formula (e.g. carbon dioxide → CO<sub>2</sub>);
- Relevance to a certain impact category should be indicated ;
- Other technical aspects like calorific value;
- Reference unit.

In general a software system used for the system modelling should already have a substantial list of predefined elementary flows, so that ideally only new product flows need to be created. Following ISO 14044 [7], elementary flows (mostly resources, emissions and wastes) refer to the material or energy flows entering or leaving the system being studied that has been drawn or released into the environment without human transformation. Product flows refer to flows entering or leaving other product system. This approach has proven its effectiveness at PE and LBP-GaBi during the creation of several LC databases within the last two decades. Example for nomenclature of flows can be seen at the e.g. GaBi databases 2006 [8] or the ELCD database. At the moment a commonly accepted nomenclature for flows used for LCA purpose is not available. But it seems the JRC is starting efforts to create such a nomenclature in the near future.

- Processes

Example: A process needs to be specified by the following aspects:

- Specification of the country;
- Name (mostly the name of the product created → which is also the functional unit of the process analysed);
- Addition to the name (e.g. polyamide 6 granulate (PA 6));
- Indication if production technology if several technologies exist to produce the material;
- More detailed information on the region which is described by the process data (e.g. South Brazil).

- Product system

Example: A product system should be named like the process created

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

Also since the combination of processes and product system in e.g. GaBi 4 affects the result analysis (not the overall LCI result) a clear definition how to do this should be defined.

### 2.8.1 Parameter

In this context a parameter is a variable within a data set, allowing the variation of process input and output flows detached from a strict relationship between input and output flows (scaling). Thereby parameters can be used to calculate flow quantities (e.g. due to the characteristics of a

used substance) based on technical conditions, e.g. efficiency of power plant using energy carrier properties or e.g. sulphur dioxide emissions in dependency of the sulphur content of the used fuel or on other parameters.

A typical application of parameterised models (processes) is the modelling of transportation processes. For instance is it possible to calculate the CO<sub>2</sub> emissions by means of a mathematical relation in dependency of the travelled distance, the utilization ratio and the specific fuel consumption of a truck.

Parameters should be used in LCI processes with a high level of variation, such as transportation processes or in processes which should be easily adaptable for the user.

### 2.8.2 Allocation principle

Allocation respectively system expansions are used to effectively handle so-called co-products. This aspect in LCA is often the reason for discussion, despite the fact that often just one useful allocation rule is applicable and often the relevance of different allocations is rather an academic question than a real difference in the result. If there is a significant influence on the results due an allocation, sensitivity analysis shows transparently the effects and enable related result interpretations.

The ISO 14044 [7] says that:

- *“If possible avoid allocation by either: dividing the unit processes so that inputs and outputs can be assigned to specific products OR expand the system to include the function of co-products.*
- *If dividing the unit processes and system expansion are not possible, the inputs and outputs of co-products should be divided based on physical relationships between the co-products (e.g., mass).*
- *If allocation cannot be accomplished based on physical relationships, then other relationships between the co-products should be used (e.g., economic value).”*

This is rather not to interpret in way that system expansion is the favourite approach. But in most cases it is the situation that system expansion is not applicable because of lack of additional LCI information needed. Hence from a practical point of view allocation and system expansion are equally favoured.

Nevertheless the system expansion approach often results that the final inventory than will have single flows included which can hardly be integrated into the interpretation of the analysed system. Therefore results are often confusing to technical experts (e.g. people who have provided data but which are not LCA experts) if they are analysing an LCI representing the field of expertise enlarged by data from totally different fields.

The solid technical interpretation of the results gets weaker and less transparent.

Measures described in the ISO standard such as system expansion or further detailing the system until only single output processes are used to avoid allocation will only be applicable to a limited degree. Therefore the applicability of those are checked as a first step

Experiences from research institutes or industry have shown over time that allocation using the appropriate allocation keys proves to be a suitable tool for distributing environmental burdens to a specific product; especially using scenario calculation and sensitivity analysis to quantify influences of changing allocation keys.

For example, applying system expansion increases the efforts for data collection massive and in most cases it is not possible to reflect the actual situation of a process step by replacing a multi output process by multiple single output processes in a feasible and technical meaningful way.

As soon as multi-output unit processes (e.g. refinery) are part of the system under consideration, it is necessary to implement allocation. That means to distribute the in- and outputs (resources, intermediates; emissions) to the different products of the processes since it is neither wanted and nor that all of these products are defined in the functional unit.

Following the ISO 14044 [7], an allocation is always necessary if the allocation of a process with two or more outputs (e.g. combined heat and power generation, atmospheric distillation) can't be avoided by dividing the multi output unit process into single output processes or by extending the product system (which is daily practice mostly the case as mentioned before). It is then necessary to determine which allocation key is used to partition the environmental burdens of the product system to the different products. This is also applicable to the recoverable process wastes. Physical properties (e.g. mass, work potential, calorific value) but also economic criteria (e.g. market value) are suitable allocation keys according to the ISO 14044 [7]. It is important to select the allocation criteria keeping in mind the original intention of the process and the system boundaries specifying which in- and outputs are associated with the functional unit. The choice of allocation method needs to be documented and sensitivity analysis for evaluating the impact of the allocation is to be conducted if necessary.

Allocation Example: Chlorine-alkali electrolysis

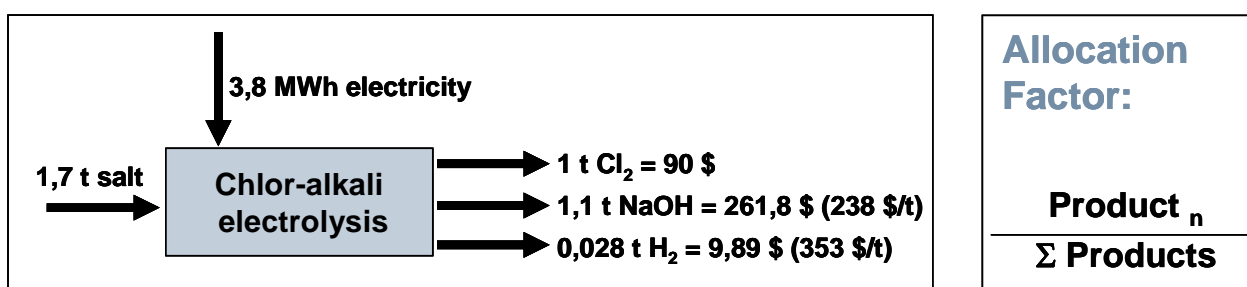


Figure 11: Chlorine-alkali electrolysis as exemplary situation for allocation

Allocation results:

Process Input	Total Process	Allocation by	1 t Cl <sub>2</sub>	1,1 t NaOH	28 kg H <sub>2</sub>
Electricity	3800 kWh	Mass	1786	1965	50
		Market value	945	2750	105
Salt	1700 kg	Mass	823	905	23
		Market value	435	1267	48

Within the Chlorine-alkali electrolysis example two different allocation methods are applied. First the inputs in the electrolysis - electricity and salt - are allocated by mass to the three products and second by market value. Taking electricity as an example and comparing the results shown in the table above, it becomes obvious, how sensitive the chosen allocation method influences the results. Whereas by using allocation by market value approx. 72% (2750 kWh) of the total electricity input are allocated to NaOH, only ~52% (1965 kWh) are allocated to them by using allocation by mass.

This shows that the chosen allocation method can be an influencing factor of the results and therefore it needs documented and a sensitivity analysis for evaluating the impact of the allocation should be conducted.

In chapter 3, using diesel as example, allocation will be performed using the above mentioned physical properties because in most cases it reflects the intention of the process best.

For allocation it is important to comply with the closing condition for mass (m) and energy H (enthalpy H = heating value h\* mass m) for the unit process under consideration

$$\frac{\sum_{Input} m_{input}}{\sum_{Output} m_{output}} = \frac{\sum_{Input} m_{input} \cdot h_{input}}{\sum_{Output} m_{output} \cdot h_{output}} = 1$$

When allocating by mass or by energy, in- and output flows of a process are leaving the system boundaries. This seems to lead to mistakes, e.g. the energy balance for a mass allocated process isn't correct or there is a defect of mass for an energy allocated process. But looking at the unallocated process it becomes clear that there is no calculation error. The reason is that the other mass and energy flows are no longer a part of the product system and therefore they are not considered in the balance. They are considered in other products system using these flows.

Making the balance over a whole company, region or nation the allocated values sum up correctly to the e.g. totals of the company, region or nation again. Hence allocated burdens are a systematic part of a consistent total, which enables to understand the life-cycle easier.

### 2.8.3 Recycling

Regarding recycling two main cases can be mentioned: closed loop recycling and open loop recycling.

Closed loop recycling involves the recovery or reuse of material in an identical secondary use. For example, the reuse of PET bottles or the recovery of PET granulates from bottles to produce new bottles.

Open loop recycling corresponds to the conversion of material from one or more products into a new product, involving a change in the inherent properties of the material itself (often with quality degradation). For example the reuse of coke PET-bottles as water bottles or the use of the PET-bottles granulate to produce T-shirts.

#### **Allocation beyond Lifecycle limits (Open loop and Closed loop Recycling)**

With allocations beyond lifecycle limits with durable products such as metals, the time aspect must be taken into account and the situation of production nowadays must be separated from that of future recycling. For production, the current average market situation must be assessed (ratio of primary material to recycled material). In parallel, the recycling potential reflecting the “value” of the product following treatment can be presented. The product part required for current secondary production should be deducted beforehand.

Taking steel as example, in other words, this means that the scrap that is treated in the End-of-Life (EoL) initially saturates the upstream lifecycle steps (production, use). In an ideal world (e.g. with a high recycling quota and simultaneously a low proportion of secondary scrap in the inputs of the production and use phase) the secondary steel would remain left over and would exceed the system limits. This flow is linked to the recycling potential of an inverse production process, i.e. secondary steel is still left over, credit (inverted process) is received. However, steel is needed from an external source to saturate the secondary steel requirement in the production and use phase, the flow to the inverse process is negative. (Negative flow + inverse process essentially mean production from additional steel).

Putting the explained example in numbers, one can say:

For the production of 1000 kg of metal product, currently 80 % primary material and 20 % secondary material are used. The production therefore comprises 800 kg primary production and 200 kg secondary production. Assuming that the secondary production presents 10 % losses, 220 kg of scrap are required for this process and therefore 780 kg of scrap are available for the secondary production as recycling potential (please refer to Figure 12). From this amount, considering the losses in the secondary production, 702 kg of secondary material can be produced. The recycling potential is therefore calculated from the “avoided production” of 702 kg of primary material.

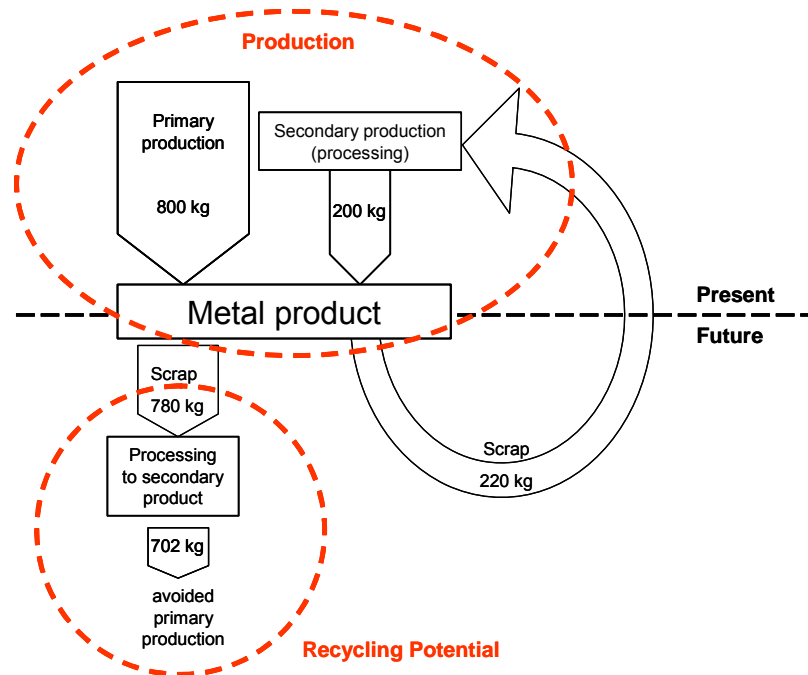


Figure 12: Recycling in LCA using metal as example

## 2.9 Plausibility

Plausibility deals with the support for data collection and systematic error tracing in inventories. It checks incorrect or missing values/ flows (type faults, conversion/ unit errors).

### 2.9.1 Plausibility and technical quality of the unit process

A possible checklist for the final check of collected data could be:

- Plausibility of type and quantity reactant/product and by-product/ waste
- Plausibility of emissions
- Plausibility of circulating flows
- All flows considered? Or still any missing?
- Efficiency/ stoichiometry check of chemical reactions; monitoring of the rate of yield (almost must-be >80 %; should-be > 90 %)
- Energy source is always included; if not electricity or steam, check if incinerated (incineration processes) or (partly) converted into products (stoichiometry)
- Inputs for exhaust air purification (lime, NH<sub>3</sub>, etc.); Are the quantities plausible?
- Do by-products accumulate?
- Allocation performed or system expansion?
- Is waste reused or disposed of? If disposed of, to landfill or incineration. If re-used, does it return to the process or any recycling process considered?

## 2.9.2 Important material and energy balances must add up on the unit process level (e.g. metal content balance ore/ product; energy balance etc)

- Energy balance: net calorific value (sum of renewable and non-renewable)
- Mass balance
- Element balance (also check for raw material recovery)

## 2.9.3 Plausibility of Emission Profiles (Ratio Input-Output)

The basic principle: avoid gross faults, both too high and (rare) too low values and/ or missing emissions. The plausibility and fault checking must therefore above all take place on the unit process level. Per process type there are typical emissions and/ or statements to be derived. The following checks result from these, which should assist the systematic fault check but these in no way replace expert knowledge, data collection or one's own reasoning!

Please find process lists in the Appendix A , with assistance as to what should be kept in mind for which process types. It is a selection of processes that should serve as a support to create one own's checklist.

## 2.10 Documentation

Whereas chapter 2.10.2 addresses the format of documentation, this chapter describes the content and the comprehensiveness of the applied documentation format. Thereby recommendations to mandatory and optional information, which are either based on international standards such as ISO 14040 [6], ISO14044 [7] and ELCD or on the experience of PE and LBP-GaBi are accounted for. All requirements of ISO 14040 [6] and 14044 [7] are considered.

An exemplary documentation of diesel fuel is given in chapter 3.

Within this chapter the documentation of flows and LCI datasets is highlighted.

### 2.10.1 Documentation of flows

The documentation of flows outlines an important component of the documentation of processes and LCI results. Because of this integral part and especially due to the large influence of the flow properties to the LCIA results, the documentation of flows should be paid a certain attention.

In the following it is distinguished between mandatory and optional documentation items following the ELCD guidelines. More detailed information can be found on the <http://lca.jrc.ec.europa.eu/> website.

#### **Mandatory items:**

- General flow information:
  - Name of flow, including specifying information like sulphur content

- Category/ subcategory of flows, e.g. resource/ non renewable resource
- Reference flow properties, e.g. net calorific value (MJ)
- Type of flow, e.g. elementary flow, product flow
- Flow properties and LCIA factors e.g. 1 kg CO<sub>2eq</sub>
- Language, e.g. Portuguese
- Documentation in terms of usage in database:
  - Administrative information, e.g. data set generator, modeller
  - Intended application, e.g. Life Cycle Inventory data for the national database
  - Publication and ownership, e.g. access restrictions

**Optional and often helpful are the following items:**

- Synonyms of flow names, e.g. power, electricity
- CAS numbers
- Valid location of the flows, e.g. region Latin America
- Field for general comments to add further information

## 2.10.2 Documentation of LCI data sets

In accordance to the documentation of flows, the documentation of the LCI data sets can be described as follows. The mandatory content of the documentation comprises the points listed below: More detailed information can be found on the <http://lca.jrc.ec.europa.eu/> website.

**Mandatory items:**

- General Data set information:
  - Name of Process or LCI result, including specifying information like electricity at 220V;
  - Category/ subcategory of the process or LCI result, e.g. energy carriers/ electricity;
  - Reference flow and reference unit, i.e. functional unit, e.g. 1 kWh electricity;
  - Reference year, e.g. 2007;
  - Representativeness country (geographical code), e.g. BR;
  - Description of product system/ process technology;
  - Reference to included datasets, e.g. linkage to other datasets;
  - Technological applicability;
  - In case of parameterised processes the mathematical relations (including name of parameter, formula, mean-, minimum- and maximum values), e.g. distance within transportation datasets;
  - Type of dataset, e.g. LCI result, unit process;
  - Data source(s), e.g. literature source, personal communication;
  - Data completeness, e.g. cut-off rules, applied extrapolation principles;

- Type of review, e.g. internal, external review;
- Coverage of review, e.g. inventory, documentation, LCI method;
- Consistency and conformity, e.g. in terms of nomenclature, methodology, documentation;
- Inputs and outputs flows, e.g. type of input and output flows including their amount;
- Representativeness technology, e.g. best practice, pilot plant;
- Language, e.g. Portuguese.
- Documentation of methodological assumptions:
  - Allocation rules, e.g. market value allocation is applied in the process refinery;
  - System expansion principles.
- Documentation in terms of usage in database:
  - Administrative information, e.g. data set generator, modeller;
  - Intended application, e.g. Life Cycle Inventory data for the national database;
  - Publication and ownership, e.g. access restrictions.

**Optional and often helpful are the following items:**

- Synonyms of process or LCI result name, e.g. electricity, power;
- Field for general comments to add further information;
- Date until data set is valid, e.g. 2008 (based on expert judgement);
- Modelling constants, e.g. all calculation of the LCI results refer to net calorific value;
- Time representative description, e.g. annual average;
- Data selection and combination principles;
- Use advice, e.g. use by electricity customers without own electricity generators or transformers;
- Data treatment and extrapolations principles, e.g. dealing of data gaps;
- Flow chart, pictures, diagrams.

## 2.11 Critical Review

A critical review is required by the ISO 14044 [7] when the study is intended to support a comparative assertion to be public available. It should be performed by interested parties, not involved in the project, but expertise in LCA and if possible involved in the field investigated (not necessarily).

### **3 Example: Diesel Pilot Study**

The objective of this chapter is to apply the methodological guidelines described in chapter 2 in a concrete case study: the diesel fuel production in Brazil. The results provided here are an outcome of the one-year work cooperation among Universidade de Brasília, Petrobrás, PE INTERNATIONAL GmbH and the department Life Cycle Engineering of the University of Stuttgart.

#### **3.1 Goal and scope definition**

The goal of the study is to provide a representative cradle to gate LCI inventory for 1 kg diesel fuel consumed in Brazil. It is intended to be applied in different studies and projects at national and international level, wherever the Brazilian diesel inventory is required. The study was carried out with the aim to form a basis for the Brazilian national LCI database, providing public available data and establishing quality guidelines for this and future inventories. Due to the fact that an international format will be applied, the LCI of diesel is intended to worldwide LCA practitioner. The use in comparative assertions is also possible as long as data is consistent. As described in chapter 1.4 regarding the differences of consumption and production mix, the consumption mix was in focus of this study. But due to the less amount of imported diesel fuel the Brazilian production mix can be seen as representative for the consumption mix.

#### **3.2 Functional unit**

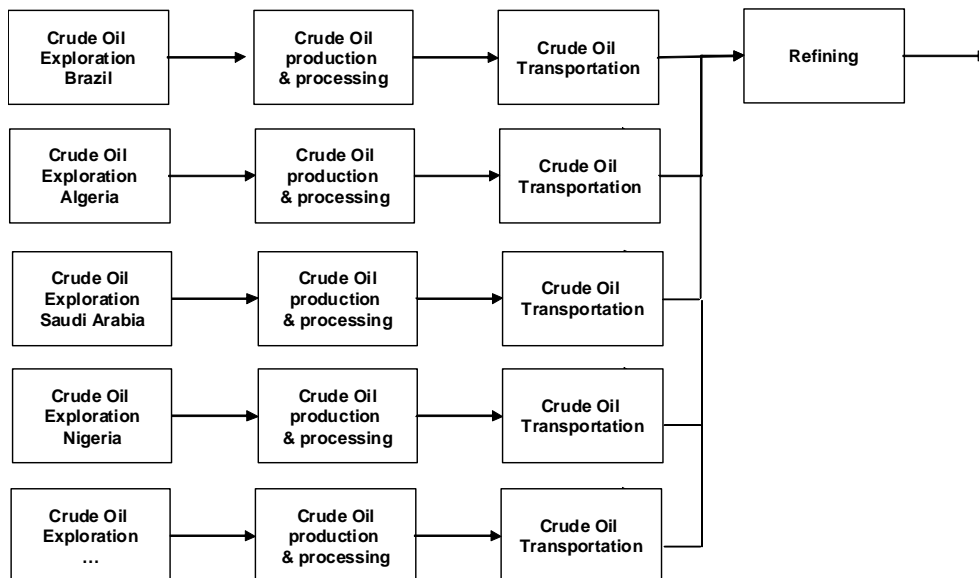
The functional unit used for this study is 1 kg of diesel, 500 ppm sulphur, sold in Brazil.

#### **3.3 System boundaries**

The system under investigation consists of a 'cradle to gate' analysis. In this way, the following processes are considered:

- Crude oil exploration;
- Crude oil production and processing;
- Crude oil transportation;
- Refining.

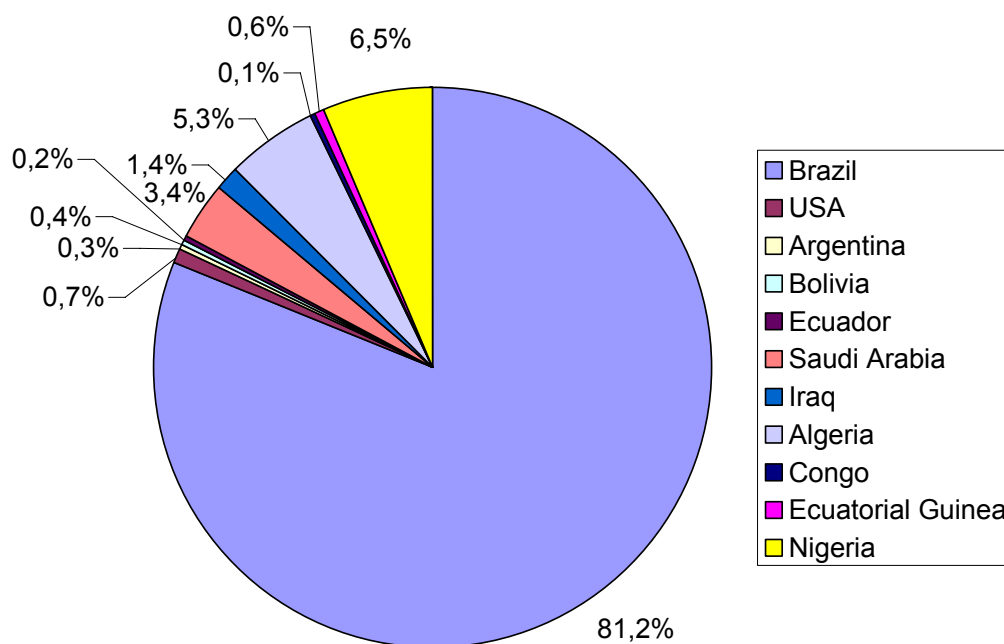
Figure 13 shows an overall scheme of these processes, considering the crude oil mix as well.



**Figure 13: Overall system boundaries for the production of diesel in Brazil**

Within the pilot study the refinery was investigated and analysed in detailed whereas the upstream processes like crude oil exploration, crude oil production & processing as well as transportation are taken from the GaBi databases 2006 [8] due to data availability reasons. Nevertheless the upstream processes are described roughly in the following.

Figure 14 presents a detailed breakdown of the different crude oils processed in Brazilian refineries. This crude oil mix was used for this study.



**Figure 14: Crude oil mix (Brazil), 2005 [1]**

### 3.3.1 Definition of system boundaries for the creation of the Diesel LCI database

As mentioned in chapter 2.3.1, within this section inclusions and exclusions within the generation of a specific inventory needs to be defined. Based on the overall system presented in Figure 13, a more detailed breakdown of the identified major process was done in order to identify which data were needed and in which level of detail they needed to be collected.

Figure 15, Figure 16, Figure 18 and Figure 18 show how this breakdown is looking like.

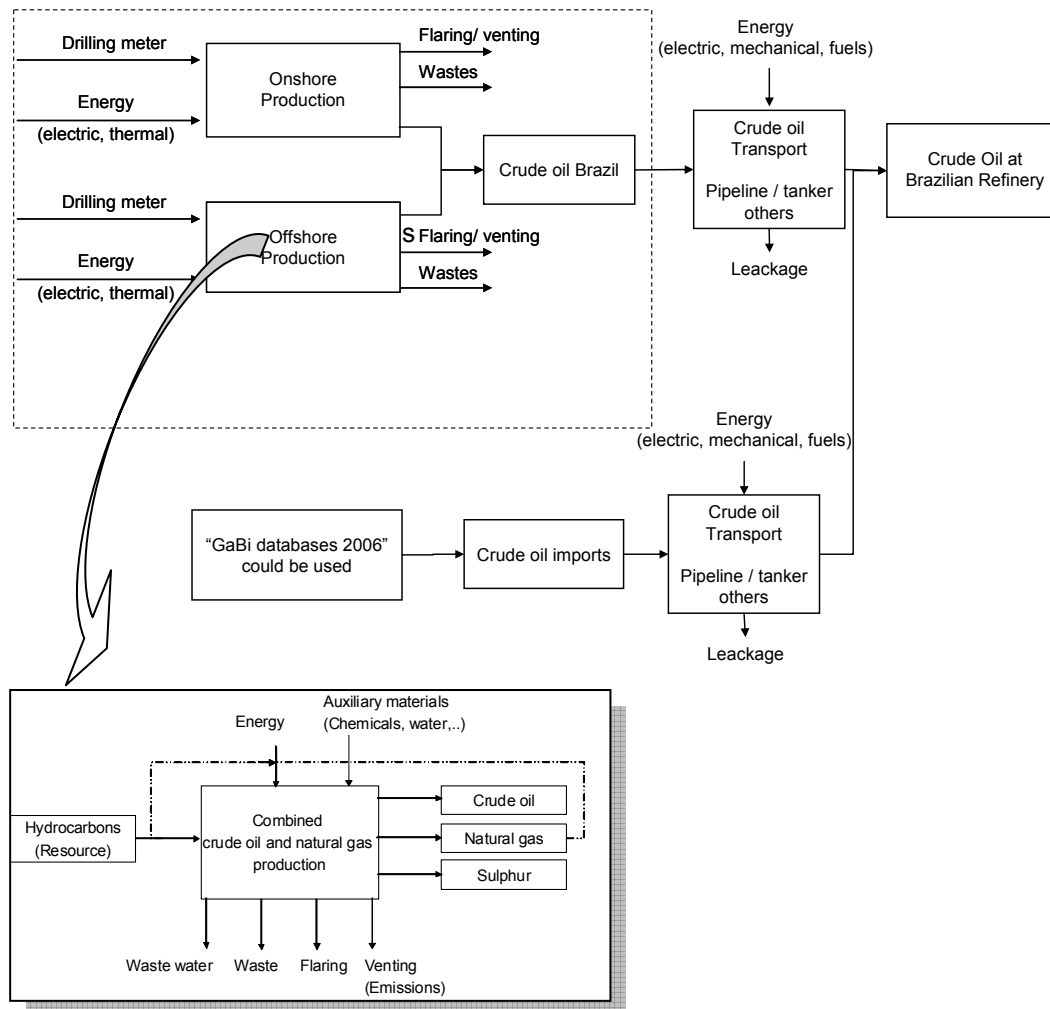


Figure 15: More detailed breakdown of the processes crude oil exploration and crude oil production with an overview of the offshore process

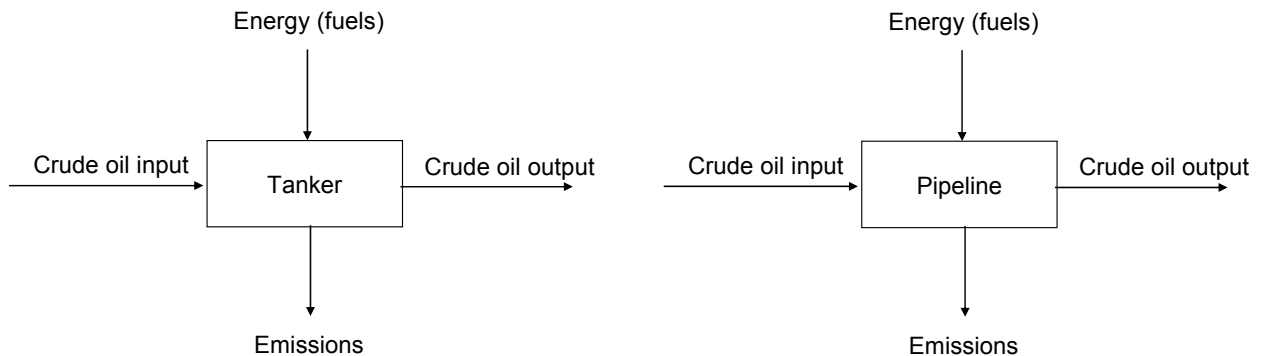
- **Crude oil exploration**

- Share between offshore and onshore, yearly basis
- Input – Materials such as bentonite, barium sulphate
- Input – Auxiliary materials, chemicals, water
- Input – Power, thermal energy
- Output – Waste
- Output – Emissions to air and water (e.g. CO<sub>2</sub>, CH<sub>4</sub>, VOC, SO<sub>2</sub>, NO<sub>x</sub>, sulphate, ammonium)
- Due to the fact, that the ratio between crude oil / natural gas (combined) (hydrocarbon) exploration and production oscillates from year to year, it would be very beneficial to get this data for several years to calculate meaningful average values per kg produced crude oil.

- **Crude oil production**

- Share between offshore and onshore, yearly basis
- Input – Materials such as hydrocarbons from well

- Input – Auxiliary materials. chemicals, water
- Input – Power, thermal energy
- Output – Waste
- Output – Emissions to air and water (e.g. CO<sub>2</sub>, CH<sub>4</sub>, VOC, SO<sub>2</sub>, NO<sub>x</sub>, sulphate, ammonium)



**Figure 16: Detailed breakdown of different crude oil transport**

In dependence of the origin of the processed crude oils either transportation by pipeline, tanker or a combination of both are used.

- **Crude oil transportation**

- Type of transportation: pipeline, vessel, tankers, etc.
- Input – Materials such as crude oil, diesel fuel, bunker oil
- Input – Auxiliary materials such as lubricants
- Output – Waste, crude oil losses
- Output – Emissions to air and water (e.g. CO<sub>2</sub>, CH<sub>4</sub>, VOC, SO<sub>2</sub>, NO<sub>x</sub>, sulphate, ammonium)

Figure 17 shows a schematic flow chart of a refinery in general. In addition to the crude oil input some refineries, like the REPLAN refinery in São Paulo, uses natural gas and purchased electricity as further input to provide the requested energy. Also water is used to operate the facility. On the output site, products, e.g. diesel fuel, gasoline, etc. emissions and waste water have to be considered.

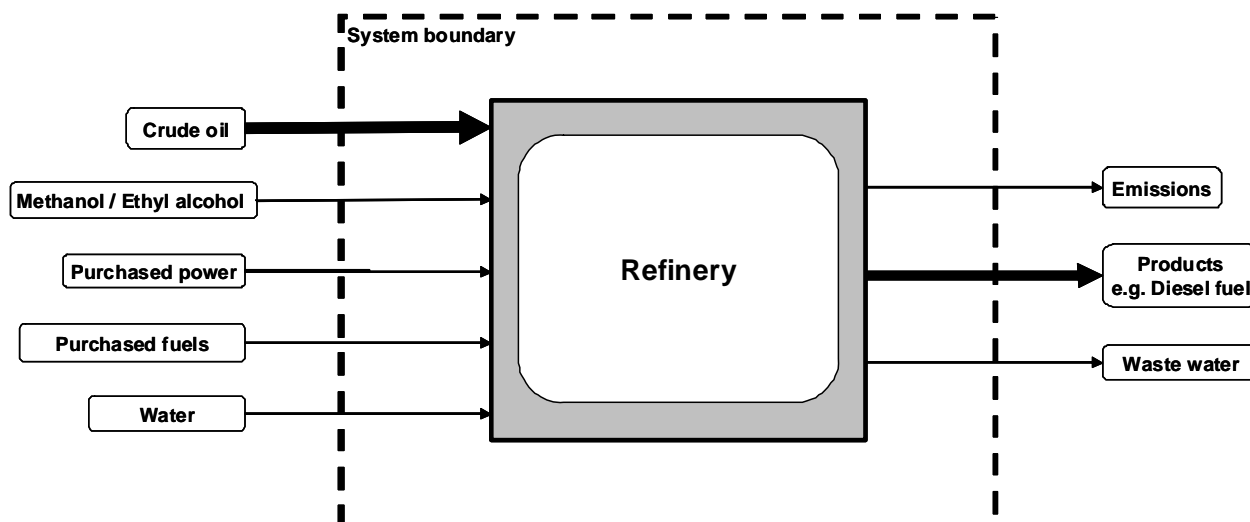


Figure 17: Refinery as a 'black box'

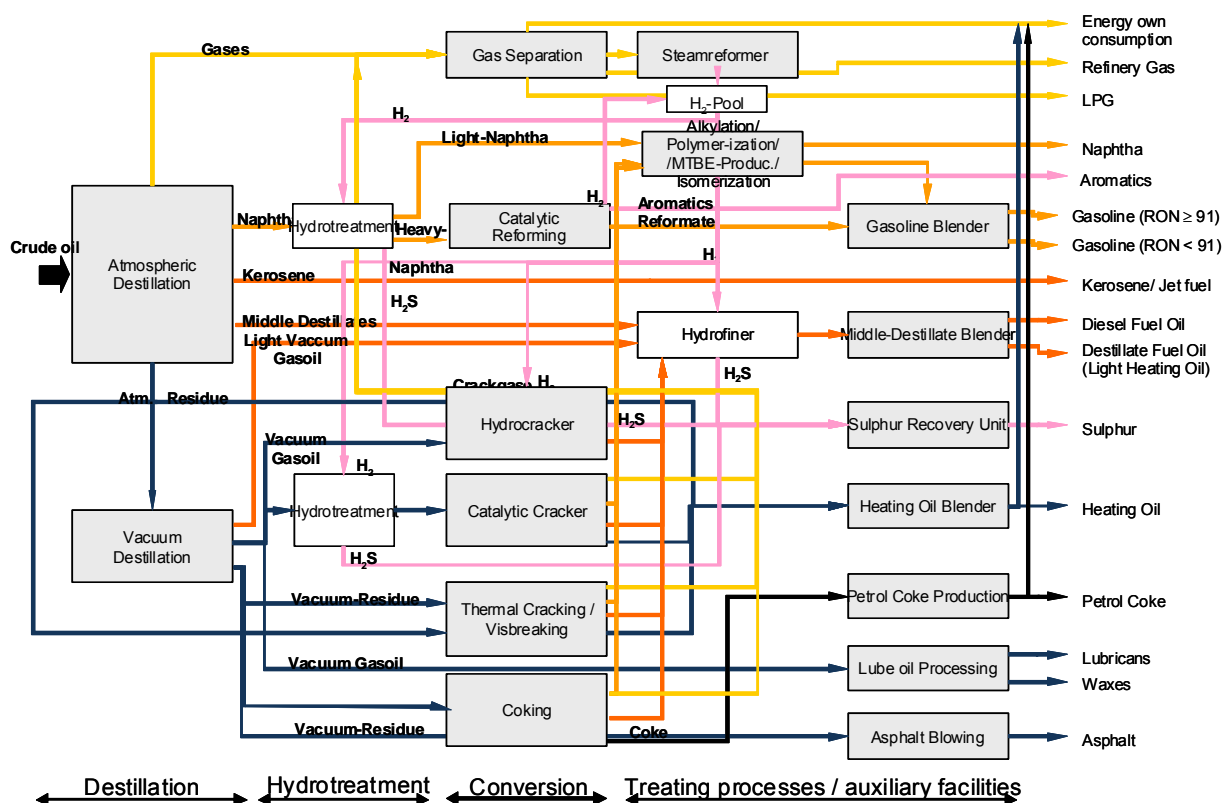


Figure 18: Detailed breakdown of the refinery

Further due to data availability not every refinery was analysed within this project. The REPLAN Refinery in Brazil – the largest refinery with a crude oil processing capacity over 20.000.000 m<sup>3</sup>/year - was chosen as Brazilian specific refinery. This refinery is located near São Paulo and can be categorized as FCC refinery with an output of almost 9.796.646 m<sup>3</sup> of diesel fuel. This amount represents approx. 26 % of the total diesel production in Brazil.

- Refinery

- Input – Materials such as crude oil, natural gas intermediates;
- Input – Auxiliary materials such as chemicals, catalysts, water;
- Input – Power from grid, power from heavy oil, thermal energy from natural gas, thermal energy from light fuel oil;
- Output – Diesel fuel, gasoline, heavy fuel oil, light fuel oil, naphtha, bitumen, etc.;
- Output – Emissions to air and water (e.g. CO<sub>2</sub>, CH<sub>4</sub>, VOC, SO<sub>2</sub>, NO<sub>x</sub>, sulphate, ammonium, BOD).

### 3.3.2 Cut-off Rules

The cut-off rules used for each unit process in this study refer to mass and energy flows as well as environmental impact. At least 95 % of mass and energy of the input and output flows were covered and 98 % of their environmental relevance (according to expert judgment) was considered. The coverage for the exploration data (crude oil) is only 90 % of mass and energy and 95 % of the environmental relevance (expert judgement).

### 3.3.3 Infrastructure

Infrastructure was not considered in the inventory of diesel.

### 3.3.4 Transports

The transports from the corresponding crude oil production countries to Brazil were considered as well as the transportation of indigenous produced crude oil in Brazil to the refinery. As already shown in chapter 2.3.1 different types of transportation systems are in place, in particular tankers and pipelines.

The tanker and pipeline processes were taken from the GaBi databases [8].

### 3.3.5 Waste

Wastes which arise along the crude oil supply chain are considered following the GaBi modelling principles corresponding to the taken datasets. Within the refinery waste were not considered due to the neglectable produced amounts.

## 3.4 Types of data

### 3.4.1 Data selected for an LCI of Diesel at refinery

As mentioned above due to data availability in Brazil, all upstream processes were taken from GaBi databases 2006 [8], whereas the downstream processes used primary and secondary data, i.e. refinery were modelled in detail. For the modelling of the diesel fuel LCI, the ELCD flow nomenclature is used, therefore an analysis of the commonly used impact categories and evaluation methods is possible in accordance with the intended use described on the ELCD platform.

### 3.4.2 Land use (optional issue)

Land use was not considered in the study.

## 3.5 Data Quality Requirements

### 3.5.1 Reference Time and Reference Area

The most up-to-date data available refer to the year 2005. The reference area corresponds to data from REPLAN refinery in Brazil which was identified by refinery experts as representative Brazilian refinery. The upstream processes taken from the GaBi databases 2006 [8] refer to the year and region described in the corresponding datasets.

### 3.5.2 Technology coverage

The technology coverage focused on REPLAN (Refinaria de Paulínia), so the refinery technology, electricity sources, waste management services, transport, etc. were checked. The REPLAN refinery is a FCC (Fluid Catalytic Cracking) refinery, which means the main conversion process of heavy fractions is a FCC. Besides the atmospheric distillation, the REPLAN refinery operates a vacuum distillation, a coking unit, a FCC unit as mentioned above as well as several hydrodesulphurization units, a petroleum coke plant, a sulphur plant, a bitumen plant and a unit to produce MTBE / ETBE. Additionally a power plant is installed as well as other several auxiliary facilities, like units for the waste water handling.

### 3.5.3 Precision, completeness, representativeness

*Precision:* Refinery and crude oil data are based on statistics and literature. The key emissions, e.g. sulphur dioxide, nitrogen oxide, etc., of the refinery are based on measured operating data. All other emissions from the refinery are based on literature data and / or calculated via energy carrier composition.

*Completeness:* All relevant flows were quantified.

*Representativeness:* The data set represents the Brazilian specific situation, focusing on the main technologies, the REPLAN refinery specific characteristics and import statistics.

### 3.5.4 Uncertainty

Due to the use of secondary data, taken from literature and other sources, uncertainties can be present in the crude oil exploration, production and transportation. Hence that for the refinery secondary data are used to complete the primary data available uncertainties in terms of heavy metal can occur.

## 3.6 Data Categories

For the modelling of the LCI of the diesel fuel the ELCD categories:

- Process categories (e.g. top category: energy carriers, Sub-category: Crude oil based energy carriers)

- Flow categories (e.g. top category: energy carriers, Sub-category: Crude oil based energy carriers)
- Flow property categories (e.g. mass)
- Unit group categories (e.g. kg)
- Contact categories (e.g. contact to Petrobras)
- Source categories (e.g. AGÊNCIA NACIONAL DO PETRÓLEO (ANP))

are used to create the LCI dataset. Details can be found in the XML Documentation file.

## 3.7 Data Collection

### 3.7.1 Team

The LCI of diesel in Brazil required a minimum of 4 people: 1 Project coordinator, 1 Engineer for data collection, 1 LCA expert and engineer and 1 expert in refinery.

### 3.7.2 Procedure adopted for the Diesel Pilot Study

In this study, the following procedure was adopted:

- At first, a meeting with the core team was organized in order to clarify the system to be investigated (Brazilian situation), define the system boundaries, selection of the approach to be adopted and check support for data supply.
- Once the system boundaries were defined, a more detailed study was done to identify the situation in Brazil especially that in this study one refinery was investigated. So the representativeness of the refinery in the Brazilian context, the technology used, the crude oil imports, etc. had to be clarified.
- In order to prepare a questionnaire, the essential single process steps were studied. With the commitment of the oil industry in the project, this work could be done with their cooperation.
- Next, a questionnaire for data collection was prepared. It was divided in different sections, one for each process with a summarized diagram, and one explanatory sheet in the beginning. Figure 19 and Figure 20 provide examples how the questionnaire was prepared for the study. The questionnaire was prepared in one Excel<sup>®</sup> Document.

**Questionnaire - Diesel fuel production in Brazil**  
by PE International and LBP-GaBi  
28.03.2007

**Goal of Questionnaire**  
Collection of all necessary data for a cradle to gate LCI inventory for 1 kg Diesel fuel sold in Brazil.

**If there are any questions or problems regarding the questionnaire, please contact:**  
 Oliver Schuller Tel. +49 711 489999-33, oliver.schuller@LBP.uni-stuttgart.de  
 Cecilia Makishi Tel. +49 711 489999-27, cecilia.makishi@LBP.uni-stuttgart.de  
 Harald Florin Tel. +49 711 341817-30, h.florin@pe-international.com

**Structure of the questionnaire**

The structure of the questionnaire is modular, i.e. for each step within the process chain, a respective questionnaire is prepared.

Each part of the questionnaire consists of Excel-sheets concerning several simplified and aggregated modules. Please feel free to add information or to provide information on a more detailed basis if available.

Please add inputs and outputs - which are missing in your opinion. (e.g. emissions).

All inputs and outputs of the questionnaires refer to a reference unit. Please provide the data in the right way related to the corresponding specific reference unit.

**Content**

- Crude oil / natural gas exploration
  - Offshore Crude oil / natural gas exploration
  - Onshore Crude oil / natural gas exploration
- Crude oil / natural gas production
  - Offshore crude oil / natural gas production
  - Onshore crude oil / natural gas production
- Crude oil transportation
  - Crude oil transportation by vessel
  - Crude oil transportation by pipeline
- Natural gas transportation
  - Natural gas transportation by pipeline
- Crude oil mix

Figure 19: Explanatory sheet from questionnaire

**Refinery - Questionnaire**

**1. Refinery - Black box**

Please fill in the following questions concerning the black box model for each refinery.  
reference unit: 1 kg crude oil input.

**1.1. Refinery black box - Inputs**

Materials	Reference Unit	Comments
Crude oil	1 kg	
Intermediates	kg/kg crude oil	if you can specify the intermediates, please specify
Natural gas	kg/kg crude oil	
<i>Add further items</i>	kg/kg crude oil	
Auxiliary materials		
Portable water	kg/kg crude oil	
Surface water	kg/kg crude oil	
Chemicals	kg/kg crude oil	if you can specify the chemicals, please specify
Catalysts	kg/kg crude oil	if you can specify the catalysts please specify
<i>Add further items</i>	kg/kg crude oil	
Energy		Please only specify energy flows which cross the system boundaries of the black box model. (see flow chart above)
Power from grid	MJ/kg crude oil	
Power from heavy fuel oil	MJ/kg crude oil	Energy which is produced within the refinery (black box model) e.g. produced fuel oil is directly used for underfiring a distillation column, do not include here.
Thermal energy from natural gas	MJ/kg crude oil	
Thermal energy from light fuel oil	MJ/kg crude oil	Reason: Environmental burdens (emissions) of the energy internal to the refinery.

Figure 20: Example of refinery questionnaire

- The questionnaire was then handed over to the data supplier. Once received, a telephone conference took place in order to explain the procedure in detail and to make sure that the questionnaire was understood correctly.
- Once the questionnaire was filled in, the LCA expert checked the returned data applying general rules which focus on consistency and overall quality of the gathered data. This included:
  - Mass and energy balance;
  - Emission balances;
  - Plausibility check focusing the general process characteristics;
  - Others;
- A feedback was provided to the data supplier and missing, inconsistent or incomplete data were then completed;
- Next a meeting with the team took place, so that a plausibility check could be confirmed with the refinery expert.

### 3.7.3 Quality check and Validation of collected data

As mentioned above, before modelling, a quality check was performed by the LCA expert and the refinery expert. For the validation, the following items were checked: cross-check with other data set, cross-check with other source, element balance, energy balance, expert judgement, mass balance, re-calculation / -modelling and re-collection / -validation of raw data.

Once data was approved and accepted by both parts, the LCA expert has started with the modelling.

### 3.7.4 Treatment of missing data

Since some primary data were not available, literature was used to fill in the gaps. Also, the experience of refinery expert in the group helped a lot whenever estimation was needed.

## 3.8 System Modelling

Petroleum refineries are complex plants. The combination and sequence of a large number of processes is usually very specific to the characteristics of the crude oil and the products to be manufactured. Additional influencing factors are the market demand for the type of products, the available crude oil quality and certain requirements set by authorities.

The manufacturing route of the every refinery product is modelled in detail in terms of mass, energy and sulphur balance and so the effort of the production of these products is calculated specifically for the REPLAN refinery.

Therefore the GaBi refinery model was used. The GaBi refinery model is a generic model: it can be adapted by means of parameter variation to different boundary conditions like the REPLAN

ones. For instance, the mass flows are flexible, processes can be switched on and off as well as the output spectrum, and the product properties (e.g. sulphur content of diesel) can be adapted.

The output spectrum of the REPLAN refinery is shown below:

**Table 3: REPLAN output spectrum**

<b>Output</b>	<b>2005 [Wt %]</b>
Refinery gas	1.03
LPG	6.04
Naphtha	3.08
Aromatics	1.00
Gasoline	20.12
Kerosene (including, Aviation Gasoline, Jet Fuel)	3.00
Diesel Oil	45.48
Heating Oil (Heavy fuel oil)	7.38
Lubricants	0.00
Waxes / Paraffins	0.00
Asphalt	1.23
Petrol Coke	5.73
Sulphur	0.28
Energy own consumption (including refinery losses)	5.63
<b>Total</b>	<b>100.00</b>

### 3.8.1 Parameter

Within the aggregated LCI dataset for diesel fuel, no parameters are in place.

### 3.8.2 Allocation principle

For the combined crude oil, natural gas and natural gas liquids production allocation by net calorific value is applied.

Within the refinery almost every units are multi-output processes, i.e. they produce two or more coupled products. In the LCA context the relevant shares of environmental impacts and energy use need to be distributed (allocation) among these coupled products.

The impacts of the following processes have to be allocated to the final products:

- Refinery facility (refinery power plant, processing units, decentralised heating systems and storage and piping of the hydrocarbon flows);
- Crude oil supply (crude oil mix);
- Purchased electricity (power grid mix);
- Natural gas (natural gas mix);

- Methanol / (Bio-) Ethanol-supply.

The emissions of the whole plant are not simply allocated among the final products by static factors (e.g. mass, energy content, market price) but are instead calculated corresponding to the production route of each individual product.

#### Allocation of crude oil feedstock

At a certain process stage, the crude oil feed  $Roh_{i,Process}$  needed for the production of a product  $i$  with mass  $m_i$  and net calorific value  $H_{u,i}$  is calculated according to the product's mass and the mean net calorific value  $H_{u,av}$  of all products from this stage. In the equation below,  $m_i$  is calculated from the mass share of the product  $m_{pi}$  (in %) and the crude oil input  $m_{Crude}$  of the process.

$$Roh_{i,Process} = \frac{m_{pi}}{100} \cdot m_{Crude} \cdot \frac{H_{u,i}}{H_{u,av}} \quad (1)$$

with:

$$H_{u,av} = \sum_{n=1}^i \frac{m_{pn}}{100} \cdot H_{u,n} \quad (2)$$

This calculation allows the allocation of the crude oil feedstock to a certain product according to its energy content. Products of high calorific value are thus labelled responsible for higher shares of the total environmental impacts than those with low calorific values. Reason suggests that impact shares be allocated according to energetic contents because it is the main goal of refineries to produce high-energy products (several units installed for conversion, reforming, etc.) due to the high demand for these and the correspondingly high market price. An allocation by market price is not practical because the numerous intermediate products are often not traded on the market.

#### Allocation of energy use (thermal energy, steam and electricity)

The energy  $E_{i,Process}$  needed for the production of a product  $i$  with mass  $m_i$  is calculated as the mass share of the product multiplied by the entire energy feed  $E_{tot}$  for the process stage in question.

$$E_{i,Process} = E_{tot,Process} \cdot \frac{m_i}{\sum_{n=1}^i m_n} = E_{tot,Process} \cdot \frac{m_{pi}}{100} \quad (3)$$

This principle is called mass allocation, since the value in question (energy) is allocated by the mass share of the individual products passing through a certain process stage.

The dominant share of thermal energy and steam in the process stage is used to heat up inputs to process temperature. Heat use for a certain temperature change  $\Delta T$  is defined by the specific heat capacity  $c$  of a substance:

$$Q = c \cdot m \cdot \Delta T \quad (4)$$

Allocation by energy content like at the crude oil feed would benefit the heavier fractions due to their relatively low net calorific values. Since these heavier fractions have on the other hand relatively high specific heat capacities, (e.g. more energy is necessary for the distillate separation and furthermore they have higher boiling points) allocation by mass is thus more justified.

Electricity is predominantly used to run pumps, mixers, etc. The model allocates electricity use by mass since the use is closely linked to the density of the medium (the heavier the products are the more electricity is used for pumping).

#### The rucksack principle

Due to significant differences of the energy- and electricity demand of the single units and due to the large differences in number of units passed by the individual products through the production route within a refinery, the rucksack principle facilitates a causer-orientated allocation which can be considered fair. The use of the described flexible methods results in a defensible allocation of environmental impacts.

### 3.8.3 Recycling

Recycling as a process itself is not included on the diesel chain. Nevertheless, the stream loops within the refinery are considered such as the fractions which are used to produce energy (electricity, heat) within the refinery like refinery gas.

## 3.9 Plausibility

Plausibility was mainly performed by LCA and refinery expert in energy and refining issues.

### 3.9.1 Plausibility and technical quality of the unit process

A plausibility check followed the points mentioned in chapter 2.9.1, 2.9.2 and 2.9.3.

## 3.10 Documentation

The ELCD conform documentation of the diesel dataset can be found in the XML file.

## 3.11 Critical Review

An internal review is performed by LBP-GaBi and PE INTERNATIONAL on the:

- Unit process(es)
- Raw data

- LCI results
- LCI method
- LCIA results

The documentation of the diesel LCI data sets is also reviewed and is in line with the ELCD data format.

An external critical review was not performed in this study, as no comparative assertion was planned.

### 3.12 Key factors during the diesel pilot study – Lessons learned

To reflect a general impression of the important lessons learned during the diesel pilot study, including the data collection, the modelling of the diesel dataset and preparing the methodology report as well as the communication between the involved partners the following points / conclusions can be drawn. It should be seen as additional help for conducting further pilot studies:

- Clear structure of the involvement of every partner, clear communication ways and workflows have to be defined before the start of the project;
- Industry commitment is essential in terms of primary data provision, system boundary definition and data validation. They are the ones, who could provide specific information to the process in the Brazilian context and say which data is available, which is not;
- Close cooperation with all involved partners makes work flow easier;
- Previous investigation regarding existing databases helps to clarify pros and cons of each structure and gives the chance to better define one own's database according to local conditions while keeping an international level.
- A clear predefined simple but objective questionnaire is necessary for the data collection and helps saving time in data acquisition;
- Capacity building is a key element to assure a harmonized work and form a solid basis for future projects.

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## Appendix A Support check-list for processes

### A.1 Mining, production, beneficiation

#### Natural gas

- CH<sub>4</sub>, CO<sub>2</sub>, H<sub>2</sub>S emission to air from exploration and production
- CH<sub>4</sub> etc. to air from flaring and venting

#### Crude oil

- CH<sub>4</sub>, NMVOC, H<sub>2</sub>S emissions to air from exploration and production
- CH<sub>4</sub>, NMVOC, CO<sub>2</sub>, CO, NO<sub>x</sub>, H<sub>2</sub>S, Particulate emissions to air flaring / venting
- Crude oil emissions to water (sea water, surface water)
- Drilling fluids (e.g. Cr- Lignosulphonate) to water

#### Solid Resource (Ore, Coal, Industrial minerals)

- CH<sub>4</sub> emissions to air from hard coal mining
- Particles (mainly at open pit mining, distinguish between > PM<sub>10</sub>, < PM<sub>10</sub> and < PM<sub>2,5</sub>)
- Heavy metals, sulphuric acid from mining dump
- Overburden
- Land Use

### A.2 Enrichment/ Separation general (ore/ coal/ gas, etc.)

- Ore / coal: COD and heavy metals in water from flotation

### A.3 Smelting

- Emissions to air such as, SO<sub>2</sub>, NO<sub>x</sub>, Particles
- Heavy metals (Pb, Zn, Cd, Hg, Cr, Ni, Co, V, Cu, As) as well as associated metals
- By the use of coke: CO<sub>2</sub>, CO, hydrocarbons, etc. (often CO rich blast furnace gas as by-product)
- Dioxine
- PAHs
- Note. Allocation of by-products, investigate modelling of slags

### A.4 Renewable Materials; Wood and Food

#### Agricultural cultivation

- NO<sub>3</sub> emissions to ground water
- N<sub>2</sub>O, NH<sub>3</sub>, CH<sub>4</sub> emissions to air
- Pesticide from application to air and surface water
- Particles (plus Corg, NO<sub>3</sub>, PO<sub>4</sub><sup>3-</sup>) in surface water from erosion
- Cd in soil from P-fertilizer
- Heavy-metal removal from harvest (mainly Zn, Cu, Mn, Ni, Pb)

- Incorporated CO<sub>2</sub> and Hu renewable.
- Note: Allocation from by-products
- Special feature: crop rotation allocation, reference system
- Land Use

#### **Livestock breeding**

- CH<sub>4</sub> emissions to air from stable
- NH<sub>3</sub> emissions to air from stable
- COD, NO<sup>3-</sup>, NH<sub>4</sub><sup>+</sup>, PO<sub>4</sub><sup>3-</sup> in sewage from stable cleaning
- Liquid manure

#### **Forestry**

- Particles, COD, NO<sup>3-</sup> in surface water from erosion,
- Inshore waste from pesticide application
- Land use

## **A.5 Chemical conversions**

- Diffusion emission from reactants, products, by-products in air depending on the substance, vapour pressure, pressure and temperature in system etc.
- Waste heat
- Waste water (if this is the case): especial treatment
- Note: Allocation from by-products

## **A.6 Processing**

- Waste: Recycling or disposal?
- Waste heat

#### **Thermal conversion**

- In most of the cases waste heat, plastics may release VOC

#### **Mechanical conversion**

- Waste heat

#### **Fragmentation (sawing, cutting, milling, grinding etc.)**

- Particles
- Waste heat
- Waste water
- VOCs from cutting oil
- Waste from washing/ processing (if this is the case)
- internal Recycling

#### **Welding, soldering, brazing**

- NO<sub>x</sub>, Metals, Particle emissions to air
- Waste water/ waste from soldering agent, washing etc.
- Potential emissions from processing

#### **Painting**

- VOCs
- Overspray/ application efficiency

## A.7 Incineration process

Inputs:

- Fuel, if applied primary-/ secondary fuel; lubricant for De-NO<sub>x</sub>, De-SO<sub>x</sub>, Particle filter, Water softening/ sterilization, cooling water consumption

Outputs:

- CO<sub>2</sub> (most of the cases), check stoichiometry for C in input
- CO (most of the cases), normal incineration: about 1/ 1000 till 1/ 100 as CO<sub>2</sub> quantity; for renewable fuel till 1/ 50
- Hydrocarbons (most of the cases)
- NO<sub>x</sub> (most of the cases)
- N<sub>2</sub>O relevant for fluidized bed
- SO<sub>2</sub>: nor for gaseous fuel (except for Biogas, blast furnace gas)
- Dioxin emissions
- PAH emissions
- Formaldehyde emission
- Hydrochloric acid (HCl) emission
- Heavy metals (check for: Pb, Zn, Cd, Hg, Cr, Ni, Co, V, Cu, As): mainly for solid fuel (not for gaseous; rarely for liquid)
- Particle: differentiate among <2,5um, 2,5-10 um, >10;
- Ash: boiler and filter ash or mix
- Waste heat: check energy balance

## A.8 Transport

- CO<sub>2</sub>, CO, VOC, NO<sub>x</sub>, SO<sub>2</sub>, particles (mostly <2,5 um), formaldehyde, PAH, Dioxin emissions to air
- Lubricant, cooling agent, etc. losses
- Ship: Antifouling agent-metal removal
- Used oil
- Waste heat

## A.9 Use

- Reparation, Maintenance, Removal/ deterioration: waste, material removal

## A.10 Other Processes

### Hydropower

- Dam (barrage) construction
- CH<sub>4</sub> in air from anaerobic conversion of organic material in reservoir hydro power plants

## A.11 Disposal

### Landfill

- Above ground
- Underground

### Incineration

- See above

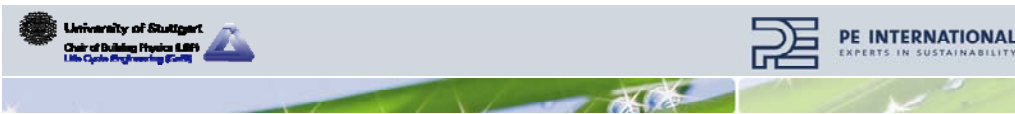
### Water treatment

- $\text{NO}_3^-$ ,  $\text{NH}_4^+$ ,  $\text{PO}_4^{3-}$ , COD, different heavy metals in water
- Check organic slime

### Recycling

- normally multiinput-allocation and at the same time normally multioutput-allocation
- Different emissions and waste/ water waste

## Appendix B Questionnaire templates



### Questionnaire - Diesel fuel production in Brazil

by PE International and LBP-GaBi

28.3.2007

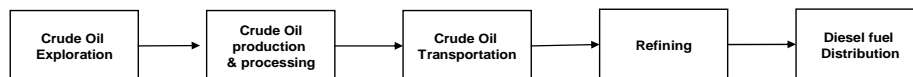
#### Goal of Questionnaire:

Collection of all necessary data for a cradle to gate LCI inventory for 1 kg Diesel fuel sold in Brazil.

#### If there are any questions or problems regarding the questionnaire, please contact:

Oliver Schuller Tel. +49 711 489999-33, oliver.schuller@LBP.uni-stuttgart.de  
Cecilia Makishi Tel. +49 711 489999-27, cecilia.makishi@LBP.uni-stuttgart.de  
Harald Florin Tel. +49 711 341817-30, h.florin@pe-international.com

#### Structure of the questionnaire



- The structure of the questionnaire is modular, i.e. for each step within the process chain, a respective questionnaire is prepared.
- Each part of the questionnaire consists of Excel-sheets concerning several simplified and aggregated modules. Please feel free to add information or to provide information on a more detailed basis if available.
- Please add inputs and outputs - which are missing in your opinion. (e.g. emissions).
- All inputs and outputs of the questionnaires refer to a reference unit.  
Please provide the data in the right way related to the corresponding specific reference unit.

#### Content

Crude oil / natural gas exploration  
    Offshore Crude oil / natural gas exploration  
    Onshore Crude oil / natural gas exploration  
Crude oil / natural gas production  
    Offshore crude oil / natural gas production  
    Onshore crude oil / natural gas production  
Crude oil transportation  
    Crude oil transportation by vessel  
    Crude oil transportation by pipeline  
Natural gas transportation  
    Natural gas transportation by pipeline  
Crude oil mix  
Natural gas mix  
Refinery  
    Refinery - Black box  
    Refinery - Hydrogen Production  
    Refinery - Hydro Desulphurisation Treatment  
    Refinery - Claus process  
    Refinery - Waste Water Treatment (WWT)  
Diesel fuel distribution

#### Reference year

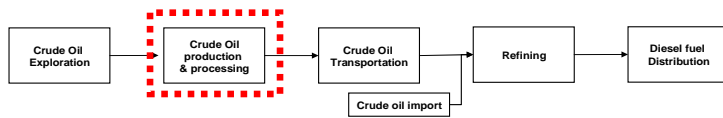
Please provide all figures preferred for the year 2006. If this is not possible, data for 2005 (2004) are also fine.  
Please indicate the data in the questionnaire which are not based on 2006.

#### Timeline

Questionnaires should be filled as soon as possible latest end of May.  
For the preparation of the scheduled visit of experts from Petrobrás to Stuttgart in May it would be very helpful to receive first data (fulfilled questionnaires) before the meeting already.

**Many thanks for your cooperation !!!**

## Crude oil / natural gas (combined) production - Questionnaire



### 1. Crude oil / natural gas (combined) production - General

The crude oil and natural gas production process (called "Crude oil production & processing" in the flow chart above) can be divided in offshore and onshore production. Questions regarding offshore production are displayed in chapter 2, regarding onshore production in chapter 3. If possible, please fill out the questionnaire for several different platforms.

Share between offshore and onshore production for crude oil / natural gas (combined)?

Crude oil / natural gas (combined) - Offshore %  
Crude oil / natural gas (combined) - Onshore %

If the data are available in a more detail way, please specify the shares for crude oil and natural gas separately.

Share between offshore and onshore production for crude oil?

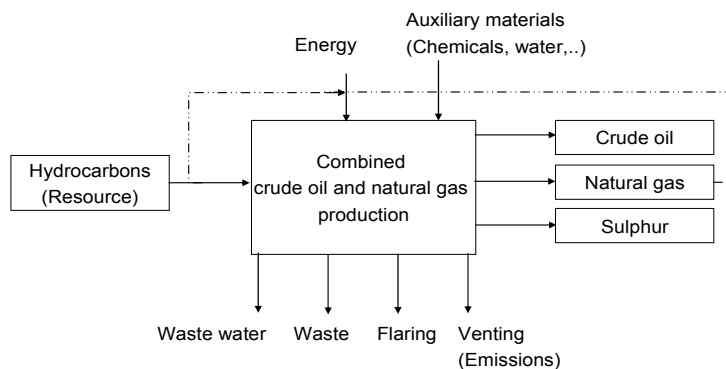
Crude oil - Offshore %  
Crude oil - Onshore %

Share between onshore and offshore production for natural gas?

Natural gas - Offshore %  
Natural gas - Onshore %

### 2. Offshore crude oil / natural gas (combined) production

Detailed breakdown of the crude oil / natural gas (combined) offshore production  
reference unit: 1 kg produced crude oil



#### 2.1. Offshore crude oil / natural gas (combined) production MAIN PRODUCTION PROCESS

##### 2.1.1. Offshore crude oil / natural gas (combined) production MAIN PRODUCTION PROCESS - Inputs

Materials

Hydrocarbons from well kg/kg produced crude oil  
*Add further items* kg/kg produced crude oil

Auxiliary materials (for energy supply, flaring, venting, waste water treatment see corresponding questions)

Chemicals kg/kg produced crude oil if you can specify the chemicals, please specify it  
Portable water kg/kg produced crude oil  
Seawater kg/kg produced crude oil  
*Add further items* kg/kg produced crude oil

Energy (for energy supply, flaring, venting, waste water treatment see corresponding questions)

Power (electricity) MJ/kg produced crude oil  
Thermal energy MJ/kg produced crude oil  
*Add further items* MJ/kg produced crude oil

**2.1.2. Offshore crude oil / natural gas (combined) production MAIN PRODUCTION PROCESS - Outputs**

Materials

<b>Crude oil</b>	<b>1 kg</b>	
Natural gas	kg/kg produced crude oil	
Sulphur	kg/kg produced crude oil	
Waste (solid)	kg/kg produced crude oil	if the composition is known, please add it to the questionnaire
Waste water	kg/kg produced crude oil	if the composition is known, please add it to the questionnaire
Amount of flaring	kg/kg produced crude oil	
Amount of venting	kg/kg produced crude oil	
<i>Add further items</i>	kg/kg produced crude oil	

Emissions to air (for energy supply, flaring, venting, waste water treatment see corresponding questions)

CO2	kg/kg produced crude oil
CH4	kg/kg produced crude oil
VOC	kg/kg produced crude oil
SO2	kg/kg produced crude oil
NOx	kg/kg produced crude oil
<i>Add further items</i>	kg/kg produced crude oil

Emissions to water (for energy supply, flaring, venting, waste water treatment see corresponding questions)

Sulfate	kg/kg produced crude oil
Ammonium	kg/kg produced crude oil
<i>Add further items</i>	kg/kg produced crude oil

**2.1.3. Offshore crude oil / natural gas (combined) production MAIN PRODUCTION PROCESS - Further questions, comments**

Properties of the crude oil from well:

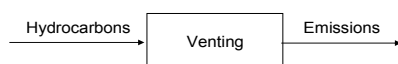
Sulphur-Content	wt. %
Net calorific value	MJ/kg
Density	kg/dm <sup>3</sup>
Composition	
- C content	wt. %
- N content	wt. %
- H content	wt. %
- S content	wt. %
<i>Add further items</i>	wt. %

Properties of the associated produced gas from well:

S-Content	wt. % / Vol. %
Net calorific value	MJ/kg
Density	kg/dm <sup>3</sup>
Composition	
- C content	wt. % / Vol. %
- N content	wt. % / Vol. %
- H content	wt. % / Vol. %
- S content	wt. % / Vol. %
<i>Add further items</i>	wt. % / Vol. %

**2.2. Offshore crude oil / natural gas (combined) production VENTING**

reference unit: 1 kg hydrocarbon input in venting



**2.2.1. Offshore crude oil / natural gas (combined) production VENTING - Inputs**

Materials

Hydrocarbons from well	<i>0,4</i> kg/kg hydrocarbon input in venting	(values for example)
Treated natural gas	<i>0,6</i> kg/kg hydrocarbon input in venting	(values for example)
<i>Add further items</i>	kg/kg hydrocarbon input in venting	

**2.2.2. Offshore crude oil / natural gas (combined) production VENTING - Outputs**

Emissions to air

CO2	kg/kg hydrocarbon input in venting
CH4	kg/kg hydrocarbon input in venting
VOC	kg/kg hydrocarbon input in venting
SO2	kg/kg hydrocarbon input in venting
NOx	kg/kg hydrocarbon input in venting
<i>Add further items</i>	kg/kg hydrocarbon input in venting

**2.2.3. Offshore crude oil / natural gas (combined) production VENTING - Further questions, comments**

Is the chemical composition of the venting input gas known? Please indicate unit. (wt.% or Vol.%)

(Composition in accordance to the emissions to air)

C content	wt.% / Vol.%
H content	wt.% / Vol.%
S content	wt.% / Vol.%
N content	wt.% / Vol.%
<i>Add further items</i>	wt.% / Vol.%

**2.3. Offshore crude oil / natural gas (combined) production FLARING**

reference unit: 1 kg hydrocarbon input in flaring



**2.3.1. Offshore crude oil / natural gas (combined) production FLARING - Inputs**

Materials

Hydrocarbons from well	0,4 kg/kg hydrocarbon input in flaring	(values for example)
Treated natural gas	0,6 kg/kg hydrocarbon input in flaring	(values for example)
<i>Add further items</i>	kg/kg hydrocarbon input in flaring	

**2.3.2. Offshore crude oil / natural gas (combined) production FLARING - Outputs**

Emissions to air

CO2	kg/kg hydrocarbon input in flaring
CH4	kg/kg hydrocarbon input in flaring
VOC	kg/kg hydrocarbon input in flaring
SO2	kg/kg hydrocarbon input in flaring
NOx	kg/kg hydrocarbon input in flaring
<i>Add further items</i>	kg/kg hydrocarbon input in flaring

**2.3.3. Offshore crude oil / natural gas (combined) production FLARING - Further questions, comments**

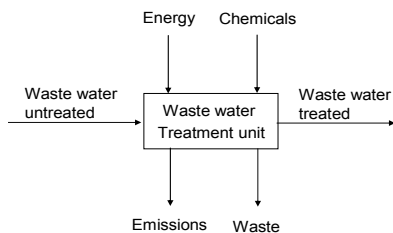
Is the chemical composition of the flaring input gas known? Please indicate unit. (wt.% or Vol.%)

(Composition in accordance to the emissions to air)

C content	wt.% / Vol.%
H content	wt.% / Vol.%
S content	wt.% / Vol.%
N content	wt.% / Vol.%
<i>Add further items</i>	wt.% / Vol.%

**2.4. Offshore crude oil / natural gas (combined) production WASTE WATER TREATMENT**

reference unit: 1 kg untreated waste water



**2.4.1. Offshore crude oil / natural gas (combined) production WASTE WATER TREATMENT - Inputs**

Materials

<b>Waste water (untreated)</b>	<b>1 kg untreated waste water</b>	if the composition is known, please add it to the questionnaire
<i>Add further items</i>	kg/kg untreated waste water	

Auxiliary materials

Chemicals	kg/kg untreated waste water	if you can specify the chemicals, please specify it
<i>Add further items</i>	kg/kg untreated waste water	

Energy

Power (electricity)	MJ/kg untreated waste water
<i>Add further items</i>	MJ/kg untreated waste water

**2.4.2. Offshore crude oil / natural gas (combined) production WASTE WATER TREATMENT - Outputs**

Materials		
Waste water (treated)	kg/kg untreated waste water	if the composition is known, please add it to the questionnaire
Waste (solid)	kg/kg untreated waste water	if the composition is known, please add it to the questionnaire
<i>Add further items</i>	kg/kg untreated waste water	
Emissions to air (e.g. from clarifier)		
CO2	kg/kg untreated waste water	
CH4	kg/kg untreated waste water	
VOC	kg/kg untreated waste water	
SO2	kg/kg untreated waste water	
NOx	kg/kg untreated waste water	
<i>Add further items</i>	kg/kg untreated waste water	
Emissions to water (ingredients after WWT)		
Sulfate	kg/kg untreated waste water	
Ammonium	kg/kg untreated waste water	
<i>Add further items</i>	kg/kg untreated waste water	

**2.4.3. Offshore crude oil / natural gas (combined) production WASTE WATER TREATMENT - Further questions, comments**

Please specify additional questions, comments or information here  
*Answer:*

**2.5. Offshore crude oil / natural gas (combined) production ENERGY SUPPLY**

**2.5.1. Offshore crude oil / natural gas (combined) production ENERGY SUPPLY - General questions**

What kind of energy is used on the platform? What is the amount per kg produced crude oil?

Electrical energy	MJ/kg produced crude oil
Thermal energy	MJ/kg produced crude oil
Mechanical energy	MJ/kg produced crude oil
<i>Add further items</i>	MJ/kg produced crude oil

Which of the following processes are used to supply power (electricity)? Please quantify the share.

Diesel generator	% of power generation
Gas turbines	% of power generation
Power (electricity) from the grid	% of power generation
<i>Add further items</i>	% of power generation

Which of the following processes are used to supply thermal energy? Please quantify the share.

Diesel generator	% of thermal energy
Gas turbines	% of thermal energy
<i>Add further items</i>	% of thermal energy

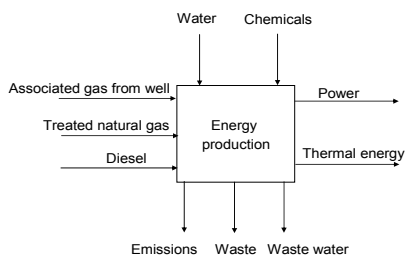
Which of the following processes are used to supply mechanical energy? Please quantify the share.

Diesel generator	% of mechanical energy
Gas turbines	% of mechanical energy
<i>Add further items</i>	% of mechanical energy

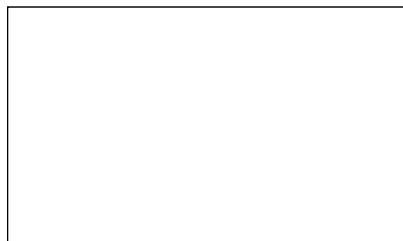
**Please specify the energy production in detail.**

**Feel free to add further energy production units or if no detailed information available, please summarize units.**

reference unit: 1 MJ produced energy



Additional flow charts:



**2.5.2. Offshore crude oil / natural gas (combined) production ENERGY SUPPLY GAS TURBINE- Inputs**

Materials		
Natural gas (treated)	kg/MJ produced energy	
Associated gas from well	kg/MJ produced energy	
<i>Add further items</i>	kg/MJ produced energy	
Auxiliary materials		
Chemicals	kg/MJ produced energy	if you can specify the chemicals, please specify it
Portable water	kg/MJ produced energy	
Fresh water	kg/MJ produced energy	
<i>Add further items</i>	kg/MJ produced energy	

**2.5.3. Offshore crude oil / natural gas (combined) production ENERGY SUPPLY GAS TURBINE - Outputs**

Materials	
Power (electricity)	MJ
Thermal energy	MJ
Mechanical energy	MJ
Emissions to air	
CO2	kg/MJ produced energy
CH4	kg/MJ produced energy
VOC	kg/MJ produced energy
SO2	kg/MJ produced energy
<i>Add further items</i>	kg/MJ produced energy
Emissions to water	
Sulfate	kg/MJ produced energy
Ammonium	kg/MJ produced energy
<i>Add further items</i>	kg/MJ produced energy

**2.5.4. Offshore crude oil / natural gas (combined) production ENERGY SUPPLY DIESEL GENERATOR - Inputs**

Materials	
Diesel	kg/MJ produced energy
<i>Add further items</i>	kg/MJ produced energy

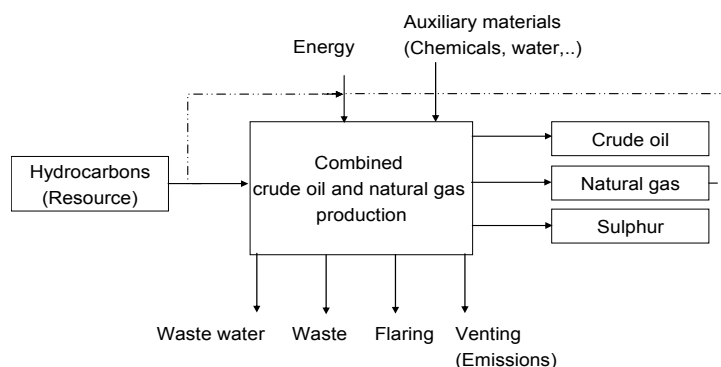
**2.5.5. Offshore crude oil / natural gas (combined) production ENERGY SUPPLY DIESEL GENERATOR - Outputs**

Materials	
Power (electricity)	MJ
Thermal energy	MJ
Mechanical energy	MJ
Emissions to air	
CO2	kg/MJ produced energy
CH4	kg/MJ produced energy
VOC	kg/MJ produced energy
SO2	kg/MJ produced energy
<i>Add further items</i>	kg/MJ produced energy
Emissions to water	
Sulfate	kg/MJ produced energy
Ammonium	kg/MJ produced energy
<i>Add further items</i>	kg/MJ produced energy

**2.5.6. Offshore crude oil / natural gas (combined) production ENERGY SUPPLY - Further questions, comments**

**3. Onshore crude oil / natural gas (combined) production**

Detailed breakdown of the crude oil / natural gas (combined) offshore production  
reference unit: 1 kg produced crude oil



**3.1. Onshore crude oil / natural gas (combined) production MAIN PRODUCTION PROCESS**

**3.1.1. Onshore crude oil / natural gas (combined) production MAIN PRODUCTION PROCESS - Inputs**

Materials	
Hydrocarbons from well	kg/kg produced crude oil
<i>Add further items</i>	kg/kg produced crude oil
Auxiliary materials (for energy supply, flaring, venting, waste water treatment see corresponding questions)	
Chemicals	kg/kg produced crude oil if you can specify the chemicals, please specify it
Portable water	kg/kg produced crude oil
Seawater	kg/kg produced crude oil
<i>Add further items</i>	kg/kg produced crude oil

Energy (for energy supply, flaring, venting, waste water treatment see corresponding questions)  
Power (electricity) MJ/kg produced crude oil  
Thermal energy MJ/kg produced crude oil  
*Add further items* MJ/kg produced crude oil

**3.1.2. Onshore crude oil / natural gas (combined) production MAIN PRODUCTION PROCESS - Outputs**

Materials

<b>Crude oil</b>	<b>1 kg</b>	
Natural gas	kg/kg produced crude oil	
Sulphur	kg/kg produced crude oil	
Waste (solid)	kg/kg produced crude oil	if the composition is known, please add it to the questionnaire
Waste water	kg/kg produced crude oil	if the composition is known, please add it to the questionnaire
Amount of flaring	kg/kg produced crude oil	
Amount of venting	kg/kg produced crude oil	
<i>Add further items</i>	kg/kg produced crude oil	

Emissions to air (for energy supply, flaring, venting, waste water treatment see corresponding questions)

CO2	kg/kg produced crude oil
CH4	kg/kg produced crude oil
VOC	kg/kg produced crude oil
SO2	kg/kg produced crude oil
NOx	kg/kg produced crude oil
<i>Add further items</i>	kg/kg produced crude oil

Emissions to water (for energy supply, flaring, venting, waste water treatment see corresponding questions)

Sulfate	kg/kg produced crude oil
Ammonium	kg/kg produced crude oil
<i>Add further items</i>	kg/kg produced crude oil

**3.1.3. Onshore crude oil / natural gas (combined) production MAIN PRODUCTION PROCESS - Further questions, comments**

Properties of the crude oil from well:

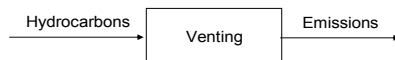
Sulphur-Content	wt. %
Net calorific value	MJ/kg
Density	kg/dm <sup>3</sup>
Composition	
- C content	wt. %
- N content	wt. %
- H content	wt. %
- S content	wt. %
<i>Add further items</i>	wt. %

Properties of the associated produced gas from well:

S-Content	wt. % / Vol. %
Net calorific value	MJ/kg
Density	kg/dm <sup>3</sup>
Composition	
- C content	wt. % / Vol. %
- N content	wt. % / Vol. %
- H content	wt. % / Vol. %
- S content	wt. % / Vol. %
<i>Add further items</i>	wt. % / Vol. %

**3.2. Onshore crude oil / natural gas (combined) production VENTING**

reference unit: 1 kg hydrocarbon input in venting



**3.2.1. Onshore crude oil / natural gas (combined) production VENTING - Inputs**

Materials

Hydrocarbons from well	0,4 kg/kg hydrocarbon input in venting	(values for example)
Treated natural gas	0,6 kg/kg hydrocarbon input in venting	(values for example)
<i>Add further items</i>	kg/kg hydrocarbon input in venting	

**3.2.2. Onshore crude oil / natural gas (combined) production VENTING - Outputs**

Emissions to air

CO2	kg/kg hydrocarbon input in venting
CH4	kg/kg hydrocarbon input in venting
VOC	kg/kg hydrocarbon input in venting
SO2	kg/kg hydrocarbon input in venting
NOx	kg/kg hydrocarbon input in venting
<i>Add further items</i>	kg/kg hydrocarbon input in venting

**3.2.3. Onshore crude oil / natural gas (combined) production VENTING - Further questions, comments**

Is the chemical composition of the venting input gas known? Please indicate unit. (wt.% or Vol.%)

(Composition in accordance to the emissions to air)

C content	wt.% / Vol.%
H content	wt.% / Vol.%
S content	wt.% / Vol.%
N content	wt.% / Vol.%
<i>Add further items</i>	wt.% / Vol.%

**3.3. Onshore crude oil / natural gas (combined) production FLARING**

reference unit: 1 kg hydrocarbon input in flaring



**3.3.1. Onshore crude oil / natural gas (combined) production FLARING - Inputs**

Materials

Hydrocarbons from well	0,4 kg/kg hydrocarbon input in flaring	(values for example)
Treated natural gas	0,6 kg/kg hydrocarbon input in flaring	(values for example)
<i>Add further items</i>	kg/kg hydrocarbon input in flaring	

**3.3.2. Onshore crude oil / natural gas (combined) production FLARING - Outputs**

Emissions to air

CO2	kg/kg hydrocarbon input in flaring
CH4	kg/kg hydrocarbon input in flaring
VOC	kg/kg hydrocarbon input in flaring
SO2	kg/kg hydrocarbon input in flaring
NOx	kg/kg hydrocarbon input in flaring
<i>Add further items</i>	kg/kg hydrocarbon input in flaring

**3.3.3. Onshore crude oil / natural gas (combined) production FLARING - Further questions, comments**

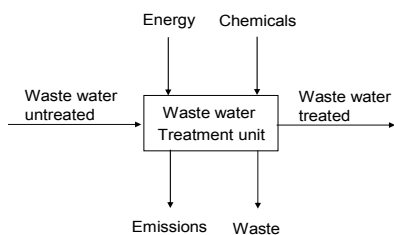
Is the chemical composition of the flaring input gas known? Please indicate unit. (wt.% or Vol.%)

(Composition in accordance to the emissions to air)

C content	wt.% / Vol.%
H content	wt.% / Vol.%
S content	wt.% / Vol.%
N content	wt.% / Vol.%
<i>Add further items</i>	wt.% / Vol.%

**3.4. Onshore crude oil / natural gas (combined) production WASTE WATER TREATMENT**

reference unit: 1 kg untreated waste water



**3.4.1. Onshore crude oil / natural gas (combined) production WASTE WATER TREATMENT - Inputs**

Materials

<b>Waste water (untreated)</b>	<b>1 kg untreated waste water</b>	if the composition is known, please add it to the questionnaire
<i>Add further items</i>	kg/kg untreated waste water	

Auxiliary materials

Chemicals	kg/kg untreated waste water	if you can specify the chemicals, please specify it
<i>Add further items</i>	kg/kg untreated waste water	

Energy

Power (electricity)	MJ/kg untreated waste water
<i>Add further items</i>	MJ/kg untreated waste water

**3.4.2. Onshore crude oil / natural gas (combined) production WASTE WATER TREATMENT - Outputs**

Materials		
Waste water (treated)	kg/kg untreated waste water	if the composition is known, please add it to the questionnaire
Waste (solid)	kg/kg untreated waste water	if the composition is known, please add it to the questionnaire
<i>Add further items</i>	kg/kg untreated waste water	
Emissions to air (e.g. from clarifier)		
CO2	kg/kg untreated waste water	
CH4	kg/kg untreated waste water	
VOC	kg/kg untreated waste water	
SO2	kg/kg untreated waste water	
NOx	kg/kg untreated waste water	
<i>Add further items</i>	kg/kg untreated waste water	
Emissions to water (ingredients after WWT)		
Sulfate	kg/kg untreated waste water	
Ammonium	kg/kg untreated waste water	
<i>Add further items</i>	kg/kg untreated waste water	

**3.4.3. Onshore crude oil / natural gas (combined) production WASTE WATER TREATMENT - Further questions, comments**

Please specify additional questions, comments or information here  
*Answer:*

**3.5. Onshore crude oil / natural gas (combined) production ENERGY SUPPLY**

**3.5.1. Onshore crude oil / natural gas (combined) production ENERGY SUPPLY - General questions**

What kind of energy is used on the platform? What is the amount per kg produced crude oil?

Electrical energy	MJ/kg produced crude oil
Thermal energy	MJ/kg produced crude oil
Mechanical energy	MJ/kg produced crude oil
<i>Add further items</i>	MJ/kg produced crude oil

Which of the following processes are used to supply power (electricity)? Please quantify the share.

Diesel generator	% of power generation
Gas turbines	% of power generation
Power (electricity) from the grid	% of power generation
<i>Add further items</i>	% of power generation

Which of the following processes are used to supply thermal energy? Please quantify the share.

Diesel generator	% of thermal energy
Gas turbines	% of thermal energy
<i>Add further items</i>	% of thermal energy

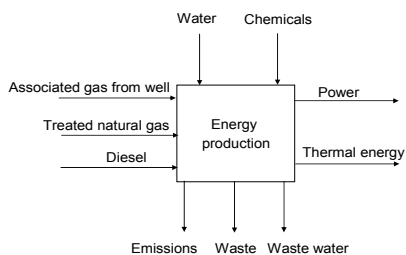
Which of the following processes are used to supply mechanical energy? Please quantify the share.

Diesel generator	% of mechanical energy
Gas turbines	% of mechanical energy
<i>Add further items</i>	% of mechanical energy

Please specify the energy production in detail.

Feel free to add further energy production units or if no detailed information available, please summarize units.

reference unit: 1 MJ produced energy



Additional flow charts:



**3.5.2. Onshore crude oil / natural gas (combined) production ENERGY SUPPLY GAS TURBINE- Inputs**

Materials	
Natural gas (treated)	kg/MJ produced energy
Associated gas from well	kg/MJ produced energy
<i>Add further items</i>	kg/MJ produced energy

Auxiliary materials		
Chemicals	kg/MJ produced energy	if you can specify the chemicals, please specify it
Portable water	kg/MJ produced energy	
Fresh water	kg/MJ produced energy	
<i>Add further items</i>	kg/MJ produced energy	

### 3.5.3. Onshore crude oil / natural gas (combined) production ENERGY SUPPLY GAS TURBINE - Outputs

Materials	
Power (electricity)	MJ
Thermal energy	MJ
Mechanical energy	MJ
Emissions to air	
CO2	kg/MJ produced energy
CH4	kg/MJ produced energy
VOC	kg/MJ produced energy
SO2	kg/MJ produced energy
<i>Add further items</i>	kg/MJ produced energy
Emissions to water	
Sulfate	kg/MJ produced energy
Ammonium	kg/MJ produced energy
<i>Add further items</i>	kg/MJ produced energy

### 3.5.4. Onshore crude oil / natural gas (combined) production ENERGY SUPPLY DIESEL GENERATOR - Inputs

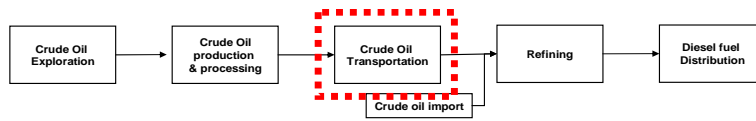
Materials	
Diesel	kg/MJ produced energy
<i>Add further items</i>	kg/MJ produced energy

### 3.5.5. Onshore crude oil / natural gas (combined) production ENERGY SUPPLY DIESEL GENERATOR - Outputs

Materials	
Power (electricity)	MJ
Thermal energy	MJ
Mechanical energy	MJ
Emissions to air	
CO2	kg/MJ produced energy
CH4	kg/MJ produced energy
VOC	kg/MJ produced energy
SO2	kg/MJ produced energy
<i>Add further items</i>	kg/MJ produced energy
Emissions to water	
Sulfate	kg/MJ produced energy
Ammonium	kg/MJ produced energy
<i>Add further items</i>	kg/MJ produced energy

### 3.5.6. Onshore crude oil / natural gas (combined) production ENERGY SUPPLY - Further questions, comments

## Crude oil transportation - Questionnaire



### 1. Transportation - General questions

Questions listed under chapter 1 are necessary for the LCI modelling. Answers to the questions listed in chapter 2 and 3 would be a nice to have. If no data are provided for chapter 2 and 3, GaBi processes could be used.

Which transportation system is used for the crude oil transportation at Petrobras?

Pipeline YES/NO *Answer:*  
coastal vessels (small) YES/NO *Answer:*  
Tankers (large/medium) YES/NO *Answer:*

What is the average transportation distance [km] for crude from wells to the refinery gates at Petrobras? (mass-weighted)

*Answer:*

How is the share between different systems, if any are used?

For instance:

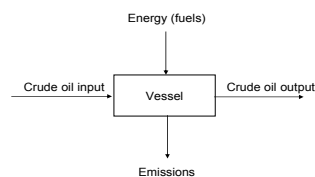
The average transportation distance between well and refinery is 700 km.

Thereof crude oil is transported in average 500 km by tankers, 50 km by coastal vessels and 150 km by pipeline. (mass-weighted)

*Answer:*

### 2. Crude oil transportation by coastal vessels

reference unit: 1 kg crude oil output and 1 km transportation



#### 2.1. Crude oil transportation by vessel - Inputs

Materials

Crude oil	kg/kg crude oil output	Cargo
Diesel fuel	kg/kgkm crude oil output and kilometer	Fuel
Bunker Oil	kg/kgkm crude oil output and kilometer	Fuel
<i>Add further items</i>	kg/kgkm crude oil output and kilometer	

Auxiliary materials

Lubricants	kg/kgkm crude oil output and kilometer
<i>Add further items</i>	kg/kgkm crude oil output and kilometer

#### 2.2. Crude oil transportation by vessel - Outputs

Materials

<b>Crude oil</b>	<b>1 kg</b>
Crude oil losses	kg/kgkm crude oil output and kilometer
Waste (solid)	kg/kgkm crude oil output and kilometer
Waste water	kg/kgkm crude oil output and kilometer
<i>Add further items</i>	kg/kgkm crude oil output and kilometer

Emissions to air (e.g. from combustion)

CO2	kg/kgkm crude oil output and kilometer
CH4	kg/kgkm crude oil output and kilometer
SO2	kg/kgkm crude oil output and kilometer
NOx	kg/kgkm crude oil output and kilometer
<i>Add further items</i>	kg/kgkm crude oil output and kilometer

Emissions to water (e.g. from spilling)

Sulfate	kg/kgkm crude oil output and kilometer
Ammonium	kg/kgkm crude oil output and kilometer
<i>Add further items</i>	kg/kgkm crude oil output and kilometer

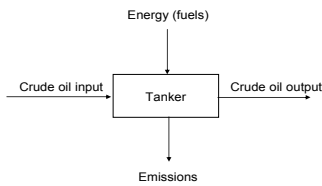
#### 2.3. Crude oil transportation by vessel - Further questions, comments

What is the average leakage rate [kg/km]?

*Answer:*

### 3. Crude oil transportation by tankers

reference unit: 1 kg crude oil output and 1 km transportation



#### 3.1. Crude oil transportation by tankers - Inputs

Materials		
Crude oil	kg/kg crude oil output	Cargo
Diesel fuel	kg/kgkm crude oil output and kilometer	Fuel
Bunker Oil	kg/kgkm crude oil output and kilometer	Fuel
<i>Add further items</i>	kg/kgkm crude oil output and kilometer	
Auxiliary materials		
Lubricants	kg/kgkm crude oil output and kilometer	
<i>Add further items</i>	kg/kgkm crude oil output and kilometer	

#### 3.2. Crude oil transportation by tankers - Outputs

Materials	
<b>Crude oil</b>	<b>1 kg</b>
Crude oil losses	kg/kgkm crude oil output and kilometer
Waste (solid)	kg/kgkm crude oil output and kilometer
Waste water	kg/kgkm crude oil output and kilometer
<i>Add further items</i>	kg/kgkm crude oil output and kilometer
Emissions to air (e.g. from combustion)	
CO <sub>2</sub>	kg/kgkm crude oil output and kilometer
CH <sub>4</sub>	kg/kgkm crude oil output and kilometer
SO <sub>2</sub>	kg/kgkm crude oil output and kilometer
NO <sub>x</sub>	kg/kgkm crude oil output and kilometer
<i>Add further items</i>	kg/kgkm crude oil output and kilometer
Emissions to water (e.g. from spilling)	
Sulfate	kg/kgkm crude oil output and kilometer
Ammonium	kg/kgkm crude oil output and kilometer
<i>Add further items</i>	kg/kgkm crude oil output and kilometer

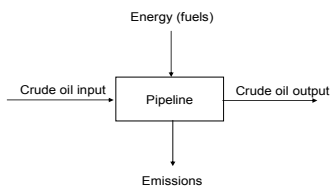
#### 3.3. Crude oil transportation by tankers - Further questions, comments

What is the average leakage rate [kg/km]?

*Answer:*

### 4. Crude oil transportation by pipeline

reference unit: 1 kg crude oil output and 1 km transportation



#### 4.1. Crude oil transportation by pipeline - Inputs

Materials		
Crude oil	kg/kg crude oil output	Cargo
Diesel fuel	kg/kgkm crude oil output and kilometer	Fuel for pumping
<i>Add further items</i>	kg/kgkm crude oil output and kilometer	
Auxiliary materials		
Lubricants	kg/kgkm crude oil output and kilometer	
<i>Add further items</i>	kg/kgkm crude oil output and kilometer	

Energy		
Power from the grid	MJ/kgkm crude oil output and kilometer	Fuel for pumping
<i>Add further items</i>	MJ/kgkm crude oil output and kilometer	

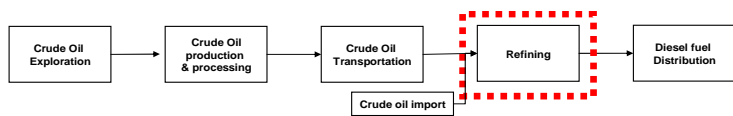
#### 4.2. Crude oil transportation by pipeline - Outputs

Materials		
<b>Crude oil</b>	<b>1 kg</b>	
Crude oil losses	kg/kgkm crude oil output and kilometer	
Waste (solid)	kg/kgkm crude oil output and kilometer	
Waste water	kg/kgkm crude oil output and kilometer	
<i>Add further items</i>	kg/kgkm crude oil output and kilometer	
Emissions to air		
CO <sub>2</sub>	kg/kgkm crude oil output and kilometer	
CH <sub>4</sub>	kg/kgkm crude oil output and kilometer	
SO <sub>2</sub>	kg/kgkm crude oil output and kilometer	
NO <sub>x</sub>	kg/kgkm crude oil output and kilometer	
<i>Add further items</i>	kg/kgkm crude oil output and kilometer	
Emissions to water		
Sulfate	kg/kgkm crude oil output and kilometer	
Ammonium	kg/kgkm crude oil output and kilometer	
<i>Add further items</i>	kg/kgkm crude oil output and kilometer	

#### 4.3. Crude oil transportation by pipeline - Further questions, comments

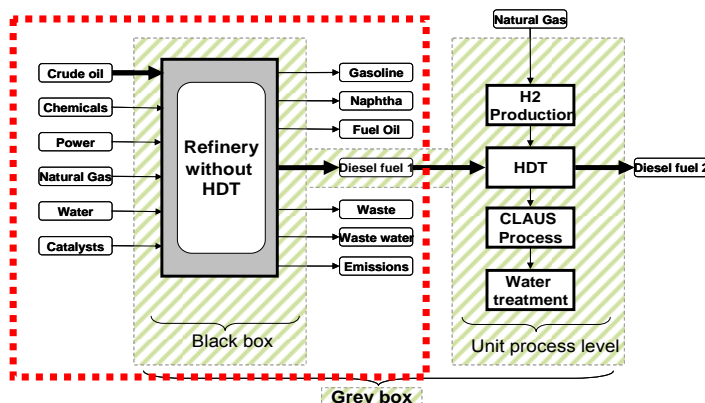
What is the average leakage rate [kg/km]?  
*Answer:*

## Refinery - Questionnaire



### 1. Refinery - Black box

Please fill in the following questions concerning the black box model for each refinery.  
reference unit: 1 kg crude oil input



#### 1.1. Refinery black box - Inputs

##### Materials

<b>Crude oil</b>	<b>1 kg</b>	
Intermediates	kg/kg crude oil	if you can specify the intermediates, please specify
Natural gas	kg/kg crude oil	
<i>Add further items</i>	kg/kg crude oil	

##### Auxiliary materials

Portable water	kg/kg crude oil	
Surface water	kg/kg crude oil	
Chemicals	kg/kg crude oil	if you can specify the chemicals, please specify
Catalysts	kg/kg crude oil	if you can specify the catalysts please specify
<i>Add further items</i>	kg/kg crude oil	

##### Energy

Power from grid	MJ/kg crude oil	Please only specify energy flows which cross the system boundaries of the black box model. (see flow chart above) Energy which is produced within the refinery (black box model) e.g. produced fuel oil is directly used for underfiring a distillation column, do not include here. Reason: Environmental burdens (emissions) of the energy internal supply should be included in the emission inventory in chapter 1.2. (to avoid double counting) I.e. specify only flows which are purchased from extern here.
Power from heavy fuel oil	MJ/kg crude oil	
Thermal energy from natural gas	MJ/kg crude oil	
Thermal energy from light fuel oil	MJ/kg crude oil	
<i>Add further items</i>	MJ/kg crude oil	

#### 1.2. Refinery black box - Outputs

##### Materials

Diesel fuel	kg/kg crude oil	
Gasoline	kg/kg crude oil	
Heavy fuel oil	kg/kg crude oil	
Light fuel oil	kg/kg crude oil	
Naphtha	kg/kg crude oil	
Petrol Coke	kg/kg crude oil	
Bitumen	kg/kg crude oil	
Lubricants	kg/kg crude oil	
Waxes / Paraffins	kg/kg crude oil	
Hydrogen	kg/kg crude oil	
Refinery gas	kg/kg crude oil	
Propane	kg/kg crude oil	
Propylen	kg/kg crude oil	
Butane	kg/kg crude oil	
Butylen	kg/kg crude oil	
Aromatics	kg/kg crude oil	
Sulphur (not from Diesel HDT)	kg/kg crude oil	for Diesel HDT see corresponding questions below
Refinery losses	kg/kg crude oil	
Waste (solid)	kg/kg crude oil	if the composition is known, please add it to the questionnaire
Waste water	kg/kg crude oil	if the composition is known, please add it to the questionnaire
<i>Add further items</i>	kg/kg crude oil	

##### Emissions to air

CO2	kg/kg crude oil
CH4	kg/kg crude oil
SO2	kg/kg crude oil
NOx	kg/kg crude oil
<i>Add further items</i>	kg/kg crude oil

Emissions to water

Sulfate kg/kg crude oil  
Ammonium kg/kg crude oil  
Add further items kg/kg crude oil

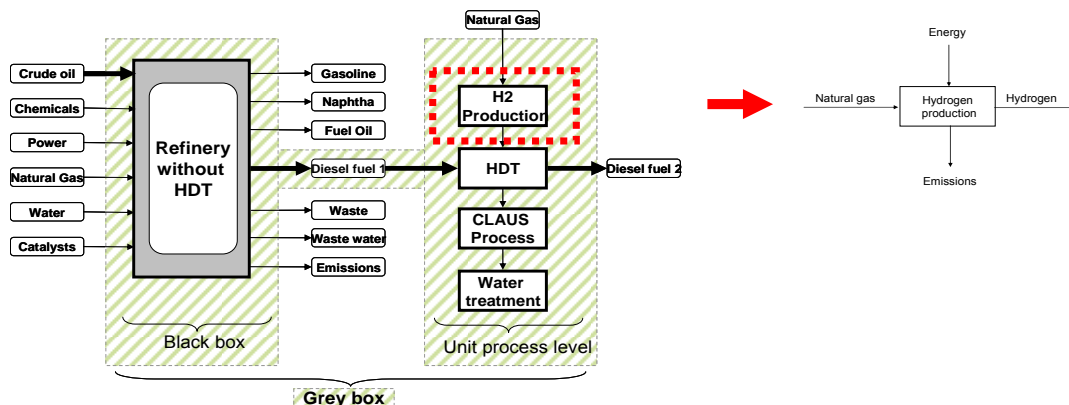
**1.2. Refinery black box - Further questions, comments**

Please describe the fuel properties:

	Net calorific value [MJ/kg]	Density [kg/dm <sup>3</sup> ]	Sulphur content [wt. %]	Add further items
Crude Oil				
Diesel fuel				
Gasoline				
Heavy fuel oil				
Naphtha				
Add further items				

**2. Refinery - Hydrogen Production**

reference unit: 1 kg produced hydrogen



**2.1. Hydrogen Production - Inputs**

Materials

Natural gas kg/kg Hydrogen  
Add further items kg/kg Hydrogen

Auxiliary materials

Portable water kg/kg Hydrogen  
Chemicals kg/kg Hydrogen if you can specify the chemicals, please specify  
Surface water kg/kg Hydrogen  
Add further items kg/kg Hydrogen

Energy

Power from grid MJ/kg Hydrogen  
Power from heavy fuel oil MJ/kg Hydrogen  
Thermal energy from natural gas MJ/kg Hydrogen  
Thermal energy from light fuel oil MJ/kg Hydrogen  
Add further items MJ/kg Hydrogen

**2.2. Hydrogen Production - Outputs**

Materials

Hydrogen 1 kg  
Waste (solid) kg/kg Hydrogen if the composition is known, please add it to the questionnaire  
Waste water kg/kg Hydrogen if the composition is known, please add it to the questionnaire  
Add further items

Emissions to air	
CO2	kg/kg Hydrogen
CH4	kg/kg Hydrogen
SO2	kg/kg Hydrogen
NOx	kg/kg Hydrogen
<i>Add further items</i>	kg/kg Hydrogen

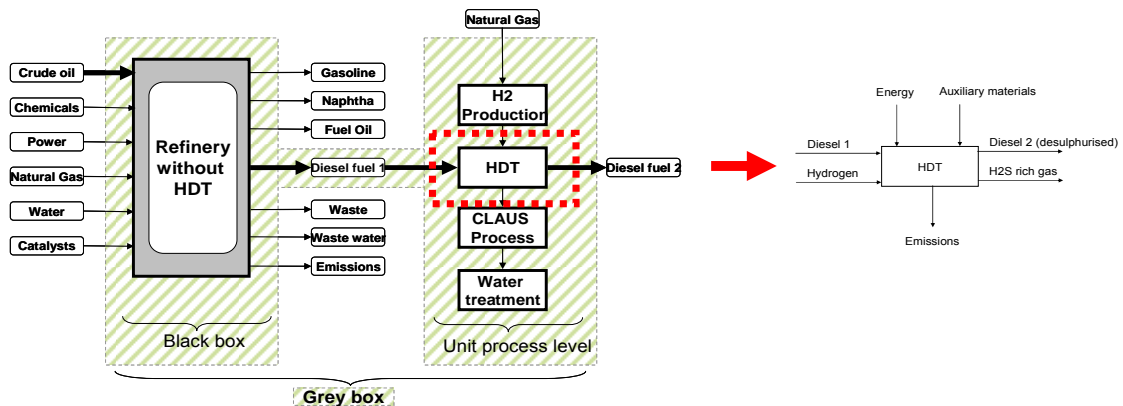
Emissions to water	
Sulfate	kg/kg Hydrogen
Ammonium	kg/kg Hydrogen
<i>Add further items</i>	kg/kg Hydrogen

**2.3. Hydrogen Production - Further questions, comments**

What is the name of this process? Please describe shortly the technology?  
*Answer:*

**3. Refinery - Hydro Desulphurisation Treatment**

reference unit: 1 kg produced desulphurised diesel fuel



**3.1. Hydro Desulphurisation Treatment - Inputs**

Materials		
Diesel 1	kg/kg desulphurised diesel	
Hydrogen	kg/kg desulphurised diesel	
<i>Add further items</i>	kg/kg desulphurised diesel	
Auxiliary materials		
Chemicals	kg/kg desulphurised diesel	if you can specify the chemicals, please specify
Portable water	kg/kg desulphurised diesel	
Surface water	kg/kg desulphurised diesel	
Catalysts	kg/kg desulphurised diesel	if you can specify the catalyst please specify
<i>Add further items</i>	kg/kg desulphurised diesel	
Energy		
Power from grid	MJ/kg desulphurised diesel	
Power from heavy fuel oil	MJ/kg desulphurised diesel	
Thermal energy from natural gas	MJ/kg desulphurised diesel	
Thermal energy from light fuel oil	MJ/kg desulphurised diesel	
<i>Add further items</i>	MJ/kg desulphurised diesel	

**3.2. Hydro Desulphurisation Treatment - Outputs**

Materials		
<b>Diesel 2</b>	<b>1 kg (desulphurised)</b>	
H2S rich gas	kg/kg desulphurised diesel	if the composition is known, please add it to the questionnaire
Waste (solid)	kg/kg desulphurised diesel	if the composition is known, please add it to the questionnaire
Waste water	kg/kg desulphurised diesel	if the composition is known, please add it to the questionnaire
<i>Add further items</i>	kg/kg desulphurised diesel	
Emissions to air		
CO2	kg/kg desulphurised diesel	
CH4	kg/kg desulphurised diesel	
SO2	kg/kg desulphurised diesel	
NOx	kg/kg desulphurised diesel	
<i>Add further items</i>	kg/kg desulphurised diesel	

Emissions to water	
Sulfate	kg/kg desulphurised diesel
Ammonium	kg/kg desulphurised diesel
<i>Add further items</i>	kg/kg desulphurised diesel

### 3.3. Hydro Desulphurisation Treatment - Further questions, comments

Please describe the sulphur content of the diesel input and of the diesel output. Please indicate unit (wt.% or ppm)

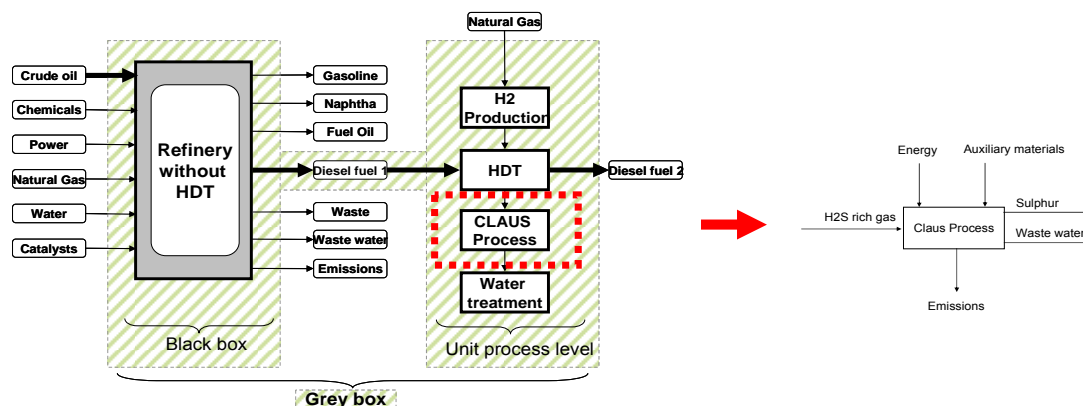
Diesel input	wt.%S / ppm S
Diesel output	wt.%S / ppm S

Is there any mathematical relation between sulphur content in the input respectively output and hydrogen demand. Please describe the relation:

*Answer:*

### 4. Refinery - Claus process

reference unit: 1 kg produced sulphur



#### 4.1. Claus process - Inputs

Materials		
H2S rich gas	kg/kg sulphur	if the composition is known, please add it to the questionnaire
<i>Add further items</i>	kg/kg sulphur	
Auxiliary materials		
Chemicals	kg/kg sulphur	if you can specify the chemicals, please specify
Portable water	kg/kg sulphur	
Surface water	kg/kg sulphur	
Catalysts	kg/kg sulphur	
<i>Add further items</i>	kg/kg sulphur	
Energy		
Power from grid	MJ/kg sulphur	
Power from heavy fuel oil	MJ/kg sulphur	
Thermal energy from natural gas	MJ/kg sulphur	
Thermal energy from light fuel oil	MJ/kg sulphur	
<i>Add further items</i>	MJ/kg sulphur	

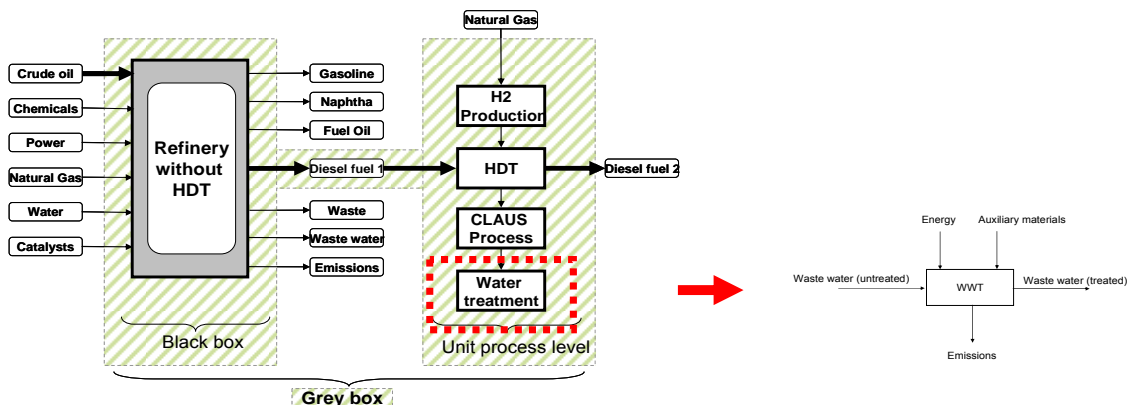
#### 4.2. Claus process - Outputs

Materials		
<b>Sulphur</b>	<b>1 kg</b>	if the composition is known, please add it to the questionnaire
Waste (solid)	kg/kg sulphur	
Waste water	kg/kg sulphur	if the composition is known, please add it to the questionnaire
<i>Add further items</i>		
Emissions to air		
CO2	kg/kg sulphur	
CH4	kg/kg sulphur	
SO2	kg/kg sulphur	
NOx	kg/kg sulphur	
<i>Add further items</i>	kg/kg sulphur	
Emissions to water		
Sulfate	kg/kg sulphur	
Ammonium	kg/kg sulphur	
<i>Add further items</i>	kg/kg sulphur	

#### 4.3. Claus process - Further questions, comments

## 5. Refinery - Waste Water Treatment (WWT) after Claus-Process

reference unit: 1 kg waste water treated



### 5.1. Waste Water Treatment (WWT) after Claus-Process - Inputs

#### Materials

**Waste water untreated** 1 kg  
kg/kg waste water untreated  
*Add further items*

#### Auxiliary materials

Chemicals kg/kg waste water untreated if you can specify the chemicals, please specify  
*Add further items* kg/kg waste water untreated

#### Energy

Power from the grid MJ/kg waste water untreated  
Power from heavy fuel oil MJ/kg waste water untreated  
Thermal energy from light fuel oil MJ/kg waste water untreated  
Thermal energy from natural gas MJ/kg waste water untreated  
*Add further items* MJ/kg waste water untreated

### 5.2. Waste Water Treatment (WWT) after Claus-Process - Outputs

#### Materials

Waste water treated kg/kg waste water untreated if the composition is known, please add it to the questionnaire  
Waste (solid) kg/kg waste water untreated if the composition is known, please add it to the questionnaire  
*Add further items*

#### Emissions to air (e.g. from clarifier)

CO2 kg/kg waste water untreated  
CH4 kg/kg waste water untreated  
SO2 kg/kg waste water untreated  
NOx kg/kg waste water untreated  
*Add further items* kg/kg waste water untreated

#### Emissions to water (ingredients after WWT)

Sulfate kg/kg waste water untreated  
Ammonium kg/kg waste water untreated  
*Add further items* kg/kg waste water untreated

### 5.3. Waste Water Treatment (WWT) after Claus-Process - Further questions, comments

Please specify additional questions, comments or information here

*Answer:*