SIXTH FRAMEWORK PROGRAMME

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NEEDS
New Energy Externalities Developments for Sustainability

INTEGRATED PROJECT

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"LCA of Background Processes"

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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Contents

1 Overview on datasets and scenarios

1.1 Introduction and overview

This report contains the documentation of life cycle inventory data on materials and transport services as used in the external costs assessment of new electricity generation technologies. The product systems of the electricity generation technologies analysed by NEEDS the research partners in Research Stream 1a make use of the ecoinvent data v1.3 in the background system. The ecoinvent data v1.3 provides datasets for the present situation. Relevant datasets are extrapolated to the 2025 and 2050 situations in the three NEEDS scenarios. This document describes the assumptions related to the scenarios and the resulting LCI data.

The following sections 1.3 and 1.4 include a list of the materials and transport services being adapted to future situations. Chapter 2 includes the description of the life cycle inventories (LCI) of metals, and Chapter 3 covers the LCI of non-metallic materials. The electricity mixes in Europe and of the Aluminium Industry are documented in Chapter 4. Finally, Chapter 5 includes a description of the transport service datasets.

1.2 Present Situation

The ecoinvent data V1.3 (ecoinvent Centre 2006) is used to model the situation in 2005 ("today"). This database provides about 2'700 datasets covering the whole range from resource extraction to final disposal. The project partners can rely on this collection to ease the compilation of their own datasets.

1.3 Modelling future states of background processes

Although most of the processes in the ecoinvent database are interlinked, only a few will become important within the NEEDS project. There are four groups of processes: metals (chapter 2), construction materials (chapter 3), electricity mix (chapter 4) and transport (chapter 5) that are thought to influence the LCI results to a significant extent. Some of the electricity generation technologies assessed within NEEDS are itself important background processes and, therefore, not assessed in this work package.

The following background processes were chosen on the basis of their importance in the energy systems. Most of them are metals, because these materials account for a great share of the environmental impacts in the energy systems based on renewables.

Table 1-1: Background processes of which future states are modelled, and corresponding dataset names in ecoinvent data v1.3.

	ecoinvent dataset name, v1.3
Metals	
- Aluminium	aluminium, primary, liquid, at plant (RER)
- Copper	copper, primary, at refinery (RER) copper, primary, at refinery (RLA)
- Nickel	Nickel, 99.5%, at plant (GLO)
- Iron and steel	sinter, at plant (GLO) pig iron, at plant (GLO) ferronickel, 25%, at plant (GLO)
- MG-silicon	MG-silicon, at plant (RER)
- Zinc	zinc for coating, at regional storage (RER)
Non metallic minerals	
- Clinker	clinker, at plant (RER)
- Flat glass	flat glass, uncoated, at plant (RER)
Electricity Mix	
- Electricity UCTE	electricity, production mix UCTE (UCTE)
- Electricity Aluminium	electricity mix, aluminium industry (GLO)
Transport	
- Van 3.5t	operation, van < 3,5t (RER)
- Lorry 16t	operation, lorry 16t (RER)
- Lorry 28t	operation, lorry 28t (CH)
- Lorry 32t	operation, lorry 32t (RER)

1.4 Scenarios

The LCI background data are investigated for three scenarios (pessimistic, optimistic realistic, very optimistic). For each scenario two time horizons with the reference years 2025 and 2050 are considered. The LCIs of the production of commodities in the future (2025 and 2050) are modelled considering further development of production techniques (in terms of energy and raw material efficiency, energy carriers used and emission factors).

The general assumptions valid for all datasets are the following:

- pessimistic
  - it is assumed that there is no technological development (i.e. the datasets are left unchanged) except for transports (due to legal requirements) and electricity mixes
  - the development of technologies covered in separate NEEDS work packages are, of course, implemented accordingly
  - the business as usual (BAU) electricity mix scenario is applied on European electricity supply

- optimistic realistic

  - the pathway of technology development is as far as possible according to predictions and goals of the industry that seem reasonable to be achieved
  - the 440 ppm electricity mix scenario (440ppm) is applied on European electricity supply

- very optimistic
  - improvements according to the optimistic-realistic scenario are introduced earlier
  - a switch to cleaner energy generating technologies (e.g. oil to gas) is more common or more pronounced
  - the enhanced renewables electricity mix scenario (Renew.) is applied on European electricity supply

2 LCI of metals

2.1 Aluminium production

The datasets for the reference situation ("today") and for the scenarios are based on the dataset "aluminium, primary, liquid, at plant, RER", which includes the electrolysis step of the aluminium production. A detailed description of this dataset can be found in Althaus et al. (2004). The electrolysis of aluminium is the most energy consuming step of the aluminium production. Secondary aluminium from scrap needs only about 5% as much energy as for the production of primary aluminium. That is why, we focus on the primary aluminium production.

2.1.1 Production technologies

Two main processes are used in the electrolysis: the prebake and the Søderberg process.

- Prebaked anodes are manufactured from a paste of calcined petroleum coke and coal tar pitch, which is formed into a block and baked in a separate anode plant. The anodes are gradually lowered as they are consumed and are replaced before the rods are attacked by the molten bath.
- Søderberg anodes are made in situ from a paste of calcined petroleum coke and coal tar pitch, which is baked by the heat arising from the molten bath. As the anode is consumed, more paste descends through the anode shell, thus providing a process that does not require changing of anodes. Søderberg anodes have an electrical resistivity about 30% higher than that of prebaked anodes. Because of the resulting lower power efficiency and the greater difficulty in collecting and disposing of baking fumes, Søderberg anodes are being replaced by prebaked anodes.

The "today" dataset describes a European aluminium mix with 85% prebake and 15% Søderberg. We assume 100% prebake for 2050 in the optimistic-realistic and very optimistic scenarios.

2.1.2 Energy and raw material use

Electricity use in the "today" dataset amounts to 15.6 kWh/kg liquid aluminium. In Europe power use for the electrolysis step ranges from 14.0–16.5 kWh/kg for the prebake process and

15.0–18.0 kWh/kg for the Søderberg process (IPPC 2001b). Voluntary objective of the International Aluminium Institute is to reduce average electricity use a further 5% until 2010[1].

For the “best practice” we use the lowest value from IPPC (2001b). This results in 13.1 kWh/kg aluminium. As a very optimistic assumption we assume a further 5% reduction in electricity consumption (Table 2-1).

Anode use ranges between 400–440 kg/t Al for a prebake plant and 500–580 kg anode paste/t Al in a Søderberg plant (IPPC 2001b). The “today” dataset accounts for 480 kg/t Al (mix of prebake and paste). In the future scenarios we use the lowest values indicated by IPPC (Table 2-1).

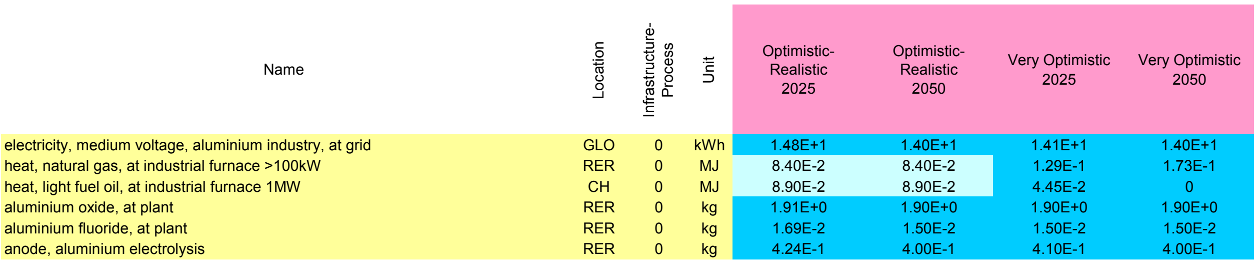
The use of aluminium fluoride (AlF_3 is an important additive of the electrolyte aluminium production because it can reduce the melting point of aluminium and increase the conductivity of the electrolyte) ranges between 15 and 25 kg/t Al for both processes (IPPC 2001b). We use the lower value in all scenarios.

The matching of the scenarios and time periods with the “today”, “best practice” and “reduced electricity” cases is indicated in Table 2-1. The realistic-optimistic scenario for 2025 is the average of “today” and “best practice”.

Table 2-1: Energy and raw material input for the production of liquid aluminium

	Unit	**Today**	**Best Practice**		**Reduced Electricity**	
		85% Prebake **15% Søderberg**	**Prebake**	**Søderberg**	**Prebake**	**Søderberg**
Electricity	kWh/kg liquid aluminium	15.6	14.0	15.0	13.3	-
Anode Use	kg/t liquid aluminium	480	400	500	400	-
AlF_3	kg/t liquid aluminium	18.7	15	15	15	-
Applied to		Pessimistic 2025 Pessimistic 2050	Realistic-Optimistic 2050 (100% prebake) Very Optimistic 2025 (90% prebake, 10% Søderberg)		Very Optimistic 2050	

Table 2-2: Energy consumption and material use of future liquid aluminium production in Europe (RER). Values are per kilogram of liquid aluminium.



Name	Location	Infrastructure-Process	Unit	Optimistic-Realistic 2025	Optimistic-Realistic 2050	Very Optimistic 2025	Very Optimistic 2050
electricity, medium voltage, aluminium industry, at grid	GLO	0	kWh	1.48E+1	1.40E+1	1.41E+1	1.40E+1
heat, natural gas, at industrial furnace >100kW	RER	0	MJ	8.40E-2	8.40E-2	1.29E-1	1.73E-1
heat, light fuel oil, at industrial furnace 1MW	CH	0	MJ	8.90E-2	8.90E-2	4.45E-2	0
aluminium oxide, at plant	RER	0	kg	1.91E+0	1.90E+0	1.90E+0	1.90E+0
aluminium fluoride, at plant	RER	0	kg	1.69E-2	1.50E-2	1.50E-2	1.50E-2
anode, aluminium electrolysis	RER	0	kg	4.24E-1	4.00E-1	4.10E-1	4.00E-1

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[1] World-aluminium.org (2005): Sustainable development. Retrieved 04.04.2006 from: http://www.world-aluminium.org/iai/publications/sustainable.html

2.1.3 Air emissions

Table 2-3 gives the ranges of selected air emissions from primary aluminium smelters for the two processes prebake and Søderberg according to IPPC (2001b). As best practice we use the value at the lower end of the range.

The prebake system is coupled with an efficient pollutant removal system that can remove more than 99% of the pollutants under optimum conditions. The emissions in Table 2-3 assume 98% removal. It is thought that further emission control systems are not implemented since the environmental impact from electricity consumption is often more important.

Table 2-3: Selected air emissions from primary aluminium smelters (IPPC 2001b)

		Prebake	**Søderberg**
HF	kg/t Al	0.15–2.0	0.2–3.5
Dust [1]	kg/t Al	0.6–7.0	1.5–10.0
SO_2 (wet scrubbing)	kg/t Al	1.0–3.5	1.0–3.5
CF_4/C_2F_6 [1]	kg/t Al	0.02–1.0	0.2–1.0
CO_2	kg/t Al	1.4–1.6	1.6–1.9
Benzo(a)pyrene	g/t Al	0	5–20

[1] We use the same proportion PM < 2.5 to PM >2.5 and < 10 and CF_4/C_2F_6 as in the today dataset.

The assumptions concerning the share of production with prebake and Søderberg anodes (Table 2-1) and the key air emissions (Table 2-3) lead to the emission factors of liquid aluminium shown in Table 2-4.

Table 2-4: Selected air emissions of future liquid aluminium production in Europe (RER). Values are per kilogram of liquid aluminium.

Name	Location	Infrastructure-Process	Unit	Optimistic-Realistic 2025	Optimistic-Realistic 2050	Very Optimistic 2025	Very Optimistic 2050
Hydrogen fluoride			kg	3.45E-4	1.50E-4	1.55E-4	1.50E-4
Particulates, > 2.5 um, and < 10um			kg	3.61E-4	1.14E-4	1.31E-4	1.14E-4
Benzo(a)pyrene			kg	6.50E-7	0	5.00E-7	0
Carbon dioxide, fossil			kg	1.45E+0	1.40E+0	1.42E+0	1.40E+0
Ethane, hexafluoro-, HFC-116			kg	1.72E-5	6.33E-6	7.20E-6	6.33E-6
Methane, tetrafluoro-, FC-14			kg	1.55E-4	5.70E-5	6.48E-5	5.70E-5
Particulates, < 2.5 um			kg	1.55E-3	4.86E-4	5.59E-4	4.86E-4
Sulfur dioxide			kg	4.92E-3	1.00E-3	1.00E-3	1.00E-3

2.1.4 Selected cumulative life cycle inventory results

According to the underlying scenarios, emissions and resource consumptions partly tend to increase in the future. The pessimistic scenario assumes no changes in process specific emissions, in energy demand nor in the aluminium specific electricity mix. That is why the results of all three time horizons are rather similar. The picture changes when going to the other two scenarios where a shift from a European to a global aluminium supply is modelled (see also Section 4.2.1). This entails a larger share of fossil based electricity in the smelters electricity mix and thus a higher coal resource consumption and partly higher CO_2 emissions. Carbon capture and storage, reduction in PFC emissions as well as a shift from coal to natural gas and renewables leads to somewhat lower emissions in the very optimistic scenario as compared to today. Due to the significantly lower share in nuclear power, the radionuclide emissions drop by a factor of 3 to 4 as compared to today's situation. The emissions of particulate matter drops to 50 % in 2050. This reduction is reached by 2025 in the very optimistic scenario and by 2050 in the realistic-optimistic scenario too.

Table 2-5: Selected cumulative life cycle inventory results of the production of 1 kg primary aluminium, pessimistic scenario

	unit	**today**	**2025PE Mix: BAU**	**2050PE Mix: BAU**
Resources				
Coal, hard, unspecified, in ground	kg	2.06E+00	100.4%	100.7%
Gas, natural, in ground	Nm^3	4.21E-01	101.1%	99.6%
Oil, crude, in ground	kg	1.19E+00	97.4%	97.2%
Uranium	kg	6.28E-05	94.8%	93.7%
Water	m^3	4.71E-02	97.0%	96.7%
Occupation agricultural and forests	m^2a	9.89E-02	113.6%	115.5%
Occupation built-up	m^2a	5.44E-02	99.5%	99.5%
selected air emissions				
CO2, fossil	kg	9.39E+00	98.2%	98.1%
NOx,	kg	1.98E-02	92.6%	92.4%
PM2.5	kg	4.97E-03	96.5%	96.5%
Rn222	kg	2.04E+03	94.8%	93.7%
selected water emissions				
C14	kBq	4.25E-02	94.7%	93.5%
Chromium VI	kg	2.72E-04	99.9%	99.9%
oils unspecified	kg	4.64E-03	97.1%	96.9%

Table 2-6: Selected cumulative life cycle inventory results of the production of 1 kg primary aluminium, realistic-optimistic scenario

	unit	**today**	**2025RO Mix: 440ppm**	**2050RO Mix: 440ppm**
Resources				
Coal, hard, unspecified, in ground	kg	2.06E+00	150.8%	137.6%
Gas, natural, in ground	Nm^3	4.21E-01	153.2%	152.8%
Oil, crude, in ground	kg	1.19E+00	88.1%	84.9%
Uranium	kg	6.28E-05	39.5%	34.9%
Water	m^3	4.71E-02	71.8%	68.7%
Occupation agricultural and forests	m^2a	9.89E-02	156.6%	137.9%
Occupation built-up	m^2a	5.44E-02	117.6%	110.8%
selected air emissions				
CO2, fossil	kg	9.39E+00	105.4%	97.6%
NOx,	kg	1.98E-02	102.9%	96.5%
PM2.5	kg	4.97E-03	72.8%	49.3%
Rn222	kg	2.04E+03	39.5%	34.9%
selected water emissions				
C14	kBq	4.25E-02	39.7%	35.8%
Chromium VI	kg	2.72E-04	99.4%	98.5%
oils unspecified	kg	4.64E-03	87.0%	83.5%

Table 2-7: Selected cumulative life cycle inventory results of the production of 1 kg primary aluminium, very optimistic scenario

	unit	today	2025VO Mix: Renew.	2050VO Mix: Renew.
Resources				
Coal, hard, unspecified, in ground	kg	2.06E+00	133.4%	124.1%
Gas, natural, in ground	Nm^3	4.21E-01	139.7%	124.2%
Oil, crude, in ground	kg	1.19E+00	85.7%	83.9%
Uranium	kg	6.28E-05	36.0%	22.4%
Water	m^3	4.71E-02	65.9%	56.7%
Occupation agricultural and forests	m^2a	9.89E-02	138.3%	160.5%
Occupation built-up	m^2a	5.44E-02	109.2%	105.5%
selected air emissions				
CO2, fossil	kg	9.39E+00	97.2%	91.9%
NOx,	kg	1.98E-02	94.8%	91.1%
PM2.5	kg	4.97E-03	50.2%	47.5%
Rn222	kBq	2.04E+03	36.0%	22.4%
selected water emissions				
C14	kBq	4.25E-02	36.3%	22.1%
Chromium VI	kg	2.72E-04	98.6%	98.4%
oils unspecified	kg	4.64E-03	84.4%	82.4%

2.2 Copper production

There are two main routes for the production of primary copper:

1) pyrometallurgical process - this is the standard
2) hydrometallurgical process – solvent extraction-electrowinning (SX-EW), which is in rapid growth stage.

SX-EW increased from 13% (1996) to 20% (2003) of world production of copper (BGR 2005). Front-runners are Chile with 50% and the USA with 33% (BGR 2005). However, this process is not used in Europe (Krauss et al. 1999).

Reverbatory furnaces accounted for most of the world's copper smelting as late as 1975. However, the last reverbatory smelter was built in 1976 and the existing furnaces are being replaced by flash and other smelting furnaces (Riekkoly-Vanhanen 1999). Reverbatory furnaces smelting is primarily a smelting process in contrast to flash smelting which is an oxidation/melting process. Reverbatory smelting makes little use of the energy from sulphur and iron oxidation for heating and melting. It also produces large quantities of fossil fuel combustion gas containing about 1% of SO_2, which is difficult to remove at this low concentration (Riekkoly-Vanhanen 1999). Some reverbatory furnaces, mainly in Chile, converted to oxygen-sprinkle flash smelters by retrofitting with feed driers, an oxygen plant and some minor modifications of the furnace itself (Ayres et al. 2002).

Pure copper sulphate dissolved in sulphuric acid is generated by the vat leaching process and the solvent extraction (SX) process. The electricity requirement is quite high because a comparatively high voltage is needed (3 V) compared to the electro-refining. The adoption of the new SX-EW (electrowinning) technology since 1995 has been very rapid. This new SX-EW capacity was mostly built up in Chile, where there are essentially no competing uses for the smelter by-product sulphuric acid (Ayres et al. 2002).

Energy use in copper production depends mainly on the concentrate (% S and Fe) but also on the smelting unit used, the degree of oxygen enrichment and the collection and use of process heat (IPPC 2001b).

Hydrometallurgical processes involving solvent extraction and electrowinning have a higher energy consumption than the pyrometallurgical processes (Norgate & Rankin 2000).

There are two reference datasets (“today”) that are adapted based on the scenarios:

1) copper, primary, at refinery (RER) – chapter 2.2.1
2) copper, primary, at refinery (RLA) – chapter 2.2.2

Both processes are described in detail in Althaus et al. (2004).

2.2.1 Primary copper production (RER)

2.2.1.1 Energy use

Primary copper production in Europe was dominated 1994 by the Outokumpu process with almost 70% of production. This process (in its continuous form) is considered, together with the continuous Mitsubishi process, as BAT (IPPC 2001b). Overall primary energy use of European primary copper production is relatively low compared to other regions (Krauss et al. 1999). Primary energy use with the Outokumpu process is described in the same source to be 6% lower than the European average. The Inco process has the lowest specific energy use with a consumption of 20% below the average European production (Krauss et al. 1999).

We assume that energy use can be reduced uniformly between the different energy sources by 6% attaining the level of the Outokumpu process. In the very optimistic case a reduction of 20% is possible attaining the level of the Inco process.

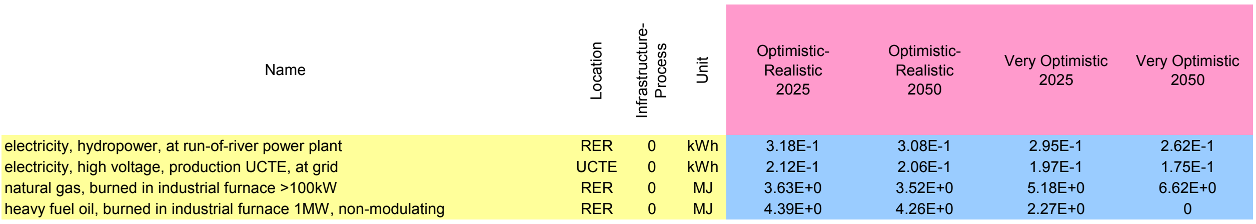
The EU-25 baseline scenario (NTUA 2003) does not anticipate a change in the share of energy sources for the iron and steel production, especially no increase of renewable energy sources. The copper production is not considered separately in that document. However, economic constraints and concurrence in the use of biomass can be assumed to be the same as for the iron and steel production. Therefore, we assume no relevant introduction of new energy sources in the future. However, heavy fuel oil is replaced by natural gas in the very optimistic scenario.

The matching of the different energy reduction levels with the scenarios is shown in Table 2-8. The values for 2025 of the realistic-optimistic and very optimistic scenario are calculated as averages of the today and their 2050 values. The final inventory data is shown in Table 2-9.

Table 2-8: Energy consumption in the primary copper production (RER)

	Unit	Today	Outokumpu-Level	Inco-Level
Electricity	kWh/kg copper	0.55	0.51	4.4
Natural Gas	MJ/kg copper	3.74	3.52	6.62
Heavy Fuel Oil	MJ/kg copper	4.53	4.26	
Total Fossil	MJ/kg copper	8.27	7.77	6.62
Applied to		Pessimistic 2025 Pessimistic 2050	Realistic-Optimistic 2050	Very Optimistic 2050

Table 2-9: Energy consumption of future primary copper production in Europe (RER). Values are per kilogram of copper.



Name	Location	Infrastructure-Process	Unit	Optimistic-Realistic 2025	Optimistic-Realistic 2050	Very Optimistic 2025	Very Optimistic 2050
electricity, hydropower, at run-of-river power plant	RER	0	kWh	3.18E-1	3.08E-1	2.95E-1	2.62E-1
electricity, high voltage, production UCTE, at grid	UCTE	0	kWh	2.12E-1	2.06E-1	1.97E-1	1.75E-1
natural gas, burned in industrial furnace >100kW	RER	0	MJ	3.63E+0	3.52E+0	5.18E+0	6.62E+0
heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	4.39E+0	4.26E+0	2.27E+0	0

2.2.1.2 Air emissions

Due to a lack of specific information on metal emission levels to air for the different processes of primary copper production we use for the scenarios the ranges of emissions given in Althaus et al. (2004). For "best practice" we use the lowest values indicated. These values are applied to the 2050 scenarios. The 2025 scenarios are the average of "today" and "best practice".

Table 2-10: Metal air emissions per kg copper in the "today" dataset and in the scenarios

		Today kg	Best Practice kg
Antimony	kg/t Cu	5.50E-3	1.00E-03
Arsenic	kg/t Cu	3.25E-2	1.50E-02
Cadmium	kg/t Cu	6.50E-3	3.00E-03
Chromium	kg/t Cu	5.00E-5	5.00E-05
Copper	kg/t Cu	2.50E-1	2.00E-01
Lead	kg/t Cu	1.50E-1	5.00E-02
Manganese	kg/t Cu	1.50E-2	5.00E-03
Mercury	kg/t Cu	1.00E-4	1.00E-04
Nickel	kg/t Cu	5.50E-2	1.00E-02
Selenium	kg/t Cu	5.50E-3	1.00E-03
Vanadium	kg/t Cu	3.75E-4	2.50E-04
Tin	kg/t Cu	6.25E-3	2.50E-03
Applied to		Pessimistic 2025 Pessimistic 2050	Realistic-Optimistic 2050 Very Optimistic 2050

Abatement of SO_2 in smelters is assumed to be 95% in the “today” dataset for Europe (Althaus et al. 2004). SO_2-emissions amount to 36 kg/t Cu. The target for best available technique in Europe is set to 6–16 kg/t Cu (IPPC 2001b). We use 16 kg/t Cu for “best practice” and 6 kg/t Cu for “further reduction”.

A range of 0.16 to 1 kg dust/t Cu is mentioned for modern European plants (IPPC 2001b). Dioxin emissions are <5 µg I-TEQ/t Cu for electric furnaces and 10 µg I-TEQ/t Cu for rotary furnaces (IPPC 2001b). (Althaus et al. 2004) describe a range of 0.25–22.0 µg I-TEQ/t Cu and uses a value of 2.0 µg I-TEQ/t Cu. We use the arithmetical average between actual “today” dataset and the lowest values for “best practice” and the lowest values as “further reduction”. In the scenarios we use the same distribution of the particulate size as in the “today” dataset.

Table 2-11: Selected air emissions of European copper production in the “today” dataset and in the scenarios

		Today	**Best Practice**	**Further Reduction**
SO_2	kg/t Cu	36	16	6
Dust	kg/t Cu	0.41	0.28	0.16
Dioxins measured as I-TEQ	kg/t Cu	2.0E-9	1.13E-9	0.25E-9
Applied to		Pessimistic 2025 Pessimistic 2050	Realistic-Optimistic 2050	Very Optimistic 2050

The inventory data resulting from the assumptions concerning air emission in Table 2-10 and Table 2-11 is summarised in Table 2-12.

Table 2-12: Selected air emissions (low population density area) of future primary copper production in Europe (RER). Values are per kilogram of copper.

Name	Location	Infrastructure-Process	Unit	Optimistic-Realistic 2025	Optimistic-Realistic 2050	Very Optimistic 2025	Very Optimistic 2050
Antimony			kg	3.25E-6	1.00E-6	3.25E-6	1.00E-6
Arsenic			kg	2.38E-5	1.50E-5	2.38E-5	1.50E-5
Cadmium			kg	4.75E-6	3.00E-6	4.75E-6	3.00E-6
Chromium			kg	5.00E-8	5.00E-8	5.00E-8	5.00E-8
Copper			kg	2.25E-4	2.00E-4	2.25E-4	2.00E-4
Lead			kg	1.00E-4	5.00E-5	1.00E-4	5.00E-5
Manganese			kg	1.00E-5	5.00E-6	1.00E-5	5.00E-6
Mercury			kg	1.00E-7	1.00E-7	1.00E-7	1.00E-7
Nickel			kg	3.25E-5	1.00E-5	3.25E-5	1.00E-5
Particulates, < 2.5 um			kg	4.31E-7	3.54E-7	3.54E-7	2.00E-7
Particulates, > 10 um			kg	8.65E-5	7.11E-5	7.11E-5	4.01E-5
Particulates, > 2.5 um, and < 10um			kg	2.58E-4	2.12E-4	2.12E-4	1.20E-4
Selenium			kg	3.25E-6	1.00E-6	3.25E-6	1.00E-6
Vanadium			kg	3.13E-7	2.50E-7	3.13E-7	2.50E-7
Tin			kg	4.38E-6	2.50E-6	4.38E-6	2.50E-6
Sulfur dioxide			kg	2.59E-2	1.60E-2	2.09E-2	6.00E-3
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin			kg	1.56E-12	1.13E-12	1.13E-12	2.50E-13

2.2.1.3 Selected cumulative life cycle inventory results

The environmental profile of European copper production shows a rather strong dependence on the scenario and time horizon chosen (see Table 2-13 to Table 2-15). The cumulative results of the pessimistic scenario reveals a drop in the share of nuclear power in the mix used in producing copper. The reduction in process specific particulate emissions (by about 50 %)

is hardly traceable in the results. Other contributions, for instance of the beneficiation of copper ores, are much more important.

Due to a major shift between hard coal and natural gas and a reduction of the energy consumption, the cumulative CO_2 emissions are expected to be reduced in 2050 by 34 % and 45 % in relation to today's value in the realistic-optimistic and very optimistic scenario, respectively.

Table 2-13: Selected cumulative life cycle inventory results of the production of 1 kg copper, pessimistic scenario

	unit	today	2025PE Mix: BAU	2050PE Mix: BAU
Resources				
Coal, hard, unspecified, in ground	kg	1.88E-01	104.8%	108.0%
Gas, natural, in ground	Nm^3	2.22E-01	102.4%	99.6%
Oil, crude, in ground	kg	1.93E-01	89.3%	89.1%
Uranium	kg	1.10E-05	69.2%	62.6%
Water	m^3	5.29E-02	97.3%	97.0%
Occupation agricultural and forests	m^2a	1.31E-01	110.8%	112.2%
Occupation built-up	m^2a	4.11E-01	99.9%	100.0%
selected air emissions				
CO2, fossil	kg	1.66E+00	92.1%	91.9%
NOx,	kg	1.94E-02	97.0%	97.0%
PM2.5	kg	1.28E-02	99.1%	99.1%
Rn222	kg	3.55E+02	69.0%	62.4%
selected water emissions				
C14	kBq	7.66E-03	69.2%	62.6%
Chromium VI	kg	1.24E-05	98.3%	98.2%
oils unspecified	kg	8.04E-04	89.0%	88.8%

Table 2-14: Selected cumulative life cycle inventory results of the production of 1 kg copper, realistic-optimistic scenario

	unit	today	2025RO Mix: 440ppm	2050RO Mix: 440ppm
Resources				
Coal, hard, unspecified, in ground	kg	1.88E-01	62.2%	39.4%
Gas, natural, in ground	Nm^3	2.22E-01	113.5%	129.3%
Oil, crude, in ground	kg	1.93E-01	86.6%	83.5%
Uranium	kg	1.10E-05	76.0%	62.1%
Water	m^3	5.29E-02	96.9%	97.7%
Occupation agricultural and forests	m^2a	1.31E-01	110.9%	104.0%
Occupation built-up	m^2a	4.11E-01	99.7%	99.6%
selected air emissions				
CO2, fossil	kg	1.66E+00	78.8%	66.3%
NOx,	kg	1.94E-02	95.9%	94.8%
PM2.5	kg	1.28E-02	98.7%	98.3%
Rn222	kg	3.55E+02	75.9%	61.9%
selected water emissions				
C14	kBq	7.66E-03	76.2%	66.4%
Chromium VI	kg	1.24E-05	102.3%	97.6%
oils unspecified	kg	8.04E-04	86.3%	83.1%

Table 2-15: Selected cumulative life cycle inventory results of the production of 1 kg copper, very optimistic scenario

	unit	today	2025VO Mix: Renew.	2050VO Mix: Renew.
Resources				
Coal, hard, unspecified, in ground	kg	1.88E-01	54.8%	35.5%
Gas, natural, in ground	Nm^3	2.22E-01	131.1%	129.8%
Oil, crude, in ground	kg	1.93E-01	56.3%	22.8%
Uranium	kg	1.10E-05	74.1%	3.5%
Water	m^3	5.29E-02	96.3%	89.9%
Occupation agricultural and forests	m^2a	1.31E-01	109.4%	131.7%
Occupation built-up	m^2a	4.11E-01	99.6%	99.5%
selected air emissions				
CO2, fossil	kg	1.66E+00	71.4%	55.6%
NOx,	kg	1.94E-02	94.2%	92.8%
PM2.5	kg	1.28E-02	97.8%	97.0%
Rn222	kBq	3.55E+02	74.0%	3.0%
selected water emissions				
C14	kBq	7.66E-03	74.3%	2.5%
Chromium VI	kg	1.24E-05	101.4%	97.0%
oils unspecified	kg	8.04E-04	54.8%	19.9%

2.2.2 Primary copper production (RLA)

In 2005, production of copper in South and Central America was 7'080'000 t of copper content (see Table 2-16). Main producer with 75% of production is Chile.

Table 2-16: Copper production 2005 of South and Central America (COCHILCO 2006).

	1'000 t of copper content	%
Chile	5'320.5	75.2
Peru	1'009.9	14.3
Mexico	428.6	6.1
Argentina	188.0	2.7
Brazil	130.0	1.8
Bolivia	0.6	0.0
Total	7'077.6	100.0

Most smelters in Chile have the El Teniente Design. The dataset “copper, primary, at refinery (RLA)” is based on a share of 23.3% reverbatory furnaces, 53.9% flash furnaces, 5.2% others and 17.6% SX-EW (Althaus et al. 2004). Today (2005), there are no more reverbatory furnaces operating in Chile[2]; smelting only occurs in Outokumpo Flash Furnaces (42% of production) and Teniente Converters (58%) (Anglo American Chile 2006).

Since 2000 the share of SX-EW process of the mine copper production in Chile is stable at about 30% (COCHILCO 2006). The SX-EW production grew very rapidly from 15.0% to 30% of mine production between 1995 and 2000 (see also Table 2-17) or from 25% to 56% of

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[2] Personal communication, Mr. J. Wiertz, Universidad de Chile, 25.8.2006

refined production respectively. This share is not expected to grow much[2]. For the scenarios 2025, we assume 32% and for 2050, 35% share of SX-EW process in the RLA production.

Table 2-17: Chilean Copper Production 2005 (COCHILCO 2006). Smelter production, cathodes SX-EW (refined production) and concentrate export add to the total mine production.

	2005		2000		1997		1995	
	1'000 t	%	1'000 t	%	1'000 t	%	1'000 t	%
Total mine production	5320.5	100.0	4602.0	100.0	3392	100.0	2488.6	100.0
Smelter production	1558.1	29.3	1460.4	31.7	1389.6	41.0	1293.7	52.0
Refined production	2824.0	53.1	2668.3	58.0	2116.6	62.4	1491.5	59.9
- Cathodes SX-EW	*1584.6*	*29.8*	*1372.3*	*29.8*	*881*	*26.0*	*372.5*	*15.0*
- Cathodes elec. refined	*1077.0*	*20.2*	*1136.7*	*24.7*	*1110.8*	*32.7*	*972.4*	*39.1*
- Cathodes fire refined	*162.4*	*3.1*	*159.3*	*3.5*	*124.8*	*3.7*	*146.6*	*5.9*
Concentrate export	2177.8	40.9	1769.3	38.4	1121.4	33.1	822.4	33.0

2.2.2.1 Energy use

Fuel oil use in the reverbatory furnace amounts to about 350 l/t Cu for the reduction step, in Teniente reactors 130 l/t and with Outokumpu 95 l/t (Krauss et al. 1999). We assume that until 2025 reverbatory furnaces in all South American countries will have been phased out and replaced with Teniente reactors.

Electricity use in the furnaces is mainly due to flue gas treatment and is not varied in this study.

The requirements of other energy sources and materials are adapted in the scenarios 2025 and 2050 to the higher SX-EW share in production of primary copper. The energy and material inputs of the primary copper production are summarized in the following table (Table 2-18).

Table 2-18: Selected energy and material inputs of the primary copper production in 2025 and 2050. Values are per kilogram of copper.

Name	Location	Infrastructure-Process	Unit	Optimistic-Realistic 2025	Optimistic-Realistic 2050	Very Optimistic 2025	Very Optimistic 2050
oxygen, liquid, at plant	RER	0	kg	1.03E-1	9.86E-2	1.03E-1	9.86E-2
silica sand, at plant	DE	0	kg	5.10E-1	4.88E-1	5.10E-1	4.88E-1
limestone, milled, packed, at plant	CH	0	kg	1.70E-1	1.63E-1	1.70E-1	1.63E-1
electricity, high voltage, production UCTE, at grid	UCTE	0	kWh	1.27E-1	1.21E-1	1.27E-1	1.21E-1
electricity, hydropower, at run-of-river power plant	RER	0	kWh	1.91E-1	1.82E-1	1.91E-1	1.82E-1
anode, aluminium electrolysis	RER	0	kg	6.80E-5	6.50E-5	6.80E-5	6.50E-5
copper, concentrate, at beneficiation	RLA	0	kg	2.16E+0	2.07E+0	2.16E+0	2.07E+0
copper, SX-EW, at refinery	GLO	0	kg	1.45E-1	1.39E-1	1.45E-1	1.39E-1
non-ferrous metal, smelter	GLO	1	unit	7.22E-12	6.90E-12	7.22E-12	6.90E-12
natural gas, burned in industrial furnace >100kW	RER	0	MJ	1.82E+0	1.74E+0	1.82E+0	1.74E+0
heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	5.10E+0	4.88E+0	5.10E+0	4.88E+0
disposal, nickel smelter slag, 0% water, to residual material landfill	CH	0	kg	5.97E-1	5.70E-1	5.97E-1	5.70E-1
treatment, sewage, unpolluted, to wastewater treatment, class 3	CH	0	m3	3.03E-3	2.90E-3	3.03E-3	2.90E-3
Water, river			m3	3.03E-3	2.90E-3	3.03E-3	2.90E-3

2.2.2.2 Air emissions

The copper smelters are the main source of SO_2 emissions in Chile. Additionally, copper smelters release also significant amounts of arsenic and particulate matter into the atmosphere. There have been reductions in the amounts of these emissions in recent years, but the problem remains serious. In 1991, the Chilean government regulated smelter operations that emit significant quantities of SO_2 or particulate matter. It makes it mandatory to present decontamination plans, determines demands on information reporting and, in some smelters, forces management to report plans for controlling high SO_2 concentration episodes (Valenzuela et al. 2003).

Arsenic emissions into atmosphere are regulated by Decree Law 165, 1999. The maximum arsenic emissions allowed (see Table 2-19) should not exceed the standards according to the type of sources and decontamination plans of each smelter (Valenzuela et al. 2003). On average, emissions are about 75% of maximum values[3].

Table 2-19: Maximum permissible arsenic emissions for 2003 (Valenzuela et al. 2003).

Smelter Name	**Concentrate smelting**	**Arsenic emissions (maximum permissible)**	
	t/a	**t/a**	**g/t concentrate**
Chuquicamata	1'400'000	400	286
Altonorte	350'000	126	360
Paipote	200'000	34	170
Cpotrerillos	500'000	800	1600
El Indio	80'000	200	2500
Chagres	350'000	95	271
Ventanas	400'000	120	300
Caletones	1'250'000	375	300
Total	*4'530'000*	*2150*	*475*
75% of Total			*356*

In 2003, the smelters' production was 1'542'000 t copper, which results in permissible arsenic emissions of about 1.4 kg/t copper. With an average of 75% of maximum permissible values the emissions were about 1 kg/t copper in 2003.

The enforcement of air quality standards, which regulate pollutants such as SO_2, particulate matter and arsenic, has resulted in the implementation of pollution abatement plans and emission reduction schedules mainly by state-owned copper concentrate smelters. Table 2-20 shows emission reductions of SO_2 and arsenic between 1995 and 2002 (Valenzuela et al. 2003). However, increase in arsenic concentration in ores may make a further significant decrease of arsenic emissions difficult[4].

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[3] Personal communication, Mr. J. Wiertz, Universidad de Chile, 25.8.2006

[4] Personal communication, Mr. J. Wiertz, Universidad de Chile, 25.8.2006

Table 2-20: Emissions of SO_2 and arsenic in the copper smelters 1995–2002 (Valenzuela et al. 2003).

	Copper smelter production	**SO_2 emissions**		**Arsenic emissions**	
	1'000 t copper/a	**1'000 t/a**	**kg/t copper**	**t/a**	**kg/t copper**
1995	1'294	1'550	1'198		
1998	1'403	1'350	962	4'600	3.28
2000	1'460	850	582		
2001	1'503	600	399	2'064	1.37
2002	1'434	500	349		

The today dataset accounts for SO_2 emissions of 327 kg/t primary copper or 397 kg/t smelter product respectively (2'500 kg/t for reverbatory furnaces and 150 kg/t for flash furnaces), which is higher than the value for 2002. We assume that until 2025 all reverbatory furnaces will be phased out and that the abatement of SO_2 will reach 75% in all smelters. For 2050 we assume a 95% abatement as defined in the “today” dataset for Europe.

Industry is investing in cleaner production and the emissions are expected to decrease[4]. We assume that metal emissions will be reduced until 2050 to the lowest values of the limited emission control range reported in Althaus et al. (2004) in the case of the optimistic scenario. In the very optimistic scenario we assume a reduction to the lowest value reported for full emission control until 2050 (Table 2-21).

Table 2-21: Air emissions in the future scenario for copper production in RLA. Values are per kilogram of copper.

Name	Location	Infrastructure-Process	Unit	Optimistic-Realistic 2025	Optimistic-Realistic 2050	Very Optimistic 2025	Very Optimistic 2050
Antimony			kg	6.78E-5	3.25E-5	5.18E-5	6.50E-7
Arsenic			kg	5.75E-4	3.25E-4	4.17E-4	9.75E-6
Cadmium			kg	2.09E-4	1.30E-4	1.45E-4	1.95E-6
Chromium			kg	7.37E-7	6.50E-7	4.28E-7	3.25E-8
Copper			kg	1.62E-3	9.75E-4	1.20E-3	1.30E-4
Lead			kg	1.36E-3	6.50E-4	1.05E-3	3.25E-5
Manganese			kg	1.56E-4	6.50E-5	1.25E-4	3.25E-6
Mercury			kg	1.54E-6	1.43E-6	8.58E-7	6.50E-8
Nickel			kg	1.10E-3	5.85E-4	8.08E-4	6.50E-6
Selenium			kg	5.75E-5	3.25E-5	4.15E-5	6.50E-7
Sulfur dioxide			kg	1.76E-1	2.44E-2	1.66E-1	4.88E-3
Tin			kg	6.78E-5	3.25E-5	5.23E-5	1.63E-6
Vanadium			kg	4.72E-6	3.25E-6	3.17E-6	1.63E-7
Zinc			kg	4.72E-4	3.25E-4	3.42E-4	6.50E-5

2.3 Iron and steel production

The blast furnace remains by far the most important process to produce pig iron from iron containing materials. Because of the high input of reducing agents (mainly coke and coal) this process consumes most of the overall energy input of an integrated steelworks (IPPC 2001c). The blast furnace technology is likely to dominate pig iron production for at least the next 20 years. The sintering process represents a major part of the burdens of blast furnaces. The most relevant environmental issues are the off-gas emissions of the sinter strand, which contain a wide range of pollutants such as dust, heavy metals, SO_2, HCl, HF; PAHs and organochlorine compounds (such as PCB and PCDD/F). Therefore, we focus the scenarios on the production of sinter and of pig iron in the blast furnace.

The datasets for the reference situation (“today”) and for the scenarios are based on the datasets “sinter, at plant (GLO)” (chapter 2.3.1) and “pig iron, at plant (GLO)” (chapter 2.3.2), which are described in detail in Althaus et al. (2004).

2.3.1 Sinter production

2.3.1.1 Energy and raw material use

Thermal energy use (solid fuels including flue dust and ignition fuel) ranges from 1'125 MJ to 1'920 MJ/t sinter with an average of 1'480 MJ/t sinter (IPPC 2001c). In the “today” dataset hard coal coke and natural gas add to 1'467 MJ/t sinter; further 36 MJ coke oven gas and blast furnace gas per metric ton of sinter are used, which results in a total of 1'500 MJ/t sinter. For “best practice” we assume a reduction of thermal energy use of 20%, which can be reached already today with heat recovery systems (IPPC 2001c). For “minimum energy” we assume a reduction of 30% compared to today. Proportion of coal coke, natural gas and blast furnace/coke oven gas is kept as in the today dataset (Table 2-22). The matching of the energy reduction level with the NEEDS scenarios and time periods is indicated in Table 2-22. Realistic-optimistic for 2025 is the average of “today” and “best practice”.

Table 2-22: Coke and gas use in the “today” dataset and in the scenarios (“today”: Althaus et al. 2004; “Best Practice”: IPPC 2001c). Values are given in MJ/kg sinter

	Today	**Best Practice**	**Minimum Energy**
Coke	1.43	1.14	1.00
Blast Furnace and Coke Oven Gas	0.036	0.029	0.025
Natural Gas	0.036	0.029	0.025
Total energy	1.50	1.20	1.05
Applied to	Pessimistic 2025 Pessimistic 2050	Realistic-Optimistic 2050 Very Optimistic 2025	Very Optimistic 2050

Table 2-23: Energy use in the future scenarios of global (GLO) sinter production. Values are per kilogram of sinter.

Name	Location	Infrastructure-Process	Unit	Optimistic-Realistic 2025	Optimistic-Realistic 2050	Very Optimistic 2025	Very Optimistic 2050
hard coal coke, at plant	RER	0	MJ	1.29E+0	1.14E+0	1.14E+0	1.00E+0
natural gas, high pressure, at consumer	RER	0	MJ	3.27E-2	2.90E-2	2.90E-2	2.54E-2

2.3.1.2 Air and water emissions

IPPC (IPPC 2001c) gives BAT values for the air emissions of the sinter production as the most relevant environmental issues. We use the minimum values reported for “optimistic-realistic” and “very optimistic” in 2050 and 2025 respectively (Table 2-24). This emission reduction can be achieved with a fabric filter (for the particles) and a wet scrubber. The wet scrubber, however, causes additional water emissions (Table 2-25).

It is assumed that with improved production technology and better emission control systems the emissions indicated as BAT can be reduced by a further 50% (“further reduction”).

The carbon dioxide emissions are reduced proportionally to the reduction in thermal heat input according to Table 2-22.

The optimistic-realistic scenario for 2025 is calculated as the average of “today” and “BAT”.

Table 2-24: Air emissions from sinter production (Althaus et al. 2004) and values for BAT (IPPC 2001c). The BAT values are based on wet scrubber technology that generates waste water treated at the plant (see Table 2-25). Values are given in kg/kg sinter

	Today	**BAT**	**Further Reduction**
Cadmium	1.93E-8	1.83E-9	9.17E-10
Carbon dioxide, fossil	2.04E-1	1.55E-1	1.42E-1
Carbon monoxide, fossil	2.57E-2	1.95E-2	1.79E-2
Chromium	2.52E-8	4.59E-9	2.29E-9
Copper	7.66E-8	6.42E-9	3.21E-9
Dioxins, measured as I-TEQ	7.00E-12	4.59E-13	2.29E-13
Hydrocarbons, aliphatic, alkanes, unspecified	1.37E-4	1.37E-4	6.87E-5
Hydrogen chloride	3.76E-5	1.56E-5	7.80E-6
Hydrogen fluoride	2.25E-6	1.28E-6	6.42E-7
Lead	3.23E-6	3.67E-8	1.83E-8
Manganese	1.93E-7	1.83E-8	9.17E-9
Mercury	7.57E-8	1.47E-8	7.34E-9
Nickel	1.93E-8	1.83E-9	9.17E-10
Nitrogen oxides	5.27E-4	4.04E-4	2.02E-4
PAH	4.72E-7	1.05E-7	5.27E-8
Particulates, < 2.5 um	2.06E-4	2.10E-5	1.05E-5
Polychlorinated biphenyls	6.42E-9	9.17E-10	4.59E-10
Sulphur dioxide	1.26E-3	8.25E-4	4.13E-4
Titanium	1.60E-8	4.59E-9	2.29E-9
Vanadium	1.15E-8	4.59E-9	2.29E-9
Zinc	8.26E-7	1.83E-9	9.17E-10
Applied to	Pessimistic 2025 Pessimistic 2050	Realistic-Optimistic 2050 Very Optimistic 2025	Very Optimistic 2050

Table 2-25: Water emissions in treated waste water due to wet scrubber technology in the scenarios (IPPC 2001c). The values stem from a reference plant in Austria. Values are given in kg/kg sinter

	Today	**BAT**	**Further Reduction**
Aluminium	0	1.80E-11	9.00E-12
Arsenic, ion	0	6.00E-14	3.00E-14
Cadmium, ion	0	1.30E-13	6.50E-14
Chloride	0	3.10E-7	1.55E-7
Chromium, ion	0	6.00E-13	3.00E-13
Copper, ion	0	4.00E-12	2.00E-12
Cyanide	0	1.30E-12	6.50E-13
Iron, ion	0	1.40E-11	7.00E-12
Mercury	0	9.00E-14	4.50E-14
Nickel, ion	0	3.00E-12	1.50E-12
Lead	0	4.00E-12	2.00E-12
Zinc, ion	0	1.60E-12	8.00E-13
Sulphate	0	1.60E-7	8.00E-8
Fluoride	0	4.30E-10	2.15E-10
Sulphide	0	4.00E-12	2.00E-12
Ammonium, ion	0	9.13E-9	4.56E-9
Nitrate	0	4.87E-9	2.44E-9
Nitrite	0	1.31E-10	6.57E-11
TOC, Total Organic Carbon	0	1.10E-9	5.50E-10
Applied to	Pessimistic 2025 Pessimistic 2050	Realistic-Optimistic 2050 Very Optimistic 2025	Very Optimistic 2050

Table 2-26: Air emissions in the future scenarios of global (GLO) sinter production. Values are per kilogram of sinter.

Name	Location	Infrastructure-Process	Unit	Optimistic-Realistic 2025	Optimistic-Realistic 2050	Very Optimistic 2025	Very Optimistic 2050
Cadmium			kg	1.06E-8	1.83E-9	1.83E-9	9.17E-10
Carbon dioxide, fossil			kg	1.79E-1	1.55E-1	1.55E-1	1.42E-1
Carbon monoxide, fossil			kg	2.26E-2	1.95E-2	1.95E-2	1.79E-2
Chromium			kg	1.49E-8	4.59E-9	4.59E-9	2.29E-9
Copper			kg	4.15E-8	6.42E-9	6.42E-9	3.21E-9
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin			kg	3.73E-12	4.59E-13	4.59E-13	2.29E-13
Hydrocarbons, aliphatic, alkanes, unspecified			kg	1.37E-4	1.37E-4	1.37E-4	6.87E-5
Hydrogen chloride			kg	2.66E-5	1.56E-5	1.56E-5	7.80E-6
Hydrogen fluoride			kg	1.77E-6	1.28E-6	1.28E-6	6.42E-7
Lead			kg	1.63E-6	3.67E-8	3.67E-8	1.83E-8
Manganese			kg	1.06E-7	1.83E-8	1.83E-8	9.17E-9
Mercury			kg	4.52E-8	1.47E-8	1.47E-8	7.34E-9
Nickel			kg	1.06E-8	1.83E-9	1.83E-9	9.17E-10
Nitrogen oxides			kg	4.65E-4	4.04E-4	4.04E-4	2.02E-4
PAH, polycyclic aromatic hydrocarbons			kg	2.89E-7	1.05E-7	1.05E-7	5.27E-8
Particulates, < 2.5 um			kg	1.14E-4	2.10E-5	2.10E-5	1.05E-5
Polychlorinated biphenyls			kg	3.67E-9	9.17E-10	9.17E-10	4.59E-10
Sulfur dioxide			kg	1.04E-3	8.25E-4	8.25E-4	4.13E-4
Titanium			kg	1.03E-8	4.59E-9	4.59E-9	2.29E-9
Vanadium			kg	8.04E-9	4.59E-9	4.59E-9	2.29E-9
Zinc			kg	4.14E-7	1.83E-9	1.83E-9	9.17E-10

2.3.2 Pig iron production

2.3.2.1 Energy and raw material use

Main energy sources of the blast furnace process are the reducing agents coke and coal. The “today” dataset uses 9.72 MJ coke/kg pig iron and 0.15 kg coal/kg pig iron. Direct injection of reducing agents allows to reduce the need for coke. It means replacing part of the coke by another hydrocarbon source, which is injected in the furnace at tuyère[5] level. Granular or pulverised coal and oil are currently used (IPPC 2001c). Best practice allows the injection of 0.210 kg coal/kg pig iron and reduces the need of coke to 0.270–0.300 kg/kg pig iron. The minimum blast furnace coke rate is approximately 200 kg/t pig iron and the theoretical maximum for coal injection 270 kg/t pig iron (Table 2-27).

The matching of the scenarios and time periods with the “today”, “best practice” and “minimum coke rate” is indicated in Table 2-27. The realistic-optimistic scenario for 2025 is the average of “today” and “best practice”.

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[5] tuyère: The pipe, nozzle, or other opening through which air is forced into a blast furnace or forge to facilitate combustion.

Table 2-27: Coke and coal use in the “today” dataset and in the scenarios (“today”: Althaus et al. 2004; “Best Practice”: IPPC 2001c). Values are given per kg pig iron

	Unit	Today	Best Practice	Minimum Coke Rate
Coke	kg	0.34	0.27	0.2
	MJ	9.72	7.72	5.72
Coal	kg	0.15	0.21	0.27
	MJ	4.50	6.30	8.10
Total energy	MJ	14.2	14.0	13.8
Applied to		Pessimistic 2025 Pessimistic 2050	Realistic-Optimistic 2050 Very Optimistic 2025	Very Optimistic 2050

Because of the lack of more specific information, we calculate the CO_2-emissions in 2025 and 2050 proportional to the total energy inputs. Therefore, CO_2-emissions decrease from 0.415 (today) to 0.409 (best practice) resp. 0.403 (minimum coke rate). These values are shown in Table 2-29.

In Brazil some efforts are made to use biomass in pig iron production (IISI 2005). A project intends to produce sinter with charcoal from eucalyptus plantation. About 40'000 ha of eucalyptus forest are required to produce 500'000 t of pig iron per year. The Brazilian government requires that an equal amount of forest be restored to its original condition, which increases the required size of forest to over 80'000 ha. To cover the world steel production from blast furnace (about 60% of 1'000 million t), a land area of about 500'000 km^2 would be needed, which corresponds to the area of France. Because of the competition in the use of biomass for different utilizations (food, construction, fuels), the limited agriculture area in Europe and the high energy demand of the pig iron production we consider this development unrealistic in a European context.

The EU-25 baseline scenario (NTUA 2003) does not anticipate a change in the share of energy sources used in the iron and steel production, especially no increase of renewable energy sources. Therefore, we assume the same energy sources in all scenarios.

Blast furnace top gas contains large amounts of particulate matter (7–40 kg/t pig iron). A large part of this particulate matter is removed in the dry first step of the blast furnace gas treatment system. The remainder (1–10 kg/t pig iron) is scrubbed from the blast furnace gas by means of wet scrubbing. After precipitation 3–5 kg sludge/t pig iron is generated. This sludge has a relatively high zinc content. By means of hydrocyclonage of the sludge, a zinc-rich and a zinc-poor sludge can be generated out of the sludge. The zinc-poor sludge can be reused in the sinter plant, whereas the zinc-rich sludge is landfilled or stored for future possibilities of processing. This technique allows to reduce the sludge quantity to be disposed of to an average of 1.5kg/t pig iron. We use this value as “best practice”. For the “minimum coke rate”-scenario we use the lowest value which is 0.2 kg/t pig iron.

Table 2-28: Energy use in the future scenarios of global (GLO) pig iron production. Values are per kilogram of pig iron.

Name	Location	Infrastructure-Process	Unit	Optimistic-Realistic 2025	Optimistic-Realistic 2050	Very Optimistic 2025	Very Optimistic 2050
hard coal coke, at plant	RER	0	MJ	8.72E+0	7.72E+0	7.72E+0	5.72E+0
hard coal mix, at regional storage	UCTE	0	kg	1.80E-1	2.10E-1	2.10E-1	2.70E-1

2.3.2.2 Air emissions

The "today" dataset uses the average of the emissions range in IPPC (2001c). We use the lowest values of the same source as "best practice". We assume that a further halving in air emissions (except Carbon dioxide which is closely related to the coke and coal input) beyond the minimum values in IPPC (2001c) is possible (Table 2-29).

The matching of the scenarios and time periods with the "today", "best practice" and "minimum coke rate" is indicated in Table 2-29. The realistic-optimistic scenario for 2025 is the average of "today" and "best practice".

Table 2-29: Air emissions per kg pig iron in the "today" dataset and the further development ("today": Althaus et al. 2004, "Best Practice": IPPC 2001c). CO_2-emissions are calculated (see chapter 2.3.2.1).

		Today	**Best Practice**	**Minimum Air Emissions**
Carbon dioxide, fossil	kg	4.15E-1	3.61E-1	3.06E-1
Carbon monoxide, fossil	kg	1.34E-3	1.17E-3	9.90E-4
Dioxins, measured as I-TEQ	kg	2.66E-15	1.06E-15	5.32E-16
Hydrogen sulphide	kg	1.07E-5	2.13E-7	1.06E-7
Lead	kg	6.91E-8	1.06E-8	5.32E-9
Manganese	kg	7.45E-8	1.06E-8	5.32E-9
Nickel	kg	1.60E-8	1.06E-8	5.32E-9
Nitrogen oxides	kg	7.98E-5	3.19E-5	1.60E-5
Particulates, < 2.5 um	kg	2.87E-5	9.57E-6	4.79E-6
Particulates, > 10 um	kg	1.60E-6	5.32E-7	2.66E-7
Particulates, > 2.5 um, and < 10um	kg	1.60E-6	5.32E-7	2.66E-7
Sulphur dioxide	kg	1.33E-4	2.13E-5	1.06E-5
Applied to		Pessimistic 2025 Pessimistic 2050	Realistic-Optimistic 2050 Very Optimistic 2025	Very Optimistic 2050

Table 2-30: Selected air and water emissions in the future scenarios of global (GLO) pig iron production. Values are per kilogram of pig iron.

Name	Location	Infrastructure-Process	Unit	Optimistic-Realistic 2025	Optimistic-Realistic 2050	Very Optimistic 2025	Very Optimistic 2050
Carbon dioxide, fossil			kg	3.88E-1	3.61E-1	3.61E-1	3.06E-1
Carbon monoxide, fossil			kg	1.25E-3	1.17E-3	1.17E-3	9.90E-4
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin			kg	1.86E-15	1.06E-15	1.06E-15	5.32E-16
Hydrogen sulfide			kg	5.46E-6	2.13E-7	2.13E-7	1.06E-7
Lead			kg	3.99E-8	1.06E-8	1.06E-8	5.32E-9
Manganese			kg	4.26E-8	1.06E-8	1.06E-8	5.32E-9
Nickel			kg	1.33E-8	1.06E-8	1.06E-8	5.32E-9
Nitrogen oxides			kg	5.59E-5	3.19E-5	3.19E-5	1.60E-5
Particulates, < 2.5 um			kg	1.91E-5	9.57E-6	9.57E-6	4.79E-6
Particulates, > 10 um			kg	1.07E-6	5.32E-7	5.32E-7	2.66E-7
Particulates, > 2.5 um, and < 10um			kg	1.07E-6	5.32E-7	5.32E-7	2.66E-7
Sulfur dioxide			kg	7.71E-5	2.13E-5	2.13E-5	1.06E-5

2.3.2.3 Selected cumulative life cycle inventory results

In the business as usual scenario, the environmental impacts of pig iron are rather stable in the coming 45 years (see Table 2-31). A substantial drop in uranium is due to the reduction of nuclear power share in the electricity mix. While natural gas consumption increases considerably in the realistic-optimistic scenario (see Table 2-32), it has a peak in 2025 of the very optimistic scenario (see Table 2-33). The CO_2 emissions are reduced by 20 % and nearly 30 % by 2050 in the realistic-optimistic and the very optimistic scenario, respectively. The process specific emissions (and their reduction) are of only minor importance with regard to the cradle to gate emissions.

Table 2-31: Selected cumulative life cycle inventory results of the production of 1 kg pig iron, pessimistic scenario

	unit	**today**	**2025PE Mix: BAU**	**2050PE Mix: BAU**
Resources				
Coal, hard, unspecified, in ground	kg	9.76E-01	100.1%	100.2%
Gas, natural, in ground	Nm^3	1.42E-02	105.7%	98.9%
Oil, crude, in ground	kg	3.95E-02	92.1%	92.0%
Uranium	kg	1.67E-06	69.6%	63.1%
Water	m^3	1.25E-02	98.3%	98.1%
Occupation agricultural and forests	m^2a	4.55E-02	104.6%	105.3%
Occupation built-up	m^2a	1.29E-02	99.7%	99.8%
selected air emissions				
CO2, fossil	kg	9.25E-01	97.9%	97.8%
NOx,	kg	3.17E-03	97.2%	97.1%
PM2.5	kg	9.64E-04	98.2%	98.2%
Rn222	kg	5.41E+01	69.6%	63.1%
selected water emissions				
C14	kBq	1.16E-03	69.5%	62.9%
Chromium VI	kg	9.88E-06	99.7%	99.7%
oils unspecified	kg	1.04E-03	98.7%	98.7%

Table 2-32: Selected cumulative life cycle inventory results of the production of 1 kg pig iron, realistic-optimistic scenario

	unit	today	2025RO Mix: 440ppm	2050RO Mix: 440ppm
Resources				
Coal, hard, unspecified, in ground	kg	9.76E-01	95.3%	91.2%
Gas, natural, in ground	Nm^3	1.42E-02	134.0%	173.4%
Oil, crude, in ground	kg	3.95E-02	90.4%	88.4%
Uranium	kg	1.67E-06	76.0%	61.7%
Water	m^3	1.25E-02	97.1%	96.5%
Occupation agricultural and forests	m^{2}a	4.55E-02	101.1%	94.7%
Occupation built-up	m^{2}a	1.29E-02	95.6%	92.0%
selected air emissions				
CO2, fossil	kg	9.25E-01	88.2%	79.0%
NOx,	kg	3.17E-03	91.4%	85.8%
PM2.5	kg	9.64E-04	84.6%	71.2%
Rn222	kg	5.41E+01	76.0%	61.6%
selected water emissions				
C14	kBq	1.16E-03	76.1%	65.5%
Chromium VI	kg	9.88E-06	100.1%	98.9%
oils unspecified	kg	1.04E-03	98.5%	98.1%

Table 2-33: Selected cumulative life cycle inventory results of the production of 1 kg pig iron, very optimistic scenario

	unit	today	2025VO Mix: Renew.	2050VO Mix: Renew.
Resources				
Coal, hard, unspecified, in ground	kg	9.76E-01	91.7%	85.2%
Gas, natural, in ground	Nm^3	1.42E-02	128.4%	84.1%
Oil, crude, in ground	kg	3.95E-02	89.0%	85.9%
Uranium	kg	1.67E-06	74.1%	5.3%
Water	m^3	1.25E-02	95.9%	90.4%
Occupation agricultural and forests	m^{2}a	4.55E-02	96.4%	99.2%
Occupation built-up	m^{2}a	1.29E-02	92.4%	87.3%
selected air emissions				
CO2, fossil	kg	9.25E-01	81.6%	71.0%
NOx,	kg	3.17E-03	86.4%	75.6%
PM2.5	kg	9.64E-04	71.2%	65.3%
Rn222	kBq	5.41E+01	74.0%	5.2%
selected water emissions				
C14	kBq	1.16E-03	74.1%	3.8%
Chromium VI	kg	9.88E-06	99.7%	98.5%
oils unspecified	kg	1.04E-03	98.2%	97.7%

2.4 Nickel and Ferronickel production

Nickel ores are classified in a sulphidic and an oxidic type. The sulphidic path of nickel production yields Class I nickel whereas the lateritic (oxidic) path yields ferronickel. The latter is mainly used in the production of stainless steel. Class I nickel is usually of a purity of 99.7% or higher. It is used in special applications such as batteries, welding products, catalysts and fuel cells.

Data for the reference situation (“today”) and for the scenarios are based on the dataset “ferronickel, 25%, at plant (GLO)” and “nickel, 99.5%, at plant” respectively. They are described in detail in Althaus et al. (2004).

The production of nickel and ferronickel can be considered similar, but not identical. However, the relative changes in energy use and emissions are assumed to develop on the same (reduction) pathway for both types as far as applicable.

2.4.1 Energy use

The greatest amount of fossil energy in the ferronickel production is used in the drying and roasting steps, whereas the main share of electricity is used in the melting step. In the case of Class I nickel the main energy consumer for both fossil and electric energy is the melting process (Krauss et al. 1999). Some companies plan to use wood chips in the ferronickel production (CDP 2005).

(Ferro)nickel producing companies report efforts to reduce the energy intensity and greenhouse gas emissions of the (ferro)nickel production (e.g. Anglo American Brazil 2005; BHP Billiton 2006; Inco 2005). It is possible to reduce energy use in the nickel and ferronickel production. The smelting of ferronickel can be improved with semi-closed furnaces with heat recovery. The current production technology of nickel, however, cannot easily be improved. It had to be replaced with a new production line of another technology to achieve significant reductions (IPPC 2001b).

We assume in the scenarios “optimistic-realistic” that the energy intensity of nickel production in the drying, roasting and melting steps is reduced by 5% until 2025 and 10% until 2050. In the very optimistic scenario we assume that the energy savings will be 10% until 2025 and 20% until 2050. Furthermore, we assume that in the “optimistic-realistic” scenario no relevant shift of energy carriers will take place. However, in the “very optimistic” scenario switching from oil and coal to natural gas and wood chips will be realised. It is assumed that until 2025 25% and until 2050 50% of oil and coal is replaced with wood and natural gas (each covering an equal amount).

Table 2-34: Energy inputs of the **ferronickel** production in the optimistic scenarios 2025 and 2050. Values are per kilogram of ferronickel.

Name	Location	Infrastructure-Process	Unit	Optimistic-Realistic 2025	Very Optimistic 2025	Optimistic-Realistic 2050	Very Optimistic 2050
electricity, high voltage, production UCTE, at grid	UCTE	0	kWh	7.40E+0	7.01E+0	7.01E+0	6.23E+0
hard coal, burned in industrial furnace 1-10MW	RER	0	MJ	3.80E+1	2.70E+1	3.60E+1	1.60E+1
wood chips, from industry, mixed, burned in furnace 1000kW	CH	0	MJ		8.16E+0		1.45E+1
electricity, hydropower, at run-of-river power plant	RER	0	kWh	1.42E+0	1.34E+0	1.34E+0	1.19E+0
natural gas, burned in industrial furnace >100kW	RER	0	MJ	2.83E+1	2.86E+1	2.69E+1	2.70E+1
heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	3.56E+0	2.53E+0	3.38E+0	1.50E+0

Table 2-35: Energy inputs of the **nickel, 99.5%** production in the optimistic scenarios 2025 and 2050. Values are per kilogram of nickel.

Name	Location	Infrastructure-Process	Unit	Optimistic-Realistic 2025	Very Optimistic 2025	Optimistic-Realistic 2050	Very Optimistic 2050
electricity, high voltage, production UCTE, at grid	UCTE	0	kWh	3.54E+0	3.36E+0	3.36E+0	2.98E+0
electricity, hydropower, at run-of-river power plant	RER	0	kWh	8.34E+0	7.90E+0	7.90E+0	7.02E+0
non-ferrous metal, smelter	GLO	1	unit	3.35E-11	3.35E-11	3.35E-11	3.35E-11
natural gas, burned in industrial furnace >100kW	RER	0	MJ	1.38E+1	1.58E+1	1.30E+1	1.65E+1
heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	2.15E+1	1.53E+1	2.04E+1	9.07E+0
wood chips, from industry, mixed, burned in furnace 1000kW	CH	0	MJ	0	2.76E+0	0	4.91E+0

2.4.2 Air emissions

(Ferro)nickel companies are also reporting efforts to reduce dust emissions in the production (e.g. BHP Billiton 2004; Inco 2005). Cerro Matoso reports a reduction of 27% of stack dust in 2003 due to increased operation of line electric furnace scrubber (BHP Billiton 2004). Their reported emissions in 2000 (0.75 kg/kg ferronickel 25%) were in the range of the "today" dataset (1 kg/kg). PT Inco reduced its emissions from 2.2 kg/kg ferronickel to 0.7 kg/kg between 2000 and 2004. We assume that it will be possible to reduce dust and metal emissions in the nickel and ferronickel production by 50% until 2025 to a total of 0.5 kg/kg and by 75% (to 0.25 kg/kg) until 2050.

Sulphur dioxide is a major issue in the nickel production. In order to follow legal requirements Inco is evaluating off-gas treatment in the short term and an improved production technology in the long term that will lead to an expected reduction of 34% and 75% respectively (Inco 2005). These two reduction values are used in all scenarios for 2025 and 2050.

Table 2-36: Selected air emissions in the scenarios 2025 and 2050 for **ferronickel**. Values are per kilogram of ferronickel.

Name	Location	Infrastructure-Process	Unit	Optimistic-Realistic 2025	Very Optimistic 2025	Optimistic-Realistic 2050	Very Optimistic 2050
Antimony			kg	1.01E-9	1.01E-9	5.05E-10	5.05E-10
Arsenic			kg	7.20E-6	7.20E-6	3.60E-6	3.60E-6
Beryllium			kg	1.32E-8	1.32E-8	6.58E-9	6.58E-9
Boron			kg	5.05E-8	5.05E-8	2.53E-8	2.53E-8
Cadmium			kg	5.55E-10	5.55E-10	2.78E-10	2.78E-10
Zinc			kg	1.25E-4	1.25E-4	6.25E-5	6.25E-5
Tin			kg	8.05E-6	8.05E-6	4.03E-6	4.03E-6
Selenium			kg	2.53E-10	2.53E-10	1.26E-10	1.26E-10
Particulates, > 2.5 um, and < 10um			kg	2.61E-3	2.61E-3	1.31E-3	1.31E-3
Particulates, > 10 um			kg	3.74E-4	3.74E-4	1.87E-4	1.87E-4
Particulates, < 2.5 um			kg	2.57E-3	2.57E-3	1.29E-3	1.29E-3
Nickel			kg	1.59E-5	1.59E-5	7.95E-6	7.95E-6
Mercury			kg	2.53E-10	2.53E-10	1.26E-10	1.26E-10
Manganese			kg	4.80E-6	4.80E-6	2.40E-6	2.40E-6
Lead			kg	3.84E-5	3.84E-5	1.92E-5	1.92E-5
Copper			kg	4.94E-5	4.94E-5	2.47E-5	2.47E-5
Cobalt			kg	1.51E-5	1.51E-5	7.55E-6	7.55E-6
Chromium			kg	5.05E-7	5.05E-7	2.53E-7	2.53E-7

Table 2-37: Selected air emissions in the scenarios 2025 and 2050 of **nickel, 99.5%**. Values are per kilogram of nickel.

Name	Location	Infrastructure-Process	Unit	Optimistic-Realistic 2025	Very Optimistic 2025	Optimistic-Realistic 2050	Very Optimistic 2050
Arsenic			kg	2.66E-6	2.66E-6	1.33E-6	1.33E-6
Silver			kg	6.31E-8	6.31E-8	3.16E-8	3.16E-8
Aluminum			kg	7.33E-4	7.33E-4	3.66E-4	3.66E-4
Zinc			kg	4.61E-5	4.61E-5	2.30E-5	2.30E-5
Tin			kg	2.98E-6	2.98E-6	1.49E-6	1.49E-6
Particulates, > 2.5 um, and < 10um			kg	6.63E-3	6.63E-3	3.32E-3	3.32E-3
Particulates, > 10 um			kg	7.68E-4	7.68E-4	3.84E-4	3.84E-4
Particulates, < 2.5 um			kg	7.47E-3	7.47E-3	3.74E-3	3.74E-3
Nickel			kg	1.95E-4	1.95E-4	9.74E-5	9.74E-5
Lead			kg	1.57E-5	1.57E-5	7.84E-6	7.84E-6
Copper			kg	1.65E-4	1.65E-4	8.26E-5	8.26E-5
Cobalt			kg	5.55E-4	5.55E-4	2.78E-4	2.78E-4

2.4.3 Selected cumulative life cycle inventory results

Table 2-38 to Table 2-40 show some selected life cycle inventory results of the production of 1 kg nickel. The results in the business as usual scenario are rather stable. The behaviour in the realistic-optimistic and the very optimistic scenario is very similar to the behaviour of pig iron: an increase in natural gas demand and a considerable drop in demand of hard coal and uranium. The CO_2 emissions are reduced by some 25 % in both optimistic scenarios. The process specific emissions of pollutants shown here and their reduction play hardly any role in the reduction of the cumulative emissions of the nickel product system.

Table 2-38: Selected cumulative life cycle inventory results of the production of 1 kg nickel, pessimistic scenario

	unit	today	2025PE Mix: BAU	2050PE Mix: BAU
Resources				
Coal, hard, unspecified, in ground	kg	8.35E-01	104.7%	108.0%
Gas, natural, in ground	Nm^3	8.68E-01	102.7%	99.4%
Oil, crude, in ground	kg	1.31E+00	91.7%	91.4%
Uranium	kg	5.18E-05	71.0%	64.9%
Water	m^3	2.81E-01	97.7%	97.5%
Occupation agricultural and forests	m^2a	7.16E-01	108.7%	109.9%
Occupation built-up	m^2a	7.51E-01	99.9%	99.9%
selected air emissions				
CO2, fossil	kg	1.01E+01	93.7%	93.5%
NOx,	kg	6.60E-02	94.1%	94.0%
PM2.5	kg	1.87E-02	96.8%	96.8%
Rn222	kg	1.68E+03	70.9%	64.7%
selected water emissions				
C14	kBq	3.56E-02	70.6%	64.3%
Chromium VI	kg	1.73E-05	94.5%	94.2%
oils unspecified	kg	5.19E-03	91.0%	90.7%

Table 2-39: Selected cumulative life cycle inventory results of the production of 1 kg nickel, realistic-optimistic scenario

	unit	today	2025RO Mix: 440ppm	2050RO Mix: 440ppm
Resources				
Coal, hard, unspecified, in ground	kg	8.35E-01	60.1%	35.5%
Gas, natural, in ground	Nm^3	8.68E-01	118.2%	139.6%
Oil, crude, in ground	kg	1.31E+00	89.9%	88.2%
Uranium	kg	5.18E-05	78.5%	65.9%
Water	m^3	2.81E-01	97.5%	98.2%
Occupation agricultural and forests	m^2a	7.16E-01	108.8%	103.1%
Occupation built-up	m^2a	7.51E-01	99.3%	99.0%
selected air emissions				
CO2, fossil	kg	1.01E+01	84.2%	75.5%
NOx,	kg	6.60E-02	90.7%	88.7%
PM2.5	kg	1.87E-02	96.2%	95.9%
Rn222	kg	1.68E+03	78.4%	65.8%
selected water emissions				
C14	kBq	3.56E-02	78.4%	69.6%
Chromium VI	kg	1.73E-05	107.8%	93.0%
oils unspecified	kg	5.19E-03	90.3%	89.0%

Table 2-40: Selected cumulative life cycle inventory results of the production of 1 kg nickel, very optimistic scenario

	unit	today	2025VO Mix: Renew.	2050VO Mix: Renew.
Resources				
Coal, hard, unspecified, in ground	kg	8.35E-01	55.0%	34.8%
Gas, natural, in ground	Nm^3	8.68E-01	116.3%	94.5%
Oil, crude, in ground	kg	1.31E+00	88.6%	85.5%
Uranium	kg	5.18E-05	78.4%	9.7%
Water	m^3	2.81E-01	97.4%	92.2%
Occupation agricultural and forests	m^2a	7.16E-01	106.4%	125.0%
Occupation built-up	m^2a	7.51E-01	99.2%	99.2%
selected air emissions				
CO2, fossil	kg	1.01E+01	82.4%	74.4%
NOx,	kg	6.60E-02	90.3%	89.5%
PM2.5	kg	1.87E-02	96.1%	95.9%
Rn222	kBq	1.68E+03	78.3%	9.3%
selected water emissions				
C14	kBq	3.56E-02	78.3%	7.3%
Chromium VI	kg	1.73E-05	106.8%	94.4%
oils unspecified	kg	5.19E-03	89.7%	87.7%

2.5 MG-silicon

Leading countries in the silicon metal production are China, the United States, Brazil, Norway, France, Russia and South Africa (Corathers 2005). World production of silicon metal is estimated to be 686'000 t in 2004, excluding China (Corathers 2005). Annual production in China is estimated to be 550'000 in 2005 (Corathers 2006). Silicon metal consumption was about 1.28 Mt in 2003 (Corathers 2005). In decreasing order of consumption, Western Europe, the United States and Japan accounted for 77% of the silicon metal consumed in 2004.

Until 2000 the traditional silicon feedstock for the PV industry consisted of rejects from the semiconductor industry. Because of the tremendous growth of the PV business the main source is now virgin silicon (IEA-PVPS 2006). The USA with its five plants is the largest worldwide supplier of this product to the PV industry (6'300 t). Most of the production is exported to Europe and Japan (IEA-PVPS 2006).

Data for the reference situation (“today”) and for the scenarios are based on the dataset “MG-silicon, at plant (RER)”, which is described in detail in Jungbluth (2003).

2.5.1 Energy use

Energy consumption of a modern furnace combined with a suitable energy recovery system can bring energy consumption down to less than 9 MWh/t (Lokke-Owre & Halvorsen 2002). The IPPC document (IPPC 2001b) gives the theoretical minimum energy consumption as 8.9 kWh electrical energy/kg MG-Si (heat of reaction: 8 kWh/kg, heat loss within metal: 0.9 kWh/kg). It is assumed that this minimum value can be achieved in the very optimistic scenario until 2050. In the optimistic-realistic scenario a value of 9.5 kWh/kg is assumed for 2050. The year 2025 is calculated as the average of “today” and 2050.

The Norwegian silicon industry is discussing the increase of wood charcoal use as a reductant (Eikeland et al. 2001). However, there is currently no production of wood charcoal in Norway, so that charcoal is being imported from Asia or South America. The authors also discuss the possibility of producing wood charcoal in Norway (Eikeland et al. 2001). In their latest report, the Norwegian silicon company Elkem writes that it is unlikely to be economically possible to expand the use of biocarbon beyond current levels (Elkem 2006). We assume only in the very optimistic scenario an increase of wood charcoal with similar shares as in Eikeland et al. (2001). We calculate with 20% of today's total coal and charcoal consumption in 2025 and 40% in 2050. We also assume that it will be possible to produce charcoal in Norway and that, therefore, transcontinental transport per ship is not necessary any more.

Table 2-41: Energy inputs of the MG-silicon production in the optimistic scenarios 2025 and 2050. Values are per kilogram of MG-silicon.

Name	Location	Infrastructure-Process	Unit	Optimistic-Realistic 2025	Optimistic-Realistic 2050	Very Optimistic 2025	Very Optimistic 2050
electricity, medium voltage, at grid	NO	0	kWh	1.03E+1	9.50E+0	9.95E+0	8.90E+0
hard coal coke, at plant	RER	0	MJ	2.60E+1	2.60E+1	2.24E+1	1.39E+1
transport, transoceanic freight ship	OCE	0	tkm	2.55E+0	2.55E+0	0	0
charcoal, at plant	GLO	0	kg	1.70E-1	1.70E-1	2.94E-1	5.88E-1
wood chips, mixed, u=120%, at forest	RER	0	m3	3.25E-3	3.25E-3	3.25E-3	3.25E-3

2.5.2 Air emissions

CO_2 emissions from combustion are calculated on the basis of the characteristics of the fuels[6]. The IPPC document gives an emission range of 0.6 –2.6 kg dust/t silicon metal (IPPC 2001b). We use the higher value in all 2025 scenarios and the lowest in all 2050 scenarios. Metal emissions of dust are calculated on the basis of the same factors as in the original dataset (Jungbluth 2003).

Table 2-42: Air emissions in the optimistic scenarios 2025 and 2050. Values are per kilogram of MG-silicon.

Name	Location	Infrastructure-Process	Unit	Optimistic-Realistic 2025	Optimistic-Realistic 2050	Very Optimistic 2025	Very Optimistic 2050
Aluminum			kg	5.20E-7	1.20E-7	5.20E-7	1.20E-7
Antimony			kg	2.63E-9	6.08E-10	2.63E-9	6.08E-10
Arsenic			kg	3.16E-9	7.29E-10	3.16E-9	7.29E-10
Boron			kg	9.36E-8	2.16E-8	9.36E-8	2.16E-8
Cadmium			kg	1.05E-10	2.43E-11	1.05E-10	2.43E-11
Calcium			kg	2.60E-7	6.00E-8	2.60E-7	6.00E-8
Carbon dioxide, biogenic			kg	1.61E+0	1.61E+0	1.97E+0	2.83E+0
Carbon dioxide, fossil			kg	3.61E+0	3.61E+0	3.28E+0	2.49E+0
Chlorine			kg	2.63E-8	6.08E-9	2.63E-8	6.08E-9
Chromium			kg	2.63E-9	6.08E-10	2.63E-9	6.08E-10
Cyanide			kg	2.30E-6	5.32E-7	2.30E-6	5.32E-7
Fluorine			kg	1.30E-8	3.00E-9	1.30E-8	3.00E-9
Iron			kg	1.30E-6	3.00E-7	1.30E-6	3.00E-7
Lead			kg	1.15E-7	2.66E-8	1.15E-7	2.66E-8
Mercury			kg	2.63E-9	6.08E-10	2.63E-9	6.08E-10
Particulates, > 10 um			kg	2.60E-3	6.00E-4	2.60E-3	6.00E-4
Silicon			kg	2.52E-3	5.81E-4	2.52E-3	5.81E-4
Sodium			kg	2.60E-7	6.00E-8	2.60E-7	6.00E-8

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[6] CO_2 factors: 2.4 kg fossil CO_2/kg petroleum coke, 2.676 kg fossil CO_2/kg hard coal coke, 2.93 kg biogenic CO_2/ kg charcoal, 2.04 kg biogenic CO_2/kg wood chips.

2.5.3 Selected cumulative life cycle inventory results

The results of the pessimistic and the realistic-optimistic scenario are rather constant over time (see Table 2-43). MG-silicon production is based on Norwegian electricity, which predominantly consists of hydro power. Hard coal coke is partly replaced in the very optimistic scenario, which leads to a reduction in CO_2 emissions by 30 % and in an increase of forest land occupation by a factor of more than two. There are no reductions assumed in the process specific emissions of particulate matter of less than 2.5μm.

Table 2-43: Selected cumulative life cycle inventory results of the production of 1 kg MG silicon, pessimistic scenario

	unit	today	2025PE Mix: BAU	2050PE Mix: BAU
Resources				
Coal, hard, unspecified, in ground	kg	1.78E+00	100.1%	100.2%
Gas, natural, in ground	Nm^3	5.22E-02	102.5%	99.3%
Oil, crude, in ground	kg	6.99E-01	99.0%	98.9%
Uranium	kg	3.85E-06	76.9%	72.0%
Water	m^3	1.32E-02	97.1%	96.8%
Occupation agricultural and forests	m^2a	1.35E+00	100.3%	100.3%
Occupation built-up	m^2a	4.96E-02	99.9%	99.9%
selected air emissions				
CO2, fossil	kg	4.34E+00	99.1%	99.0%
NOx,	kg	1.44E-02	98.0%	97.9%
PM2.5	kg	8.63E-04	95.4%	95.4%
Rn222	kg	1.25E+02	76.9%	72.0%
selected water emissions				
C14	kBq	2.64E-03	76.6%	71.5%
Chromium VI	kg	3.50E-06	98.4%	98.3%
oils unspecified	kg	2.99E-03	99.0%	98.9%

Table 2-44: Selected cumulative life cycle inventory results of the production of 1 kg MG silicon, realistic-optimistic scenario

	unit	today	2025RO Mix: 440ppm	2050RO Mix: 440ppm
Resources				
Coal, hard, unspecified, in ground	kg	1.78E+00	98.9%	98.2%
Gas, natural, in ground	Nm^3	5.22E-02	116.7%	136.6%
Oil, crude, in ground	kg	6.99E-01	98.8%	98.6%
Uranium	kg	3.85E-06	80.8%	69.1%
Water	m^3	1.32E-02	96.2%	96.5%
Occupation agricultural and forests	m^2a	1.35E+00	100.2%	100.0%
Occupation built-up	m^2a	4.96E-02	98.9%	98.3%
selected air emissions				
CO2, fossil	kg	4.34E+00	97.7%	96.4%
NOx,	kg	1.44E-02	97.4%	96.8%
PM2.5	kg	8.63E-04	93.8%	92.4%
Rn222	kg	1.25E+02	80.8%	69.1%
selected water emissions				
C14	kBq	2.64E-03	80.7%	72.1%
Chromium VI	kg	3.50E-06	100.3%	94.1%
oils unspecified	kg	2.99E-03	98.9%	98.7%

Table 2-45: Selected cumulative life cycle inventory results of the production of 1 kg MG silicon, very optimistic scenario

	unit	**today**	**2025VO Mix: Renew.**	**2050VO Mix: Renew.**
Resources				
Coal, hard, unspecified, in ground	kg	1.78E+00	85.4%	53.4%
Gas, natural, in ground	Nm^3	5.22E-02	112.3%	90.6%
Oil, crude, in ground	kg	6.99E-01	97.7%	97.3%
Uranium	kg	3.85E-06	77.7%	26.3%
Water	m^3	1.32E-02	91.6%	76.1%
Occupation agricultural and forests	m^2a	1.35E+00	138.7%	230.6%
Occupation built-up	m^2a	4.96E-02	104.1%	116.8%
selected air emissions				
CO2, fossil	kg	4.34E+00	89.0%	69.0%
NOx,	kg	1.44E-02	93.3%	89.6%
PM2.5	kg	8.63E-04	91.7%	89.8%
Rn222	kBq	1.25E+02	77.7%	26.2%
selected water emissions				
C14	kBq	2.64E-03	77.4%	24.1%
Chromium VI	kg	3.50E-06	97.1%	89.0%
oils unspecified	kg	2.99E-03	97.7%	97.3%

2.6 Zinc production

Data for the reference situation ("today") and for the scenarios are based on the dataset "zinc for coating, at regional storage (RER)", which is described in detail in Althaus et al. (2004).

2.6.1 Energy use

The "today" dataset accounts for 3.43 kWh/kg electricity, 1.16 MJ/kg natural gas and 4.95 MJ/kg hard coal. Due to lack of data on the development of the metallurgy of the zinc production we make the same assumptions as for the nickel production (see chapter 2.4.1).

We assume in the scenario "optimistic-realistic" that it will be possible to reduce energy intensity of zinc metallurgy by 5% until 2025 and 10% until 2050. In the very optimistic scenario we assume that the energy savings will be 10% until 2025 and 20% until 2050. Furthermore, we assume in the very optimistic scenario that it will be possible to switch from coal to natural gas with a share of 25% in 2025 and 50% in 2050. As the share of hydropower is already high in the electricity mix with 60%, we do not assume a further increase in the share of renewable sources in the electricity mix.

Table 2-46: Energy inputs of the zinc production in the optimistic scenarios 2025 and 2050.

Name	Location	Infrastructure-Process	Unit	Optimistic Realistic 2025	Very Optimistic 2025	Optimistic Realistic 2050	Very Optimistic 2050
electricity, medium voltage, production UCTE, at grid	UCTE	0	kWh	1.30E+0	1.23E+0	1.23E+0	1.10E+0
hard coal, burned in industrial furnace 1-10MW	RER	0	MJ	4.70E+0	4.12E+0	4.46E+0	2.44E+0
electricity, hydropower, at run-of-river power plant	RER	0	kWh	1.96E+0	1.85E+0	1.85E+0	1.65E+0
natural gas, burned in industrial furnace >100kW	RER	0	MJ	1.10E+0	1.37E+0	1.04E+0	2.44E+0

2.6.2 Air emissions

EEA 2003 gives ranges for lead, mercury and zinc air emissions of the primary zinc production (Table 2-47). We assume in the scenarios 2025 that emissions can be reduced by 50% from "today" and in 2050 attain the lowest value of the range. The share of thermal and electrolytic production way is assumed to remain at 20% and 80% until 2050.

Table 2-47: Range of the heavy metal emissions of the primary zinc production (EEA 2003). The values used in the "today" dataset are also shown. The split thermal to electrolytic production is 20 % to 80 % in all scenarios.

	Thermal		**Electrolytic**	
	Range g/t zinc	**„Today" g/t zinc**	**Range g/t zinc**	**„Today" g/t zinc**
Lead	31–1900	500	2.3–467	5
Mercury	5–50	20	–	–
Zinc	120–16'000	10'000	6–3800	100

Due to lack of specific data, we assume that the dust and SO_2 emissions can be reduced by 25% until 2025 and by 50% until 2050 in both technologies.

Table 2-48: Air emissions in the optimistic scenarios 2025 and 2050. Values are per kilogram of zinc.

Name	Location	Infrastructure-Process	Unit	Optimistic Realistic 2025	Very Optimistic 2025	Optimistic Realistic 2050	Very Optimistic 2050
Lead			kg	5.20E-5	5.20E-5	8.04E-6	8.04E-6
Mercury			kg	2.00E-6	2.00E-6	1.00E-6	1.00E-6
Particulates, < 2.5 um			kg	1.41E-4	1.41E-4	9.40E-5	9.40E-5
Particulates, > 10 um			kg	2.70E-5	2.70E-5	1.80E-5	1.80E-5
Particulates, > 2.5 um, and < 10um			kg	2.70E-5	2.70E-5	1.80E-5	1.80E-5
Sulfur dioxide			kg	1.31E-2	1.31E-2	8.74E-3	8.74E-3
Zinc			kg	1.04E-3	1.04E-3	2.88E-5	2.88E-5

2.6.3 Selected cumulative life cycle inventory results

Table 2-49 to Table 2-51 show the cumulative results of the production of 1 kg of zinc according to the three scenarios and the three time horizons. The cumulative life cycle inventory results of zinc are rather strongly influenced by the electricity mix developments. The reductions in emissions are less important. This gets obvious when comparing the cumulative PM2.5 emissions with the process specific emissions shown in Table 2-40. The CO_2 emissions are expected to be reduced by more than 40 % by 2050 in the very optimistic scenario. Like with other materials, the uranium demand and radionuclide emissions drop dramatically in the very optimistic scenario, where no nuclear power plants contribute to the European electricity mix anymore.

Table 2-49: Selected cumulative life cycle inventory results of the production of 1 kg zinc, pessimistic scenario

	unit	today	2025PE Mix: BAU	2050PE Mix: BAU
Resources				
Coal, hard, unspecified, in ground	kg	4.54E-01	103.0%	105.1%
Gas, natural, in ground	Nm^3	2.18E-01	103.6%	99.1%
Oil, crude, in ground	kg	1.74E-01	77.1%	76.2%
Uranium	kg	1.72E-05	69.5%	63.0%
Water	m^3	8.97E-02	97.5%	97.2%
Occupation agricultural and forests	m^2a	1.08E-01	120.1%	122.9%
Occupation built-up	m^2a	1.15E-01	99.7%	99.7%
selected air emissions				
CO2, fossil	kg	2.32E+00	90.1%	89.7%
NOx,	kg	1.39E-02	89.0%	88.8%
PM2.5	kg	3.19E-03	93.1%	93.1%
Rn222	kg	5.57E+02	69.4%	62.9%
selected water emissions				
C14	kBq	1.19E-02	69.5%	62.9%
Chromium VI	kg	4.74E-06	92.9%	92.5%
oils unspecified	kg	6.92E-04	75.1%	74.1%

Table 2-50: Selected cumulative life cycle inventory results of the production of 1 kg zinc, realistic-optimistic scenario

	unit	today	2025RO Mix: 440ppm	2050RO Mix: 440ppm
Resources				
Coal, hard, unspecified, in ground	kg	4.54E-01	71.9%	55.1%
Gas, natural, in ground	Nm^3	2.18E-01	121.9%	146.5%
Oil, crude, in ground	kg	1.74E-01	74.0%	70.3%
Uranium	kg	1.72E-05	75.0%	60.1%
Water	m^3	8.97E-02	97.0%	97.5%
Occupation agricultural and forests	m^2a	1.08E-01	118.9%	105.4%
Occupation built-up	m^2a	1.15E-01	98.3%	97.4%
selected air emissions				
CO2, fossil	kg	2.32E+00	74.6%	60.9%
NOx,	kg	1.39E-02	84.7%	81.7%
PM2.5	kg	3.19E-03	90.4%	88.2%
Rn222	kg	5.57E+02	74.9%	60.0%
selected water emissions				
C14	kBq	1.19E-02	75.1%	63.9%
Chromium VI	kg	4.74E-06	108.4%	89.5%
oils unspecified	kg	6.92E-04	73.4%	69.9%

Table 2-51: Selected cumulative life cycle inventory results of the production of 1 kg zinc, very optimistic scenario

	unit	today	2025VO Mix: Renew.	2050VO Mix: Renew.
Resources				
Coal, hard, unspecified, in ground	kg	4.54E-01	63.3%	35.0%
Gas, natural, in ground	Nm^3	2.18E-01	121.4%	106.4%
Oil, crude, in ground	kg	1.74E-01	71.8%	65.6%
Uranium	kg	1.72E-05	72.1%	5.3%
Water	m^3	8.97E-02	96.6%	91.2%
Occupation agricultural and forests	m^2a	1.08E-01	111.7%	142.9%
Occupation built-up	m^2a	1.15E-01	97.9%	97.0%
selected air emissions				
CO2, fossil	kg	2.32E+00	70.7%	56.3%
NOx,	kg	1.39E-02	83.0%	79.7%
PM2.5	kg	3.19E-03	89.7%	86.9%
Rn222	kg	5.57E+02	72.1%	5.1%
selected water emissions				
C14	kBq	1.19E-02	72.2%	4.0%
Chromium VI	kg	4.74E-06	105.4%	88.1%
oils unspecified	kg	6.92E-04	72.0%	66.8%

3 LCI of non metallic minerals

3.1 Clinker production

The datasets for the reference situation (“today”) and for the scenarios are based on the dataset “clinker, at plant, CH”, which includes the whole manufacturing process to produce clinker (raw material provision, grinding, and mixing) and internal processes (transport, etc.). A detailed description of this dataset can be found in Kellenberger et al. (2004).

3.1.1 Energy use

Energy use in the “today” dataset is a total of 3.42 MJ/kg (Table 3-1) consisting of secondary fuels (dried sludge, used oil, waste solvent, plastics, meat-and-bone meal, animal fat etc.) and primary fuels (fuel oil, hard coal, natural gas, petroleum coke). Actual fuel energy use for different kiln systems in the European industry ranges from 3.0 MJ/kg to 6.0 MJ/kg (IPPC 2001a).

Actual best available techniques (BAT) values are 2.9–3.2 MJ/kg clinker (IPPC 2001a) and are used for the scenario “optimistic-realistic” 2025 (3.2 MJ/kg) and 2050 (2.9 MJ/kg). Fluidised bed technology is an emerging technique for cement production and allows a reduction of thermal energy use of 10–12% (IPPC 2001a). This value is used for the scenario “very optimistic” 2025 (2.55 MJ/kg). Theoretical thermal energy requirement (IPPC 2001a) is 1.7-1.8 MJ/kg clinker and is the basis for the scenario “very optimistic” in 2050.

Share of secondary fuels in European countries varied in 2000 between 0% (Ireland) and 72% (Netherlands) and was about 35% in Germany in 2002. The “today” dataset uses 36%. In 2004 the Swiss cement industry used 43 % secondary fuels as a source for thermal energy. This share is not expected to grow much due to the competitive use of waste by different industries. We assume only a slight increase until 2025. However, in the very optimistic case two third of the energy stems from secondary fuels in 2050 (Table 3-1).

Use of primary biomass in clinker production is inexistent today. The cement industry concentrates its efforts in increasing the share of secondary fuels and decreasing the share of clinker in cement because renewable fuels are more expensive than secondary fuels and because the market for residual wood is already dried up. It can be expected to remain so in the future. Therefore, the share of renewable primary fuels is not increased in any of the scenarios.

Table 3-1: Energy use per kg clinker and CO_2 emissions of the clinker production in the “today” dataset and in the scenarios. Values are given per kg clinker

	unit	today	2025		2050	
			Optimistic-Realistic	Very Optimistic	Optimistic-Realistic	Very Optimistic
Share of sec. fuels		36%	45%	50%	50%	75%
Energy use total thermal	MJ	3.41	3.20	2.55	2.90	1.70
Energy secondary fuels	MJ	1.22	1.44	1.28	1.45	1.28
Thereof renewable		14%	14%	14%	14%	14%
Energy primary fuels	MJ	2.19	1.76	1.28	1.45	0.43
Thereof renewable		0%	0%	0%	0%	0%
CO_2 secondary	kg	0.036	0.123	0.109	0.124	0.109
thereof renewable	kg	0.005	0.018	0.016	0.018	0.016
CO_2 primary	kg	0.283	0.168	0.122	0.138	0.041
thereof renewable	kg	0	0	0	0	0

The calculated quantities of fuels are shown in Table 3-2

Table 3-2: Quantities of fuels per kg clinker in the different scenarios. Values are given in kg per kg clinker

	today	2025		2050	
		Optimistic-Realistic	Very Optimistic	Optimistic-Realistic	Very Optimistic
Fuel oil heavy/medium	0.0255	0.0183	0.0132	0.0151	0.0044
Fuel oil light	0.0004	0.0003	0.0002	0.0002	0.0001
Hard coal	0.0354	0.0284	0.0206	0.0210	0.0061
Natural gas	0.0002	0.0032	0.0024	0.0052	0.0015
Petroleum coke (average value)	0.0039	0.0031	0.0023	0.0026	0.0008

3.1.2 Air emissions

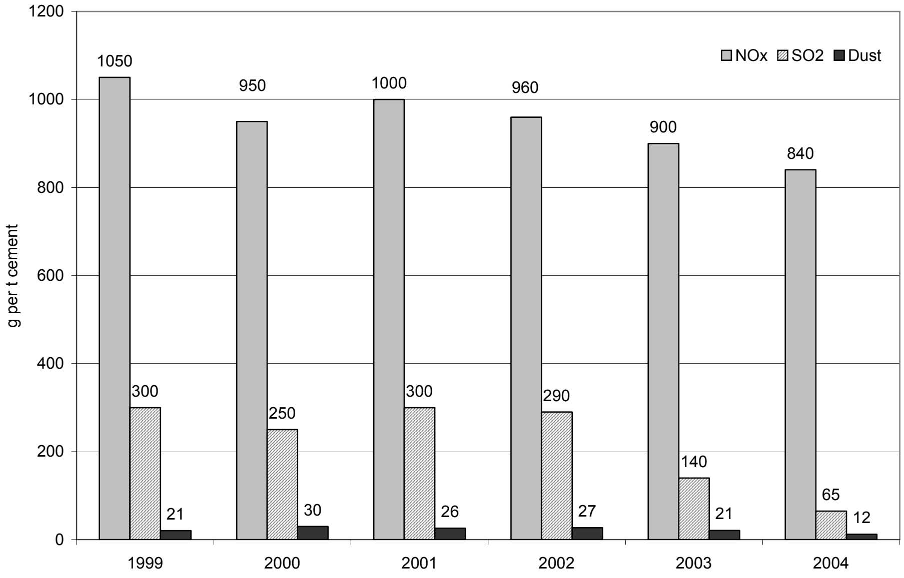
Clinker production causes emissions of CO_2, NO_x, SO_2 and dust. Calcination of raw materials results in about 525 kg CO_2/t clinker (Holcim 2004). This geogenic part of the CO_2 emissions is determined by stoichiometry. The only measure to reduce it is to reduce the clinker quantity in cement. The Swiss cement industry reduced this fraction from 95% to 82% and plans to reduce it further. A German plant already reached a clinker to cement fraction of 76% (Rüdersdorfer Zement GmbH 2003). The minimal share of clinker is, however, also determined by the characteristics and the utilisation of the cement. In the NEEDS energy systems the dataset “concrete, normal, at plant” is mostly used. This concrete uses Portland cement

CEM I 42.5 for which the norm SN EN 197-1:2000 defines a clinker share of 95–100% (CRB 2004). Therefore, the clinker share is not varied in this project.

Combustion of fuels is the other source of CO_2 emissions and causes about 200–550 kg CO_2/t clinker (Holcim 2004). Total CO_2 emissions of the European cement kilns range from 800 to 1040 kg/t clinker (IPPC 2001a).

Swiss legal maximal permissible values for nitrogen oxides and sulphur dioxide emissions of cement production are much higher than those of waste incineration plants. The cement industry has decreased air emissions on a voluntary basis. Evolution of dust, NO_x and SO_2 emissions of the Swiss cement production from 1999 to 2003 is shown in Fig. 3.1.

Fig. 3.1: Evolution of air emissions of the Swiss cement industry 1999–2003.



Emission ranges from European cement kilns were 1998 400–6'000 g NO_x/t clinker, 20–7'000 g SO_2/t clinker and 10–400 g dust/t clinker (IPPC 2001a).

Table 3-3 compares values from different sources for air emissions incl. calculated emissions with maximal permissible emissions for waste incineration plants. It shows that for some emissions (dust, sulphur dioxide) the Swiss industry is already below the values for best available techniques (BAT).

Table 3-3: Comparison of air emission values of ecoinvent dataset for “today” (Kellenberger et al. 2004), values 2004 of Swiss industry (Holcim 2005), values 2002 of a German plant (Rüdersdorfer Zement GmbH 2003), values calculated on the basis of the maximal permissible values for waste incineration plants (LRV 2000) and BAT values according to (IPPC 2001a).

Name	Unit	clinker, at plant (today)	Holcim 2004	Cement plant Rüdersdorf 2003	Values calculated with max. permissible values for waste incineration plants	BAT values after IPCC 2001
Location						
InfrastructureProcess						
Unit		kg clinker	kg clinker	kg cement	kg clinker	kg clinker
Ammonia	kg	2.28E-5			1.00E-5	
Carbon dioxide, fossil	kg	8.39E-1		7.33E-1		
Carbon monoxide, fossil	kg	4.72E-4			1.00E-4	
Hydrogen chloride	kg	6.31E-6			4.00E-5	
Lead	kg	8.50E-8			1.17E-6	
Nitrogen oxides	kg	1.08E-3	1.10E-3	9.05E-4	1.60E-4	4.00E-4
Zinc	kg	6.00E-8			8.28E-7	
Sulfur dioxide	kg	3.55E-4	7.93E-5	7.76E-4	1.00E-4	4.00E-4
Particulates, < 2.5 um	kg	2.41E-5		3.01E-5		
Particulates, > 10 um	kg	5.66E-6				
Particulates, > 2.5 um, and < 10um	kg	7.92E-6				
Total Particulates		3.77E-5	1.46E-5	4.70E-5		4.00E-5

Values for 2025 scenarios are based on values for best available techniques (BAT) as described in IPPC (2001a). Some air emissions in the today dataset (sulphur dioxide, dust) are already below BAT values. In this case, values for maximal permissible values for air emissions of waste incineration plants or values from the best Holcim plant are assumed. Table 3-4 and Table 3-5 summarise selected key inputs and outputs.

Main assumption of the scenarios for 2050 is that clinker production will achieve or for some emissions even fall below the maximal permissible values for air emissions of waste incineration plants. In the second case the assumptions are based on the lowest actual values of Holcim plants (Holcim 2005). Table 3-4 and Table 3-5 summarise selected key inputs and outputs for the 2050 datasets.

Table 3-4: Selected key inputs and outputs for the optimistic-realistic scenarios for clinker production. MPV = maximal permissible value, MSWI = municipal solid waste incinerator. Values are per kilogram of clinker production.

Name	Unit	Optimistic-Realistic 2025	Comment	Optimistic-Realistic 2050	Comment
Carbon dioxide, fossil	kg	7.99E-1	Geogen share of CO2 stays equal, rest varies with the fuels used.	7.70E-1	Geogen share of CO2 stays equal, rest varies with the fuels used.
Carbon monoxide, fossil	kg	1.00E-4	Until 2050 50 mg/m3, like MSWI, 2 m3 raw gas/kg clinker	1.00E-4	Until 2050 50 mg/m3, like MSWI, 2 m3 raw gas/kg clinker
Hydrogen chloride	kg	6.31E-6	Value is already below MSWI	6.31E-6	Value is already below MSWI
Lead	kg	8.50E-8	Value is already below MSWI	8.50E-8	Value is already below MSWI
Nitrogen oxides	kg	4.00E-4	BAT from IPPC 200 mg/m3, 2 m3 raw gas/kg clinker	1.60E-4	Until 2050 80 mg/m3, like MSWI, 2 m3 raw gas/kg clinker
Zinc	kg	6.00E-8	Value is already below MSWI	6.00E-8	Value is already below MSWI
Sulfur dioxide	kg	3.96E-5	SO2 emissions 2004 of Swiss cement production can be halved again until 2025 (actual values already better as BAT from IPPC)	1.00E-5	Until 2050 5 mg/m3 SO2 like lowest value of Holcim plant (in 2004)
Particulates, < 2.5 um	kg	1.28E-5	MPV for MSWI reached already in 2025 (actual values already better as BAT from IPPC)	6.40E-6	Until 2050 5 mg/m3 total dust like lowest value of Holcim plant (in 2004)
Particulates, > 10 um	kg	3.00E-6	MPV for MSWI reached already in 2025 (actual values already better as BAT from IPPC)	1.50E-6	Until 2050 5 mg/m3 total dust like lowest value of Holcim plant (in 2004)
Particulates, > 2.5 um, and < 10um	kg	4.20E-6	MPV for MSWI reached already in 2025 (actual values already better as BAT from IPPC)	2.10E-6	Until 2050 5 mg/m3 total dust like lowest value of Holcim plant (in 2004)

Table 3-5: Selected key inputs and outputs for the very optimistic scenarios for clinker production. MPV = maximal permissible value, MSWI = municipal solid waste incinerator. Values are per kilogram of clinker production.

Name	Unit	Very Optimistic 2025	Comment	Very Optimistic 2050	Comment
Carbon dioxide, fossil	kg	7.40E-1	Geogen share of CO2 stays equal, rest varies with the fuels used.	6.59E-1	Geogen share of CO2 stays equal, rest varies with the fuels used.
Carbon monoxide, fossil	kg	1.00E-4	Until 2050 50 mg/m3, like MSWI, 2 m3 raw gas/kg clinker	1.00E-4	Until 2050 50 mg/m3, like MSWI, 2 m3 raw gas/kg clinker
Hydrogen chloride	kg	6.31E-6	Value is already below MSWI	6.31E-6	Value is already below MSWI
Lead	kg	8.50E-8	Value is already below MSWI	8.50E-8	Value is already below MSWI
Nitrogen oxides	kg	4.00E-4	BAT from IPCC 2001 mg/m3, 2 m3 raw gas/kg clinker	1.60E-4	Until 2050 80 mg/m3, like MSWI, 2 m3 raw gas/kg clinker
Zinc	kg	6.00E-8	Value is already below MSWI	6.00E-8	Value is already below MSWI
Sulfur dioxide	kg	3.96E-5	SO2 emissions 2004 of Swiss cement production can be halved again until 2025 (actual values already better as BAT from IPCC)	1.00E-5	Until 2050 5 mg/m3 SO2 like lowest value of Holcim plant (in 2004)
Particulates, < 2.5 um	kg	1.28E-5	MPV for MSWI reached already in 2025 (actual values already better as BAT from IPCC)	6.40E-6	Until 2050 5 mg/m3 total dust like lowest value of Holcim plant (in 2004)
Particulates, > 10 um	kg	3.00E-6	MPV for MSWI reached already in 2025 (actual values already better as BAT from IPCC)	1.50E-6	Until 2050 5 mg/m3 total dust like lowest value of Holcim plant (in 2004)
Particulates, > 2.5 um, and < 10um	kg	4.20E-6	MPV for MSWI reached already in 2025 (actual values already better as BAT from IPCC)	2.10E-6	Until 2050 5 mg/m3 total dust like lowest value of Holcim plant (in 2004)

3.1.3 Selected cumulative life cycle inventory results

Table 3-6 to Table 3-8 show selected cumulative results of the production of 1 kg of clinker. The pessimistic scenario assumes no changes in the clinker production. Hence, changes in the background system are the only reasons for the small changes in the cumulative results of future production.

The expected reductions in process specific PM2.5 emissions are visible (minus 40 to minus 45 % by 2050). NO_X emissions are reduced by about three quarter by 2050, mainly due to flue gas treatment in the clinker process. The reduction in fossil energy resources does not lead to a similar reduction in fossil CO_2 emissions, because a considerable share of the emissions are geogenic, and because fossil based secondary fuels such as spent oil, tyres, plastics and the like emit fossil CO_2, too. Because grid electricity plays a minor role in the product system of clinker, uranium demand and radionuclide emissions do not change that much.

Table 3-6: Selected cumulative life cycle inventory results of the production of 1 kg clinker, pessimistic scenario

	unit	**today**	**2025PE Mix: BAU**	**2050PE Mix: BAU**
Resources				
Coal, hard, unspecified, in ground	kg	5.78E-02	100.1%	100.2%
Gas, natural, in ground	Nm^3	5.31E-03	100.6%	99.7%
Oil, crude, in ground	kg	3.73E-02	99.4%	99.3%
Uranium	kg	8.48E-07	97.2%	96.6%
Water	m^3	2.62E-03	99.6%	99.6%
Occupation agricultural and forests	m^2a	3.45E-03	102.9%	103.3%
Occupation built-up	m^2a	9.96E-04	99.8%	99.8%
selected air emissions				
CO2, fossil	kg	8.82E-01	99.9%	99.9%
NOx,	kg	1.28E-03	99.1%	99.1%
PM2.5	kg	4.91E-05	97.6%	97.6%
Rn222	kg	2.76E+01	97.2%	96.6%
selected water emissions				
C14	kBq	4.70E-04	96.5%	95.7%
Chromium VI	kg	1.47E-07	98.9%	98.8%
oils unspecified	kg	5.57E-05	98.4%	98.3%

Table 3-7: Selected cumulative life cycle inventory results of the production of 1 kg clinker, realistic-optimistic scenario

	unit	today	2025RO Mix: 440ppm	2050RO Mix: 440ppm
Resources				
Coal, hard, unspecified, in ground	kg	5.78E-02	80.5%	60.1%
Gas, natural, in ground	Nm^3	5.31E-03	136.5%	163.2%
Oil, crude, in ground	kg	3.73E-02	76.2%	65.0%
Uranium	kg	8.48E-07	96.7%	95.1%
Water	m^3	2.62E-03	97.7%	96.5%
Occupation agricultural and forests	m^{2}a	3.45E-03	86.4%	67.6%
Occupation built-up	m^{2}a	9.96E-04	87.7%	76.1%
selected air emissions				
CO2, fossil	kg	8.82E-01	94.8%	91.2%
NOx,	kg	1.28E-03	44.6%	25.2%
PM2.5	kg	4.91E-05	72.2%	57.8%
Rn222	kg	2.76E+01	96.7%	95.1%
selected water emissions				
C14	kBq	4.70E-04	96.0%	94.2%
Chromium VI	kg	1.47E-07	96.4%	91.5%
oils unspecified	kg	5.57E-05	83.2%	74.1%

Table 3-8: Selected cumulative life cycle inventory results of the production of 1 kg clinker, very optimistic scenario

	unit	today	2025VO Mix: Renew.	2050VO Mix: Renew.
Resources				
Coal, hard, unspecified, in ground	kg	5.78E-02	59.4%	20.5%
Gas, natural, in ground	Nm^3	5.31E-03	108.0%	68.3%
Oil, crude, in ground	kg	3.73E-02	58.7%	28.2%
Uranium	kg	8.48E-07	95.7%	90.5%
Water	m^3	2.62E-03	96.0%	92.6%
Occupation agricultural and forests	m^{2}a	3.45E-03	67.6%	37.0%
Occupation built-up	m^{2}a	9.96E-04	75.1%	52.1%
selected air emissions				
CO2, fossil	kg	8.82E-01	87.8%	78.0%
NOx,	kg	1.28E-03	43.5%	23.0%
PM2.5	kg	4.91E-05	70.4%	54.5%
Rn222	kBq	2.76E+01	95.7%	90.5%
selected water emissions				
C14	kBq	4.70E-04	94.7%	88.1%
Chromium VI	kg	1.47E-07	90.1%	78.6%
oils unspecified	kg	5.57E-05	68.9%	44.0%

3.2 Flat glass production

Data for the reference situation (“today”) and for the scenarios are based on the dataset “flat glass, uncoated, at plant (RER)”, which is described in detail in Kellenberger et al. (2004).

3.2.1 Energy use

The “today” dataset accounts for a total of 8 MJ end energy/kg flat glass, of which 57% are provided with natural gas, 38% with fuel oil and 5% with electricity. Energy levels for melting are typically 5.5 to 8.0 GJ/t (IPPC 2000). Environmental reports of the glass industry (e.g. Pilkington 2006; St Gobain 2006) announce efforts to increase energy efficiency but report an increase of energy consumption because of aging furnaces and an increased variety in the product mix. In the optimistic-realistic scenarios, the efforts to reduce energy use will only allow to compensate in 2025 the increase in specific energy consumption and will have first positive effects only in 2050. Overall end energy use stays at 8.0 GJ/t in 2025 and is reduced by 10% in 2050. We also assume that the share of natural gas is kept at 57% in 2025 and increases to 70% in 2050.

In the very optimistic scenarios we assume an increase of energy efficiency already in 2025 with a reduction of 10% of energy consumption and of 20% in 2050. According to Sinton (2005), landfill gas is actually the most appropriate fuel to replace thermal energy sources in the furnace without changing the burners. Therefore, we assume that in 2025 5% and in 2050 10% of thermal energy is replaced with landfill gas. Furthermore, the share of fuel oil is reduced to 20% in 2025 and to 0% in 2050.

Table 3-9: Energy inputs of the flat glass production in the optimistic scenarios 2025 and 2050. Values are per kilogram of flat glass.

Name	Location	Infrastructure-Process	Unit	Optimistic Realistic 2025	Optimistic Realistic 2050	Very Optimistic 2025	Very Optimistic 2050
electricity, medium voltage, production UCTE, at grid	UCTE	0	kWh	1.11E-1	1.00E-1	1.00E-1	8.89E-2
natural gas, high pressure, at consumer	RER	0	MJ	4.56E+0	5.04E+0	5.04E+0	5.44E+0
heavy fuel oil, at regional storage	RER	0	kg	7.38E-2	4.37E-2	3.50E-2	0

3.2.2 Air emissions

CO_2 emissions from combustion are calculated on the basis of the characteristics of the fuels[7]. For the main air emissions in the “today” dataset (Kellenberger et al. 2004), the authors assume 50% abated and 50% unabated furnaces based on the data in IPPC (2000). In the scenarios 2025 we assume 75% and in 2050 100% abated furnaces. The values of the scenarios are shown in Table 3-10. The lead emissions amount to 23% of total dust.

Table 3-10: Air emissions in the scenarios 2025 and 2050. The values are per kilogram of flat glass.

Name	Location	Infrastructure-Process	Unit	Optimistic Realistic 2025	Optimistic Realistic 2050	Very Optimistic 2025	Very Optimistic 2050
Carbon dioxide, fossil			kg	6.93E-1	6.26E-1	6.37E-1	5.12E-1
Hydrogen chloride			kg	6.88E-5	4.50E-5	6.88E-5	4.50E-5
Hydrogen fluoride			kg	1.35E-5	6.00E-6	1.35E-5	6.00E-6
Lead			kg	3.34E-5	1.38E-5	3.34E-5	1.38E-5
Nitrogen oxides			kg	2.64E-3	2.00E-3	2.64E-3	2.00E-3
Particulates, < 2.5 um			kg	1.16E-4	4.80E-5	1.16E-4	4.80E-5
Particulates, > 10 um			kg	1.45E-5	6.00E-6	1.45E-5	6.00E-6
Particulates, > 2.5 um, and < 10um			kg	1.45E-5	6.00E-6	1.45E-5	6.00E-6
Sulfur dioxide			kg	3.15E-3	2.27E-3	3.15E-3	2.27E-3

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[7] CO_2 factors: natural gas: 56 g/MJ, heavy fuel oil: 75.6 g/MJ, landfill gas: 106 g/MJ.

3.2.3 Selected cumulative life cycle inventory results

Table 3-11 to Table 3-13 show selected cumulative results of the production of 1 kg of flat glass. The pessimistic scenario assumes no changes in the flat glass production. Hence, the results are rather stable with time. There is a shift in energy carriers from coal and heavy fuel oil to natural gas and at the same time a reduction in energy consumption. The cumulative PM2.5 emissions are reduced by about two third by 2050 in the two optimistic scenarios, which is mainly due to reductions of the process specific emissions. Flat glass production is not very much dependent on the electricity grid mix. That is why the reduction in uranium consumption and radionuclide emissions is rather moderate. The cumulative CO_2 emissions are reduced by 16 % and nearly 30 % (realistic-optimistic and very optimistic scenario, respectively).

Table 3-11: Selected cumulative life cycle inventory results of the production of 1 kg flat glass, pessimistic scenario

	unit	**today**	**2025PE Mix: BAU**	**2050PE Mix: BAU**
Resources				
Coal, hard, unspecified, in ground	kg	5.27E-02	102.4%	104.0%
Gas, natural, in ground	Nm^3	1.52E-01	100.5%	99.9%
Oil, crude, in ground	kg	9.58E-02	96.3%	96.1%
Uranium	kg	1.62E-06	70.8%	64.6%
Water	m^3	8.97E-03	97.8%	97.5%
Occupation agricultural and forests	m^2a	4.19E-02	104.7%	105.4%
Occupation built-up	m^2a	6.13E-03	99.4%	99.5%
selected air emissions				
CO2, fossil	kg	9.40E-01	97.8%	97.7%
NOx,	kg	4.01E-03	96.6%	96.6%
PM2.5	kg	2.58E-04	92.4%	92.4%
Rn222	kg	5.26E+01	70.7%	64.5%
selected water emissions				
C14	kBq	1.12E-03	70.5%	64.1%
Chromium VI	kg	8.23E-07	96.3%	96.1%
oils unspecified	kg	4.13E-04	96.3%	96.1%

Table 3-12: Selected cumulative life cycle inventory results of the production of 1 kg flat glass, realistic-optimistic scenario

	unit	today	2025RO Mix: 440ppm	2050RO Mix: 440ppm
Resources				
Coal, hard, unspecified, in ground	kg	5.27E-02	80.9%	69.7%
Gas, natural, in ground	Nm^3	1.52E-01	102.7%	113.1%
Oil, crude, in ground	kg	9.58E-02	96.1%	61.7%
Uranium	kg	1.62E-06	78.8%	60.9%
Water	m^3	8.97E-03	97.6%	96.5%
Occupation agricultural and forests	m^{2}a	4.19E-02	104.8%	101.4%
Occupation built-up	m^{2}a	6.13E-03	97.3%	93.6%
selected air emissions				
CO2, fossil	kg	9.40E-01	94.7%	83.8%
NOx,	kg	4.01E-03	80.1%	62.4%
PM2.5	kg	2.58E-04	64.9%	36.4%
Rn222	kg	5.26E+01	78.7%	60.8%
selected water emissions				
C14	kBq	1.12E-03	78.7%	64.1%
Chromium VI	kg	8.23E-07	105.2%	90.7%
oils unspecified	kg	4.13E-04	96.1%	61.3%

Table 3-13: Selected cumulative life cycle inventory results of the production of 1 kg flat glass, very optimistic scenario

	unit	today	2025VO Mix: Renew.	2050VO Mix: Renew.
Resources				
Coal, hard, unspecified, in ground	kg	5.27E-02	78.4%	71.0%
Gas, natural, in ground	Nm^3	1.52E-01	109.5%	111.7%
Oil, crude, in ground	kg	9.58E-02	52.1%	12.1%
Uranium	kg	1.62E-06	71.7%	9.5%
Water	m^3	8.97E-03	95.4%	89.4%
Occupation agricultural and forests	m^{2}a	4.19E-02	103.0%	110.5%
Occupation built-up	m^{2}a	6.13E-03	93.8%	90.9%
selected air emissions				
CO2, fossil	kg	9.40E-01	87.1%	70.7%
NOx,	kg	4.01E-03	78.4%	61.2%
PM2.5	kg	2.58E-04	62.6%	34.2%
Rn222	kBq	5.26E+01	71.6%	9.2%
selected water emissions				
C14	kBq	1.12E-03	71.4%	7.2%
Chromium VI	kg	8.23E-07	97.2%	83.8%
oils unspecified	kg	4.13E-04	51.6%	11.2%

4 LCI of Electricity Mixes

4.1 European electricity mix

The electricity supply mix in Europe is modelled in three different ways:

- business as usual electricity mix
- 440 ppm electricity mix
- enhanced renewables electricity mix.

The electricity mixes business as usual and 440 ppm are supplied by the NEEDS partners from RS2a. The enhanced renewables electricity mix is derived from the DLR energy scenario study (Krewitt et al. 2007). The technology shares are dependent on the time horizon (2025 or 2050) and the scenario (pessimistic (PE), realistic-optimistic (RO), very optimistic (VO)). Table 4-1 to Table 4-6 show the technology shares of the electricity mixes underlying the LCI results shown in this report.

The share of hard coal based electricity is substantially smaller in the realistic-optimistic and very optimistic scenarios (6.8 % and 10.7 %, respectively), whereas the share of natural gas based electricity is higher (40.6 % and 35.2 %, respectively) as compared to the pessimistic scenario. Lignite based electricity plays a rather important role in the pessimistic scenario (9.2 %), whereas its contribution is much lower in the two optimistic scenarios (3.2 % and 1 %, respectively). The share in nuclear power is highest in the pessimistic scenario (24.4 %) whereas it is 0 in the very optimistic scenario. Hydro power contributes with shares between 15 % and nearly 18 %. Wind power electricity contributes 3.6 %, 4.6 % and 22.5 % and biomass based electricity 3.2 %, 3.8 % and 8.2 % to the electricity mix in the pessimistic, realistic-optimistic and very optimistic scenario, respectively. A similarly strong difference in share is observed with regard to photovoltaic electricity with 0.2 % (pessimistic and realistic-optimistic scenario) and 3.1 % (very optimistic scenario).

From 2025 to 2050 the pessimistic scenario shows an increase in hard coal and wind based power. Carbon capture and storage (CCS) is hardly applied in this scenario. The changes in technology shares are rather small. The realistic-optimistic scenario shows a nearly complete shift to CCS and an increase in the shares of natural gas based and nuclear power. The very optimistic scenario shows substantial increases in renewable energy, with 32.3 % wind power, 6.5 % photovoltaics and nearly 16 % biomass based power in the European electricity mix.

Table 4-1: Electricity mix UCTE, pessimistic (PE), business as usual (BAU), 2025

	Name	Location	InfrastructureProcess	Unit	electricity, production mix UCTE	UncertaintyStandardDeviation95%	
	Location				UCTE		
	InfrastructureProcess				0		
	Unit				kWh		
product	electricity, production mix UCTE	UCTE	0	kWh	1.00E+0		
technosphere	electricity, hardcoal, average	UCTE	0	kWh	2.34E-1	1	1.05
	electricity, hardcoal with CCS, average	UCTE	0	kWh	0	1	1.05
	electricity, hard coal, at IGCC power plant 450MW	RER	0	kWh	2.35E-3	1	1.05
	electricity, hardcoal IGCC with CCS, average	UCTE	0	kWh	0	1	1.05
	electricity, lignite, at power plant 950 MW	RER	0	kWh	9.10E-2	1	1.05
	electricity, lignite with CCS, average	UCTE	0	kWh	0	1	1.05
	electricity, lignite, at IGCC power plant 450MW	RER	0	kWh	0	1	1.05
	electricity, lignite IGCC with CCS, average	UCTE	0	kWh	8.54E-4	1	1.05
	electricity, oil, at power plant	UCTE	0	kWh	6.46E-3	1	1.05
	electricity, natural gas, at combined cycle plant, 500MWe	RER	0	kWh	1.39E-1	1	1.05
	electricity, natural gas, at turbine, 50MWe	RER	0	kWh	5.56E-2	1	1.05
	electricity, natural gas, CC plant, 500MWe post CCS, 400km&2500m deplet gasfield	RER	0	kWh	3.26E-5	1	1.05
	electricity, fuel cell, natural gas, average	UCTE	0	kWh	0	1	1.05
	electricity, nuclear, average	UCTE	0	kWh	2.44E-1	1	1.05
	electricity, biomass, average	UCTE	0	kWh	3.25E-2	1	1.11
	electricity, hydropower, at run-of-river power plant	RER	0	kWh	6.16E-2	1	1.11
	electricity, hydropower, at reservoir power plant, alpine region	RER	0	kWh	8.60E-2	1	1.21
	electricity, hydropower, at pumped storage power plant	UCTE	0	kWh	7.67E-3	1	1.24
	electricity, at wind power plant	RER	0	kWh	2.83E-2	1	1.24
	electricity, at offshore wind park 752MW	DK	0	kWh	8.39E-3	1	1.05
	electricity, photovoltaic, average	UCTE	0	kWh	1.90E-3	1	1.05
	electricity, solar thermal, average	UCTE	0	kWh	4.60E-4	1	1.05

Table 4-2: Electricity mix UCTE, pessimistic (PE), business as usual (BAU), 2050

	Name	Location	InfrastructureProcess	Unit	electricity, production mix UCTE	Uncertainty	StandardDeviation95%
	Location				UCTE		
	InfrastructureProcess				0		
	Unit				kWh		
product	electricity, production mix UCTE	UCTE	0	kWh	1.00E+0		
technosphere	electricity, hardcoal, average	UCTE	0	kWh	2.64E-1	1	1.05
	electricity, hardcoal with CCS, average	UCTE	0	kWh	0	1	1.05
	electricity, hard coal, at IGCC power plant 450MW	RER	0	kWh	0	1	1.05
	electricity, hardcoal IGCC with CCS, average	UCTE	0	kWh	0	1	1.05
	electricity, lignite, at power plant 950 MW	RER	0	kWh	9.68E-2	1	1.05
	electricity, lignite with CCS, average	UCTE	0	kWh	0	1	1.05
	electricity, lignite, at IGCC power plant 450MW	RER	0	kWh	0	1	1.05
	electricity, lignite IGCC with CCS, average	UCTE	0	kWh	0	1	1.05
	electricity, oil, at power plant	UCTE	0	kWh	6.02E-3	1	1.05
	electricity, natural gas, at combined cycle plant, 500MWe	RER	0	kWh	1.56E-1	1	1.05
	electricity, natural gas, at turbine, 50MWe	RER	0	kWh	2.98E-2	1	1.05
	electricity, natural gas, CC plant, 500MWe post CCS, 400km&2500m deplet gasfield	RER	0	kWh	0	1	1.05
	electricity, fuel cell, natural gas, average	UCTE	0	kWh	0	1	1.05
	electricity, nuclear, average	UCTE	0	kWh	2.20E-1	1	1.05
	electricity, biomass, average	UCTE	0	kWh	3.64E-2	1	1.11
	electricity, hydropower, at run-of-river power plant	RER	0	kWh	5.59E-2	1	1.11
	electricity, hydropower, at reservoir power plant, alpine region	RER	0	kWh	7.96E-2	1	1.21
	electricity, hydropower, at pumped storage power plant	UCTE	0	kWh	6.57E-3	1	1.24
	electricity, at wind power plant	RER	0	kWh	3.19E-2	1	1.24
	electricity, at offshore wind park 1440MW	DK	0	kWh	1.40E-2	1	1.05
	electricity, photovoltaic, average	UCTE	0	kWh	3.17E-3	1	1.05
	electricity, solar thermal, average	UCTE	0	kWh	5.69E-4	1	1.05

Table 4-3: Electricity mix UCTE, realistic-optimistic (RO), 440ppm, 2025

	Name	Location	InfrastructureProcess	Unit	electricity, production mix UCTE	Uncertainty	StandardDeviation95%
	Location				UCTE		
	InfrastructureProcess				0		
	Unit				kWh		
product	electricity, production mix UCTE	UCTE	0	kWh	1.00E+0		
technosphere	electricity, hardcoal, average	UCTE	0	kWh	4.25E-2	1	1.05
	electricity, hardcoal with CCS, average	UCTE	0	kWh	1.01E-2	1	1.05
	electricity, hard coal, at IGCC power plant 450MW	RER	0	kWh	2.38E-3	1	1.05
	electricity, hardcoal IGCC with CCS, average	UCTE	0	kWh	1.26E-2	1	1.05
	electricity, lignite, at power plant 950 MW	RER	0	kWh	2.95E-2	1	1.05
	electricity, lignite with CCS, average	UCTE	0	kWh	0	1	1.05
	electricity, lignite, at IGCC power plant 450MW	RER	0	kWh	1.29E-3	1	1.05
	electricity, lignite IGCC with CCS, average	UCTE	0	kWh	9.14E-4	1	1.05
	electricity, oil, at power plant	UCTE	0	kWh	6.96E-3	1	1.05
	electricity, natural gas, at power plant	UCTE	0	kWh	1.75E-3	1	1.05
	electricity, natural gas, at combined cycle plant, 500MWe	RER	0	kWh	2.95E-1	1	1.05
	electricity, natural gas, at turbine, 50MWe	RER	0	kWh	1.03E-2	1	1.05
	electricity, natural gas, CC plant, 500MWe post CCS, 400km&2500m deplet gasfield	RER	0	kWh	9.07E-3	1	1.05
	electricity, natural gas, at cogeneration 200kWe lean burn, allocation exergy	RER	0	kWh	8.98E-2	1	1.05
	electricity, fuel cell, natural gas, average	UCTE	0	kWh	0	1	1.05
	electricity, nuclear, average	UCTE	0	kWh	2.16E-1	1	1.05
	electricity, biomass, average	UCTE	0	kWh	3.76E-2	1	1.11
	electricity, hydropower, at run-of-river power plant	RER	0	kWh	6.73E-2	1	1.11
	electricity, hydropower, at reservoir power plant, alpine region	RER	0	kWh	1.08E-1	1	1.21
	electricity, hydropower, at pumped storage power plant	UCTE	0	kWh	7.77E-3	1	1.24
	electricity, at wind power plant	RER	0	kWh	3.83E-2	1	1.24
	electricity, at offshore wind park 1068MW	DK	0	kWh	8.52E-3	1	1.05
	electricity, photovoltaic, average	UCTE	0	kWh	1.93E-3	1	1.05
	electricity, from wave energy, 7MW	RER	0	kWh	1.40E-3	1	1.05
	electricity, solar thermal, average	UCTE	0	kWh	4.67E-4	1	1.05

Table 4-4: Electricity mix UCTE, realistic-optimistic (RO), 440ppm, 2050

	Name	Location	Infrastructu reProcess	Unit	electricity, production mix UCTE	Uncertainty StandardD eviation95 %	
	Location				UCTE		
	InfrastructureProcess				0		
	Unit				kWh		
product	electricity, production mix UCTE	UCTE	0	kWh	1.00E+0		
technosphere	electricity, hardcoal, average	UCTE	0	kWh	0	1	1.05
	electricity, hardcoal with CCS, average	UCTE	0	kWh	3.37E-5	1	1.05
	electricity, hard coal, at IGCC power plant 450MW	RER	0	kWh	0	1	1.05
	electricity, hardcoal IGCC with CCS, average	UCTE	0	kWh	5.83E-2	1	1.05
	electricity, lignite, at power plant 950 MW	RER	0	kWh	0	1	1.05
	electricity, lignite with CCS, average	UCTE	0	kWh	0	1	1.05
	electricity, lignite, at IGCC power plant 450MW	RER	0	kWh	0	1	1.05
	electricity, lignite IGCC with CCS, average	UCTE	0	kWh	1.49E-6	1	1.05
	electricity, oil, at power plant	UCTE	0	kWh	1.82E-3	1	1.05
	electricity, natural gas, at power plant	UCTE	0	kWh	0	1	1.05
	electricity, natural gas, at combined cycle plant, 500MWe	RER	0	kWh	3.13E-2	1	1.05
	electricity, natural gas, at turbine, 50MWe	RER	0	kWh	0	1	1.05
	electricity, natural gas, CC plant, 500MWe post CCS, 400km&2500m deplet gasfield	RER	0	kWh	3.83E-1	1	1.05
	electricity, natural gas, at cogeneration 200kWe lean burn, allocation exergy	RER	0	kWh	6.33E-4	1	1.05
	electricity, fuel cell, natural gas, average	UCTE	0	kWh	1.34E-3	1	1.05
	electricity, nuclear, average	UCTE	0	kWh	2.44E-1	1	1.05
	electricity, biomass, average	UCTE	0	kWh	3.29E-2	1	1.11
	electricity, hydropower, at run-of-river power plant	RER	0	kWh	4.42E-2	1	1.11
	electricity, hydropower, at reservoir power plant, alpine region	RER	0	kWh	1.02E-1	1	1.21
	electricity, hydropower, at pumped storage power plant	UCTE	0	kWh	4.91E-3	1	1.24
	electricity, at wind power plant	RER	0	kWh	3.43E-2	1	1.24
	electricity, at offshore wind park 1944MW	DK	0	kWh	3.57E-2	1	1.05
	electricity, photovoltaic, average	UCTE	0	kWh	3.36E-3	1	1.05
	electricity, solar thermal, average	UCTE	0	kWh	4.55E-4	1	1.05
	electricity, from wave energy, 7MW	RER	0	kWh	2.15E-2	1	1.05

Table 4-5: Electricity mix UCTE, very optimistic (VO), enhanced renewables (Renew.), 2025

	Name	Location	Infrastructu reProcess	Unit	electricity, production mix UCTE	Uncertainty StandardD eviation95 %	
	Location				UCTE		
	InfrastructureProcess				0		
	Unit				kWh		
product	electricity, production mix UCTE	UCTE	0	kWh	1.00E+0		
technosphere	electricity, hardcoal, average	UCTE	0	kWh	5.94E-2	1	1.05
	electricity, hardcoal with CCS, average	UCTE	0	kWh	2.99E-2	1	1.05
	electricity, hard coal, at IGCC power plant 450MW	RER	0	kWh	3.04E-3	1	1.05
	electricity, hardcoal IGCC with CCS, average	UCTE	0	kWh	1.51E-2	1	1.05
	electricity, lignite, at power plant 950 MW	RER	0	kWh	1.64E-3	1	1.05
	electricity, lignite with CCS, average	UCTE	0	kWh	0	1	1.05
	electricity, lignite, at IGCC power plant 450MW	RER	0	kWh	2.07E-4	1	1.05
	electricity, lignite IGCC with CCS, average	UCTE	0	kWh	8.22E-3	1	1.05
	electricity, oil, at power plant	UCTE	0	kWh	5.28E-3	1	1.05
	electricity, natural gas, at combined cycle plant, 500MWe	RER	0	kWh	2.46E-1	1	1.05
	electricity, natural gas, at turbine, 50MWe	RER	0	kWh	1.00E-1	1	1.05
	electricity, natural gas, CC plant, 500MWe post CCS, 400km&2500m deplet gasfield	RER	0	kWh	5.81E-3	1	1.05
	electricity, fuel cell, natural gas, average	UCTE	0	kWh	0	1	1.05
	electricity, nuclear, average	UCTE	0	kWh	0	1	1.05
	electricity, biomass, average	UCTE	0	kWh	8.23E-2	1	1.11
	electricity, hydropower, at run-of-river power plant	RER	0	kWh	6.10E-2	1	1.11
	electricity, hydropower, at reservoir power plant, alpine region	RER	0	kWh	1.09E-1	1	1.21
	electricity, hydropower, at pumped storage power plant	UCTE	0	kWh	7.70E-3	1	1.24
	electricity, at wind power plant	RER	0	kWh	1.81E-1	1	1.24
	electricity, at offshore wind park 1332MW	DK	0	kWh	4.40E-2	1	1.05
	electricity, photovoltaic, average	UCTE	0	kWh	3.07E-2	1	1.05
	electricity, solar thermal, average	UCTE	0	kWh	9.51E-3	1	1.05

Table 4-6: Electricity mix UCTE, very optimistic (VO), enhanced renewables (Renew.), 2050

	Name	Location	InfrastructureProcess	Unit	electricity, production mix UCTE	Uncertainty	StandardDeviation95%
	Location				UCTE		
	InfrastructureProcess				0		
	Unit				kWh		
product	electricity, production mix UCTE	UCTE	0	kWh	1.00E+0		
technosphere	electricity, hardcoal, average	UCTE	0	kWh	1.63E-2	1	1.05
	electricity, hardcoal with CCS, average	UCTE	0	kWh	8.19E-3	1	1.05
	electricity, hard coal, at IGCC power plant 450MW	RER	0	kWh	8.33E-4	1	1.05
	electricity, hardcoal IGCC with CCS, average	UCTE	0	kWh	4.13E-3	1	1.05
	electricity, lignite, at power plant 950 MW	RER	0	kWh	2.42E-10	1	1.05
	electricity, lignite with CCS, average	UCTE	0	kWh	0	1	1.05
	electricity, lignite, at IGCC power plant 450MW	RER	0	kWh	3.04E-11	1	1.05
	electricity, lignite IGCC with CCS, average	UCTE	0	kWh	1.21E-9	1	1.05
	electricity, oil, at power plant	UCTE	0	kWh	1.56E-9	1	1.05
	electricity, natural gas, at combined cycle plant, 500MWe	RER	0	kWh	1.17E-1	1	1.05
	electricity, natural gas, at turbine, 50MWe	RER	0	kWh	4.77E-2	1	1.05
	electricity, natural gas, CC plant, 500MWe post CCS, 400km&2500m deplet gasfield	RER	0	kWh	2.76E-3	1	1.05
	electricity, fuel cell, natural gas, average	UCTE	0	kWh	0	1	1.05
	electricity, nuclear, average	UCTE	0	kWh	0	1	1.05
	electricity, biomass, average	UCTE	0	kWh	1.58E-1	1	1.11
	electricity, hydropower, at run-of-river power plant	RER	0	kWh	7.21E-2	1	1.11
	electricity, hydropower, at reservoir power plant, alpine region	RER	0	kWh	1.61E-1	1	1.21
	electricity, hydropower, at pumped storage power plant	UCTE	0	kWh	9.10E-3	1	1.24
	electricity, at wind power plant	RER	0	kWh	2.60E-1	1	1.24
	electricity, at offshore wind park 2496MW	DK	0	kWh	6.30E-2	1	1.05
	electricity, photovoltaic, average	UCTE	0	kWh	6.53E-2	1	1.05
	electricity, solar thermal, average	UCTE	0	kWh	1.43E-2	1	1.05

4.2 Electricity mix of the aluminium industry

4.2.1 Development of electricity mix

The electricity supply mix of the global aluminium industry has a relatively high share of hydropower (52.6%). However, in 2005 the overall share of hydropower was slightly lower (51.4%) as the share of electricity from natural gas raised with the increase of production in the Middle East and in the Gulf states. Due to the ongoing globalisation and the ongoing relocation of the primary aluminium industry away from Europe to other regions (Middle East, Gulf states, South Africa, China), the share of renewable energy sources (other than hydropower) is not expected to rise[8]. We assume that in 2025 and 2050 aluminium is provided on a global market and thus apply the global electricity mix according to the IAI. This leads to an increase in coal based electricity from 20 % to about 33 % and a reduction in nuclear power from 13.5 % to about 5 %.

The aluminium industry is, however, keen to keep the share of hydropower at its actual level. The International Aluminium Institute even expects this share to rise to 55% in the next years[9]. For the optimistic realistic scenario 2025 we assume that the aluminium industry keeps the 2005 structure of the electricity production (which does not include any more electricity from lignite, but an increased share from hard coal instead) and increases the hydropower share to the “today” level in 2050. For the very optimistic scenario we assume that the aluminium industry is able to increase the share of hydropower to 55% in 2025 and 57.5% in 2050. The rest of the energy sources keep the same proportions as in 2005.

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[8] Personal communication, Mr. Dr. C. Bayliss, International Aluminium Institute, 05.05.2006

[9] http://www.world-aluminium.org/environment/electric.html, retrieved 11.4.2006.

Table 4-7: Share of the energy sources in the electricity mix of the aluminium industry in the optimistic scenarios (assumptions see text).

Name	Location	Infrastructure-Process	Unit	electricity mix, aluminium industry, optimistic-realistic 2025	electricity mix, aluminium industry, optimistic-realistic 2050	electricity mix, aluminium industry, very optimistic 2025	electricity mix, aluminium industry, very optimistic 2050
Location				GLO	GLO	GLO	GLO
InfrastructureProcess				0	0	0	0
Unit				kWh	kWh	kWh	kWh
electricity, hard coal, at power plant	UCTE	0	kWh	3.37E-1	3.29E-1	3.12E-1	2.95E-1
electricity, hydropower, at power plant	FR	0	kWh	5.14E-1	5.26E-1	5.50E-1	5.75E-1
electricity, lignite, at power plant	UCTE	0	kWh				
electricity, natural gas, at power plant	UCTE	0	kWh	9.42E-2	9.19E-2	8.73E-2	8.24E-2
electricity, nuclear, at power plant	UCTE	0	kWh	4.81E-2	4.69E-2	4.45E-2	4.21E-2
electricity, oil, at power plant	IT	0	kWh	6.46E-3	6.30E-3	5.98E-3	5.65E-3

4.2.2 Selected cumulative life cycle inventory results

The selected cumulative resource consumptions and emissions (shown in Table 4-8 to Table 4-10) are mainly dominated by the technology shares in the different time horizons and scenarios. The results of the pessimistic scenario are rather stable. In this case, no changes in the electricity mix are assumed. The results of the realistic-optimistic and the very optimistic scenario are distinctly different from the ones of the pessimistic scenario with a higher coal and natural gas resource consumption and higher CO_2 emissions but lower Uranium consumption and lower radionuclide emissions. This is due to a change from the European aluminium supply mix to the global aluminium supply mix. The share of hydro power tends to rise from 2025 to 2050, which results in moderately lower emissions in 2050 as compared to 2025. The very optimistic scenario results in lower emissions compared to the optimistic-realistic scenario.

Table 4-8 Selected life cycle inventory results of the production of 1 kWh electricity used in Aluminium smelters; pessimistic scenario, business as usual electricity mix in background

	unit	**today**	**2025PE Mix: BAU**	**2050PE Mix: BAU**
Resources				
Coal, hard, unspecified, in ground	kg	1.19E-01	100.1%	100.1%
Gas, natural, in ground	Nm^3	1.45E-02	100.3%	99.9%
Oil, crude, in ground	kg	1.04E-02	97.9%	97.9%
Uranium	kg	3.37E-06	99.1%	98.9%
Water	m^3	2.15E-03	99.4%	99.3%
Occupation agricultural and forests	m^2a	4.77E-03	102.7%	103.1%
Occupation built-up	m^2a	1.61E-03	99.8%	99.9%
selected air emissions				
CO2, fossil	kg	3.17E-01	99.6%	99.5%
NOx,	kg	6.42E-04	98.9%	98.9%
PM2.5	kg	7.03E-05	98.4%	98.4%
Rn222	kg	1.10E+02	99.1%	98.9%
selected water emissions				
C14	kBq	2.27E-03	99.1%	98.8%
Chromium VI	kg	2.70E-07	99.2%	99.2%
oils unspecified	kg	4.55E-05	98.0%	97.9%

Table 4-9 Selected life cycle inventory results of the production of 1 kWh electricity used in Aluminium smelters; realistic-optimistic scenario, business as usual electricity mix in background

			2025RO	**2050RO**
	unit	**today**	**Mix: 440ppm**	**Mix: 440ppm**
Resources				
Coal, hard, unspecified, in ground	kg	1.19E-01	167.0%	162.5%
Gas, natural, in ground	Nm^3	1.45E-02	197.3%	194.0%
Oil, crude, in ground	kg	1.04E-02	51.2%	49.7%
Uranium	kg	3.37E-06	35.0%	33.6%
Water	m^3	2.15E-03	69.0%	67.6%
Occupation agricultural and forests	m^2a	4.77E-03	167.7%	161.5%
Occupation built-up	m^2a	1.61E-03	150.4%	146.5%
selected air emissions				
CO2, fossil	kg	3.17E-01	124.2%	120.3%
NOx,	kg	6.42E-04	127.9%	124.2%
PM2.5	kg	7.03E-05	95.4%	92.9%
Rn222	kg	1.10E+02	35.0%	33.6%
selected water emissions				
C14	kBq	2.27E-03	35.0%	33.8%
Chromium VI	kg	2.70E-07	100.0%	95.5%
oils unspecified	kg	4.55E-05	52.4%	50.9%

Table 4-10 Selected life cycle inventory results of the production of 1 kWh electricity used in Aluminium smelters; very optimistic scenario, business as usual electricity mix in background

			2025VO	**2050VO**
	unit	**today**	**Mix: Renew.**	**Mix: Renew.**
Resources				
Coal, hard, unspecified, in ground	kg	1.19E-01	154.6%	145.7%
Gas, natural, in ground	Nm^3	1.45E-02	181.5%	167.2%
Oil, crude, in ground	kg	1.04E-02	47.5%	44.6%
Uranium	kg	3.37E-06	32.4%	28.1%
Water	m^3	2.15E-03	64.0%	59.0%
Occupation agricultural and forests	m^2a	4.77E-03	154.6%	152.6%
Occupation built-up	m^2a	1.61E-03	139.7%	132.3%
selected air emissions				
CO2, fossil	kg	3.17E-01	114.9%	108.0%
NOx,	kg	6.42E-04	118.3%	111.6%
PM2.5	kg	7.03E-05	88.5%	83.7%
Rn222	kBq	1.10E+02	32.4%	28.1%
selected water emissions				
C14	kBq	2.27E-03	32.5%	28.1%
Chromium VI	kg	2.70E-07	93.9%	87.9%
oils unspecified	kg	4.55E-05	48.7%	45.8%

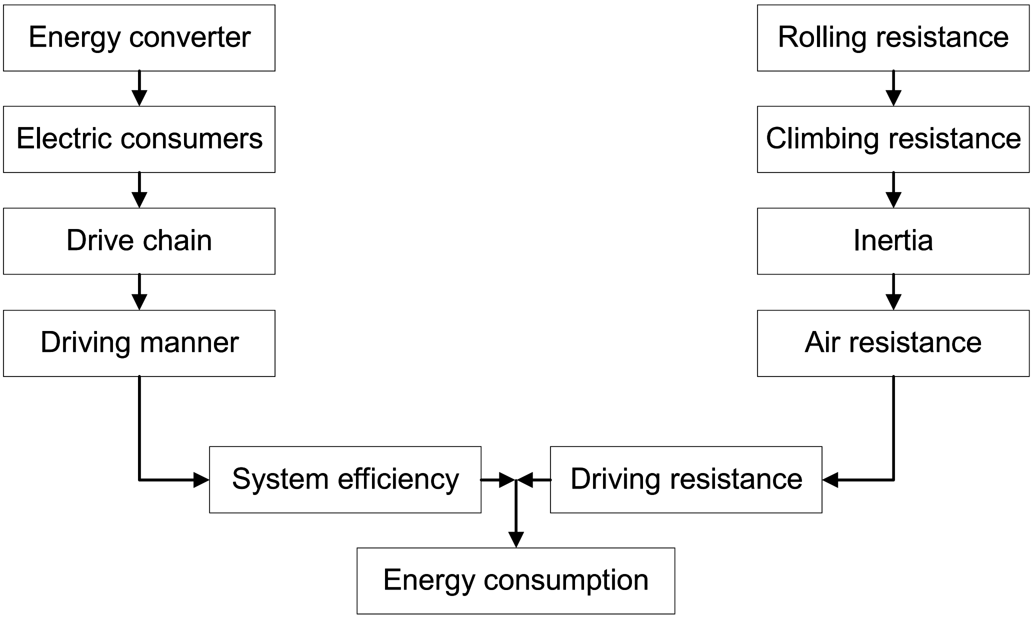
5 LCI of Transports

In this chapter, the origin and utilisation of the data regarding transports are documented. Chapter 5.1 gives a general overview of possible developments in fuel consumption and emissions of vehicles, precisely vans and lorries. Chapters 5.2 to 5.5 describe the future values derived for the different vehicles in detail. A van (less than 3.5 tonnes, chapter 5.2) and three different sizes of lorries (16 to 32 tonnes) are investigated.

5.1 General overview

One important aspect of the future environmental impact of transport are the technical measures taken on the vehicle which can lead to a reduction of the specific energy consumption and thus contribute to a reduction of greenhouse gas emissions; in many cases, this applies independent of the type of fuel which is used. The end energy consumption is reduced by an improved system efficiency regarding the energy converter and consumers as well as the reduction of the driving resistance (see Fig. 5.1). A thorough investigation on this can be found in IFEU (2005b).

Fig. 5.1: Influences on the energy consumption of a vehicle (NRC 2002)



Regarding the technological possibilities to reduce the pollutant emissions, the range of requirements and reduction possibilities is too large, complex and unreliable for it to be analysed in detail here. For the deduction of the future emission data, general values for all scenarios are derived consulting the database TREMOD (2007). Consequently, technically determined reductions of the fuel consumption and with it climate-relevant emissions are focused on in this overview.

Engine

Compared to equivalent petrol-fuelled ones, diesel engines have a general process-based consumption advantage. In commercial vehicles it is the leading engine model, not only due to its performance characteristics, longevity and economic advantage.

The possibilities to further increase fuel savings are clearly smaller for diesel than for petrol engines. The diesel engine has already been optimised regarding fuel consumption and in this aspect has reached a fairly high development stage, with the electronic direct injection being a crucial element. The study of publications on this topic shows that in the near future, only minor increases in fuel savings can be expected to result from the optimisation of technologies that are already used today in diesel vehicles (e.g. minimisation of engine friction, improved exhaust recirculation). The main limitation arises from the goal conflict between efficiency increases and further reductions of pollutants.

- The estimates of possible further fuel savings in diesel vehicles in general range from 0.5 % to 4 % (AEA 2001, Argonne 2002, DLR 2003, NRC 2002, OECD 2005).
- The consequences of a stricter regulation of pollutants are judged as being ambiguous. The use of selective catalytic reduction (SCR) filters causes a specific fuel reduction of 5% for Euro 5 versus Euro 3 (SRU 2005); NO_X accumulative catalytic converters, on the other hand, lead to a 2 % specific increase in fuel consumption (Bay. LfU 2003).

The so-called **HCCI technology** (homogenous compression combustion ignition) combines the advantages of petrol and diesel engines and can lead to fuel savings. It is very likely that synthetic fuels will be used in combination with this technology which at the moment is still in a development stage and is not expected to be ready to go into production before 2015 (Shell 2004).

- The publications studied predict a general HCCI-related reduction in fuel consumption between 5 % and 15 % (Bay. LfU 2004, CARB 2004, Shell 2004)
- Based on NESCCAF (2004), CARB (2004) differentiates between types of vehicles and states a 3 % reduction in fuel consumption of mini vans, 4 % for small lorries and 5 % for large lorries.

Emission reduction and fuel consumption

Certain schemes to reduce emissions directly influence the fuel consumption:

- The introduction of closed-loop three-way **catalytic converters** in Germany, for example, inhibited the use of a fuel-economic lean burn for partial-load operation, leading to a considerable increase in fuel consumption, which was eventually overcompensated by further developments of the engine.
- As the reduction of fuel consumption and of CO_2 emissions gained importance, the development of engines designed for (temporary) **lean operation** became more attractive, since the advantages of direct injection (stratified load) are realised especially in this operation mode. Accumulative catalytic converters can help reduce NO_X emissions but cause higher fuel consumption.
- Due to the lower specific fuel consumption of diesel engines, a **relative increase of diesel-fuelled vehicles** and reduction of petrol engines would lead to an overall reduction in fuel consumption. As a consequence, however, CO_2, NO_X and particle emissions would increase.
- Additional units in the **exhaust system** such as particle filters for diesel engines are already in use or will be in the future in order to meet the requirements of stricter emission control legislation. They increase the exhaust back pressure, however, and consequently the fuel consumption of the engine.
- The **reduction of NO_X emissions** is also an element of (future) emission control policies. If engine-internal adaptations are implemented for this purpose, as is the current practice, efficiency losses are the consequence. Different catalyst concepts can also be used, which – as additional units in the exhaust system (see description in previous point) and due to regeneration processes – lead to a higher fuel consumption. The balances are ambiguous: The use of selective catalytic reduction (SCR) filters causes a reduction in fuel consumption (SRU 2005). NO_X accumulative catalytic converters, on the other hand, lead to an increase (Bay. LfU 2003).

Hybrid vehicles

Hybrid vehicles combine several energy converters and storage systems in the vehicle, typically combustion and electric engines with a tank and battery. In **parallel** hybrids, combustion and electric engines can each drive the wheels separately or together. In **serial** hybrids the wheel drive takes place exclusively with electric power. **Mixed** hybrids combine the operation modes of parallel and serial hybrids by means of a variable power split, through which the internal combustion engine drives the wheels directly and simultaneously indirectly via a generator and electric motor. In the hybrid concept the lower fuel consumption in comparison to conventional vehicles at the same development stage results from the following properties of the drive train or the operation mode:

Due to specific consumption reductions (reference: vehicle kilometre) and costs (relevant for the penetration of markets or fleets) considerable potentials for the reduction of fuel consumption and CO_2 emissions may be expected. The market launch of single vehicles has already initiated the tapping of these potentials which exist mostly for urban areas, however, for which other options including the reduction of motorised traffic itself are also relevant. In the following, data on the total reductions through future hybrid vehicles from different sources and with different references (type of vehicle, conventional reference, etc.) are summarised:

- EUC (2004): vehicle class: light-duty commercial vehicles; cycle: not specified; CO_2 reduction without explicit reference (probably new vehicles from 200x or later): 11 to 20 %.
- IEA (2004): vehicle class: light-duty commercial vehicles, e.g. SUV’s, pick-up trucks, vans; cycle: not specified; reduction refers to petrol-fuelled light-duty commercial vehicles 2000: petrol hybrid 2000: 25%; petrol or diesel hybrid 2020: 40 or 45%; 2030: 46 % or 51 %.

Drive chain

Apart from the actual motor, other parts of the drive chain of vehicles can be subject of amendments which can influence the engine’s efficiency. By increasing the number of transmission gears, for example, the engine operating point can be moved to areas with better efficiencies (CARB 2004). Therefore, 6 gears will become increasingly common both in automatic and stick shift transmissions. Automatic transmissions, in which the manual gear shifting process is supported hydraulically or electrically, show a great potential to save fuel. The continuously variable transmission (CVT) that allows a virtually stageless user-defined transmission ratio represents another approach. Starter generators will allow the realisation of convenient start-stop automatics which can help avoid idle / lost motion phases and with this, unnecessary fuel consumption. This last option, however, mostly applies to utilisation ways of vehicles for which other alternatives such as the restraint from motorised transportation also exist.

- The general improvement of fuel efficiency due to application of the CVT technology is estimated in the range of 5 % - 8 % (AEA 2001, OECD 2005).
- Automatic transmissions are believed to reach a 3-5 % increase in fuel efficiency (SAM & WRI based on NRC 2002), or even up to 10 % in combination with 6-7 gear transmissions (SRU 2005).
- Starter generators are expected to allow for a fuel efficiency increase of 4 % to more than 10 %, e.g. when an automatic motor shutoff is included (DLR 2003, SAM & WRI based on NRC 2002).

Auxiliary consumers

Auxiliary appliances for the fuel consumption of a vehicle will play an increasingly important role as the fuel demand for the drive chain decreases. However, in heavy-duty vehicles, this will most likely have a smaller influence than in personal transportation.

Driving resistances

Apart from the nature of the drive chain, the physical driving resistances – along with the driving manner – are of relevance for the fuel consumption of a vehicle engine. The energy consumption and the potential savings possibilities therefore vary with the type of vehicle and the utilisation pattern. The most important resistances for road (and track) vehicles are: the rolling, climbing and air resistances as well as inertia.

With the exception of the air resistance, all of these resistances are directly proportional to the vehicle's mass. **Lightweight construction** is therefore a central possibility to reduce the driving resistances – due to frequent acceleration especially for vehicles in city traffic.

Lightweight constructions can be based on material substitution (lightweight instead of heavy), shape design (minimising of materials) and general construction concepts (reduced number of parts).

- Models and estimations on the amount of fuel savings that can be achieved through lightweight constructions have produced the following results for heavy-duty vehicles: for a EURO III articulate lorry (42 tonnes) in Germany: 0,06 l / (100 km × 100 kg) on average (IFEU 2005a), for an average size lorry for deliveries in urban areas: 30 % fuel savings (US DoE 2000)

For vehicles in goods traffic a higher energy efficiency through lightweight construction is attained in two ways: (1) through a lower total mass of a lighter vehicle and a constant transport goods mass (for partial-capacity payload; e.g. voluminous transport goods) and (2) through an increased freight share while the total mass remains constant (for full-capacity payload) and the vehicle is lighter. The second measure can have a clearly greater effect than the first one (IFEU 2003).

The **air resistance** depends on the front area and the surface properties of the vehicle and the squared speed. Therefore, an improvement of the aerodynamics is especially interesting when it comes to vehicles that travel long distances – or at high speeds. For heavy lorries, for example, a considerable reduction of fuel consumption has already been achieved through the installation of roof spoilers.

- US DoE (2000, 2004) provides figures for the fuel consumption decrease through the reduction of air resistance of heavy-duty vehicles: 10 % - 15 % for an articulate lorry, 10 % for a heavy lorry – both at constant motorway speed.

Furthermore, the **rolling resistance** of road vehicles – resulting from the elastic deformation of the tires – can also be optimised, thus leading to lower fuel consumption. This is only possible to a certain extent however, since tires also serve important functions of acceleration and deceleration: security aspects must be weighted against the technical possibilities and may thus limit their implementation.

- The general improvement of fuel efficiency due to rolling resistance reduction ranges from 1 % - 6 %, depending on the type of traffic (AEA 2001, Friedrich 2002).
- For heavy-duty vehicles, the range found in the regarded studies is smaller: US DoE (2000) notes 4 % - 5 % for an articulate lorry, NRC (2002) 2 % on motor-way traffic and 1 % in urban traffic for light-duty commercial vehicles.

Conclusions

From the different aspects mentioned above and by combining the figures given in the different sources, we can expect a 20 to 50 % reduction in fuel consumption, depending on the type of vehicle, the cost of realisation (i.e. the scenario) and the time horizon. Changes in pollutant emissions are, as pointed out, bound into a system of interdependencies between legal requirements for emission reductions and fuel savings. They are therefore estimated on the basis of future prospects derived in other projects and used by the German Government for official statistics (TREMOD 2007). In the following chapters, the future changes for the single transport means (van and lorries) are described.

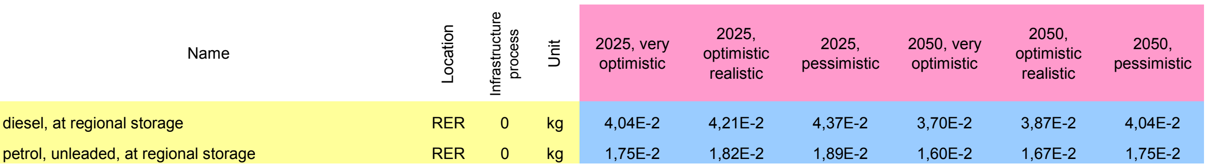
5.2 Transport in Van (below 3.5 tonnes)

Data for the reference situation ("today") are based on the dataset "operation, van < 3,5t (RER)", which is described in detail in Spielmann et al. (2004). The development into the future scenarios is based on the Transport Emission Model (TREMOD 2007) and own expert judgements (IFEU 2007).

5.2.1 Energy use

The "today" dataset for transport in an average 3.5-tonne van accounts for a total of about 4 MJ end energy per vehicle kilometre, of which 70% are provided with diesel and 30% with petrol. Regarding the future, in the pessimistic scenario, the development is inter- and extrapolated on the basis of TREMOD (2007) and an expert judgement (IFEU 2007). This accounts for the optimisations due to legal requirements already under way. In the very optimistic scenarios we assume an increase of energy efficiency with a reduction of energy consumption exceeding the reduction in the pessimistic scenario by a total of about 5 percentage points in both time horizons. On the basis of the literature cited in chapter 5.1, this covers the largest part of the optimisations described there. For the optimistic-realistic scenarios, the same reduction in fuel consumption is estimated to be reached, however with a delay: the reduction is estimated to be the mean of the "very optimistic" and the "pessimistic" reduction in both time frames. Therefore, the end energy use reduces down to 2.3 MJ/km in the "very optimistic" case and to 2.4 MJ/km in the "optimistic-realistic" scenario in 2050 (cf. Table 5-1).

Table 5-1: Energy inputs of the 3.5-t van transport in all scenarios in 2025 and 2050. Values are given per vehicle kilometre.



Name	Location	Infrastructure process	Unit	2025, very optimistic	2025, optimistic realistic	2025, pessimistic	2050, very optimistic	2050, optimistic realistic	2050, pessimistic
diesel, at regional storage	RER	0	kg	4,04E-2	4,21E-2	4,37E-2	3,70E-2	3,87E-2	4,04E-2
petrol, unleaded, at regional storage	RER	0	kg	1,75E-2	1,82E-2	1,89E-2	1,60E-2	1,67E-2	1,75E-2

5.2.2 Air emissions

CO_2, SO_2 and heavy metal emissions from combustion are calculated on the basis of the fuel characteristics. Also, waste heat per driven kilometre is proportional to the fuel consumed. With respect to the other main air emissions in the "today" dataset (Spielmann et al. 2004), the changes expected for the future scenarios are derived from TREMOD (2007). Since a more detailed analysis of possible changes in pollutant emissions seems impossible due to the complexity of possible reductions and the interdependencies with fuel consumption, these changes are assumed to occur in all three scenarios and both time horizons (see Table 5-2). The emission values given in the table represent the multiplying factor for the future emission based on the amount of fuel consumed in the future, i.e. in order to give this emission based on the vehicle kilometre this value is to be decreased by the reduction in fuel consumption. Since the focus already in the pessimistic scenario is on greenhouse gas reduction the emissions presented rise due to the fact that technological means for consumption decrease and pollutant decrease are in most cases contradictory. However, in virtually no scenario a significant increase is predicted. The figures derived from these findings are listed in Table 5-3.

Table 5-2: Air emission changes of relevant pollutants with respect to the “today” dataset. The percentage is the multiplying factor for the future emission on the basis of the consumed fuel amount.

Name	Location	Infrastructure process	Unit	Future values
Ammonia				155%
Benzene				147%
Carbon monoxide, fossil				147%
Dinitrogen monoxide				155%
Methane, fossil				147%
Nitrogen oxides				134%
NMVOC, non-methane volatile organic compounds, unspecified origin				147%
Particulates, < 2.5 um				129%
Particulates, > 10 um				129%
Particulates, > 2.5 um, and < 10um				129%

Table 5-3: Air emissions of relevant pollutants in the different future scenarios. The values are given per vehicle kilometre.

Name	Location	Infrastructure process	Unit	2025, very optimistic	2025, optimistic realistic	2025, pessimistic	2050, very optimistic	2050, optimistic realistic	2050, pessimistic
Ammonia			kg	7,31E-6	7,61E-6	7,92E-6	6,70E-6	7,00E-6	7,31E-6
Benzene			kg	3,21E-5	3,35E-5	3,48E-5	2,95E-5	3,08E-5	3,21E-5
Cadmium			kg	8,70E-10	9,06E-10	9,43E-10	7,98E-10	8,34E-10	8,70E-10
Carbon dioxide, fossil			kg	1,80E-1	1,88E-1	1,95E-1	1,65E-1	1,73E-1	1,80E-1
Carbon monoxide, fossil			kg	7,17E-3	7,47E-3	7,77E-3	6,58E-3	6,87E-3	7,17E-3
Chromium VI			kg	1,22E-11	1,28E-11	1,33E-11	1,12E-11	1,17E-11	1,22E-11
Dinitrogen monoxide			kg	1,52E-5	1,59E-5	1,65E-5	1,40E-5	1,46E-5	1,52E-5
Heat, waste			MJ	2,62E+0	2,73E+0	2,84E+0	2,40E+0	2,51E+0	2,62E+0
Lead			kg	2,73E-9	2,84E-9	2,96E-9	2,50E-9	2,62E-9	2,73E-9
Mercury			kg	2,21E-12	2,31E-12	2,40E-12	2,03E-12	2,12E-12	2,21E-12
Methane, fossil			kg	3,49E-5	3,63E-5	3,78E-5	3,20E-5	3,34E-5	3,49E-5
Nickel			kg	6,54E-9	6,81E-9	7,09E-9	6,00E-9	6,27E-9	6,54E-9
Nitrogen oxides			kg	1,58E-3	1,64E-3	1,71E-3	1,45E-3	1,51E-3	1,58E-3
NMVOC, non-methane volatile organic compounds, unspecified origin			kg	6,96E-4	7,25E-4	7,54E-4	6,38E-4	6,67E-4	6,96E-4
Particulates, < 2.5 um			kg	1,84E-4	1,92E-4	2,00E-4	1,69E-4	1,77E-4	1,84E-4
Particulates, > 10 um			kg	6,81E-5	7,09E-5	7,38E-5	6,24E-5	6,53E-5	6,81E-5
Particulates, > 2.5 um, and < 10um			kg	2,53E-5	2,64E-5	2,74E-5	2,32E-5	2,43E-5	2,53E-5
Sulfur dioxide			kg	2,90E-5	3,03E-5	3,15E-5	2,66E-5	2,78E-5	2,90E-5

5.2.3 Selected cumulative life cycle inventory results

Table 5-4 and Table 5-5 show selected cumulative results of 1 km load transport in a 3.5-tonne van for different future scenarios.

Table 5-4: Selected cumulative life cycle inventory results of 1 km load transport in a 3.5-tonne van, realistic-optimistic scenario

	unit	2025RO	2050RO
Resources			
Oil, crude, in ground	kg	6,76E-02	6,21E-02
Selected air emissions			
Carbon dioxide, fossil	kg	2,19E-01	2,00E-01
Methane, fossil	kg	1,51E-04	1,39E-04
Nitrogen oxides	kg	1,75E-03	1,61E-03
NMVOC total	kg	8,98E-04	8,26E-04
PM2.5	kg	2,03E-04	1,87E-04
Sulfur dioxide	kg	3,19E-04	2,93E-04

Table 5-5: Selected cumulative life cycle inventory results of 1 km load transport in a 3.5-tonne van, very optimistic scenario

	unit	2025VO	2050VO
Resources			
Oil, crude, in ground	kg	6,49E-02	5,94E-02
Selected air emissions			
Carbon dioxide, fossil	kg	2,09E-01	1,92E-01
Methane, fossil	kg	1,45E-04	1,33E-04
Nitrogen oxides	kg	1,69E-03	1,55E-03
NMVOC total	kg	8,62E-04	7,90E-04
PM2.5	kg	1,94E-04	1,78E-04
Sulfur dioxide	kg	3,06E-04	2,80E-04

5.3 Transport in Lorry (16 Tonnes)

Data for the reference situation (“today”) are based on the dataset “operation, lorry 16t (RER)”, which is described in detail in Spielmann et al. (2004). The development into the future scenarios is based on the Transport Emission Model (TREMOD 2007) and own expert judgements (IFEU 2007).

5.3.1 Energy use

The “today” dataset for transport in an average 16-tonne lorry accounts for a total of about 6 MJ end energy per vehicle kilometre, which are provided exclusively with diesel fuel. Regarding the future, in the pessimistic scenario, the development is inter- and extrapolated on the basis of TREMOD (2007) and an expert judgement (IFEU 2007). This accounts for the optimisations due to legal requirements already under way. In the very optimistic scenarios we assume an increase of energy efficiency with a reduction of energy consumption exceeding the reduction in the pessimistic scenario by about 4 percentage points in both time horizons. On the basis of the literature cited in chapter 5.1, this covers the largest part of the optimisations described there. For the optimistic-realistic scenarios, the same reduction in fuel consumption is estimated to be reached, however with a delay: the reduction is estimated to be the mean of the “very optimistic” and the “pessimistic” reduction in both time frames. Therefore, the end energy use reduces down to 4.4 MJ/km in the “very optimistic” case and to 4.6 MJ/km in the “optimistic-realistic” scenario in 2050 (cf. Table 5-6).

Table 5-6: Energy inputs of the 16-t lorry transport in all scenarios in 2025 and 2050. Values are given per vehicle kilometre.

Name	Location	Infrastructure process	Unit	2025, very optimistic	2025, optimistic realistic	2025, pessimistic	2050, very optimistic	2050, optimistic realistic	2050, pessimistic
diesel, at regional storage	RER	0	kg	1,10E-1	1,13E-1	1,15E-1	1,03E-1	1,07E-1	1,10E-1

5.3.2 Air emissions

CO_2, SO_2 and heavy metal emissions from combustion are calculated on the basis of the fuel characteristics. Also, waste heat per driven kilometre is proportional to the fuel consumed. With respect to the other main air emissions in the “today” dataset (Spielmann et al. 2004), the changes expected for the future scenarios are derived from TREMOD (2007). Since a more detailed analysis of possible changes in emissions seems impossible due to the complexity of possible reductions and the interdependencies with fuel consumption, these changes are assumed to occur in all three scenarios and both time horizons (see Table 5-7). The emission values given in the table represent the multiplying factor for the future emission based on the amount of fuel consumed in the future, i.e. in order to give this emission based on the vehicle kilometre this value is to be decreased by the reduction in fuel consumption. Since the focus already in the pessimistic scenario is on greenhouse gas reduction some of the emissions presented rise due to the fact that technological means for consumption decrease and pollutant decrease are in most cases contradictory. However, in virtually no scenario a significant increase is predicted. The figures derived from these findings are listed in Table 5-8.

Table 5-7: Air emission changes of relevant pollutants with respect to the “today” dataset. The percentage is the multiplying factor for the future emission on the basis of the consumed fuel amount.

Name	Location	Infrastructure process	Unit	Future values
Ammonia				128%
Benzene				154%
Carbon monoxide, fossil				91%
Dinitrogen monoxide				127%
Methane, fossil				154%
Nitrogen oxides				48%
NMVOC, non-methane volatile organic compounds, unspecified origin				154%
Particulates, < 2.5 um				33%
Particulates, > 10 um				33%
Particulates, > 2.5 um, and < 10um				33%

Table 5-8: Air emissions of relevant pollutants in the different future scenarios. The values are given per vehicle kilometre.

Name	Location	Infrastructure process	Unit	2025, very optimistic	2025, optimistic realistic	2025, pessimistic	2050, very optimistic	2050, optimistic realistic	2050, pessimistic
Ammonia			kg	2,87E-6	2,94E-6	3,01E-6	2,68E-6	2,78E-6	2,87E-6
Benzene			kg	3,24E-5	3,32E-5	3,39E-5	3,02E-5	3,13E-5	3,24E-5
Cadmium			kg	3,98E-9	4,08E-9	4,17E-9	3,72E-9	3,85E-9	3,98E-9
Carbon dioxide, fossil			kg	3,43E-1	3,51E-1	3,59E-1	3,20E-1	3,31E-1	3,43E-1
Carbon monoxide, fossil			kg	1,62E-3	1,66E-3	1,70E-3	1,51E-3	1,57E-3	1,62E-3
Chromium VI			kg	6,51E-11	6,66E-11	6,82E-11	6,08E-11	6,29E-11	6,51E-11
Dinitrogen monoxide			kg	2,86E-5	2,93E-5	3,00E-5	2,67E-5	2,77E-5	2,86E-5
Heat, waste			MJ	5,00E+0	5,12E+0	5,24E+0	4,67E+0	4,84E+0	5,00E+0
Lead			kg	1,58E-8	1,62E-8	1,66E-8	1,48E-8	1,53E-8	1,58E-8
Mercury			kg	1,65E-12	1,69E-12	1,73E-12	1,54E-12	1,60E-12	1,65E-12
Methane, fossil			kg	4,50E-5	4,60E-5	4,71E-5	4,20E-5	4,35E-5	4,50E-5
Nickel			kg	3,11E-8	3,18E-8	3,25E-8	2,90E-8	3,00E-8	3,11E-8
Nitrogen oxides			kg	1,42E-3	1,45E-3	1,49E-3	1,33E-3	1,37E-3	1,42E-3
NMVOC, non-methane volatile organic compounds, unspecified origin			kg	1,60E-3	1,64E-3	1,68E-3	1,50E-3	1,55E-3	1,60E-3
Particulates, < 2.5 um			kg	9,58E-5	9,80E-5	1,00E-4	8,94E-5	9,26E-5	9,58E-5
Particulates, > 10 um			kg	1,10E-4	1,12E-4	1,15E-4	1,02E-4	1,06E-4	1,10E-4
Particulates, > 2.5 um, and < 10um			kg	2,50E-5	2,56E-5	2,62E-5	2,33E-5	2,42E-5	2,50E-5
Sulfur dioxide			kg	6,56E-5	6,71E-5	6,87E-5	6,12E-5	6,34E-5	6,56E-5

5.3.3 Selected cumulative life cycle inventory results

Table 5-9 and Table 5-10 show selected cumulative results of 1 km of transport in a 16-tonne lorry for different future scenarios.

Table 5-9: Selected cumulative life cycle inventory results of 1 km load transport in a 16-t lorry, realistic-optimistic scenario

	unit	2025RO	2050RO
Resources			
Oil, crude, in ground	kg	1,25E-01	1,19E-01
Selected air emissions			
Carbon dioxide, fossil	kg	4,02E-01	3,79E-01
Methane, fossil	kg	2,55E-04	2,41E-04
Nitrogen oxides	kg	1,65E-03	1,56E-03
NMVOC total	kg	1,86E-03	1,76E-03
PM2.5	kg	1,17E-04	1,10E-04
Sulfur dioxide	kg	5,59E-04	5,29E-04

Table 5-10: Selected cumulative life cycle inventory results of 1 km load transport in 16-t lorry, very optimistic scenario

	unit	2025VO	2050VO
Resources			
Oil, crude, in ground	kg	1,22E-01	1,14E-01
Selected air emissions			
Carbon dioxide, fossil	kg	3,92E-01	3,66E-01
Methane, fossil	kg	2,48E-04	2,32E-04
Nitrogen oxides	kg	1,61E-03	1,51E-03
NMVOC total	kg	1,82E-03	1,70E-03
PM2.5	kg	1,14E-04	1,07E-04
Sulfur dioxide	kg	5,44E-04	5,09E-04

5.4 Transport in Lorry (28 Tonnes)

Data for the reference situation (“today”) are based on the dataset “operation, lorry 28t (CH)”, which is described in detail in Spielmann et al. (2004). The development into the future scenarios is based on the Transport Emission Model (TREMOD 2007) and own expert judgements (IFEU 2007).

5.4.1 Energy use

The “today” dataset for transport in an average 28-tonne lorry accounts for a total of about 12 MJ end energy per vehicle kilometre, which are provided exclusively with diesel fuel. Regarding the future, in the pessimistic scenario, the development is inter- and extrapolated on the basis of TREMOD (2007) and an expert judgement (IFEU 2007). This accounts for the optimisations due to legal requirements already under way. In the very optimistic scenarios we assume an increase of energy efficiency with a reduction of energy consumption exceeding the reduction in the pessimistic scenario by about 4 percentage points in both time horizons. On the basis of the literature cited in chapter 5.1, this covers the largest part of the optimisations described there. For the optimistic-realistic scenarios, the same reduction in fuel consumption is estimated to be reached, however with a delay: the reduction is estimated to be the mean of the “very optimistic” and the “pessimistic” reduction in both time frames. Therefore, the end energy use reduces down to 8.7 MJ/km in the “very optimistic” case and to 9.0 MJ/km in the “optimistic-realistic” scenario in 2050 (cf. Table 5-11).

Table 5-11: Energy inputs of the 28-t lorry transport in all scenarios in 2025 and 2050. Values are given per vehicle kilometre.

Name	Location	Infrastructure process	Unit	2025, very optimistic	2025, optimistic realistic	2025, pessimistic	2050, very optimistic	2050, optimistic realistic	2050, pessimistic
diesel, at regional storage	CH	0	kg	2,18E-1	2,23E-1	2,28E-1	2,03E-1	2,10E-1	2,18E-1

5.4.2 Air emissions

CO_2, SO_2 and heavy metal emissions from combustion are calculated on the basis of the fuel characteristics. Also, waste heat per driven kilometre is proportional to the fuel consumed. With respect to the other main air emissions in the “today” dataset (Spielmann et al. 2004), the changes expected for the future scenarios are derived from TREMOD (2007). Since a more detailed analysis of possible changes in emissions seems impossible due to the complexity of possible reductions and the interdependencies with fuel consumption, these changes are assumed to occur in all three scenarios and both time horizons (see Table 5-12). The emission values given in the table represent the multiplying factor for the future emission based on the amount of fuel consumed in the future, i.e. in order to give this emission based on the vehicle kilometre this value is to be decreased by the reduction in fuel consumption. Since the focus already in the pessimistic scenario is on greenhouse gas reduction some of the emissions presented rise due to the fact that technological means for consumption decrease and pollutant decrease are in most cases contradictory. However, in virtually no scenario a significant increase is predicted. The figures derived from these findings are listed in Table 5-13.

Table 5-12: Air emission changes of relevant pollutants with respect to the "today" dataset. The percentage is the multiplying factor for the future emission on the basis of the consumed fuel amount.

Name	Location	Infrastructure process	Unit	Future values
Ammonia				128%
Benzene				154%
Carbon monoxide, fossil				91%
Dinitrogen monoxide				127%
Methane, fossil				154%
Nitrogen oxides				48%
NMVOC, non-methane volatile organic compounds, unspecified origin				154%
Particulates, < 2.5 um				33%
Particulates, > 10 um				33%
Particulates, > 2.5 um, and < 10um				33%

Table 5-13: Air emissions of relevant pollutants in the different future scenarios. The values are given per vehicle kilometre.

Name	Location	Infrastructure process	Unit	2025, very optimistic	2025, optimistic realistic	2025, pessimistic	2050, very optimistic	2050, optimistic realistic	2050, pessimistic
Ammonia			kg	3,16E-5	3,23E-5	3,31E-5	2,95E-5	3,05E-5	3,16E-5
Benzene			kg	1,97E-5	2,02E-5	2,07E-5	1,84E-5	1,91E-5	1,97E-5
Cadmium			kg	4,79E-9	4,90E-9	5,01E-9	4,47E-9	4,63E-9	4,79E-9
Carbon dioxide, fossil			kg	6,85E-1	7,01E-1	7,17E-1	6,39E-1	6,62E-1	6,85E-1
Carbon monoxide, fossil			kg	8,57E-4	8,78E-4	8,98E-4	8,00E-4	8,29E-4	8,57E-4
Chromium VI			kg	7,31E-11	7,49E-11	7,66E-11	6,83E-11	7,07E-11	7,31E-11
Dinitrogen monoxide			kg	3,15E-5	3,22E-5	3,30E-5	2,94E-5	3,04E-5	3,15E-5
Heat, waste			MJ	9,90E+0	1,01E+1	1,04E+1	9,24E+0	9,57E+0	9,90E+0
Lead			kg	1,58E-8	1,62E-8	1,66E-8	1,48E-8	1,53E-8	1,58E-8
Mercury			kg	3,26E-12	3,34E-12	3,42E-12	3,05E-12	3,15E-12	3,26E-12
Methane, fossil			kg	2,49E-5	2,55E-5	2,61E-5	2,33E-5	2,41E-5	2,49E-5
Nickel			kg	3,67E-8	3,75E-8	3,84E-8	3,42E-8	3,55E-8	3,67E-8
Nitrogen oxides			kg	3,20E-3	3,27E-3	3,35E-3	2,99E-3	3,09E-3	3,20E-3
NMVOC, non-methane volatile organic compounds, unspecified origin			kg	1,01E-3	1,04E-3	1,06E-3	9,47E-4	9,81E-4	1,01E-3
Particulates, < 2.5 um			kg	9,70E-5	9,93E-5	1,02E-4	9,05E-5	9,38E-5	9,70E-5
Particulates, > 10 um			kg	1,10E-4	1,12E-4	1,15E-4	1,02E-4	1,06E-4	1,10E-4
Particulates, > 2.5 um, and < 10um			kg	2,53E-5	2,58E-5	2,64E-5	2,36E-5	2,44E-5	2,53E-5
Sulfur dioxide			kg	1,31E-4	1,34E-4	1,37E-4	1,22E-4	1,26E-4	1,31E-4

5.4.3 Selected cumulative life cycle inventory results

Table 5-14 and Table 5-15 show selected cumulative results of 1 km of transport in a 28-t lorry for different future scenarios.

Table 5-14: Selected cumulative life cycle inventory results of 1 km load transport in a 28-t lorry, realistic-optimistic scenario

	unit	2025RO	2050RO
Resources			
Oil, crude, in ground	kg	2,46E-01	2,31E-01
Selected air emissions			
Carbon dioxide, fossil	kg	8,11E-01	7,65E-01
Methane, fossil	kg	8,38E-04	7,89E-04
Nitrogen oxides	kg	3,74E-03	3,53E-03
NMVOC total	kg	1,59E-03	1,49E-03
PM2.5	kg	1,34E-04	1,27E-04
Sulfur dioxide	kg	8,14E-04	7,65E-04

Table 5-15: Selected cumulative life cycle inventory results of 1 km load transport in 28-t lorry, very optimistic scenario

	unit	2025VO	2050VO
Resources			
Oil, crude, in ground	kg	2,39E-01	2,23E-01
Selected air emissions			
Carbon dioxide, fossil	kg	7,92E-01	7,38E-01
Methane, fossil	kg	8,15E-04	7,62E-04
Nitrogen oxides	kg	3,65E-03	3,41E-03
NMVOC total	kg	1,54E-03	1,44E-03
PM2.5	kg	1,31E-04	1,22E-04
Sulfur dioxide	kg	7,92E-04	7,39E-04

5.5 Transport in Lorry (32 Tonnes)

Data for the reference situation (“today”) are based on the dataset “operation, lorry 32t (RER)”, which is described in detail in Spielmann et al. (2004). The development into the future scenarios is based on the Transport Emission Model (TREMOD 2007) used by the German Government for official statistics and own expert judgements (IFEU 2007).

5.5.1 Energy use

The “today” dataset for transport in an average 32-tonne lorry accounts for a total of about 12 MJ end energy per vehicle kilometre, which are provided exclusively with diesel fuel. Regarding the future, in the pessimistic scenario, the development is inter- and extrapolated on the basis of TREMOD (2007) and an expert judgement (IFEU 2007). This accounts for the optimisations due to legal requirements already under way. In the very optimistic scenarios we assume an increase of energy efficiency with a reduction of energy consumption exceeding the reduction in the pessimistic scenario by about 4 percentage points in both time horizons. On the basis of the literature cited in chapter 5.1, this covers the largest part of the optimisations described there. For the optimistic-realistic scenarios, the same reduction in fuel consumption is estimated to be reached, however with a delay: the reduction is estimated to be the mean of the “very optimistic” and the “pessimistic” reduction in both time frames. Therefore, the end energy use reduces down to 8.1 MJ/km in the “very optimistic” case and to 8.4 MJ/km in the “optimistic-realistic” scenario in 2050 (cf. Table 5-16).

Table 5-16: Energy inputs of the 32-t lorry transport in all scenarios in 2025 and 2050. Values are given per vehicle kilometre.

Name	Location	Infrastructure process	Unit	2025, very optimistic	2025, optimistic realistic	2025, pessimistic	2050, very optimistic	2050, optimistic realistic	2050, pessimistic
diesel, at regional storage	RER	0	kg	2,02E-1	2,07E-1	2,11E-1	1,88E-1	1,95E-1	2,02E-1

5.5.2 Air emissions

CO_2, SO_2 and heavy metal emissions from combustion are calculated on the basis of the fuel characteristics. Also, waste heat per driven kilometre is proportional to the fuel consumed. With respect to the other main air emissions in the “today” dataset (Spielmann et al. 2004), the changes expected for the future scenarios are derived from TREMOD (2007). Since a more detailed analysis of possible changes in emissions seems impossible due to the complexity of possible reductions and the interdependencies with fuel consumption, these changes are assumed to occur in all three scenarios and both time horizons (see Table 5-17). The emission values given in the table represent the multiplying factor for the future emission based on the amount of fuel consumed in the future, i.e. in order to give this emission based on the vehicle kilometre this value is to be decreased by the reduction in fuel consumption. Since the focus already in the pessimistic scenario is on greenhouse gas reduction some of the emissions presented rise due to the fact that technological means for consumption decrease and pollutant decrease are in most cases contradictory. However, in virtually no scenario a significant increase is predicted. The figures derived from these findings are listed in Table 5-18.

Table 5-17: Air emission changes of relevant pollutants with respect to the “today” dataset. The percentage is the multiplying factor for the future emission on the basis of the consumed fuel amount.

Name	Location	Infrastructure process	Unit	Future values
Ammonia				128%
Benzene				154%
Carbon monoxide, fossil				91%
Dinitrogen monoxide				127%
Methane, fossil				154%
Nitrogen oxides				48%
NMVOC, non-methane volatile organic compounds, unspecified origin				154%
Particulates, < 2.5 um				33%
Particulates, > 10 um				33%
Particulates, > 2.5 um, and < 10um				33%

Table 5-18: Air emissions of relevant pollutants in the different future scenarios. The values are given per vehicle kilometre.

Name	Location	Infrastructure process	Unit	2025, very optimistic	2025, optimistic realistic	2025, pessimistic	2050, very optimistic	2050, optimistic realistic	2050, pessimistic
Ammonia			kg	2,87E-6	2,94E-6	3,01E-6	2,68E-6	2,78E-6	2,87E-6
Benzene			kg	2,35E-5	2,41E-5	2,46E-5	2,20E-5	2,27E-5	2,35E-5
Cadmium			kg	4,67E-9	4,78E-9	4,89E-9	4,36E-9	4,52E-9	4,67E-9
Carbon dioxide, fossil			kg	6,29E-1	6,43E-1	6,58E-1	5,87E-1	6,08E-1	6,29E-1
Carbon monoxide, fossil			kg	1,35E-3	1,38E-3	1,41E-3	1,26E-3	1,30E-3	1,35E-3
Chromium VI			kg	7,19E-11	7,36E-11	7,53E-11	6,71E-11	6,95E-11	7,19E-11
Dinitrogen monoxide			kg	2,86E-5	2,93E-5	3,00E-5	2,67E-5	2,77E-5	2,86E-5
Heat, waste			MJ	9,15E+0	9,37E+0	9,58E+0	8,54E+0	8,85E+0	9,15E+0
Lead			kg	1,58E-8	1,62E-8	1,66E-8	1,48E-8	1,53E-8	1,58E-8
Mercury			kg	3,03E-12	3,10E-12	3,17E-12	2,83E-12	2,93E-12	3,03E-12
Methane, fossil			kg	9,01E-5	9,22E-5	9,43E-5	8,41E-5	8,71E-5	9,01E-5
Nickel			kg	3,59E-8	3,67E-8	3,75E-8	3,35E-8	3,47E-8	3,59E-8
Nitrogen oxides			kg	2,92E-3	2,99E-3	3,06E-3	2,72E-3	2,82E-3	2,92E-3
NMVOC, non-methane volatile organic compounds, unspecified origin			kg	1,10E-3	1,13E-3	1,16E-3	1,03E-3	1,07E-3	1,10E-3
Particulates, < 2.5 um			kg	1,24E-4	1,27E-4	1,30E-4	1,16E-4	1,20E-4	1,24E-4
Particulates, > 10 um			kg	1,11E-4	1,13E-4	1,16E-4	1,03E-4	1,07E-4	1,11E-4
Particulates, > 2.5 um, and < 10um			kg	2,75E-5	2,82E-5	2,88E-5	2,57E-5	2,66E-5	2,75E-5
Sulfur dioxide			kg	1,20E-4	1,23E-4	1,26E-4	1,12E-4	1,16E-4	1,20E-4

5.5.3 Selected cumulative life cycle inventory results

Table 5-19 and Table 5-20 show selected cumulative results of 1 km of transport in a 32-t lorry for different future scenarios.

Table 5-19: Selected cumulative life cycle inventory results of 1 km load transport in a 32-t lorry, realistic-optimistic scenario

	unit	2025RO	2050RO
Resources			
Oil, crude, in ground	kg	2,30E-01	2,16E-01
Selected air emissions			
Carbon dioxide, fossil	kg	7,36E-01	6,96E-01
Methane, fossil	kg	4,74E-04	4,47E-04
Nitrogen oxides	kg	3,35E-03	3,16E-03
NMVOC total	kg	1,48E-03	1,40E-03
PM2.5	kg	1,62E-04	1,52E-04
Sulfur dioxide	kg	1,02E-03	9,64E-04

Table 5-20: Selected cumulative life cycle inventory results of 1 km load transport in 32-t lorry, very optimistic scenario

	unit	2025VO	2050VO
Resources			
Oil, crude, in ground	kg	2,24E-01	2,09E-01
Selected air emissions			
Carbon dioxide, fossil	kg	7,19E-01	6,71E-01
Methane, fossil	kg	4,63E-04	4,30E-04
Nitrogen oxides	kg	3,27E-03	3,05E-03
NMVOC total	kg	1,44E-03	1,35E-03
PM2.5	kg	1,58E-04	1,47E-04
Sulfur dioxide	kg	9,99E-04	9,29E-04

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