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Summary

Data for mechanical engineering processes based on literature sources and industry values are compiled in this report. As there are a lot of machining processes used in factories, the coverage is limited by data availability. Most of the data available is incomplete with regard to the use in a life cycle inventory. The focus is often only on electricity and sometimes also on other energy carriers. Data on the infrastructure or possible emissions are rarely found.

As a result of this most datasets are a combination of process specific data (at least electricity) and average data filling in the data gaps as far as possible. The datasets provided are, therefore, often rough estimates and it is recommended to check the appropriateness if one of these datasets becomes important in a product system.

This report covers three aspects of mechanical engineering:

1) *machining processes*
2) *ancillary machining processes*
3) *compressed air supply.*

There are basically two types of *machining:*

a) **chipping:** material is removed from the raw part (turning, milling, drilling)
b) **chipless machining:** the raw part is only reshaped and no material is lost (impact extrusion, deep drawing, laser machining)

Furthermore, average machining datasets are provided to be used when the type of machining is unknown. This encompasses on the one hand average machines and machine operation but on the other hand also average factory infrastructure and factory operation.

Concerning *ancillary machining processes*, there is the dataset "degreasing" which is commonly used together with a machining process and can be added as necessary.

Finally, datasets for a range of *compressed air supply* systems is provided. Most of the machines in a mechanical engineering factory make use of compressed air. Moreover, it is sometimes also used for small devices such as screwdrivers and for cleaning purposes.

All in all, the datasets provided encompass a decent range of common metal processing systems covering not only the direct but also the most relevant indirect aspects.

The LCI results show a clear correlation between the energy requirements and the cumulative emissions. This comes not as a surprise with electricity and thermal energy being one of the most relevant inputs to the processes. Chipping processes are additionally dependent on the material processed.

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1 Introduction

1.1 Motivation

It is common practice to neglect machining processes in LCA by assuming that this aspect is of low importance. While this might be true in cases of low machining intensity this assumption will not hold for heavily machined parts. When minimal weight is a primary goal, for example when constructing an airplane, the parts are machined as intensely as possible removing a large fraction of the initial material.

It was realised in recent years that compressed air supply is often a relevant consumer of electricity in a factory. Therefore, this aspect was also investigated.

The datasets compiled in this report permit to include machining processes (including compressed air) in LCAs and to estimate the relevance of machining processes in the product under study.

1.2 Principles Applied

1.2.1 Factory Infrastructure

In some cases a raw metal part is undergoing a single machining step, in other cases a sequence of different types of machining is necessary to realise the final shape. If more than one type of machining is applied this can be either done in the same or in a sequence of factories. These different workflows are relevant when it comes to include the factory infrastructure in the inventory of the machining datasets. It was decided to include the infrastructure in all datasets which represents the single machining and the sequence of factories cases. As it was not possible to make a relationship between factory infrastructure and laser machining hours, no factory hall infrastructure is included there. The manufacture of the laser equipment is included, however.

Compressed air supply is considered an ancillary process in a factory. The factory infrastructure use of ancillary processes is already included in the factory infrastructure dataset and, as a consequence, also in the machining processes. Therefore, the compressed air supply are inventoried without factory infrastructure.

1.2.2 Degreasing

A dataset concerning the degreasing of metal parts is compiled to complete the machining datasets. Although it is a common pre-processing step it is not added to any of the machining datasets. This is because the machining datasets are based on mass (or time in the case of laser machining) but degreasing is based on area. The ratio between mass and area can vary to a large extent. Comparing a spherically shaped part with a thin sheet, 1 m^2 of surface involve much more mass in the first case.

Therefore, the dataset "degreasing" can only be applied correctly when the approximate area vs. mass ratio of the part under study is known. It is the practitioner's responsibility to add degreasing in an appropriate amount to machining processes.

1.2.3 Reference Unit and Material Input

In the case of machining datasets where material is removed during processing (chipping), the reference unit is always the amount of material removed, i.e. 1 kg of chipping machining removes 1 kg of material. The amount of material removed is always included in these types of machining datasets and needs not to be added separately.[1] That is why individual datasets per type of material processed (steel, copper, etc.) are developed. It is assumed that the material removed is recycled.

As chipless machining occurs without the loss of material it is not necessary to include it. Furthermore, the reference unit of the dataset always relates to the total weight of the product, i.e. 1 kg of chipless machining reshapes a raw part of 1 kg. Laser machining is considered as a chipless technology since the amount of material vaporised by the laser beam is extremely low (a few mg per second) and, therefore, has no metal input considered.

1.2.4 Data Gaps

In most cases manufacturing data reported for metal working processes is limited to electricity consumption. In these cases the information gathered in chapter 2 on average machine processing is used to fill the gaps with average values as necessary.

1.3 Uncertainty

There is a broad range of manufacturing efficiency depending not only on the type of manufacturing but also on different practices for the same manufacturing work. For example the energy consumption of a machine during setup and waiting is significantly higher in the case of small series compared to mass production. Bongard & Jufer (1992) have found an utilisation rate of as low as 15% for small to medium series and about 50% in the case of mass production. These influences have to be considered when using the manufacturing processes provided.

Furthermore, about every time series in the environmental report of a manufacturing company shows that within a short time period significant reductions in the environmental impact of the production are feasible as soon as a certain environmental awareness arises in a company (e.g. by deciding to publish an environmental or sustainability report).

As a consequence of this, the datasets compiled and presented in this report are only an indication, i.e. one value out of a broad range. If it is realised that machining processes are important in the system under study it is important to compile data for the specific situation.

1.4 Overview of Content

There are basically two types of machining:

c) **chipping:** material is removed from the raw part (e.g. drilling)

d) **chipless machining:** the raw part is only reshaped and no material is lost (e.g. deep drawing)

A special case is laser machining, where the laser only removes (vaporises) small amounts of the raw material but by cutting closed (circle-like) shapes allows to remove significant shares.

This report presents on one hand machining processes on two different levels:

a) average machining (chapter 2) – to be applied in cases the type of machining is not known

b) for a number of different types of machining (chapter 3 to 9)

[1] For example 0.2 kg are removed from a raw copper part initially weighting 1 kg. In this case you have to inventory 0.2 kg of the machining process and 0.8 kg of copper.

and on the other hand on the ancillary process:

c) compressed air supply (chapter 0)

In the case of machining processes as well as compressed air not only one but in each case a range of datasets is provided. In the case of machining the differentiation is based on the type of metal and sometimes divided further into subtypes of the machining process. Compressed air supply datasets are made available for different pressure levels, which has a direct impact on electricity consumption, as well as different quality levels of the installations.

2 Average Machine Processing

2.1 Introduction

In the literature environmentally relevant data for mechanical engineering processes are often limited to electricity consumption. While electricity is often one relevant aspect, others, such as lighting, heating, waste disposal, administration department, land use and last but not least the construction of the machine itself can be of relevance too.

In this chapter, five average manufacturing processes are described (the main processes in Tab. 2.1). Each of these processes contains five inputs (the sup-processes in Tab. 2.1). These sub-processes can be used as an average input in metal working datasets where only limited information (e.g. electricity consumption of the machine) is known. The amount of each process that is needed (based on metal removed or metal processed) is indicated in Fig. 2.1.

Tab. 2.1: Overview of the average metal product manufacturing processes, their sub-process and the reference for the inventory of each

	Reference unit of the Inventory	Chapter
Main Processes		
steel product manufacturing	per kg of *steel in product*	2.3
chromium steel product manufacturing	per kg of *chromium steel in product*	2.3
aluminium product manufacturing	per kg of *aluminium in product*	2.3
copper product manufacturing	per kg of *copper in product*	2.3
metal product manufacturing	per kg of *metal in product*	2.3
Sub-Processes		
metal working machine	per kg of *machine*	2.5
metal working machine operation	per kg of *metal in product*	2.4
metal working factory	per unit of *factory*	2.7
metal working factory operation	per kg of *metal in product*	2.6
metal input (i.e. steel, chromium steel, aluminium or a mix of these)	kg *metal*	ecoinvent report on metals (Classen et al. 2007)

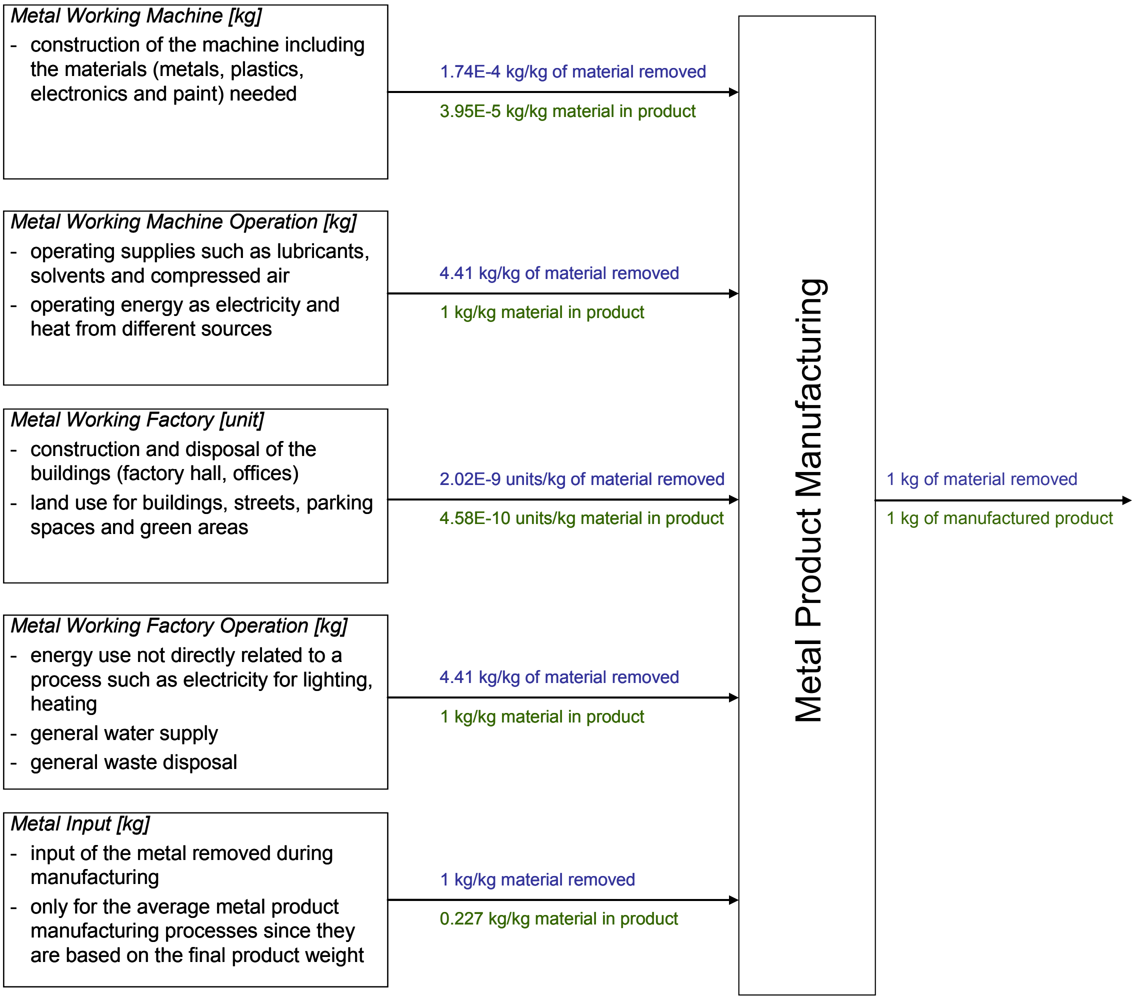

Fig. 2.1: Diagram outlining the structure of the processes of average metal product manufacturing. Also indicated are the demand of each sub-process per kg of metal removed and per kg of metal product.

2.2 Data Sources and Quality

The material composition of machines is rarely indicated by the manufacturers. *Environmental Product Declarations* (EPDs) of manufacturing machines containing material composition data was searched for but no information could be obtained. Therefore, public EPD data on similar machines had to be taken as a substitute to achieve at least a rough average estimation on the machine infrastructure (chapter 2.5). As a consequence, the uncertainty of the machine infrastructure data is rather high.

A large number of environmental reports of companies in the engineering business were analysed to be able to calculate average inventories of machine operation, factory operation and factory infrastructure (chapters 2.4, 2.6 and 2.7 respectively). Eight reports were finally chosen mainly based on the broadness of data reported and mechanical engineering being a main activity of the reporting company or site (Tab. 2.2). The data covers on one hand a variety of company sizes but also different areas of mechanical engineering. Furthermore, the data is thought to be reliable. This leads to a data quality thought to be appropriate. However, it has to be kept in mind that companies publishing environmental reports have a certain environmental awareness and are possibly producing with an environmental impact below the average industry.

Because good and up-to-date information is scarce, some calculations are based on rather old studies such as Boustead & Hancock (1979) and Degner & Wolfram (1990) as well as own estimations.

Tab. 2.2: Description of the companies of which the environmental reports have been used for data collection.

	Danfoss	**Enz Technik AG**	**Festo AG**	**Witzenmann GmbH**	**Palfinger**
Data Source	(Danfoss 2006)	(enz 2005)	(Festo 2003)	(Witzenmann 2004)	(Palfinger 2006)
Year of Data	2005	2004	2002	2003	2005
Employees	18000		10000	2500	3300
Business Area	Mechanical and electronic products for heating, cooling and production line controls	Pipe cleaning tools for industry and municipalities	Automation with pneumatic and electric components and systems	Production of flexible metal elements	Manufacturing of hydraulic lifting, loading and handling systems

Tab. 2.2 (continued)

	Huber	**Gorenje**	**Bitzer (Hailfingen)**
Data Source	(Huber 2004)	(Gorenje 2004)	(Bitzer 2006)
Year of Data	2002	2003	2005
Employees	450	9146	50
Business Area	Plant engineering in the area of water technology (processes almost exclusively stainless steel)	Mainly production of household appliances (cookers, washing machines and fridge freezers)	Production of auxiliary equipment for cooling systems such as heat exchanger and liquid collectors

2.3 Metal Product Manufacturing

2.3.1 System Boundaries

The metal product manufacturing encompasses the machine and factory infrastructure (chapter 2.5 and 2.7) as well as their operation (chapter 2.4 and 2.6). Furthermore, it includes the metal removed during machining, which is assumed to be recycled.

2.3.2 Reference Unit

The reference unit of metal product manufacturing is 1 kg of manufactured product (see also Fig. 2.1).

2.3.3 Life Cycle Inventory

There are five average manufacturing datasets. These are identical except for the metal input considered:

1. *steel product manufacturing, average metal working*
   the product is made of low-alloy steel
2. *chromium steel product manufacturing, average metal working*
   the product is made of chromium steel

3. *aluminium product manufacturing, average metal working*
   the product is made of aluminium
4. *copper product manufacturing, average metal working*
   the product is made of copper
5. *metal product manufacturing, average metal working*
   the product is made of an average of low-alloy and chromium steel as well as aluminium and copper (can be used when the metal composition is completely unknown)

As on average 18% of the metal is removed during manufacturing (Tab. 2.12) an additional 0.227 kg (ca. 18% / 82%) has to be considered as input. Danfoss (2006) provides a statistic on the different metals processed in its plants (Tab. 2.3). As Danfoss is the largest producer, these values are thought to be suitable for the fifth dataset representing a mix of different metals.

Tab. 2.3: Share of the different types of metals for one company

Data Source		**Danfoss** (Danfoss 2006)	**Remark**
Metal Input	t/a	208'281	
Metal in Products	t/a	152'160	
Share in Products		73%	
Metal Input Shares			
Iron and low-alloy Steel		82.5%	inventoried as low-alloy steel
Chromium Steel		2.0%	
Aluminium		3.3%	
Brass, Copper, Copper alloys		12.3%	Inventoried as copper

Tab. 2.4: Unit process raw data of the five "product manufacturing" datasets

	Name	Location	InfrastructureProcess	Unit	metal product manufacturing, average metal working	steel product manufacturing, average metal working	chromium steel product manufacturing, average metal working	aluminium product manufacturing, average metal working	copper product manufacturing, average metal working	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0	0			
	Unit				kg	kg	kg	kg	kg			
product	metal product manufacturing, average metal working	RER	0	kg	1							
product	steel product manufacturing, average metal working	RER	0	kg		1						
product	chromium steel product manufacturing, average metal working	RER	0	kg			1					
product	aluminium product manufacturing, average metal working	RER	0	kg				1				
product	copper product manufacturing, average metal working	RER	0	kg					1			
technosphere	metal working machine, unspecified, at plant	RER	1	kg	3.95E-5	3.95E-5	3.95E-5	3.95E-5	3.95E-5	1	1.24	(1,3,2,1,3,4);
	operation, metal working machine, average process heat	RER	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.24	(1,3,2,1,3,4);
	metal working factory	RER	1	unit	4.58E-10	4.58E-10	4.58E-10	4.58E-10	4.58E-10	1	1.24	(1,3,2,1,3,4);
	operation, metal working factory, average heat energy	RER	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.24	(1,3,2,1,3,4);
	steel, low-alloyed, at plant	RER	0	kg	1.87E-1	2.27E-1				1	1.25	(2,3,2,3,3,4);
	chromium steel 18/8, at plant	RER	0	kg	4.47E-3		2.27E-1			1	1.25	(2,3,2,3,3,4);
	aluminium, production mix, at plant	RER	0	kg	7.43E-3			2.27E-1		1	1.25	(2,3,2,3,3,4);
	copper, at regional storage	RER	0	kg	2.78E-2				2.27E-1	1	1.25	(2,3,2,3,3,4);

2.4 Machine Operation

2.4.1 System Boundaries

The operation of the machine normally encompasses electricity, lubricant and compressed air consumption as well as solvent use. The abrasion of tools in use and their replacement are not accounted for due to lack of data. Disposal and emissions of lubricant, solvents and water vapour are taken into account as far as possible.

2.4.2 Reference Unit

The demand for machine operation is 1 kg per 1 kg of metal in product. If the reference is 1 kg of metal removed, then 4.41 kg of machine operation is needed.

2.4.3 Life Cycle Inventory

A share of 40 % (Degner & Wolfram 1990) to 47 % (Boustead & Hancock 1979) of the total energy consumption of a factory is directly related to production. The values from Boustead & Hancock (1979) are used in the following since he further differentiates between energy carriers (Tab. 2.5). These values are used to split the total energy consumption for each energy carrier mentioned in the environmental reports into a part "machine operation" (this chapter) and a part "factory operation" (chapter 2.6).

Since the heat energy used by one machine is normally from single energy source, the machine operation process is not only provided as an average of different energy carriers but also for the single sources hard coal, heavy and light fuel oil as well as natural gas (see Tab. 2.7).

Tab. 2.5: Contribution of different energy carriers to machine operation and factory operation. Calculated from data in Boustead & Hancock (1979)

	Electricity	Oil fuels[2]	Other fuels	Overall
Machine Operation				
Average	96.0%	87.8%	0.0%	47.0%
Minimum Reported	94.6%	0.0%	0.0%	34.3%
Maximum Reported	97.6%	96.2%	0.0%	60.6%
Factory Operation				
Average	4.0%	12.2%	100.0%	53.0%

The data for deducing the operation of mechanical engineering machines (Tab. 2.6) is taken from the most current environmental reports of these companies. The average values used in this study are calculated as the arithmetic mean of the reported values. Inputs not reported by the companies were assumed to be lacking (and not zero) with the exception of the energy carriers where lacking energy carriers are likely to be zero. Tetrachloroethene is included in the average of the solvents

The electricity consumption is reduced by the amount needed for the compressed air since otherwise the electricity would be counted twice. The estimation of the electricity consumption for compressed air generation is based on the average installation of a larger (> 30 kW) system at 7 bar (see chapter 10.3.3).

[2] As natural gas has been replacing fuel oil in recent years, it is assumed that its share is comparable to the category oil fuels.

Tab. 2.6: Data of the operation of mechanical engineering machines

		Danfoss	**Enz Technik AG**	**Festo AG**	**Witzenmann GmbH**	**Palfinger**
Data Source		(Danfoss 2006)	(enz 2005)	(Festo 2003)	(Witzenmann 2004)	(Palfinger 2006)
Metal Input	t/a	208'281	44	17'063	11'000	33'326
Metal in Products	t/a	152'160	17	14'006	10'250	26'732
Share in Products		73%	39%	82%	93%	80%
Technosphere Inputs per kg of Metal in Product						
Solvents	kg	1.92E-03	4.34E-03			
Tetrachloroethene	kg				2.93E-04	
Lubricating Oil	kg					
Compressed Air	m^3					
Natural Gas	MJ	3.19	0	5.76	0.46	5.02
Fuel Oil	MJ	0.22	12.79	0.92	1.17	0.25
Heavy Fuel Oil	MJ	0.26	0	0	0	0
District Heat	MJ	0	0	0	0	0
Electricity	kWh	1.65	0.63	2.49	1.22	0.98
Electricity without compressed air	kWh					
Emissions to Air per kg of Metal in Product						
Solvents	kg	4.93E-04	1.11E-03			
Tetrachlorethene	kg				7.51E-05	
Water Vapour	kg			1.25E+00		

Tab. 2.6 (continued)

Data Source		**Huber** (Huber 2004)	**Gorenje** (Gorenje 2004)	**Bitzer (Hailfingen)** (Bitzer 2006)	**This Study**
Metal Input	t/a	2'906	155'390	635	**53'580**
Metal in Products	t/a	2'035	143'688	509	**43'675**
Share in Products		70%	92%	80%	**82%**
Technosphere Inputs per kg of Metal in Product					
Solvents	kg	1.60E-04	2.63E-04		**1.40E-03**
Tetrachloroethene	kg				incl. in solvents
Lubricating Oil	kg	1.04E-03		6.99E-04	**8.67E-04**
Compressed Air	m^3		0.29		**0.29**
Natural Gas	MJ	1.21	0.63	0	**2.03**
Fuel Oil	MJ	0	0	5.48	**2.60**
Heavy Fuel Oil	MJ	0	0	0	**0.033**
District Heat	MJ	0	0	0	**0**
Electricity	kWh	1.09	0.41	1.21	1.21
Electricity without compressed air	kWh				**1.15**
Emissions to Air per kg of Metal in Product					
Solvents	kg		6.75E-05		**5.58E-04**
Tetrachlorethene	kg				**7.51E-05**
Water Vapour	kg	9.98E-01			**1.12E+00**

Tab. 2.7: Unit process raw data of the five "metal working machine operation" datasets

	Name	Location	InfrastructureProcess	Unit	operation, metal working machine, average process heat	operation, metal working machine, process heat from hard coal	operation, metal working machine, process heat from light fuel oil	operation, metal working machine, process heat from heavy fuel oil	operation, metal working machine, process heat from natural gas	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER	RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0	0			
	Unit				kg	kg	kg	kg	kg			
product	operation, metal working machine, average process heat	RER	0	kg	1							
product	operation, metal working machine, process heat from hard coal	RER	0	kg		1						
product	operation, metal working machine, process heat from light fuel oil	RER	0	kg			1					
product	operation, metal working machine, process heat from heavy fuel oil	RER	0	kg				1				
product	operation, metal working machine, process heat from natural gas	RER	0	kg					1			
technosphere	solvents, organic, unspecified, at plant	GLO	0	kg	1.40E-3	1.40E-3	1.40E-3	1.40E-3	1.40E-3	1	1.24	(1,3,2,1,3,4); average of 8 companies
	tetrachloroethylene, at plant	WEU	0	kg	0	0	0	0	0	1	1.24	(1,3,2,1,3,4); average of 8 companies
	lubricating oil, at plant	RER	0	kg	8.67E-4	8.67E-4	8.67E-4	8.67E-4	8.67E-4	1	1.24	(1,3,2,1,3,4); average of 8 companies
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	8.67E-4	8.67E-4	8.67E-4	8.67E-4	8.67E-4	1	1.33	(4,3,2,1,3,4); assumption for disposal route
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3	2.91E-1	2.91E-1	2.91E-1	2.91E-1	2.91E-1	1	1.24	(1,3,2,1,3,4); average of 8 companies
	hard coal, burned in industrial furnace 1-10MW	RER	0	MJ	0	4.67E+0				1	1.24	(1,3,2,1,3,4); average of 8 companies
	light fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	2.60E+0		4.67E+0			1	1.24	(1,3,2,1,3,4); average of 8 companies
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	3.28E-2			4.67E+0		1	1.24	(1,3,2,1,3,4); average of 8 companies
	natural gas, burned in boiler modulating >100kW	RER	0	MJ	2.03E+0				4.67E+0	1	1.24	(1,3,2,1,3,4); average of 8 companies
	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	1.15E+0	1.15E+0	1.15E+0	1.15E+0	1.15E+0	1	1.24	(1,3,2,1,3,4); average of 8 companies
emission air, high population density	Hydrocarbons, aliphatic, alkanes, unspecified	-	-	kg	5.58E-4	5.58E-4	5.58E-4	5.58E-4	5.58E-4	1	1.58	(1,3,2,1,3,4); average of 8 companies
	Ethene, tetrachloro-	-	-	kg	7.51E-5	7.51E-5	7.51E-5	7.51E-5	7.51E-5	1	1.58	(1,3,2,1,3,4); average of 8 companies
	water	-	-	kg	1.12E+0	1.12E+0	1.12E+0	1.12E+0	1.12E+0	1	1.58	(1,3,2,1,3,4); average of 8 companies
	Heat, waste	-	-	MJ	4.13E+0	4.13E+0	4.13E+0	4.13E+0	4.13E+0	1	1.24	(1,3,2,1,3,4); average of 8 companies

Tab. 2.8: Metainformation of the datasets "metal product manufacturing" (all datasets contain the same information, therefore, only one is shown here)

ReferenceFunction	Name	metal product manufacturing, average metal working
Geography	Location	RER
ReferenceFunction	InfrastructureProcess	0
ReferenceFunction	Unit	kg
	IncludedProcesses	This dataset encompasses manufacturing processes to make a semi-manufactured product into a final product. It includes average values for the processing by machines as well as the factory infrastructure and operation. Furthermore, an additional metal input is considered for the loss during processsing.
	Amount	1
	LocalName	Metallproduktherstellung, durchschnittliche Metallbearbeitung
	Synonyms	
	GeneralComment	1 kg of this process is needed to produce 1 kg of final product.
	InfrastructureIncluded	1
	Category	metals
	SubCategory	general manufacturing
	LocalCategory	Metalle
	LocalSubCategory	Fertigung, allgemein
	Formula	
	StatisticalClassification	
	CASNumber	
TimePeriod	StartDate	2006
	EndDate	2007
	DataValidForEntirePeriod	1
	OtherPeriodText	
Geography	Text	Average data from several local to global sized companies. The main focus is on Germany and Europe.
Technology	Text	The data is an average of mostly European companies and their production technologies.
Representativeness	Percent	0
	ProductionVolume	unknown
	SamplingProcedure	unknown
	Extrapolations	none
	UncertaintyAdjustments	none

2.5 Machine Infrastructure

2.5.1 System Boundaries

The machine infrastructure encompasses primarily the parts that are directly needed for the operation of the machines. This is the machine itself but it also covers for example trays that are necessary to feed a machine. However, it does for example not include a centralised lubricant distribution installation[3] or the installation of a safety fence.

[3] since the lubricant barrel can be placed directly next to the machine, a centralised system is considered a separate installation

2.5.2 Reference Unit

The reference unit of the metal working machine is 1 kg of this dataset per 1 kg of machine installed. In order to calculate the demand per kilogram of metal in product or metal removed, one has to know two aspects:

1. the total weight of the machine(s) installed
2. the amount (weight) of the products produced over the whole lifetime (e.g. estimated by the annual production multiplied with the expected service life span of the machine)

This information is rarely known. Furthermore, it is very much dependent on the production pattern. A mechanical engineering shop producing mainly small series cannot utilise the machines as intensively as a production centre that is part of a mass production line. It was possible to estimate two values in the case of deep drawing (Tab. 7.2, page 53) of which the average is 40 mg machine/kg product. If the reference is “metal removed” then the machine infrastructure demand amounts to 174 mg machine/kg material removed.

2.5.3 Life Cycle Inventory

The specified machines in Tab. 2.9 cover a typical range of mechanical engineering machines. While the TetraPak A3/Flex is very similar to a fully enclosed machining centre the AC- and DC-machines cover different sizes of less complex machines.

Although different machines and machine sizes are included in Tab. 2.9, the amount of ferrous and non-ferrous metal leads to a very similar share in all four cases.

Tab. 2.9: Material composition of the four machines used for the calculation of an average value for the machine infrastructure.

	TetraPak A3/Flex	**GBA 800**	**DMI 180**	**DMI 280**	**This Study**
Type of Machine	Filling Machine	AC-Machine	DC-Machine	DC-Machine	Average
Data Source	(Tetra Pak 2005)	(ABB 2001)	(ABB 2000)	(ABB 2000)	
Chromium Steel	58.0%	5.8%	6.6%	3.4%	18.5%
Low-alloy Steel	0%	29.4%	59.5%	63.9%	38.2%
Unalloyed Steel	11.5%	44.0%	6.2%	6.8%	17.1%
Cast Iron	0%	2.4%	10.6%	11.0%	6.00%
Ferrous Metal	***69.5%***	***81.7%***	***82.9%***	***85.1%***	***79.8%***
Aluminium	8.6%	0.2%	0.2%	0.3%	2.32%
Copper	3.7%	10.4%	12.4%	11.2%	9.43%
Non-Ferrous Metal	***12.3%***	***10.6%***	***12.6%***	***11.5%***	***11.8%***
HDPE	6.2%	0%	0%	0%	1.55%
PP	0.2%	0%	0%	0%	0.06%
PA	1.8%	0%	0%	0%	0.45%
PVC	2.7%	0%	0%	0%	0.68%
Polycarbonate	0.1%	0%	0%	0%	0.02%
PUR	0.1%	1.9%	0.8%	0.6%	0.85%
Thermosets&-plasts	***11.1%***	***1.9%***	***0.8%***	***0.6%***	***3.60%***
Rubber	3.7%	0%	0%	0%	0.93%
Silicone	1.7%	0%	0%	0%	0.43%
Rubbers	***5.5%***	***0%***	***0%***	***0%***	***1.36%***
Glass	1.5%	0%	0%	0%	0.38%
Printed Wiring Board	0.1%	0%	0%	0%	0.02%
Wooden board[4]	0%	5.8%	3.6%	2.8%	3.03%
Paint	0%	0.1%	0.1%	0.1%	0.05%
Miscellaneous Materials	***1.6%***	***5.8%***	***3.7%***	***2.8%***	***3.48%***
Materials Considered (kg)	8'891	27'852	977	2'836	
Share of Total Weight	99.97%	99.71%	99.60%	99.61%	

[4] Included as HDPE in the inventory since wood is considered an unusual material in a metal working machine

Tab. 2.10: Unit process raw data of the five "metal working machine operation" datasets

	Name	Location	InfrastructureProcess	Unit	metal working machine, unspecified, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				1			
	Unit				kg			
product	metal working machine, unspecified, at plant	RER	1	kg	1			
technosphere	chromium steel 18/8, at plant	RER	0	kg	1.85E-1	1	1.60	(1,5,2,5,4,4); average of 4 machines
	steel, low-alloyed, at plant	RER	0	kg	3.82E-1	1	1.60	(1,5,2,5,4,4); average of 4 machines
	reinforcing steel, at plant	RER	0	kg	1.71E-1	1	1.60	(1,5,2,5,4,4); average of 4 machines
	cast iron, at plant	RER	0	kg	6.00E-2	1	1.60	(1,5,2,5,4,4); average of 4 machines
	aluminium, production mix, at plant	RER	0	kg	2.32E-2	1	1.60	(1,5,2,5,4,4); average of 4 machines
	copper, at regional storage	RER	0	kg	9.43E-2	1	1.60	(1,5,2,5,4,4); average of 4 machines
	polyethylene, HDPE, granulate, at plant	RER	0	kg	4.57E-2	1	1.60	(1,5,2,5,4,4); average of 4 machines
	polypropylene, granulate, at plant	RER	0	kg	5.67E-4	1	1.60	(1,5,2,5,4,4); average of 4 machines
	nylon 6, at plant	RER	0	kg	4.45E-3	1	1.60	(1,5,2,5,4,4); average of 4 machines
	polyvinylchloride, at regional storage	RER	0	kg	6.82E-3	1	1.60	(1,5,2,5,4,4); average of 4 machines
	polycarbonate, at plant	RER	0	kg	2.12E-4	1	1.60	(1,5,2,5,4,4); average of 4 machines
	polyurethane, flexible foam, at plant	RER	0	kg	8.47E-3	1	1.60	(1,5,2,5,4,4); average of 4 machines
	synthetic rubber, at plant	RER	0	kg	9.33E-3	1	1.60	(1,5,2,5,4,4); average of 4 machines
	silicone product, at plant	RER	0	kg	4.31E-3	1	1.60	(1,5,2,5,4,4); average of 4 machines
	flat glass, uncoated, at plant	RER	0	kg	3.83E-3	1	1.60	(1,5,2,5,4,4); average of 4 machines
	printed wiring board, surface mount, at plant	GLO	0	m2	5.16E-5	1	1.60	(1,5,2,5,4,4); average of 4 machines
	alkyd paint, white, 60% in solvent, at plant	RER	0	kg	4.97E-4	1	1.60	(1,5,2,5,4,4); average of 4 machines
	injection moulding	RER	0	kg	5.78E-2	1	1.86	(5,5,2,5,4,4); assumed type of processing
	foaming, expanding	RER	0	kg	8.47E-3	1	1.86	(5,5,2,5,4,4); assumed type of processing
	sheet rolling, copper	RER	0	kg	9.43E-2	1	1.86	(5,5,2,5,4,4); assumed type of processing
	steel product manufacturing, average metal working	RER	0	kg	6.13E-1	1	1.86	(5,5,2,5,4,4); assumed type of processing
	chromium steel product manufacturing, average metal working	RER	0	kg	1.85E-1	1	1.86	(5,5,2,5,4,4); assumed type of processing
	aluminium product manufacturing, average metal working	RER	0	kg	2.32E-2	1	1.86	(5,5,2,5,4,4); assumed type of processing
	disposal, electronics for control units	RER	0	kg	5.16E-5	1	1.86	(5,5,2,5,4,4); assumed route of disposal
	disposal, polyethylene, 0.4% water, to municipal incineration	CH	0	kg	4.57E-2	1	1.86	(5,5,2,5,4,4); assumed route of disposal
	disposal, polyurethane, 0.2% water, to municipal incineration	CH	0	kg	8.47E-3	1	1.86	(5,5,2,5,4,4); assumed route of disposal
	disposal, rubber, unspecified, 0% water, to municipal incineration	CH	0	kg	9.33E-3	1	1.86	(5,5,2,5,4,4); assumed route of disposal
	disposal, polyvinylchloride, 0.2% water, to municipal incineration	CH	0	kg	6.82E-3	1	1.86	(5,5,2,5,4,4); assumed route of disposal
	disposal, plastic, industr. electronics, 15.3% water, to municipal incineration	CH	0	kg	9.54E-3	1	1.86	(5,5,2,5,4,4); assumed route of disposal
	disposal, glass, 0% water, to inert material landfill	CH	0	kg	3.83E-3	1	1.86	(5,5,2,5,4,4); assumed route of disposal

Tab. 2.11: Metainformation of the datasets "operation, metal working machine" (all datasets contain the same information, therefore, only one is shown here)

ReferenceFunction	Name	operation, metal working machine, average process heat
Geography	Location	RER
ReferenceFunction	InfrastructureProcess	0
ReferenceFunction	Unit	kg
	IncludedProcesses	This dataset includes the materials, energies and emissions related to the machines used for machining metal products. This is mainly electricity, compressed air and solvents. Process heat is from average sources.
	Amount	1
	LocalName	Betrieb, Metallbearbeitungsmaschine, durchschnittliche Prozesswärme
	Synonyms	
	GeneralComment	1 kg of this process is needed to produce 1 kg of final product. The data is an estimation based on the average consumption of factories separated into process specific (included here) and ancillary processes (included in metal working factory operation).
	InfrastructureIncluded	1
	Category	mechanical engineering
	SubCategory	equipment and buildings
	LocalCategory	Fertigungsprozesse
	LocalSubCategory	Einrichtungen und Gebäude
	Formula	
	StatisticalClassification	
	CASNumber	
TimePeriod	StartDate	2006
	EndDate	2007
	DataValidForEntirePeriod	1
	OtherPeriodText	
Geography	Text	Average data from several local to global sized companies. The main focus is on Germany and Europe.
Technology	Text	The companies are expected to cover the whole range of metal working.
Representativeness	Percent	0
	ProductionVolume	unknown
	SamplingProcedure	unknown
	Extrapolations	none
	UncertaintyAdjustments	none

2.6 Factory Operation

2.6.1 System Boundaries

The operation of the factory includes supplies that are not directly linked with a machining process but are rather related to the existence of the factory such as general electricity consumption (e.g. lighting), heating, water consumption as well as the disposal of municipal and hazardous waste. It also encompasses the offices.

2.6.2 Reference Unit

The reference unit for factory operation datasets is 1 kg of *metal in final product*. That is for the production of a part of 1 kg one needs 1 kg of factory operation. If the reference is *metal removed* one needs 4.41 kg (ca. 82%/18%) of factory operation for 1 kg of material removed. In both cases it is assumed that on average 18% of the material of the unmachined part is removed by machining (Tab. 2.12).

2.6.3 Life Cycle Inventory

A share of 60% of the total energy consumption of a factory is not directly used by the machines, but by heating, lighting and climatisation (Degner & Wolfram 1990). From the data reported in Boustead & Hancock (1979) one can calculate a similar value of 53% ancillary energy consumption. The detailed information in Boustead & Hancock (1979) is used to divide the total energy consumption reported by the companies into a part "machine operation" and a part "factory operation" (Tab. 2.5).

Since the energy carrier or the mix of energy carriers used for generating heat differs from site to site, the factory operation process is not only provided as an average but also for the single sources hard coal, heavy and light fuel oil as well as natural gas (Tab. 2.13). Natural gas is used as a proxy for district heat because one of the manufacturers using district heat (Witzenmann GmbH), purchases it from a local co-generation plant.

The average value reported in Tab. 2.12 is the arithmetic mean of the data reported by the companies. Values not reported by the companies were assumed to be lacking (and not zero) with the exception of the energy carriers where it is reasonable to assume that those energy carriers not reported are zero.

Tab. 2.12: Input data for the metal working factory operation

		Danfoss	Enz Technik AG	Festo AG	Witzenmann GmbH	Palfinger
Data Source		(Danfoss 2006)	(enz 2005)	(Festo 2003)	(Witzenmann 2004)	(Palfinger 2006)
Metal Input	t/a	208'281	44	17'063	11'000	33'326
Metal in Products	t/a	152'160	17	14'006	10'250	26'732
Share in Products		73%	39%	82%	93%	80%
Technosphere Inputs per kg of Metal in Product						
Tap Water	kg	3.70	57.9	4.74		1.62
Waste Water to Treatment Plant	m^3	3.70E-03	5.79E-02	3.49E-03		1.62E-03
Natural Gas	MJ	0.44	0	0.80	0.06	0.70
Fuel Oil	MJ	0.03	1.79	0.13	0.16	0.04
Heavy Fuel Oil	MJ	0.04	0	0	0	0
District Heat	MJ	0.69	0	0	3.02	0
Electricity	kWh	0.07	0.03	0.10	0.05	0.04
Municipal Waste per kg of Metal in Product						
Incinerated	kg	0.008	0.753		0.002	0.051
Landfilled	kg	0.006				
Hazardous Waste per kg of Metal in Product						
Incinerated	kg	0.041			0.001	0.038

Tab. 2.12 (continued)

Data Source		**Huber** (Huber 2004)	**Gorenje** (Gorenje 2004)	**Bitzer (Hailfingen)** (Bitzer 2006)	**This Study (Average)**
Metal Input	t/a	2'906	155'390	635	**53'580**
Metal in Products	t/a	2'035	143'688	509	**43'675**
Share in Products		70%	92%	80%	**82%**
Technosphere Inputs per kg of Metal in Product					
Tap Water	kg	3.08	3.76		**12.5**
Waste Water to Treatment Plant	m^3	2.08E-03	3.76E-03		**1.21E-02**
Natural Gas	MJ	0.17	0.09	0	**0.283**
Fuel Oil	MJ	0	0	0.76	**0.363**
Heavy Fuel Oil	MJ	0	0	0	**0.005**
District Heat	MJ	0	1.68	0	**0.674**
Electricity	kWh	0.05	0.02	0.05	**0.051**
Municipal Waste per kg of Metal in Product					
Incinerated	kg	0.025	0.084	0.034	**0.137**
Landfilled	kg	0	0	0	**0.006**
Hazardous Waste per kg of Metal in Product					
Incinerated	kg	0.037	0.003	0.027	**0.024**

Tab. 2.13: Unit process raw data of the five "metal working factory operation" datasets

	Name	Location	InfrastructureProcess	Unit	operation, metal working factory, average heat energy	operation, metal working factory, heat energy from hard coal	operation, metal working factory, heat energy from light fuel oil	operation, metal working factory, heat energy from heavy fuel oil	operation, metal working factory, heat energy from natural gas	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0	0			
	Unit				kg	kg	kg	kg	kg			
product	operation, metal working factory, average heat energy	RER	0	kg	1							
product	operation, metal working factory, heat energy from hard coal	RER	0	kg		1						
product	operation, metal working factory, heat energy from light fuel oil	RER	0	kg			1					
product	operation, metal working factory, heat energy from heavy fuel oil	RER	0	kg				1				
product	operation, metal working factory, heat energy from natural gas	RER	0	kg					1			
technosphere	tap water, at user	RER	0	kg	1.25E+1	1.25E+1	1.25E+1	1.25E+1	1.25E+1	1	1.24	(1,3,2,1,3,4); average value of factories with different sizes
	treatment, sewage, to wastewater treatment, class 1	CH	0	m3	1.21E-2	1.21E-2	1.21E-2	1.21E-2	1.21E-2	1	1.24	(1,3,2,1,3,4); average value of factories with different sizes
	hard coal, burned in industrial furnace 1-10MW	RER	0	MJ	0	1.32E+0				1	1.24	(1,3,2,1,3,4); average value of factories with different sizes
	light fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	3.63E-1		1.32E+0			1	1.24	(1,3,2,1,3,4); average value of factories with different sizes
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	4.58E-3			1.32E+0		1	1.24	(1,3,2,1,3,4); average value of factories with different sizes
	natural gas, burned in boiler modulating >100kW	RER	0	MJ	9.57E-1				1.32E+0	1	1.24	(1,3,2,1,3,4); average value of factories with different sizes
	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	5.09E-2	5.09E-2	5.09E-2	5.09E-2	5.09E-2	1	1.24	(1,3,2,1,3,4); average value of factories with different sizes
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	1.37E-1	1.37E-1	1.37E-1	1.37E-1	1.37E-1	1	1.24	(1,3,2,1,3,4); average value of factories with different sizes
	disposal, municipal solid waste, 22.9% water, to sanitary landfill	CH	0	kg	6.24E-3	6.24E-3	6.24E-3	6.24E-3	6.24E-3	1	1.24	(1,3,2,1,3,4); average value of factories with different sizes
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	2.45E-2	2.45E-2	2.45E-2	2.45E-2	2.45E-2	1	1.24	(1,3,2,1,3,4); average value of factories with different sizes
emission air, high population density	Heat, waste	-	-	MJ	1.83E-1	1.83E-1	1.83E-1	1.83E-1	1.83E-1	1	1.24	(1,3,2,1,3,4); average value of factories with different sizes

Tab. 2.14: Metainformation of the datasets "operation, metal working factory" (all datasets contain the same information, therefore, only one is shown here)

ReferenceFunction	Name	operation, metal working factory, average heat energy
Geography	Location	RER
ReferenceFunction	InfrastructureProcess	0
ReferenceFunction	Unit	kg
	IncludedProcesses	This dataset includes ancillary processes to operate a metal working factory. This encompasses electricity for lighting and general water consumption. Heat energy is from average sources.
	Amount	1
	LocalName	Betriebsaufwand, Metallbearbeitungsfabrik, durchschnittliche Wärmeenergie
	Synonyms	
	GeneralComment	1 kg of this process is needed to produce 1 kg of final product. The data is an estimation based on the average consumption of factories separated into process specific (included in metal working machine operation) and ancillary processes (included here).
	InfrastructureIncluded	1
	Category	mechanical engineering
	SubCategory	equipment and buildings
	LocalCategory	Fertigungsprozesse
	LocalSubCategory	Einrichtungen und Gebäude
	Formula	
	StatisticalClassification	
	CASNumber	
TimePeriod	StartDate	2006
	EndDate	2007
	DataValidForEntirePeriod	1
	OtherPeriodText	
Geography	Text	Average data from several local to global sized companies. The main focus is on Germany and Europe.
Technology	Text	The companies are expected to cover the whole range of metal working.
Representativeness	Percent	0
	ProductionVolume	unknown
	SamplingProcedure	unknown
	Extrapolations	none
	UncertaintyAdjustments	none

2.7 Factory Infrastructure

2.7.1 System Boundaries

The factory infrastructure consists of the buildings (factory hall and offices) and the land use for the premises.

2.7.2 Reference Unit

The reference unit of the metal working factory is one unit with an annual output of 43’675 t of metals in products. The service life of the factory is assumed to be 50 years. Hence, the production of 1 kg of metal product needs 4.58E-10 units of the factory. If the reference is 1 kg of metal removed, the demand is 2.02E-9 units of the factory. The average removal rate is in both cases 18% based on the unmachined part (Tab. 2.15).

2.7.3 Life Cycle Inventory

There is no distinction in the environmental reports between factory halls and office buildings. As a simple approximation, the whole indicated building area is counted as factory hall.

Sealed areas not covered by buildings are assumed to be roads and parking spaces on the factory's premises.

Land occupation (as m^2a) is calculated from the average of the companies using the default land use periods (Tab. 2.16), i.e. 50 years for buildings and green spaces and 100 years for roads (Frischknecht et al. 2004).

Tab. 2.15: Land use data for the metal working factory infrastructure

		Danfoss	**Enz Technik AG**	**Festo AG**	**Witzenmann GmbH**	**Palfinger**
Data Source		(Danfoss 2006)	(enz 2005)	(Festo 2003)	(Witzenmann 2004)	(Palfinger 2006)
Metal Input	t/a	208'281	44	17'063	11'000	33'326
Metal in Products	t/a	152'160	17	14'006	10'250	26'732
Share in Products		73%	39%	82%	93%	80%
Technosphere Inputs per factory unit						
Factory Building	m^2			1.21E+05	3.20E+04	
Factory Roads	m^2			6.39E+04	2.56E+04	
Green Space	m^2			2.19E+05	6.40E+03	

Tab. 2.15 (continued)

		Huber	**Gorenje**	**Bitzer (Hailfingen)**	**This Study (average)[a]**	
Data Source		(Huber 2004)	(Gorenje 2004)	(Bitzer 2006)		
Metal Input	t/a	2'906	155'390	635	**53'580**	
Metal in Products	t/a	2'035	143'688	509	**43'675**	
Share in Products		70%	92%	80%	**82%**	
Technosphere Inputs per factory unit						
Factory Building	m^2			2.63E+03	**2.74E+05**	
Factory Roads	m^2			2.11E+03	**1.62E+05**	
Green Space	m^2			1.13E+04	**4.18E+057.90E +04**	

[a] The area is calculated considering the three factories reporting land use figures. The sum of area occupied divided by the sum of metals in products of the three factories are multiplied by the metals in products used in this study (43'675 tons per year).

Tab. 2.16: Unit process raw data of the dataset "metal working factory"

	Name	Location	InfrastructureProcess	Unit	metal working factory	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				1			
	Unit				unit			
product	metal working factory	RER	1	unit	1			
technosphere	building, hall	CH	1	m2	2.74E+5	1	3.06	(1,3,2,1,3,4); average value of three companies
	roads, company, internal	CH	1	m2a	1.62E+7	1	3.06	(1,3,2,1,3,4); average value of three companies
resource, land	Occupation, industrial area, built up	-	-	m2a	1.37E+7	1	1.58	(1,3,2,1,3,4); average value of three companies
	Occupation, traffic area, road network	-	-	m2a	1.62E+7	1	1.58	(1,3,2,1,3,4); average value of three companies
	Occupation, industrial area, vegetation	-	-	m2a	2.09E+7	1	1.58	(1,3,2,1,3,4); average value of three companies
	Transformation, from unknown	-	-	m2	8.54E+5	1	2.07	(1,3,2,1,3,4); average value of three companies
	Transformation, to industrial area, built up	-	-	m2	2.74E+5	1	2.07	(1,3,2,1,3,4); average value of three companies
	Transformation, to traffic area, road network	-	-	m2	1.62E+5	1	2.07	(1,3,2,1,3,4); average value of three companies
	Transformation, to industrial area, vegetation	-	-	m2	4.18E+5	1	2.07	(1,3,2,1,3,4); average value of three companies

Tab. 2.17: Metainformation of the dataset "metal working factory"

ReferenceFunction	Name	metal working factory
Geography	Location	RER
ReferenceFunction	InfrastructureProcess	1
ReferenceFunction	Unit	unit
	IncludedProcesses	This dataset includes the infrastructure of a metal working factory. This encompasses the buildings, roads and parking spaces on the premises as well as other land occupation.
	Amount	1
	LocalName	Metallverarbeitungsfabrik
	Synonyms	
	GeneralComment	1 kg of this process is needed to produce 1 kg of final product. This dataset can be used in combination with the metal working factory operation to get the operation plus infrastructure of metal working without the machine processing.
	InfrastructureIncluded	1
	Category	mechanical engineering
	SubCategory	equipment and buildings
	LocalCategory	Fertigungsprozesse
	LocalSubCategory	Einrichtungen und Gebäude
	Formula	
	StatisticalClassification	
	CASNumber	
TimePeriod	StartDate	2006
	EndDate	2007
	DataValidForEntirePeriod	1
	OtherPeriodText	
Geography	Text	Average data from several local to global sized companies. The main focus is on Germany and Europe.
Technology	Text	The companies are expected to cover the whole range of metal working.
Representativeness	Percent	0
	ProductionVolume	unknown
	SamplingProcedure	unknown
	Extrapolations	none
	UncertaintyAdjustments	none

3 Ancillary Process: Degreasing of Metal Surfaces

3.1 Introduction

Unfinished parts tend to corrode when left exposed to air for a while. This occurs for example when semi-finished have to be stored parts or when they are transported from factory to factory. To prevent this undesired corrosion the simplest option is to grease the surfaces. In that case the part should be degreased before it is machined. Otherwise undesired contaminations can be introduced into the production process.

There are several ways for degreasing metal surfaces. One common type is based on alkaline degreasing baths containing surfactants, which remove oil and grease from the metal surface. The resulting oil-detergent emulsion floats on the surface of the bath and can be removed by gravitational separators, skimmers, micro- or ultra-filtration or other appropriate means (IPPC 2001). This is the process used for the following life cycle inventory.

3.2 Data Sources and Quality

The data was provided by a European producer of household devices. The natural gas data is based on measurements in their factory. The electricity consumption was estimated based on the installed power of the electric devices. The amount of auxiliary supplies is taken from purchase statistics. As there is a wide range of parts that is degreased, it was not possible to determine the exact amount of surface treated, but it was estimated.

IPPC (2001) also reports on degreasing but gives a large range based on the mass of metals treated, which is considered a non-meaningful reference unit. For this reason, it as not possible to use this source of data.

3.3 System Boundaries

The dataset of degreasing encompasses the energy consumption as well as the operating materials needed to operate the degreasing baths. Softening of the water is considered. Transport of the materials is also included. The degreasing facility (infrastructure) is not included.

3.4 Reference Unit

The reference unit of degreasing is 1 m^2 of degreased metal surface.

3.5 Life Cycle Inventory

The data collection in the factory is based on the consumption in the year 2006 and related to square metres based on an estimate concerning the amount of surface degreased in that year (Tab. 3.1).

Electricity is used for pumps and ventilation. The heating of the degreasing bath is operated with natural gas. The waste heat is used to dry the parts after degreasing. Sodium chloride is used in softening the water. Sulphuric acid is needed to neutralise the waste water from the alkaline degreasing bath.

The industrial cleaning detergent used is P3-Saxin from Henkel (2000). The composition was estimated from the ranges given in the safety data sheet (Henkel 2000).

There was no data available concerning the composition of the waste water. Furthermore, it was not possible to retrive data on the installation nor was it possible to relate it to the avarage datasets.

The transport service requirements are calculated with 600 km lorry and 100 km railway for all materials, except for natural gas and tap water.

Tab. 3.1: Energy and operation materials for degreasing metal surfaces

			Degreasing Metal Surfaces per year	Degreasing Metal Surfaces per m^2
Electricity	kWh		311	5.75E-04
Natural Gas	MJ		4680	8.64E-03
Industrial Cleaning Detergent	kg	100%	495	
- Sodium Carbonate	kg	43%	213	3.93E-04
- Sodium Metasilicate	kg	43%	213	3.93E-04
- Phosphate	kg	10%	50	9.13E-05
- non-ionic tensides	kg	4%	20	3.65E-05
Sodium Chloride	kg		2600	4.80E-03
Sulphuric Acid	kg		109	2.01E-04
Water	l		7'038'000	13.0
Surface Degreased	m^2		542'000	1

Tab. 3.2: Unit process raw data of the dataset "degreasing"

	Name	Location	InfrastructureProcess	Unit	degreasing, metal part in alkaline bath	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				m2			
product	degreasing, metal part in alkaline bath	RER	0	m2	1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	5.75E-4	1	1.26	(3,4,1,1,1,5); industry value from one factory
	natural gas, burned in industrial furnace >100kW	RER	0	MJ	8.63E-3	1	1.26	(3,4,1,1,1,5); industry value from one factory
	soda, powder, at plant	RER	0	kg	3.93E-4	1	1.26	(3,4,1,1,1,5); industry value from one factory
	sodium metasilicate pentahydrate, 58%, powder, at plant	RER	0	kg	3.93E-4	1	1.26	(3,4,1,1,1,5); industry value from one factory
	sodium tripolyphosphate, at plant	RER	0	kg	9.13E-5	1	1.26	(3,4,1,1,1,5); industry value from one factory
	ethoxylated alcohols, unspecified, at plant	RER	0	kg	3.65E-5	1	1.26	(3,4,1,1,1,5); industry value from one factory
	sodium chloride, powder, at plant	RER	0	kg	4.80E-3	1	1.26	(3,4,1,1,1,5); industry value from one factory
	sulphuric acid, liquid, at plant	RER	0	kg	2.01E-4	1	1.26	(3,4,1,1,1,5); industry value from one factory
	tap water, at user	RER	0	kg	1.30E+1	1	1.26	(3,4,1,1,1,5); industry value from one factory
	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	1.30E+1	1	1.26	(3,4,1,1,1,5); industry value from one factory
	transport, lorry >16t, fleet average	RER	0	tkm	3.55E-3	1	2.14	(4,5,1,1,1,5); standard distances
	transport, freight, rail	RER	0	tkm	5.91E-4	1	2.14	(4,5,1,1,1,5); standard distances

Tab. 3.3: Metainformation of the dataset "degreasing"

Name	degreasing, metal part in alkaline bath
Location	RER
InfrastructureProcess	0
Unit	m2
IncludedProcesses	The dataset of degreasing encompasses the energy consumption as well as the operating materials needed to operate the degreasing baths. Softening of the water is considered. Transport of the materials is also included. The degreasing facility (infrastructure) is not included.
Amount	1
LocalName	Entfetten, Metallteil in alkalischem Bad
Synonyms	
GeneralComment	The reference unit of degreasing is 1 m2 of degreased metal surface. As there is a large variation from factory to factory with regard to the LCI, it is advised that in case this dataset becomes important in the results, it has to be investigated further if the rough estimations made are applicable or not.
InfrastructureIncluded	1
Category	metals
SubCategory	general manufacturing
LocalCategory	Metalle
LocalSubCategory	Fertigung, allgemein
Formula	
StatisticalClassification	
CASNumber	
StartDate	2007
EndDate	2007
DataValidForEntirePeriod	1
OtherPeriodText	
Text	Geographical coverage encompasses the industrialised countries.
Text	Average technology
Percent	0
ProductionVolume	unknown
SamplingProcedure	unknown
Extrapolations	none
UncertaintyAdjustments	none

3.6 Data Quality

The quality of the received data is considered as good but incomplete since the infrastructure is lacking. Furthermore, there is a possibility for oil and heavy metal emissions with the waste water, which is not covered. Finally, it was not possible to verify the data with other installations since no comparable data is available.

4 Turning

4.1 Introduction

Turning is a chipping process where the piece of material is rotating while the cutting tool is not. Turning can be applied to both the inside and the outside of the piece to be machined. It is normally used to produce cylindrical shapes. While turning can be applied to metals, wood and plastic materials, only the metal processing part is considered in the following.

Turning can be divided into two sub-operations:

1. **roughing:** removing large amounts of material at once, used to give the shape to the piece of material
2. **dressing:** removing only minor amounts of material in order to produce the exact dimensions as well as a smooth surface

There are two main types of machines :

1. the conventional ones that are controlled manually and need constant supervision
2. CNC machines that are working autonomously once programmed (the degree of autonomy depends on the type of machine – i.e. with or without automatic feeder – as well as on the automatisation of the factory)

The trend is towards CNC machines. These machines or machining centres are more versatile in the shapes able to produce as well as less labour intensive. Moreover, they can be easily integrated in modern computer aided manufacturing (CAM) processes. CNC machines are the standard in large scale manufacturing.

4.2 Data Sources and Quality

There are two literature sources stating electricity consumption for turning. While Degner & Wolfram (1990) seem to have taken values measured during a dissertation, it is not clear whether the data mentioned in Barnes (1976) is based on own measurements, estimations or literature. Although there is about 15 years between the two publications the values stated correspond quite closely (between 2% and 30% deviation depending on the assumptions). Therefore, it can be thought that the sources are reliable as far as electricity consumption is concerned.

The main data gaps concern compressed air consumption and cooling lubricant. While conventional machines are assumed to have no or only insignificant need of those ancillary materials, they are becoming relevant in the case of automated machines and are estimated with the values for average machine operation (chapter 2.4).

4.3 System Boundaries

These datasets encompass the direct electricity consumption of the machine as well as compressed air and lubricant oil. Furthermore, the metal removed is included. Factory infrastructure and operation is considered as well. The disposal of the lubricant oil is also included while the metal removed is assumed to be recycled.

4.4 Reference Unit

The reference unit of turning is *1 kg of metal removed*.

4.5 Life Cycle Inventory

From Barnes (1976) it is obvious that the energy consumption of turning is dependent on the material processed (Tab. 4.1). However, Degner & Wolfram (1990) provide data on a broader range of processing types, but not on different materials (Tab. 4.2). As a first estimate it is assumed that the values in Degner & Wolfram (1990) represent steel machining and the energy consumption ratios of Barnes (1976) can be applied to extend these values to other materials.

The calculation of the average turning data (Tab. 4.2) is based on simple averaging the values of roughing and dressing due to the lack of more specific indications.

As far as factory infrastructure, compressed air consumption and cooling lubricant are concerned, the average values of a metal working machine operation estimated in chapter 2.4 (Tab. 2.6) are applied here in the case of the automated (CNC) machines, but not for the conventional ones. Since the data in chapter 2.4 is based on "kilogram material input" it has to be recalculated to be based on the "kilogram material removed" used here using the average removal rate mentioned in chapter 2.3.3.

Tab. 4.1: Electricity consumption for turning of different types of metals according to Barnes (1976); values are given per ton of metal removed

	Steel MJ/t	NiCr-Steel MJ/t	Cast Iron MJ/t	Aluminium MJ/t	Brass MJ/t
Turning	340	480	220	350	190
Energy intensity relative to steel	100%	141%	65%	103%	56%

Tab. 4.2: Electricity consumption data for different metals and types of turning processing; values are given per mm^3 or kg of metal removed.

	Average kWh/mm^3	Steel kWh/kg	NiCr-Steel kWh/kg	Cast Iron kWh/kg	Aluminium kWh/kg	Brass kWh/kg
Turning, conventional, average		0.338	0.477	0.218	0.347	0.189
Turning, conventional, primarily roughing	1.03E-06	0.130	0.184	0.084	0.134	0.073
Turning, conventional, primarily dressing	4.31E-06	0.545	0.769	0.353	0.561	0.305
Turning, CNC, average		1.776	2.507	1.149	1.828	0.992
Turning, CNC, primarily roughing	2.78E-06	0.352	0.496	0.228	0.362	0.196
Turning, CNC, primarily dressing	2.53E-05	3.200	4.517	2.070	3.294	1.788
Source	(Degner & Wolfram 1990)					

Tab. 4.3: Unit process raw data of the datasets "turning, steel"

	Name	Location	InfrastructureProcess	Unit	turning, steel, conventional, average	turning, steel, conventional, primarily roughing	turning, steel, conventional, primarily dressing	turning, steel, CNC, average	turning, steel, CNC, primarily roughing	turning, steel, CNC, primarily dressing	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0	0	0			
	Unit				kg	kg	kg	kg	kg	kg			
product	turning, steel, conventional, average	RER	0	kg	1								
product	turning, steel, conventional, primarily roughing	RER	0	kg		1							
product	turning, steel, conventional, primarily dressing	RER	0	kg			1						
product	turning, steel, CNC, average	RER	0	kg				1					
product	turning, steel, CNC, primarily roughing	RER	0	kg					1				
product	turning, steel, CNC, primarily dressing	RER	0	kg						1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	3.38E-1	1.30E-1	5.45E-1	1.78E+0	3.52E-1	3.20E+0	1	1.24	(1,3,2,1,3,4); literature value
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3				1.28E+0	1.28E+0	1.28E+0	1	1.63	(4,3,2,1,4,5); estimated
	lubricating oil, at plant	RER	0	kg				3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg				3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated disposal pathway
	metal working machine, unspecified, at plant	RER	1	kg	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1	1.63	(4,3,2,1,4,5); estimated
	metal working factory	RER	1	unit	2.02E-9	2.02E-9	2.02E-9	2.02E-9	2.02E-9	2.02E-9	1	1.63	(4,3,2,1,4,5); estimated
	operation, metal working factory, average heat energy	RER	0	kg	4.41E+0	4.41E+0	4.41E+0	4.41E+0	4.41E+0	4.41E+0	1	1.63	(4,3,2,1,4,5); estimated
	steel, low-alloyed, at plant	RER	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.05	(1,1,1,1,1,1);
emission air, high population density	Heat, waste	-	-	MJ	1.22E+0	4.68E-1	1.96E+0	6.39E+0	1.27E+0	1.15E+1	1	1.63	(4,3,2,1,4,5); due to electricity consumption

Tab. 4.4: Unit process raw data of the datasets "turning, chromium steel"

	Name	Location	InfrastructureProcess	Unit	turning, chromium steel, conventional, average	turning, chromium steel, conventional, primarily roughing	turning, chromium steel, conventional, primarily dressing	turning, chromium steel, CNC, average	turning, chromium steel, CNC, primarily roughing	turning, chromium steel, CNC, primarily dressing	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0	0	0			
	Unit				kg	kg	kg	kg	kg	kg			
product	turning, chromium steel, conventional, average	RER	0	kg	1								
product	turning, chromium steel, conventional, primarily roughing	RER	0	kg		1							
product	turning, chromium steel, conventional, primarily dressing	RER	0	kg			1						
product	turning, chromium steel, CNC, average	RER	0	kg				1					
product	turning, chromium steel, CNC, primarily roughing	RER	0	kg					1				
product	turning, chromium steel, CNC, primarily dressing	RER	0	kg						1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	4.77E-1	1.84E-1	7.69E-1	2.51E+0	4.96E-1	4.52E+0	1	1.24	(1,3,2,1,3,4); literature value
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3				1.28E+0	1.28E+0	1.28E+0	1	1.63	(4,3,2,1,4,5); estimated
	lubricating oil, at plant	RER	0	kg				3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg				3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated disposal pathway
	metal working machine, unspecified, at plant	RER	1	kg	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1	1.63	(4,3,2,1,4,5); estimated
	metal working factory	RER	1	unit	2.02E-9	2.02E-9	2.02E-9	2.02E-9	2.02E-9	2.02E-9	1	1.63	(4,3,2,1,4,5); estimated
	operation, metal working factory, average heat energy	RER	0	kg	4.41E+0	4.41E+0	4.41E+0	4.41E+0	4.41E+0	4.41E+0	1	1.63	(4,3,2,1,4,5); estimated
	chromium steel 18/8, at plant	RER	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.05	(1,1,1,1,1,1);
emission air, high population density	Heat, waste	-	-	MJ	1.72E+0	6.61E-1	2.77E+0	9.02E+0	1.79E+0	1.63E+1	1	1.63	(4,3,2,1,4,5); due to electricity consumption

Tab. 4.5: Unit process raw data of the datasets "turning, cast iron"

	Name	Location	InfrastructureProcess	Unit	turning, cast iron, conventional, average	turning, cast iron, conventional, primarily roughing	turning, cast iron, conventional, primarily dressing	turning, cast iron, CNC, average	turning, cast iron, CNC, primarily roughing	turning, cast iron, CNC, primarily dressing	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0	0	0			
	Unit				kg	kg	kg	kg	kg	kg			
product	turning, cast iron, conventional, average	RER	0	kg	1								
product	turning, cast iron, conventional, primarily roughing	RER	0	kg		1							
product	turning, cast iron, conventional, primarily dressing	RER	0	kg			1						
product	turning, cast iron, CNC, average	RER	0	kg				1					
product	turning, cast iron, CNC, primarily roughing	RER	0	kg					1				
product	turning, cast iron, CNC, primarily dressing	RER	0	kg						1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	2.18E-1	8.42E-2	3.53E-1	1.15E+0	2.28E-1	2.07E+0	1	1.24	(1,3,2,1,3,4); literature value
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3				1.28E+0	1.28E+0	1.28E+0	1	1.63	(4,3,2,1,4,5); estimated
	lubricating oil, at plant	RER	0	kg				3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg				3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated disposal pathway
	metal working machine, unspecified, at plant	RER	1	kg	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1	1.63	(4,3,2,1,4,5); estimated
	metal working factory	RER	1	unit	2.02E-9	2.02E-9	2.02E-9	2.02E-9	2.02E-9	2.02E-9	1	1.63	(4,3,2,1,4,5); estimated
	operation, metal working factory, average heat energy	RER	0	kg	4.41E+0	4.41E+0	4.41E+0	4.41E+0	4.41E+0	4.41E+0	1	1.63	(4,3,2,1,4,5); estimated
	cast iron, at plant	RER	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.05	(1,1,1,1,1,1);
emission air, high population density	Heat, waste	-	-	MJ	7.86E-1	3.03E-1	1.27E+0	4.14E+0	8.19E-1	7.45E+0	1	1.63	(4,3,2,1,4,5); due to electricity consumption

Tab. 4.6: Unit process raw data of the datasets "turning, aluminium"

	Name	Location	InfrastructureProcess	Unit	turning, aluminium, conventional, average	turning, aluminium, conventional, primarily roughing	turning, aluminium, conventional, primarily dressing	turning, aluminium, CNC, average	turning, aluminium, CNC, primarily roughing	turning, aluminium, CNC, primarily dressing	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0	0	0			
	Unit				kg	kg	kg	kg	kg	kg			
product	turning, aluminium, conventional, average	RER	0	kg	1								
product	turning, aluminium, conventional, primarily roughing	RER	0	kg		1							
product	turning, aluminium, conventional, primarily dressing	RER	0	kg			1						
product	turning, aluminium, CNC, average	RER	0	kg				1					
product	turning, aluminium, CNC, primarily roughing	RER	0	kg					1				
product	turning, aluminium, CNC, primarily dressing	RER	0	kg						1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	3.47E-1	1.34E-1	5.61E-1	1.83E+0	3.62E-1	3.29E+0	1	1.24	(1,3,2,1,3,4); literature value
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3				1.28E+0	1.28E+0	1.28E+0	1	1.63	(4,3,2,1,4,5); estimated
	lubricating oil, at plant	RER	0	kg				3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg				3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated disposal pathway
	metal working machine, unspecified, at plant	RER	1	kg	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1	1.63	(4,3,2,1,4,5); estimated
	metal working factory	RER	1	unit	2.02E-9	2.02E-9	2.02E-9	2.02E-9	2.02E-9	2.02E-9	1	1.63	(4,3,2,1,4,5); estimated
	operation, metal working factory, average heat energy	RER	0	kg	4.41E+0	4.41E+0	4.41E+0	4.41E+0	4.41E+0	4.41E+0	1	1.63	(4,3,2,1,4,5); estimated
	aluminium, production mix, at plant	RER	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.05	(1,1,1,1,1,1);
emission air, high population density	Heat, waste	-	-	MJ	1.25E+0	4.82E-1	2.02E+0	6.58E+0	1.30E+0	1.19E+1	1	1.63	(4,3,2,1,4,5); due to electricity consumption

Tab. 4.7: Unit process raw data of the datasets “turning, brass”

	Name	Location	InfrastructureProcess	Unit	turning, brass, conventional, average	turning, brass, conventional, primarily roughing	turning, brass, conventional, primarily dressing	turning, brass, CNC, average	turning, brass, CNC, primarily roughing	turning, brass, CNC, primarily dressing	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0	0	0			
	Unit				kg	kg	kg	kg	kg	kg			
product	turning, brass, conventional, average	RER	0	kg	1								
product	turning, brass, conventional, primarily roughing	RER	0	kg		1							
product	turning, brass, conventional, primarily dressing	RER	0	kg			1						
product	turning, brass, CNC, average	RER	0	kg				1					
product	turning, brass, CNC, primarily roughing	RER	0	kg					1				
product	turning, brass, CNC, primarily dressing	RER	0	kg						1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	1.89E-1	7.27E-2	3.05E-1	9.92E-1	1.96E-1	1.79E+0	1	1.24	(1,3,2,1,3,4); literature value
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3				1.28E+0	1.28E+0	1.28E+0	1	1.63	(4,3,2,1,4,5); estimated
	lubricating oil, at plant	RER	0	kg				3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg				3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated disposal pathway
	metal working machine, unspecified, at plant	RER	1	kg	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1	1.63	(4,3,2,1,4,5); estimated
	metal working factory	RER	1	unit	2.02E-9	2.02E-9	2.02E-9	2.02E-9	2.02E-9	2.02E-9	1	1.63	(4,3,2,1,4,5); estimated
	operation, metal working factory, average heat energy	RER	0	kg	4.41E+0	4.41E+0	4.41E+0	4.41E+0	4.41E+0	4.41E+0	1	1.63	(4,3,2,1,4,5); estimated
	brass, at plant	CH	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.05	(1,1,1,1,1,1);
emission air, high population density	Heat, waste	-	-	MJ	6.79E-1	2.62E-1	1.10E+0	3.57E+0	7.07E-1	6.44E+0	1	1.63	(4,3,2,1,4,5); due to electricity consumption

Tab. 4.8: Metainformation of the datasets "turning" (all datasets contain the same information, therefore, only one is shown here)

ReferenceFunction	Name	turning, steel, conventional, average
Geography	Location	RER
ReferenceFunction	InfrastructureProcess	0
ReferenceFunction	Unit	kg
	IncludedProcesses	This dataset encompasses the direct electricity consumption of the machine as well as compressed air and lubricant oil. Furthermore, the metal removed is included. Machine as well as factory infrastructure and operation are considered as well. The disposal of the lubricant oil is also included while the metal removed is assumed to be recycled.
	Amount	1
	LocalName	Drehen, Stahl, konventionell, Durchschnitt
	Synonyms	
	GeneralComment	The reference for turning is 1 kg of metal removed. As there is a large variation from factory to factory with regard to the LCI, it is advised that in case this dataset becomes important in the results, it has to be investigated further if the rough estimations made are applicable or not. If you do not know how much has been removed by turning you can use 0.23kg of this process per kg of final product as an average assumption.
	InfrastructureIncluded	1
	Category	metals
	SubCategory	chipping
	LocalCategory	Metalle
	LocalSubCategory	Spanende Bearbeitung
	Formula	
	StatisticalClassification	
	CASNumber	
TimePeriod	StartDate	2006
	EndDate	2007
	DataValidForEntirePeriod	1
	OtherPeriodText	
Geography	Text	Geographical coverage encompasses the industrialised countries.
Technology	Text	Average technology
Representativeness	Percent	0
	ProductionVolume	unknown
	SamplingProcedure	unknown
	Extrapolations	none
	UncertaintyAdjustments	none

4.6 Selected cumulative results and interpretation

4.6.1 Introduction

Selected LCI results and values for the cumulative energy demand are presented and discussed in this chapter. Please note that only a small part of the about 1000 elementary flows is presented here. The selection of the elementary flows shown in the tables is not based on their environmental relevance. It rather allows to show by examples the contributions of the different life cycle phases, or specific inputs from the technosphere to the selected elementary flows. Please refer to the ecoinvent database for the complete LCIs.

The shown selection is not suitable for a life cycle assessment of the analysed processes and products. Please use the data from the database for your own calculations, also because of possible minor deviations between the presented results and the database due to corrections and changes in background data used as inputs in the dataset of interest.

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

4.6.2 Results

The non renewable cumulative energy demand of turning metals ranges between about 40 MJ-eq per kg material removed (cast iron, conventional, primarily roughing) to more than 170 MJ-eq/kg (aluminium, CNC, primarily dressing). The CNC turning shows higher results within one metal's category. It requires more electricity plus compressed heat and lubricating oil. Dressing is more energy intensive as compared to roughing, which leads to lower cumulative results of the latter on a per kg metal removed basis.

Besides this difference between CNC and conventional turning, the results reflect the difference in the energy and environmental intensity of the material removed (current market mix of primary and secondary metal). The sequence of metals from low to high cumulative resource consumptions and emissions is cast iron, steel, brass, stainless steel and aluminium.

Fossil CO_2 emissions vary between 3 and 10 kg per kg of metal removed. Land use is below 1 m^2a per kg metal removed and criteria pollutants are emitted in the amounts of grams to tens of grams. Cadmium emissions to soil are six orders of magnitude lower (few micrograms per kg metal removed).

Tab. 4.9: Selected LCI results and cumulative energy demand of turning, steel

	Name		turning, steel, conventional, average	turning, steel, conventional, primarily roughing	turning, steel, conventional, primarily dressing	turning, steel, CNC, average	turning, steel, CNC, primarily roughing	turning, steel, CNC, primarily dressing
	Location		RER	RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0	0
	Infrastructure		kg	kg	kg	kg	kg	kg
CED	fossil	MJ-Eq	40.4	38.9	41.9	52.9	42.6	63.2
CED	nuclear	MJ-Eq	7.0	6.1	8.0	15.1	8.3	21.8
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	0.8	0.7	0.8	1.0	0.8	1.3
CED	geothermal, converted	MJ-Eq	-	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	1.3	1.2	1.4	2.2	1.5	3.0
CED	kinetic (in wind), converted	MJ-Eq	0.1	0.1	0.1	0.3	0.1	0.4
land occupation	resource	m2a	3.0E-1	3.0E-1	3.1E-1	3.3E-1	3.1E-1	3.4E-1
CO2, fossil	air	kg	3.1E+0	3.0E+0	3.2E+0	4.0E+0	3.2E+0	4.8E+0
NMVOC	air	kg	2.0E-3	1.9E-3	2.0E-3	2.2E-3	2.0E-3	2.4E-3
nitrogen oxides	air	kg	6.7E-3	6.5E-3	6.9E-3	8.4E-3	7.0E-3	9.8E-3
sulphur dioxide	air	kg	6.2E-3	5.8E-3	6.6E-3	9.6E-3	6.8E-3	1.2E-2
particulates, <2.5	air	kg	2.1E-3	2.0E-3	2.1E-3	2.3E-3	2.1E-3	2.5E-3
BOD	water	kg	9.1E-3	9.0E-3	9.1E-3	9.6E-3	9.2E-3	9.9E-3
cadmium	soil	kg	2.6E-9	2.6E-9	2.7E-9	3.1E-9	2.7E-9	3.4E-9

Tab. 4.10: Selected LCI results and cumulative energy demand of turning, chromium steel

	Name	Unit	turning, chromium steel, conventional, average	turning, chromium steel, conventional, primarily roughing	turning, chromium steel, conventional, primarily dressing	turning, chromium steel, CNC, average	turning, chromium steel, CNC, primarily roughing	turning, chromium steel, CNC, primarily dressing
	Location		RER	RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0	0
	Infrastructure		kg	kg	kg	kg	kg	kg
CED	fossil	MJ-Eq	83.0	80.9	85.1	99.8	85.3	114.3
CED	nuclear	MJ-Eq	19.3	18.0	20.7	30.2	20.6	39.7
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	1.4	1.3	1.4	1.8	1.4	2.1
CED	geothermal, converted	MJ-Eq	-	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	6.3	6.1	6.4	7.5	6.4	8.6
CED	kinetic (in wind), converted	MJ-Eq	0.3	0.3	0.4	0.5	0.4	0.7
land occupation	resource	m2a	4.1E-1	4.1E-1	4.2E-1	4.4E-1	4.2E-1	4.7E-1
CO2, fossil	air	kg	6.4E+0	6.3E+0	6.6E+0	7.7E+0	6.6E+0	8.9E+0
NMVOC	air	kg	3.3E-3	3.2E-3	3.3E-3	3.6E-3	3.3E-3	3.8E-3
nitrogen oxides	air	kg	1.5E-2	1.5E-2	1.5E-2	1.7E-2	1.5E-2	1.9E-2
sulphur dioxide	air	kg	2.0E-2	1.9E-2	2.0E-2	2.4E-2	2.0E-2	2.8E-2
particulates, <2.5 um	air	kg	1.0E-2	1.0E-2	1.0E-2	1.0E-2	1.0E-2	1.1E-2
BOD	water	kg	1.8E-2	1.8E-2	1.8E-2	1.8E-2	1.8E-2	1.9E-2
cadmium	soil	kg	3.4E-9	3.3E-9	3.5E-9	4.0E-9	3.5E-9	4.5E-9

Tab. 4.11: Selected LCI results and cumulative energy demand of turning, cast iron

	Name	Unit	turning, cast iron, conventional, average	turning, cast iron, conventional, primarily roughing	turning, cast iron, conventional, primarily dressing	turning, cast iron, CNC, average	turning, cast iron, CNC, primarily roughing	turning, cast iron, CNC, primarily dressing
	Location		RER	RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0	0
	Infrastructure		kg	kg	kg	kg	kg	kg
CED	fossil	MJ-Eq	37.2	36.2	38.1	46.0	39.3	52.7
CED	nuclear	MJ-Eq	5.8	5.2	6.5	11.4	7.0	15.8
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	0.7	0.7	0.7	0.9	0.7	1.0
CED	geothermal, converted	MJ-Eq	-	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	0.8	0.7	0.9	1.4	0.9	1.9
CED	kinetic (in wind), converted	MJ-Eq	0.1	0.1	0.1	0.2	0.1	0.3
land occupation	resource	m2a	2.5E-1	2.5E-1	2.6E-1	2.7E-1	2.6E-1	2.8E-1
CO2, fossil	air	kg	2.7E+0	2.7E+0	2.8E+0	3.4E+0	2.9E+0	3.9E+0
NMVOC	air	kg	1.4E-3	1.4E-3	1.5E-3	1.6E-3	1.5E-3	1.7E-3
nitrogen oxides	air	kg	5.5E-3	5.4E-3	5.6E-3	6.7E-3	5.8E-3	7.6E-3
sulphur dioxide	air	kg	5.3E-3	5.0E-3	5.5E-3	7.6E-3	5.8E-3	9.4E-3
particulates, <2.5 um	air	kg	1.2E-3	1.1E-3	1.2E-3	1.3E-3	1.2E-3	1.5E-3
BOD	water	kg	8.3E-3	8.2E-3	8.3E-3	8.7E-3	8.4E-3	8.9E-3
cadmium	soil	kg	2.6E-9	2.5E-9	2.6E-9	2.9E-9	2.6E-9	3.1E-9

Tab. 4.12: Selected LCI results and cumulative energy demand of turning, aluminium

	Name	Unit	turning, aluminium, conventional, average	turning, aluminium, conventional, primarily roughing	turning, aluminium, conventional, primarily dressing	turning, aluminium, CNC, average	turning, aluminium, CNC, primarily roughing	turning, aluminium, CNC, primarily dressing
	Location		RER	RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0	0
	Infrastructure		kg	kg	kg	kg	kg	kg
CED	fossil	MJ-Eq	106.5	105.0	108.1	119.4	108.8	129.9
CED	nuclear	MJ-Eq	26.5	25.5	27.5	34.7	27.7	41.6
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	1.2	1.1	1.2	1.5	1.2	1.7
CED	geothermal, converted	MJ-Eq	-	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	23.4	23.3	23.5	24.3	23.5	25.1
CED	kinetic (in wind), converted	MJ-Eq	0.1	0.1	0.2	0.3	0.2	0.4
land occupation	resource	m2a	3.7E-1	3.7E-1	3.7E-1	3.9E-1	3.7E-1	4.1E-1
CO2, fossil	air	kg	8.2E+0	8.0E+0	8.3E+0	9.2E+0	8.3E+0	1.0E+1
NMVOC	air	kg	3.4E-3	3.4E-3	3.5E-3	3.7E-3	3.5E-3	3.9E-3
nitrogen oxides	air	kg	1.6E-2	1.6E-2	1.6E-2	1.8E-2	1.7E-2	1.9E-2
sulphur dioxide	air	kg	2.9E-2	2.9E-2	2.9E-2	3.2E-2	3.0E-2	3.5E-2
particulates, <2.5 um	air	kg	3.7E-3	3.6E-3	3.7E-3	3.9E-3	3.7E-3	4.1E-3
BOD	water	kg	2.1E-2	2.1E-2	2.1E-2	2.2E-2	2.1E-2	2.2E-2
cadmium	soil	kg	3.0E-9	2.9E-9	3.0E-9	3.4E-9	3.0E-9	3.8E-9

Tab. 4.13: Selected LCI results and cumulative energy demand of turning, brass

	Name	Unit	turning, brass, conventional, average	turning, brass, conventional, primarily roughing	turning, brass, conventional, primarily dressing	turning, brass, CNC, average	turning, brass, CNC, primarily roughing	turning, brass, CNC, primarily dressing
	Location		RER	RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0	0
	Infrastructure		kg	kg	kg	kg	kg	kg
CED	fossil	MJ-Eq	45.6	44.7	46.4	53.5	47.7	59.2
CED	nuclear	MJ-Eq	9.7	9.2	10.3	14.7	10.9	18.5
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	1.0	1.0	1.0	1.2	1.1	1.3
CED	geothermal, converted	MJ-Eq	-	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	5.7	5.6	5.7	6.2	5.8	6.7
CED	kinetic (in wind), converted	MJ-Eq	0.1	0.1	0.1	0.2	0.2	0.3
land occupation	resource	m2a	8.4E-1	8.4E-1	8.5E-1	8.6E-1	8.5E-1	8.7E-1
CO2, fossil	air	kg	3.6E+0	3.6E+0	3.7E+0	4.2E+0	3.8E+0	4.7E+0
NMVOC	air	kg	4.3E-3	4.3E-3	4.3E-3	4.5E-3	4.4E-3	4.6E-3
nitrogen oxides	air	kg	2.2E-2	2.1E-2	2.2E-2	2.3E-2	2.2E-2	2.3E-2
sulphur dioxide	air	kg	8.3E-2	8.3E-2	8.4E-2	8.6E-2	8.4E-2	8.7E-2
particulates, <2.5 um	air	kg	8.2E-3	8.2E-3	8.2E-3	8.4E-3	8.3E-3	8.5E-3
BOD	water	kg	1.1E-2	1.1E-2	1.1E-2	1.1E-2	1.1E-2	1.1E-2
cadmium	soil	kg	2.9E-9	2.9E-9	2.9E-9	3.2E-9	3.0E-9	3.4E-9

4.7 Data Quality

The life cycle inventory is based on two main sources that are combined to achieve a certain diversification. As the methods and assumptions of their data collection is not known the uncertainty involved remains somewhat undetermined. As both studies report comparable values for electricity consumption it is thought that this aspect is reasonable reliable.

All other inputs were taken from the average machining datasets and contain, therefore, a higher uncertainty.

The main data gap concerns possible air emissions as no data was available. The extent and exact composition is dependent on process conditions as well as the material processed.

5 Milling

5.1 Introduction

Milling is a chipping process where the piece of material is fixed to a moveable table while the cutting energy is provided by the rotating cutting tool (in contrast to turning where the work piece is rotating). The cutting tool is generally stationary or only moveable along the rotational axis. The cutting is accomplished by moving the table. Milling is used for complex shaping. Especially, when CNC-machines are used with computer aided manufacturing (CAM) almost any type of shape becomes feasible. While milling can be applied to metals, wood and plastic materials equally, only the metal processing part is considered in the following.

5.2 Data Sources and Quality

There are two literature sources stating electricity consumption for milling. While Degner et al. (1990 seems to have taken values measured during a dissertation, it is not clear whether the data mentioned in Barnes (1976) is based on measurements or estimations. Although there is about 15 years between the two publications the values stated correspond quite closely (about 5% difference assuming large part milling). Therefore, it can be thought that the sources are reliable as far as electricity consumption is concerned.

The main data gaps concern compressed air consumption and cooling lubricant. These ancillary materials are relevant in the case of automated machines and are estimated from the average machine operation (chapter 2.4)

5.3 System Boundaries

These datasets encompass the direct electricity consumption of the machine as well as compressed air and lubricant oil. Furthermore, the metal removed is included. Machine as well as factory infrastructure and operation are considered as well. The disposal of the lubricant oil is also included while the metal removed is assumed to be recycled.

5.4 Reference Unit

The reference unit of milling is *1 kg of metal removed*.

5.5 Life Cycle Inventory

From Barnes (1976) it is obvious that the energy consumption of milling is dependent on the material processed (Tab. 5.1). However, Degner & Wolfram (1990) provides data for a broader range of processing types, but not for different materials (Tab. 5.2). As a first estimate it is assumed that the values in Degner et al. (1990) represent steel machining and the energy consumption ratios of Barnes (1976) can be applied to extend these values to other materials.

The electricity consumption of milling chromium steel is estimated assuming the same ratio of consumption between steel and chromium steel as for turning (chapter 4.5).

In order to have also an average milling dataset, it is necessary to assume a certain contribution from large and small parts milling as well as from dressing. As the average value from Barnes (1976) corresponded very much to the value of large parts in Degner & Wolfram (1990), it is assumed that large parts make up 90% of material removal and that dressing merely contributes based on mass removed (Tab. 5.2).

As far as factory infrastructure, compressed air consumption and cooling lubricant are concerned, the average values of a metal working machine operation estimated in chapter 2.4 (Tab. 2.6) are applied here. Since the data in chapter 2.4 is based on “kilogram material input” it is recalculated to be based on the “kilogram material removed” using the average removal rate mentioned in chapter 2.3.3.

Tab. 5.1: Electricity consumption per kg metal removed of milling of different types of metals according to Barnes (1976)

	Steel MJ/t	Chromium Steel MJ/t	Cast Iron MJ/t	Aluminium MJ/t	
Milling	800	1130	250	600	
Proportion relative to steel	100%	141%	31%	75%	

Tab. 5.2: Electricity consumption per kg metal removed of different metals and types of milling processing.

	Average kWh/mm^3	Steel kWh/kg	Chromium Steel kWh/kg	Cast Iron kWh/kg	Aluminium kWh/kg	Share on Average
Milling, average		0.474	0.670	0.148	0.356	
Milling, large parts	1.67E-06	0.211	0.298	0.066	0.158	90%
Milling, small parts	1.78E-05	2.259	3.191	0.706	1.694	9%
Milling, dressing	6.42E-05	8.122	11.47	2.538	6.092	1%
Source	(Degner & Wolfram 1990)					see text above for explanation

Tab. 5.3: Unit process raw data of the datasets “milling, steel”

	Name	Location	InfrastructureProcess	Unit	milling, steel, average	milling, steel, large parts	milling, steel, small parts	milling, steel, dressing	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				kg	kg	kg	kg			
product	milling, steel, average	RER	0	kg	1						
product	milling, steel, large parts	RER	0	kg		1					
product	milling, steel, small parts	RER	0	kg			1				
product	milling, steel, dressing	RER	0	kg				1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	4.74E-1	2.11E-1	2.26E+0	8.12E+0	1	1.24	(1,3,2,1,3,4); literature value
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3	1.28E+0	1.28E+0	1.28E+0	1.28E+0	1	1.63	(4,3,2,1,4,5); estimated
	lubricating oil, at plant	RER	0	kg	3.82E-3	3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	3.82E-3	3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated disposal pathway
	metal working machine, unspecified, at plant	RER	1	kg	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1	1.63	(4,3,2,1,4,5); estimated
	metal working factory	RER	1	unit	2.02E-9	2.02E-9	2.02E-9	2.02E-9	1	1.63	(4,3,2,1,4,5); estimated
	operation, metal working factory, average heat energy	RER	0	kg	4.41E+0	4.41E+0	4.41E+0	4.41E+0	1	1.63	(4,3,2,1,4,5); estimated
	steel, low-alloyed, at plant	RER	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.05	(1,1,1,1,1,1);
emission air, high population density	Heat, waste	-	-	MJ	1.71E+0	7.59E-1	8.13E+0	2.92E+1	1	1.63	(4,3,2,1,4,5); due to electricity consumption

Tab. 5.4: Unit process raw data of the datasets "milling, chromium steel"

	Name	Location	InfrastructureProcess	Unit	milling, chromium steel, average	milling, chromium steel, large parts	milling, chromium steel, small parts	milling, chromium steel, dressing	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				kg	kg	kg	kg			
product	milling, chromium steel, average	RER	0	kg	1						
product	milling, chromium steel, large parts	RER	0	kg		1					
product	milling, chromium steel, small parts	RER	0	kg			1				
product	milling, chromium steel, dressing	RER	0	kg				1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	6.70E-1	2.98E-1	3.19E+0	1.15E+1	1	1.24	(1,3,2,1,3,4); literature value
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3	1.28E+0	1.28E+0	1.28E+0	1.28E+0	1	1.63	(4,3,2,1,4,5); estimated
	lubricating oil, at plant	RER	0	kg	3.82E-3	3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	3.82E-3	3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated disposal pathway
	metal working machine, unspecified, at plant	RER	1	kg	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1	1.63	(4,3,2,1,4,5); estimated
	metal working factory	RER	1	unit	2.02E-9	2.02E-9	2.02E-9	2.02E-9	1	1.63	(4,3,2,1,4,5); estimated
	operation, metal working factory, average heat energy	RER	0	kg	4.41E+0	4.41E+0	4.41E+0	4.41E+0	1	1.63	(4,3,2,1,4,5); estimated
	chromium steel 18/8, at plant	RER	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.63	(4,3,2,1,4,5);
emission air, high population density	Heat, waste	-	-	MJ	2.41E+0	1.07E+0	1.15E+1	4.13E+1	1	1.63	(4,3,2,1,4,5); due to electricity consumption

Tab. 5.5: Unit process raw data of the datasets "milling, cast iron"

	Name	Location	InfrastructureProcess	Unit	milling, cast iron, average	milling, cast iron, large parts	milling, cast iron, small parts	milling, cast iron, dressing	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				kg	kg	kg	kg			
product	milling, cast iron, average	RER	0	kg	1						
product	milling, cast iron, large parts	RER	0	kg		1					
product	milling, cast iron, small parts	RER	0	kg			1				
product	milling, cast iron, dressing	RER	0	kg				1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	1.48E-1	6.59E-2	7.06E-1	2.54E+0	1	1.24	(1,3,2,1,3,4); literature value
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3	1.28E+0	1.28E+0	1.28E+0	1.28E+0	1	1.63	(4,3,2,1,4,5); estimated
	lubricating oil, at plant	RER	0	kg	3.82E-3	3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	3.82E-3	3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated disposal pathway
	metal working machine, unspecified, at plant	RER	1	kg	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1	1.63	(4,3,2,1,4,5); estimated
	metal working factory	RER	1	unit	2.02E-9	2.02E-9	2.02E-9	2.02E-9	1	1.63	(4,3,2,1,4,5); estimated
	operation, metal working factory, average heat energy	RER	0	kg	4.41E+0	4.41E+0	4.41E+0	4.41E+0	1	1.63	(4,3,2,1,4,5); estimated
	cast iron, at plant	RER	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.05	(1,1,1,1,1,1);
emission air, high population density	Heat, waste	-	-	MJ	5.34E-1	2.37E-1	2.54E+0	9.14E+0	1	1.63	(4,3,2,1,4,5); due to electricity consumption

Tab. 5.6: Unit process raw data of the datasets "milling, aluminium"

	Name	Location	InfrastructureProcess	Unit	milling, aluminium, average	milling, aluminium, large parts	milling, aluminium, small parts	milling, aluminium, dressing	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				kg	kg	kg	kg			
product	milling, aluminium, average	RER	0	kg	1						
product	milling, aluminium, large parts	RER	0	kg		1					
product	milling, aluminium, small parts	RER	0	kg			1				
product	milling, aluminium, dressing	RER	0	kg				1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	3.56E-1	1.58E-1	1.69E+0	6.09E+0	1	1.24	(1,3,2,1,3,4); literature value
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3	1.28E+0	1.28E+0	1.28E+0	1.28E+0	1	1.63	(4,3,2,1,4,5); estimated
	lubricating oil, at plant	RER	0	kg	3.82E-3	3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	3.82E-3	3.82E-3	3.82E-3	3.82E-3	1	1.63	(4,3,2,1,4,5); estimated disposal pathway
	metal working machine, unspecified, at plant	RER	1	kg	1.74E-4	1.74E-4	1.74E-4	1.74E-4	1	1.63	(4,3,2,1,4,5); estimated
	metal working factory	RER	1	unit	2.02E-9	2.02E-9	2.02E-9	2.02E-9	1	1.63	(4,3,2,1,4,5); estimated
	operation, metal working factory, average heat energy	RER	0	kg	4.41E+0	4.41E+0	4.41E+0	4.41E+0	1	1.63	(4,3,2,1,4,5); estimated
	aluminium, production mix, at plant	RER	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.05	(1,1,1,1,1,1);
emission air, high population density	Heat, waste	-	-	MJ	1.28E+0	5.70E-1	6.10E+0	2.19E+1	1	1.63	(4,3,2,1,4,5); due to electricity consumption

Tab. 5.7: Metainformation of the datasets milling (all datasets contain the same information, therefore, only one is shown here)

ReferenceFunction	Name	milling, steel, average
Geography	Location	RER
ReferenceFunction	InfrastructureProcess	0
ReferenceFunction	Unit	kg
	IncludedProcesses	This dataset encompasses the direct electricity consumption of the machine as well as compressed air and lubricant oil. Furthermore, the metal removed is included. Machine as well as factory infrastructure and operation are considered as well. The disposal of the lubricant oil is also included while the metal removed is assumed to be recycled.
	Amount	1
	LocalName	Fräsen, Stahl, Durchschnitt
	Synonyms	
	GeneralComment	The reference for turning is 1 kg of metal removed. As there is a large variation from factory to factory with regard to the LCI, it is advised that in case this dataset becomes important in the results, it has to be investigated further if the rough estimations made are applicable or not. If you do not know how much has been removed by turning you can use 0.23kg of this process per kg of final product as an average assumption.
	InfrastructureIncluded	1
	Category	metals
	SubCategory	chipping
	LocalCategory	Metalle
	LocalSubCategory	Spanende Bearbeitung
	Formula	
	StatisticalClassification	
	CASNumber	
TimePeriod	StartDate	2006
	EndDate	2007
	DataValidForEntirePeriod	1
	OtherPeriodText	
Geography	Text	Geographical coverage encompasses the industrialised countries.
Technology	Text	Average technology
Representativeness	Percent	0
	ProductionVolume	unknown
	SamplingProcedure	unknown
	Extrapolations	none
	UncertaintyAdjustments	none

5.6 Selected cumulative results and interpretation

5.6.1 Introduction

Selected LCI results and values for the cumulative energy demand are presented and discussed in this chapter. Please note that only a small part of the about 1000 elementary flows is presented here. The selection of the elementary flows shown in the tables is not based on their environmental relevance. It rather allows to show by examples the contributions of the different life cycle phases, or specific inputs from the technosphere to the selected elementary flows. Please refer to the ecoinvent database for the complete LCIs.

The shown selection is not suitable for a life cycle assessment of the analysed processes and products. Please use the data from the database for your own calculations, also because of possible minor deviations between the presented results and the database due to corrections and changes in background data used as inputs in the dataset of interest.

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

5.6.2 Results

The non renewable cumulative energy demand of milling metals ranges between about 45 MJ-eq per kg material removed (cast iron, large parts) to more than 240 MJ-eq/kg (chomium steel, dressing). Within one metal's category, milling of large pieces shows the lowest, dressing the highest cumulative energy intensity.

Besides this difference, the results reflect the difference in the energy and environmental intensity of the material removed (current market mix of primary and secondary metal). The sequence of metals from low to high cumulative resource consumptions and emissions is cast iron, steel, aluminium and stainless steel (dressing only). Stainless steel shows the highest dependency on the kind of work performed (milling or dressing).

Fossil CO_2 emissions vary between nearly 3 and 13 kg per kg of metal removed. Land use is below 1 m^2a per kg metal removed and criteria pollutants are emitted in the amounts of grams to tens of grams. Cadmium emissions to soil are six orders of magnitude lower (few micrograms per kg metal removed).

Tab. 5.8: Selected LCI results and cumulative energy demand of milling, steel and chromium steel

	Name		milling, chromium steel, dressing	milling, chromium steel, small parts	milling, chromium steel, large parts	milling, chromium steel, average	milling, steel, average	milling, steel, large parts	milling, steel, small parts	milling, steel, dressing
	Location		RER	RER	RER	RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0	0	0	0
	Infrastructure		kg	kg	kg	kg	kg	kg	kg	kg
CED	fossil	MJ-Eq	164.8	104.7	83.8	86.5	43.5	41.6	56.4	98.8
CED	nuclear	MJ-Eq	72.8	33.4	19.7	21.4	8.9	7.6	17.3	45.1
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	3.2	1.9	1.4	1.5	0.8	0.8	1.1	2.1
CED	geothermal, converted	MJ-Eq	-	-	-	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	12.3	7.8	6.3	6.5	1.5	1.4	2.5	5.6
CED	kinetic (in wind), converted	MJ-Eq	1.3	0.6	0.4	0.4	0.2	0.1	0.3	0.8
land occupation	resource	m2a	5.5E-1	4.5E-1	4.2E-1	4.2E-1	3.1E-1	3.1E-1	3.3E-1	4.1E-1
CO2, fossil	air	kg	1.3E+1	8.1E+0	6.5E+0	6.7E+0	3.3E+0	3.2E+0	4.3E+0	7.6E+0
NMVOC	air	kg	4.6E-3	3.7E-3	3.3E-3	3.4E-3	2.1E-3	2.0E-3	2.3E-3	3.0E-3
nitrogen oxides	air	kg	2.6E-2	1.8E-2	1.5E-2	1.5E-2	7.1E-3	6.8E-3	8.9E-3	1.5E-2
sulphur dioxide	air	kg	4.2E-2	2.5E-2	2.0E-2	2.0E-2	7.0E-3	6.5E-3	1.0E-2	2.2E-2
particulates, <2.5 um	air	kg	1.2E-2	1.0E-2	1.0E-2	1.0E-2	2.1E-3	2.1E-3	2.4E-3	3.2E-3
BOD	water	kg	2.0E-2	1.8E-2	1.8E-2	1.8E-2	9.3E-3	9.2E-3	9.7E-3	1.1E-2
cadmium	soil	kg	6.2E-9	4.1E-9	3.4E-9	3.5E-9	2.7E-9	2.7E-9	3.2E-9	4.7E-9

Tab. 5.9: Selected LCI results and cumulative energy demand of milling, cast iron and aluminium

	Name		milling, cast iron, average	milling, cast iron, large parts	milling, cast iron, small parts	milling, cast iron, dressing	milling, aluminium, average	milling, aluminium, large parts	milling, aluminium, small parts	milling, aluminium, dressing
	Location		RER	RER	RER	RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0	0	0	0
	Infrastructure		kg	kg	kg	kg	kg	kg	kg	kg
CED	fossil	MJ-Eq	38.8	38.2	42.8	56.1	108.7	107.3	118.4	150.2
CED	nuclear	MJ-Eq	6.7	6.3	9.3	18.0	27.7	26.8	34.0	54.9
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	0.7	0.7	0.8	1.1	1.2	1.2	1.4	2.2
CED	geothermal, converted	MJ-Eq	-	-	-	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	0.9	0.8	1.2	2.2	23.5	23.4	24.2	26.6
CED	kinetic (in wind), converted	MJ-Eq	0.1	0.1	0.2	0.3	0.2	0.1	0.3	0.7
land occupation	resource	m2a	2.6E-1	2.5E-1	2.6E-1	2.9E-1	3.7E-1	3.7E-1	3.9E-1	4.5E-1
CO2, fossil	air	kg	2.8E+0	2.8E+0	3.2E+0	4.2E+0	8.3E+0	8.2E+0	9.1E+0	1.2E+1
NMVOC	air	kg	1.5E-3	1.5E-3	1.6E-3	1.8E-3	3.5E-3	3.5E-3	3.7E-3	4.2E-3
nitrogen oxides	air	kg	5.7E-3	5.6E-3	6.3E-3	8.1E-3	1.7E-2	1.6E-2	1.8E-2	2.2E-2
sulphur dioxide	air	kg	5.6E-3	5.5E-3	6.7E-3	1.0E-2	3.0E-2	2.9E-2	3.2E-2	4.1E-2
particulates, <2.5 um	air	kg	1.2E-3	1.2E-3	1.3E-3	1.5E-3	3.7E-3	3.7E-3	3.9E-3	4.5E-3
BOD	water	kg	8.4E-3	8.4E-3	8.6E-3	9.0E-3	2.1E-2	2.1E-2	2.2E-2	2.3E-2
cadmium	soil	kg	2.6E-9	2.6E-9	2.8E-9	3.2E-9	3.0E-9	3.0E-9	3.4E-9	4.5E-9

5.7 Data Quality

The life cycle inventory is based on two main sources that are combined to achieve a certain diversification. As the methods and assumptions of their data collection is not known the uncertainty involved remains somewhat undetermined. As both studies report comparable values for electricity consumption it is thought that this aspect is reasonable reliable.

All other inputs were taken from the average machining datasets and contain, therefore, a higher uncertainty.

The main data gap concerns possible air emissions as no data was available. The extent and exact composition is dependent on process conditions as well as the material processed.

6 Impact Extrusion

6.1 Introduction

Impact extrusion is a type of pressure forming. This technology takes advantage of the change in hardness of materials under high pressure. The slug (the massive raw part) is placed between a ram and a mould of defined shape. A pressure force of typically 3.2 to 10 MN is applied, which leads to yielding (flowing) of the material and a forming of the slug according to the mould's shape. Using multiple strokes it is possible to produce complex shapes.

The advantages are the high quality of the surface after processing (mainly the case with cold impact extrusion), almost no loss of material and speed of processing. The material qualities change as a result of the impact extrusion. The increase in hardness, tensile strength and yield strength is normally regarded as an improvement. As long as the shape is simple, it is also possible to achieve results of high accuracy. As a result further processing steps such as chipping or surface treatment and finishing are reduced or can even be avoided completely.

Impact extrusion is distinguished according to the temperature of the slug at the time of processing (typical values are given in parentheses as the ratio between the melting and the plastic deformation temperature of the metal):

- cold impact extrusion: processing at room temperature ($T/T_{melt} < 0.3$)
- warm impact extrusion: processing occurs at temperatures between hot and cold impact extrusion, since it is a compromise between the two ($0.3 < T/T_{melt} < 0.5$)
- hot impact extrusion: plastic deformation is carried out at temperatures above the recrystallisation temperature of the processed material ($T/T_{melt} > 0.6$)

The processing is further categorised according to the direction of the flowing material during impact extrusion (combinations are also possible):

- forward impact extrusion: the material flow is in the same direction as the pressing ram
- backward impact extrusion: the material flows in the opposite direction of the pressing ram
- transversal impact extrusion: the material flow is sideways away from the pressing ram

The processing pathway encompasses different steps depending on the type of impact extrusion used. The typical steps for each type of impact extrusion according to Herlan (1989) are summarised in Tab. 6.1. He has also measured in a real production system the energy consumption for impact extrusion of aluminium and unalloyed as well as alloyed steel. The datasets are based on these measurements.

Tab. 6.1: Processing steps typically applied in each of the types of impact extrusion (Herlan 1989)

	Type of Impact Extrusion		
	Cold	**Warm**	**Hot**
Cutting the raw part to length	if necessary	if necessary	if necessary
Surface treatment (bonderising and (de-) greasing)	Yes	No	No
Warming	No	Yes	Yes
Deformation (single- or multi- stage)	Yes	Yes	Yes
Heat treatment	Yes	Not common	Yes

6.2 Data Sources and Quality

Herlan (1989) has conducted a thorough evaluation of a number of impact extrusion processes. On one hand he measured the energy consumption directly at the machines but also calculated the energy use based on a computer model. The comparison of the results of the two approaches was used for a verification of his results.

Nevertheless, it seems that the values reported in the text and the tables occasionally contradict each other. This is probably due to the sometimes lacking statement of the reference (e.g. per kg vs. per piece, primary energy vs. consumed final energy, normalised to single stroke or not). As a consequence only the values mentioned in the process chain diagrams and the accompanying text are used but not the values in lists and tables.

6.3 System Boundaries

This dataset encompasses the electricity consumption of the machine as well as common pre- and post treatments. Furthermore, machine as well as factory infrastructure and operation are considered as well.

6.4 Reference Unit

The reference unit of impact extrusion is *1 kg of metal formed by impact extrusion*.

6.5 Life Cycle Inventory

The study by Herlan (1989) has the focus on energy consumption and on a wider context on costs. Therefore, the life cycle inventory of impact extrusion is limited to energy. Further requirements, such as chemicals for surface treatment as well as emissions are not considered. The energy consumption data of impact extrusion is summarised in Tab. 6.2 to Tab. 6.4. The data in the tables is based on the measured results from Herlan (1989). He studied batch sizes of about 1'000 work pieces.

Deformation is in most cases of minor importance when only a single stroke is needed. However, a piece needing multiple strokes is common and can render this source of energy consumption to be equally important as (energy intensive) warming or heat treatment. From the examples in Herlan (1989) it seems that up to five strokes per working piece are common. Therefore, each type of impact extrusion leads to five datasets, each consisting of an input for surface treatment, warming, heat treatment and 1 to 5 deformation strokes as applicable.

For factory infrastructure and operation as well as the machine infrastructure the average values are used according to chapter 2.3.3. Compressed air consumption is assumed to be related to the number of strokes. It is assumed that for each stroke the average amount from chapter 2.4.3 is consumed.

Tab. 6.2: Inventory data of cold impact extrusion of steel and aluminium

kWh/kg		Cold Impact Extrusion of Steel		Cold Impact Extrusion of Aluminium		
		Steel (unalloyed)	**This Study (average)**	**Aluminium (batch 1)**	**Aluminium (batch 2)**	**This Study (average)**
Surface treatment (bonderising, (de-)greasing)	Fuel Oil	0.51	**0.51**	0	0	**0**
	Electricity	0.20	**0.20**	0	0.40	**0.20**
Warming	Electricity	0	**0**	0	0	**0**
Deformation (average for a single stroke)	Electricity	0.11	**0.11**	0.44	0.62	**0.53**
Heat treatment	Natural Gas	0.72	**0.72**	0.61	0.52	**0.57**
Total Energy		1.55	1.55	1.05	1.54	1.29
Source		(Herlan 1989)		(Herlan 1989)	(Herlan 1989)	

Tab. 6.3: Inventory data of warm impact extrusion of steel

kWh/kg		Warm Impact Extrusion of Steel		
		Steel (stainless)	**Steel (low alloyed)**	**This Study (average)**
Surface treatment (bonderising, (de-)greasing)	Fuel Oil	0	0	**0**
	Electricity	0	0	**0**
Warming	Electricity	0.88	0.52	**0.70**
Deformation (average for a single stroke)	Electricity	0.16	0.14	**0.15**
Heat treatment	Natural Gas	0	0	**0**
Total Energy		1.04	0.66	0.85
Source		(Herlan 1989)	(Herlan 1989)	

Tab. 6.4: Inventory data for hot impact extrusion of steel

kWh/kg		Hot Impact Extrusion of Steel		
		Steel (batch 1)	Steel (batch 2)	This Study (average)
Surface treatment (bonderising, (de-)greasing)	Fuel Oil	0	0	**0**
	Electricity	0	0	**0**
Warming	Electricity	0.71	1.29	**1.00**
Deformation (average for a single stroke)	Electricity	0.14	0.16	**0.15**
Heat treatment	Natural Gas	0.07	0.07	**0.07**
Total Energy		0.92	1.51	1.21
Source		(Herlan 1989)	(Herlan 1989)	

Tab. 6.5: Unit process raw data of the datasets "surface treatment, cold impact extrusion"

	Name	Location	InfrastructureProcess	Unit	surface treatment, cold impact extrusion, steel	surface treatment, cold impact extrusion, aluminium	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER			
	InfrastructureProcess				0	0			
	Unit				kg	kg			
product	surface treatment, cold impact extrusion, steel	RER	0	kg	1				
product	surface treatment, cold impact extrusion, aluminium	RER	0	kg		1			
technosphere	heat, light fuel oil, at industrial furnace 1MW	RER	0	MJ	1.83E+0	0	1	1.57	(1,3,5,3,1,5); literature value
	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	2.03E-1	1.99E-1	1	1.57	(1,3,5,3,1,5); literature value
emission air, high population density	Heat, waste	-	-	MJ	7.33E-1	7.18E-1	1	1.57	(1,3,5,3,1,5); from electricity

Tab. 6.6: Unit process raw data of the datasets "warming, warm/hot impact extrusion"

	Name	Location	InfrastructureProcess	Unit	warming, warm impact extrusion, steel	warming, hot impact extrusion, steel	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER			
	InfrastructureProcess				0	0			
	Unit				kg	kg			
product	warming, warm impact extrusion, steel	RER	0	kg	1				
product	warming, hot impact extrusion, steel	RER	0	kg		1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	7.01E-1	9.97E-1	1	1.57	(1,3,5,3,1,5); literature value
emission air, high population density	Heat, waste	-	-	MJ	2.52E+0	3.59E+0	1	1.57	(1,3,5,3,1,5); from electricity

Tab. 6.7: Unit process raw data of the datasets "deformation stroke, cold/warm/hot impact extrusion"

	Name	Location	InfrastructureProcess	Unit	deformation stroke, cold impact extrusion, steel	deformation stroke, warm impact extrusion, steel	deformation stroke, hot impact extrusion, steel	deformation stroke, cold impact extrusion, aluminium	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				kg	kg	kg	kg			
product	deformation stroke, cold impact extrusion, steel	RER	0	kg	1						
product	deformation stroke, warm impact extrusion, steel	RER	0	kg		1					
product	deformation stroke, hot impact extrusion, steel	RER	0	kg			1				
product	deformation stroke, cold impact extrusion, aluminium	RER	0	kg				1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	1.15E-1	1.49E-1	1.48E-1	5.27E-1	1	1.57	(1,3,5,3,1,5); literature value
emission air, high population density	Heat, waste	-	-	MJ	4.13E-1	5.38E-1	5.32E-1	1.90E+0	1	1.57	(1,3,5,3,1,5); from electricity

Tab. 6.8: Unit process raw data of the datasets “heat treatment, cold/hot impact extrusion”

	Name	Location	InfrastructureProcess	Unit	heat treatment, cold impact extrusion, steel	heat treatment, cold impact extrusion, aluminium	heat treatment, hot impact extrusion, steel	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				kg	kg	kg			
product	heat treatment, cold impact extrusion, steel	RER	0	kg	1					
product	heat treatment, cold impact extrusion, aluminium	RER	0	kg		1				
product	heat treatment, hot impact extrusion, steel	RER	0	kg			1			
technosphere	natural gas, burned in industrial furnace >100kW	RER	0	MJ	2.59E+0	2.04E+0	2.48E-1	1	1.57	(1,3,5,3,1,5); literature value

Tab. 6.9: Unit process raw data of the datasets “cold impact extrusion, steel”

	Name	Location	InfrastructureProcess	Unit	cold impact extrusion, steel, 1 stroke	cold impact extrusion, steel, 2 strokes	cold impact extrusion, steel, 3 strokes	cold impact extrusion, steel, 4 strokes	cold impact extrusion, steel, 5 strokes	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0	0			
	Unit				kg	kg	kg	kg	kg			
product	cold impact extrusion, steel, 1 stroke	RER	0	kg	1							
product	cold impact extrusion, steel, 2 strokes	RER	0	kg		1						
product	cold impact extrusion, steel, 3 strokes	RER	0	kg			1					
product	cold impact extrusion, steel, 4 strokes	RER	0	kg				1				
product	cold impact extrusion, steel, 5 strokes	RER	0	kg					1			
technosphere	deformation stroke, cold impact extrusion, steel	RER	0	kg	1	2	3	4	5	1	1.05	(1,1,1,1,1,1);
	surface treatment, cold impact extrusion, steel	RER	0	kg	1	1	1	1	1	1	1.05	(1,1,1,1,1,1);
	heat treatment, cold impact extrusion, steel	RER	0	kg	1	1	1	1	1	1	1.05	(1,1,1,1,1,1);
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3	2.91E-1	5.82E-1	8.73E-1	1.16E+0	1.45E+0	1	1.63	(4,3,2,1,4,5); estimated
	metal working machine, unspecified, at plant	RER	1	kg	3.95E-5	3.95E-5	3.95E-5	3.95E-5	3.95E-5	1	1.63	(4,3,2,1,4,5); estimated
	metal working factory	RER	1	unit	4.58E-10	4.58E-10	4.58E-10	4.58E-10	4.58E-10	1	1.63	(4,3,2,1,4,5); estimated
	metal working factory operation, average heat energy	RER	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.63	(4,3,2,1,4,5); estimated

Tab. 6.10: Unit process raw data of the datasets “cold impact extrusion, aluminium”

	Name	Location	InfrastructureProcess	Unit	cold impact extrusion, aluminium, 1 stroke	cold impact extrusion, aluminium, 2 strokes	cold impact extrusion, aluminium, 3 strokes	cold impact extrusion, aluminium, 4 strokes	cold impact extrusion, aluminium, 5 strokes	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0	0			
	Unit				kg	kg	kg	kg	kg			
product	cold impact extrusion, aluminium, 1 stroke	RER	0	kg	1							
product	cold impact extrusion, aluminium, 2 strokes	RER	0	kg		1						
product	cold impact extrusion, aluminium, 3 strokes	RER	0	kg			1					
product	cold impact extrusion, aluminium, 4 strokes	RER	0	kg				1				
product	cold impact extrusion, aluminium, 5 strokes	RER	0	kg					1			
technosphere	deformation stroke, cold impact extrusion, aluminium	RER	0	kg	1	2	3	4	5	1	1.05	(1,1,1,1,1,1);
	surface treatment, cold impact extrusion, aluminium	RER	0	kg	1	1	1	1	1	1	1.05	(1,1,1,1,1,1);
	heat treatment, cold impact extrusion, aluminium	RER	0	kg	1	1	1	1	1	1	1.05	(1,1,1,1,1,1);
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3	2.91E-1	5.82E-1	8.73E-1	1.16E+0	1.45E+0	1	1.63	(4,3,2,1,4,5); estimated
	metal working machine, unspecified, at plant	RER	1	kg	3.95E-5	3.95E-5	3.95E-5	3.95E-5	3.95E-5	1	1.63	(4,3,2,1,4,5); estimated
	metal working factory	RER	1	unit	4.58E-10	4.58E-10	4.58E-10	4.58E-10	4.58E-10	1	1.63	(4,3,2,1,4,5); estimated
	metal working factory operation, average heat energy	RER	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.63	(4,3,2,1,4,5); estimated

Tab. 6.11: Unit process raw data of the datasets “warm impact extrusion, steel”

	Name	Location	InfrastructureProcess	Unit	warm impact extrusion, steel, 1 stroke	warm impact extrusion, steel, 2 strokes	warm impact extrusion, steel, 3 strokes	warm impact extrusion, steel, 4 strokes	warm impact extrusion, steel, 5 strokes	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0	0			
	Unit				kg	kg	kg	kg	kg			
product	warm impact extrusion, steel, 1 stroke	RER	0	kg	1							
product	warm impact extrusion, steel, 2 strokes	RER	0	kg		1						
product	warm impact extrusion, steel, 3 strokes	RER	0	kg			1					
product	warm impact extrusion, steel, 4 strokes	RER	0	kg				1				
product	warm impact extrusion, steel, 5 strokes	RER	0	kg					1			
technosphere	deformation stroke, warm impact extrusion, steel	RER	0	kg	1	2	3	4	5	1	1.05	(1,1,1,1,1,1);
	warming, warm impact extrusion, steel	RER	0	kg	1	1	1	1	1	1	1.05	(1,1,1,1,1,1);
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3	2.91E-1	5.82E-1	8.73E-1	1.16E+0	1.45E+0	1	1.63	(4,3,2,1,4,5); estimated
	metal working machine, unspecified, at plant	RER	1	kg	3.95E-5	3.95E-5	3.95E-5	3.95E-5	3.95E-5	1	3.32	(4,3,2,1,4,5); estimated
	metal working factory	RER	1	unit	4.58E-10	4.58E-10	4.58E-10	4.58E-10	4.58E-10	1	3.32	(4,3,2,1,4,5); estimated
	metal working factory operation, average heat energy	RER	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.63	(4,3,2,1,4,5); estimated

Tab. 6.12: Unit process raw data of the datasets "hot impact extrusion, steel"

	Name	Location	InfrastructureProcess	Unit	hot impact extrusion, steel, 1 stroke	hot impact extrusion, steel, 2 strokes	hot impact extrusion, steel, 3 strokes	hot impact extrusion, steel, 4 strokes	hot impact extrusion, steel, 5 strokes	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0	0			
	Unit				kg	kg	kg	kg	kg			
product	hot impact extrusion, steel, 1 stroke	RER	0	kg	1							
product	hot impact extrusion, steel, 2 strokes	RER	0	kg		1						
product	hot impact extrusion, steel, 3 strokes	RER	0	kg			1					
product	hot impact extrusion, steel, 4 strokes	RER	0	kg				1				
product	hot impact extrusion, steel, 5 strokes	RER	0	kg					1			
technosphere	deformation stroke, hot impact extrusion, steel	RER	0	kg	1	2	3	4	5	1	1.05	(1,1,1,1,1,1);
	warming, hot impact extrusion, steel	RER	0	kg	1	1	1	1	1	1	1.05	(1,1,1,1,1,1);
	heat treatment, hot impact extrusion, steel	RER	0	kg	1	1	1	1	1	1	1.05	(1,1,1,1,1,1);
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3	2.91E-1	5.82E-1	8.73E-1	1.16E+0	1.45E+0	1	1.63	(4,3,2,1,4,5); estimated
	metal working machine, unspecified, at plant	RER	1	kg	3.95E-5	3.95E-5	3.95E-5	3.95E-5	3.95E-5	1	1.63	(4,3,2,1,4,5); estimated
	metal working factory	RER	1	unit	4.58E-10	4.58E-10	4.58E-10	4.58E-10	4.58E-10	1	1.63	(4,3,2,1,4,5); estimated
	metal working factory operation, average heat energy	RER	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.63	(4,3,2,1,4,5); estimated

Tab. 6.13: Metainformation of the datasets "impact extrusion", "surface treatment", "warming", "heat treatment" and "deformation stroke" (as all datasets of a category contain the same information, only one of each is shown here)

ReferenceFunction	Name	cold impact extrusion, steel, 1 stroke	surface treatment, cold impact extrusion, steel	warming, warm impact extrusion, steel	heat treatment, cold impact extrusion, steel	deformation stroke, cold impact extrusion, steel
Geography	Location	RER	RER	RER	RER	RER
ReferenceFunction	InfrastructureProcess	0	0	0	0	0
ReferenceFunction	Unit	kg	kg	kg	kg	kg
	IncludedProcesses	This dataset encompasses the electricity consumption of the machine as well as common pre- and post treatments. Furthermore, machine as well as factory infrastructure and operation are considered as well.	This dataset encompasses the energy consumption for the surface treatment before cold impact extrusion. Infrastructure is not included since it is thought that this process is an integral part of the impact extrusion dataset where infrastructure is included.	This dataset encompasses the energy consumption for the warming of the steel before it is deformed by impact extrusion. Infrastructure is not included since it is thought that this process is an integral part of the impact extrusion dataset where infrastructure is included.	This dataset encompasses the energy consumption for the heat treatment of the metal after it has been deformed by impact extrusion. Infrastructure is not included since it is thought that this process is an integral part of the impact extrusion dataset where infrastructure is included.	This dataset encompasses the electricity consumption of the machine as well as common pre- and post treatments. Furthermore, machine as well as factory infrastructure and operation are considered as well.
	Amount	1	1	1	1	1
	LocalName	Kaltfliesspressen, Stahl, 1 Hub	Oberflächenbehandlung, Kaltfliesspressen, Stahl	Erwärmen, Halbwarmfliesspressen, Stahl	Wärmebehandlung, Kaltfliesspressen, Stahl	Umformhub, Kaltfliesspressen, Stahl
	Synonyms					
	GeneralComment	The reference for impact extrusion is 1 kg of metal formed by impact extrusion. As there is a large variation from factory to factory with regard to the LCI, it is advised that in case this dataset becomes important in the results, it has to be investigated further if the rough estimations made are applicable or not.	The reference for impact extrusion is 1 kg of metal formed by impact extrusion. As there is a large variation from factory to factory with regard to the LCI, it is advised that in case this dataset becomes important in the results, it has to be investigated further if the rough estimations made are applicable or not.	The reference for impact extrusion is 1 kg of metal formed by impact extrusion. As there is a large variation from factory to factory with regard to the LCI, it is advised that in case this dataset becomes important in the results, it has to be investigated further if the rough estimations made are applicable or not.	The reference for impact extrusion is 1 kg of metal formed by impact extrusion. As there is a large variation from factory to factory with regard to the LCI, it is advised that in case this dataset becomes important in the results, it has to be investigated further if the rough estimations made are applicable or not.	The reference for impact extrusion is 1 kg of metal formed by impact extrusion. As there is a large variation from factory to factory with regard to the LCI, it is advised that in case this dataset becomes important in the results, it has to be investigated further if the rough estimations made are applicable or not.
	InfrastructureIncluded	1	1	1	1	1
	Category	metals	metals	metals	metals	metals
	SubCategory	chipless shaping	chipless shaping	chipless shaping	chipless shaping	chipless shaping
	LocalCategory	Metalle	Metalle	Metalle	Metalle	Metalle
	LocalSubCategory	Spanlose Bearbeitung	Spanlose Bearbeitung	Spanlose Bearbeitung	Spanlose Bearbeitung	Spanlose Bearbeitung
	Formula					
	StatisticalClassification					
	CASNumber					
TimePeriod	StartDate	2006	2006	2006	2006	2006
	EndDate	2007	2007	2007	2007	2007
	DataValidForEntirePeriod	1	1	1	1	1
	OtherPeriodText					
Geography	Text	Geographical coverage encompasses the industrialised countries.	Geographical coverage encompasses the industrialised countries.	Geographical coverage encompasses the industrialised countries.	Geographical coverage encompasses the industrialised countries.	Geographical coverage encompasses the industrialised countries.
Technology	Text	Average technology	Average technology	Average technology	Average technology	Average technology
Representativeness	Percent	0	0	0	0	0
	ProductionVolume	unknown	unknown	unknown	unknown	unknown
	SamplingProcedure	unknown	unknown	unknown	unknown	unknown
	Extrapolations	none	none	none	none	none
	UncertaintyAdjustments	none	none	none	none	none

6.6 Selected cumulative results and interpretation

6.6.1 Introduction

Selected LCI results and values for the cumulative energy demand are presented and discussed in this chapter. Please note that only a small part of the about 1000 elementary flows is presented here. The selection of the elementary flows shown in the tables is not based on their environmental relevance. It rather allows to show by examples the contributions of the different life cycle phases, or specific inputs from the technosphere to the selected elementary flows. Please refer to the ecoinvent database for the complete LCIs.

The shown selection is not suitable for a life cycle assessment of the analysed processes and products. Please use the data from the database for your own calculations, also because of possible minor deviations between the presented results and the database due to corrections and changes in background data used as inputs in the dataset of interest.

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

6.6.2 Results

The results are shown per kg of material processed. There is hardly any difference between aluminium and steel (same temperature level) nor between different temperature levels (steel). With increasing number of strokes however, the gap between the cumulative results of cold impact extrusion of steel and aluminium is increasing.

The cumulative results of cold impact extrusion are only slightly lower than for warm or hot impact extrusion. There is no heat treatment required during warm impact extrusion and hot impact extrusion has a substantially lower energy demand during heat treatment as compared to cold impact extrusion.

The non renewable energy demand of impact extrusion varies between 14.5 and 18.3 MJ-eq (one stroke) and between 24 and 43 MJ-eq (five strokes) per kg material treated.

Tab. 6.14: Selected LCI results and cumulative energy demand of cold impact extrusion, steel

	Name	Unit	cold impact extrusion, steel, 1 stroke	cold impact extrusion, steel, 2 strokes	cold impact extrusion, steel, 3 strokes	cold impact extrusion, steel, 4 strokes	cold impact extrusion, steel, 5 strokes
	Location		RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0
	Infrastructure		kg	kg	kg	kg	kg
CED	fossil fuels	MJ-Eq	11.4	12.6	13.8	15.1	16.3
CED	nuclear	MJ-Eq	2.3	3.1	3.9	4.7	5.5
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	0.2	0.2	0.2	0.3	0.3
CED	geothermal, converted	MJ-Eq	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	0.3	0.4	0.5	0.6	0.7
CED	kinetic (in wind), converted	MJ-Eq	0.0	0.1	0.1	0.1	0.1
land occupation	resource	m2a	5.0E-2	5.2E-2	5.4E-2	5.6E-2	5.8E-2
CO2, fossil	air	kg	8.3E-1	9.2E-1	1.0E+0	1.1E+0	1.2E+0
NMVOC	air	kg	3.7E-4	3.9E-4	4.1E-4	4.3E-4	4.5E-4
nitrogen oxides	air	kg	1.1E-3	1.3E-3	1.5E-3	1.6E-3	1.8E-3
sulphur dioxide	air	kg	1.4E-3	1.8E-3	2.1E-3	2.4E-3	2.8E-3
particulates, <2.5 um	air	kg	1.1E-4	1.3E-4	1.6E-4	1.8E-4	2.1E-4
BOD	water	kg	2.3E-3	2.4E-3	2.4E-3	2.4E-3	2.5E-3
cadmium	soil	kg	6.3E-10	6.7E-10	7.1E-10	7.6E-10	8.0E-10

Tab. 6.15: Selected LCI results and cumulative energy demand of cold impact extrusion, aluminium

	Name	Unit	cold impact extrusion, aluminium, 1 stroke	cold impact extrusion, aluminium, 2 strokes	cold impact extrusion, aluminium, 3 strokes	cold impact extrusion, aluminium, 4 strokes	cold impact extrusion, aluminium, 5 strokes
	Location		RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0
	Infrastructure		kg	kg	kg	kg	kg
CED	fossil fuels	MJ-Eq	11.2	15.4	19.7	23.9	28.1
CED	nuclear	MJ-Eq	4.2	6.9	9.7	12.5	15.2
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	0.2	0.3	0.4	0.5	0.6
CED	geothermal, converted	MJ-Eq	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	0.5	0.8	1.1	1.4	1.8
CED	kinetic (in wind), converted	MJ-Eq	0.1	0.1	0.2	0.2	0.3
land occupation	resource	m2a	5.4E-2	6.1E-2	6.9E-2	7.6E-2	8.3E-2
CO2, fossil	air	kg	8.6E-1	1.2E+0	1.5E+0	1.8E+0	2.2E+0
NMVOC	air	kg	3.3E-4	4.0E-4	4.7E-4	5.4E-4	6.1E-4
nitrogen oxides	air	kg	1.3E-3	1.9E-3	2.5E-3	3.0E-3	3.6E-3
sulphur dioxide	air	kg	1.9E-3	3.1E-3	4.2E-3	5.4E-3	6.5E-3
particulates, <2.5 um	air	kg	1.6E-4	2.4E-4	3.3E-4	4.1E-4	5.0E-4
BOD	water	kg	1.7E-3	1.9E-3	2.0E-3	2.1E-3	2.3E-3
cadmium	soil	kg	7.3E-10	8.7E-10	1.0E-9	1.2E-9	1.3E-9

Tab. 6.16: Selected LCI results and cumulative energy demand of warm impact extrusion, steel

	Name	Unit	warm impact extrusion, steel, 1 stroke	warm impact extrusion, steel, 2 strokes	warm impact extrusion, steel, 3 strokes	warm impact extrusion, steel, 4 strokes	warm impact extrusion, steel, 5 strokes
	Location		RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0
	Infrastructure		kg	kg	kg	kg	kg
CED	fossil fuels	MJ-Eq	9.7	11.2	12.7	14.2	15.7
CED	nuclear	MJ-Eq	4.8	5.7	6.7	7.7	8.6
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	0.3	0.3	0.3	0.4	0.4
CED	geothermal, converted	MJ-Eq	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	0.6	0.7	0.8	0.9	1.0
CED	kinetic (in wind), converted	MJ-Eq	0.1	0.1	0.1	0.1	0.2
land occupation	resource	m2a	5.6E-2	5.8E-2	6.1E-2	6.3E-2	6.6E-2
CO2, fossil	air	kg	8.0E-1	9.1E-1	1.0E+0	1.1E+0	1.3E+0
NMVOC	air	kg	2.9E-4	3.2E-4	3.4E-4	3.7E-4	3.9E-4
nitrogen oxides	air	kg	1.3E-3	1.6E-3	1.8E-3	2.0E-3	2.2E-3
sulphur dioxide	air	kg	2.1E-3	2.5E-3	2.9E-3	3.3E-3	3.7E-3
particulates, <2.5 um	air	kg	1.7E-4	2.0E-4	2.3E-4	2.6E-4	2.9E-4
BOD	water	kg	1.7E-3	1.8E-3	1.8E-3	1.9E-3	1.9E-3
cadmium	soil	kg	7.6E-10	8.1E-10	8.6E-10	9.1E-10	9.6E-10

Tab. 6.17: Selected LCI results and cumulative energy demand of hot impact extrusion, steel

	Name	Unit	hot impact extrusion, steel, 1 stroke	hot impact extrusion, steel, 2 strokes	hot impact extrusion, steel, 3 strokes	hot impact extrusion, steel, 4 strokes	hot impact extrusion, steel, 5 strokes
	Location		RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0
	Infrastructure		kg	kg	kg	kg	kg
CED	fossil fuels	MJ-Eq	12.1	13.6	15.1	16.6	18.1
CED	nuclear	MJ-Eq	6.2	7.1	8.1	9.1	10.0
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	0.3	0.3	0.4	0.4	0.4
CED	geothermal, converted	MJ-Eq	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	0.7	0.8	0.9	1.0	1.2
CED	kinetic (in wind), converted	MJ-Eq	0.1	0.1	0.1	0.2	0.2
land occupation	resource	m2a	5.9E-2	6.2E-2	6.4E-2	6.7E-2	7.0E-2
CO2, fossil	air	kg	9.8E-1	1.1E+0	1.2E+0	1.3E+0	1.4E+0
NMVOC	air	kg	3.3E-4	3.6E-4	3.8E-4	4.1E-4	4.3E-4
nitrogen oxides	air	kg	1.7E-3	1.9E-3	2.1E-3	2.3E-3	2.5E-3
sulphur dioxide	air	kg	2.7E-3	3.1E-3	3.5E-3	3.9E-3	4.3E-3
particulates, <2.5 um	air	kg	2.2E-4	2.5E-4	2.8E-4	3.1E-4	3.4E-4
BOD	water	kg	1.8E-3	1.9E-3	1.9E-3	2.0E-3	2.0E-3
cadmium	soil	kg	8.3E-10	8.8E-10	9.3E-10	9.8E-10	1.0E-9

6.7 Data Quality

The life cycle inventory is based on one source that seems to provide thoroughly researched data concerning energy consumption (electricity as well as fossil fuels). These data are considered as reliable.

All other inputs (compressed air, infrastructure and factory operation) were taken from the average machining datasets and contain, therefore, a higher uncertainty.

7 Deep Drawing

7.1 Introduction

Deep drawing is the technology of stretching a sheet metal (called blank) into a hollow shape. A punch presses the blank through the die cavity that defines the shape. The thickness as well as the surface area of the blank is not changed under normal circumstances.

There are different types of deep drawing depending on the way the pressure is applied as well as the material and construction used for the die. Deep drawing with rigid tools, i.e. punch and die made of steel, is the most common type.

Typical applications are the production of sleeves, air grilles, bathing tubes, car doors and others.

7.2 Data Sources and Quality

Doege et al. (2001) conducted a study with the goal of reducing energy consumption in deep drawing. They measured three presses of different press capacities under real operation conditions. The quality of the data for the researched applications is high.

Furthermore, an energy analysis of a press shop by Jörg & Wagener (1987) showed that the energy consumption remains almost constant while the sheet metal throughput changes. The study has discovered that the presses are in standby at about 50% of their operation time. Therefore, the energy consumption per blank is largely determined by the standby time.

7.3 System Boundaries

This dataset encompasses the process of deep drawing a part; this is electricity, compressed air as well as factory infrastructure and operation. The machine infrastructure is also considered.

7.4 Reference Unit

The reference unit of deep drawing is *1 kg of metal formed by deep drawing*.

7.5 Life Cycle Inventory

Data covering four presses are available in two literature sources. However, only one source reports the amounts of products produced (Jörg & Wagener 1987). The other source analysed three presses of different size and reports on energy consumption of different modes of operation. While Jörg & Wagener (1987) reports the amount of products produced as well as compressed air consumed for the one press covered, Doege et al. (2001) does not for any of the three presses under study (Tab. 7.1). It is, therefore, necessary to make assumptions and interpolations to be able to calculate operation data on material throughput (Tab. 7.2). The procedure is as follows:

1. Calculation of the inventory data of the 10’000 kN press in single stroke mode from the data in Jörg & Wagener (1987)
2. Estimation of the electricity consumption of the 10’000 kN press in automode by interpolating the electricity per stroke data from the other three presses (data from Jörg & Wagener 1987)
3. Electricity and compressed air consumption per kilogram of product in automode is then estimated assuming the same ratio as for the electricity per stroke (calculated in step 2), using the values of the 10'000 kN press calculated in step 1 as the reference

4. Electricity and compressed air consumption per kg product in single stroke mode are extrapolated from the 10'000 kN press to the others using the ratio of electricity consumption per kg product in automode.
5. The utilisation of the machine infrastructure is calculated for the 10’000 kN press for single stroke and automode and assumed to be identical for all press sizes

Tab. 7.1: Operation and infrastructure data of different sizes of deep drawing presses

		Small Part Press	Medium Part Press	Medium Part Press	Large Part Press	Remark
Press Capacity	kN	650	3'500	10'000	38'000	
Machine Weight	kg	9'100		224'300		Value for small part press from manufacturer's website (http://www.platarg.com)
Life Span	a	35	35	35	35	Average of the estimation for a medium to large part press of 20 to 50 years[5]
Measuring Period	h	20	40	720	20	Reference period for products, electricity and compressed air
Products	kg			6'760'000		
Electricity	kWh	30	315	1'338'000	2000	
Compressed Air	m^3			274'980		
Strokes	min^{-1}	70	28	14	12	
Source		(Doege et al. 2001)	(Doege et al. 2001)	(Jörg & Wagener 1987)	(Doege et al. 2001)	

[5] personal communication by M Wiedmann from MüllerWeingarten on 5. March 2007

Tab. 7.2: Estimation of the inventory data of the four presses. Data in *italic* is interpolated or based on major assumptions as outlined in the text.

		Small Part Press	Medium Part Press	Medium Part Press	Large Part Press	Remark
Press Capacity	kN	650	3'500	10'000	38'000	
Single Stroke Mode						
Electricity	kWh/stroke			2.21E+00		
Electricity	kWh/kg product	*3.33E-02*	*8.12E-02*	1.98E-01	*2.22E-01*	
Compressed Air	m^3/kg product	*4.45E-04*	*5.84E-03*	4.07E-02	*1.73E-01*	
Machine Weight	kg/kg product	*7.79E-05*	*7.79E-05*	7.79E-05	*7.79E-05*	Assumption: identical for all machines
Auto-(Continuous-) mode						
Electricity	kWh/stroke	3.57E-04	4.69E-03	*3.26E-02*	1.39E-01	
Electricity	kWh/kg product	*4.92E-04*	*1.20E-03*	*2.92E-03*	*3.27E-03*	
Compressed Air	m^3/kg product	*6.57E-06*	*8.62E-05*	*6.00E-04*	*2.55E-03*	
Machine Weight	kg/kg product	*1.15E-06*	*1.15E-06*	1.15E-06	*1.15E-06*	Assumption: identical for all machines

Tab. 7.3: Unit process raw data of the datasets “deep drawing, steel, single stroke operation”

	Name	Location	InfrastructureProcess	Unit	deep drawing, steel, 650 kN press, single stroke operation	deep drawing, steel, 3500 kN press, single stroke operation	deep drawing, steel, 10000 kN press, single stroke operation	deep drawing, steel, 38000 kN press, single stroke operation	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				kg	kg	kg	kg			
product	deep drawing, steel, 650 kN press, single stroke operation	RER	0	kg	1						
product	deep drawing, steel, 3500 kN press, single stroke operation	RER	0	kg		1					
product	deep drawing, steel, 10000 kN press, single stroke operation	RER	0	kg			1				
product	deep drawing, steel, 38000 kN press, single stroke operation	RER	0	kg				1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	3.33E-2	8.12E-2	1.98E-1	2.22E-1	1	1.37	(3,4,2,5,3,5); estimated from literature
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3	4.45E-4	5.84E-3	4.07E-2	1.73E-1	1	1.37	(3,4,2,5,3,5); estimated from literature
	metal working machine, unspecified, at plant	RER	1	kg	7.79E-5	7.79E-5	7.79E-5	7.79E-5	1	3.13	(3,4,2,5,3,5); estimated from literature
	metal working factory operation, average heat energy	RER	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.37	(3,4,2,5,3,5); estimated from literature
	metal working factory	RER	1	unit	4.58E-10	4.58E-10	4.58E-10	4.58E-10	1	3.13	(3,4,2,5,3,5); estimated from literature
emission air, high population density	Heat, waste	-	-	MJ	1.20E-1	2.92E-1	7.13E-1	7.98E-1	1	1.37	(3,4,2,5,3,5); from electricity

Tab. 7.4: Unit process raw data of the datasets "deep drawing, steel, automode"

	Name	Location	InfrastructureProcess	Unit	deep drawing, steel, 650 kN press, automode operation	deep drawing, steel, 3500 kN press, automode operation	deep drawing, steel, 10000 kN press, automode operation	deep drawing, steel, 38000 kN press, automode operation	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				kg	kg	kg	kg			
product	deep drawing, steel, 650 kN press, automode operation	RER	0	kg	1						
product	deep drawing, steel, 3500 kN press, automode operation	RER	0	kg		1					
product	deep drawing, steel, 10000 kN press, automode operation	RER	0	kg			1				
product	deep drawing, steel, 38000 kN press, automode operation	RER	0	kg				1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	4.92E-4	1.20E-3	2.92E-3	3.27E-3	1	1.24	(1,3,2,1,3,4); Literature value
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3	6.57E-6	8.62E-5	6.00E-4	2.55E-3	1	1.37	(3,4,2,5,3,5); estimated from literature
	metal working machine, unspecified, at plant	RER	1	kg	1.15E-6	1.15E-6	1.15E-6	1.15E-6	1	3.13	(3,4,2,5,3,5); estimated from literature
	metal working factory operation, average heat energy	RER	0	kg	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1	1.37	(3,4,2,5,3,5); estimated from literature
	metal working factory	RER	1	unit	4.58E-10	4.58E-10	4.58E-10	4.58E-10	1	3.13	(3,4,2,5,3,5); estimated from literature
emission air, high population density	Heat, waste	-	-	MJ	1.77E-3	4.31E-3	1.05E-2	1.18E-2	1	1.37	(3,4,2,5,3,5); from electricity

Tab. 7.5: Metainformation of the datasets "deep drawing" (all datasets contain the same information, therefore, only one is shown here)

ReferenceFunction	Name	deep drawing, steel, 650 kN press, single stroke operation
Geography	Location	RER
ReferenceFunction	InfrastructureProcess	0
ReferenceFunction	Unit	kg
	IncludedProcesses	This dataset encompasses the process of deep drawing a part; this is electricity, compressed air as well as factory infrastructure and operation. The machine infrastructure is also considered.
	Amount	1
	LocalName	Tiefziehen, Stahl, 650 kN Presse, Einzelhub-Betrieb
	Synonyms	
	GeneralComment	The reference for deep drawing is 1 kg of metal formed by deep drawing. As there is a large variation from factory to factory with regard to the LCI, it is advised that in case this dataset becomes important in the results, it has to be investigated further if the rough estimations made are applicable or not.
	InfrastructureIncluded	1
	Category	metals
	SubCategory	chipless shaping
	LocalCategory	Metalle
	LocalSubCategory	Spanlose Bearbeitung
	Formula	
	StatisticalClassification	
	CASNumber	
TimePeriod	StartDate	2006
	EndDate	2007
	DataValidForEntirePeriod	1
	OtherPeriodText	
Geography	Text	Geographical coverage encompasses the industrialised countries.
Technology	Text	Average technology
Representativeness	Percent	0
	ProductionVolume	unknown
	SamplingProcedure	unknown
	Extrapolations	none
	UncertaintyAdjustments	none

7.6 Selected cumulative results and interpretation

7.6.1 Introduction

Selected LCI results and values for the cumulative energy demand are presented and discussed in this chapter. Please note that only a small part of the about 1000 elementary flows is presented here. The selection of the elementary flows shown in the tables is not based on their environmental relevance. It rather allows to show by examples the contributions of the different life cycle phases, or specific inputs from the technosphere to the selected elementary flows. Please refer to the ecoinvent database for the complete LCIs.

The shown selection is not suitable for a life cycle assessment of the analysed processes and products. Please use the data from the database for your own calculations, also because of possible minor deviations between the presented results and the database due to corrections and changes in background data used as inputs in the dataset of interest.

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

7.6.2 Results

The environmental impacts of deep drawing of 1 kg steel product is dependent on the size of the press (single stroke mode) and on the operating mode. In the automode the general energy and water requirements are much more important than the specific requirements of the presses (of different size). That is why the LCI results and the CED indicator results are identical. In contrast to that, the differences in the specific energy requirements of the press are relevant in the single stroke mode. The emissions and resources requirements are higher with larger presses.

The non renewable CED per kg steel processed is between 4.6 and 6.7 MJ-eq (single stroke operation) and 3.6 MJ-eq (automode operation). The CO_2 emissions are between about 300 and 430 grams per kg steel processed. Deep drawing occupies about 4.5 dm^2a of land.

Tab. 7.6: Selected LCI results and cumulative energy demand of deep drawing processes

	Name		deep drawing, steel, 38000 kN press, single stroke operation	deep drawing, steel, 10000 kN press, single stroke operation	deep drawing, steel, 3500 kN press, single stroke operation	deep drawing, steel, 650 kN press, single stroke operation	deep drawing, steel, 38000 kN press, automode operation	deep drawing, steel, 10000 kN press, automode operation	deep drawing, steel, 3500 kN press, automode operation	deep drawing, steel, 650 kN press, automode operation
	Location		RER	RER	RER	RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0	0	0	0
	Infrastructure		kg	kg	kg	kg	kg	kg	kg	kg
CED	fossil fuels	MJ-Eq	5.0	4.6	3.7	3.4	3.2	3.2	3.2	3.1
CED	nuclear	MJ-Eq	1.7	1.4	0.9	0.6	0.5	0.5	0.5	0.5
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
CED	geothermal, converted	MJ-Eq	-	-	-	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
CED	kinetic (in wind), converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
land occupation	resource	m2a	4.8E-2	4.7E-2	4.5E-2	4.5E-2	4.4E-2	4.4E-2	4.4E-2	4.4E-2
CO2, fossil	air	kg	4.3E-1	4.0E-1	3.3E-1	3.0E-1	2.9E-1	2.9E-1	2.9E-1	2.9E-1
NMVOC	air	kg	2.2E-4	2.1E-4	1.9E-4	1.9E-4	1.9E-4	1.9E-4	1.8E-4	1.8E-4
nitrogen oxides	air	kg	7.0E-4	6.6E-4	5.3E-4	4.8E-4	4.5E-4	4.5E-4	4.5E-4	4.5E-4
sulphur dioxide	air	kg	8.5E-4	7.5E-4	5.1E-4	4.1E-4	3.5E-4	3.5E-4	3.5E-4	3.4E-4
particulates, <2.5 um	air	kg	7.8E-5	7.1E-5	5.3E-5	4.6E-5	4.1E-5	4.1E-5	4.1E-5	4.1E-5
BOD	water	kg	1.6E-3	1.6E-3	1.6E-3	1.5E-3	1.5E-3	1.5E-3	1.5E-3	1.5E-3
cadmium	soil	kg	5.9E-10	5.8E-10	5.5E-10	5.4E-10	5.3E-10	5.3E-10	5.3E-10	5.3E-10

7.7 Data Quality

The life cycle inventory is based on two sources that provide thoroughly researched data concerning energy consumption. Reliable compressed air consumption is available from one source.

Other inputs (infrastructure and factory operation) were taken from the average machining datasets and contain, therefore, a higher uncertainty.

There is some uncertainty concerning the amount of products produced over the whole life span, which determines the amount of machine infrastructure needed. On one hand, the presses are often in use for up to 50 years. On the other hand, changing requirements in production leads to a likely decrease of the utilisation intensity over time. It was not possible to include this effect and this may lead to an underestimation of the machine infrastructure demand.

8 Drilling

8.1 Introduction

Drilling uses a rotating cutting tool (the drill bit) to remove material from the work piece and is in this respect similar to milling. In contrast to milling where the cutting occurs mainly at the outer side of the tool, drilling predominantly uses the front end for cutting. The result of pushing the rotating drill bit on the work piece is a circular cavity or hole.

The diameter of the hole can be as small as 0.05 mm (micro-drilling) and go up to a diameter of several meters (drilling of tunnels). When it comes to material processing the size of a drill is typically in the order of millimetres up to a few centimetres.

The shape of the cutting edge of the drill bit depends largely on the material processed, the application, the size of the intended hole and whether the drilling is done manually or by a machine. The most commonly used bits are variations of the twist drill design.

Machines for drilling come in a large variety. The most basic ones are free-standing pillar drilling machines with a lever to manually lower the drill bit onto the work piece. The same design is also available as automated models. CNC type drilling machines permit more complex drilling operations. Finally, drilling can also be accomplished in a multi-axes CNC machining centre, which allows for the highest degree of flexibility. Furthermore, there is a range of machines developed for specific applications such as drilling metal sheets or profiles.

8.2 Data Sources and Quality

An older study (Barnes 1976) reports energy consumption values of drilling machines differentiating also according to the type of metal being drilled. The study does not clearly state how the values were obtained or where they stem from. Therefore, no statement on the reliability of the data is possible. As the study is quite old, it can be supposed that the values are only indicative for modern machines, but are a reasonable estimate in case of old machines still in operation.

8.3 System Boundaries

This dataset encompasses the direct electricity consumption of the machine. In the case of CNC drilling compressed air and lubricant oil (incl. disposal) are accounted for. Furthermore, the metal removed is already included. Machine as well as factory infrastructure and operation are considered as well. The metal removed is assumed to be recycled. Maintenance and tool (bit) replacements are not included.

8.4 Reference Unit

The reference unit of drilling is *1 kg of metal removed by drilling.*

8.5 Life Cycle Inventory

The inventory data is divided into conventional and CNC drilling. The main difference is that the CNC machines also need compressed air and cooling lubricant for operation. Furthermore, it is assumed that the energy consumption increase is comparable to conventional vs. CNC turning. The energy consumption increases in this case by a factor of about three according to Degner & Wolfram (1990).

As far as factory and machine infrastructure, compressed air consumption and cooling lubricant are concerned, the average values of a metal working machine operation estimated in chapter 2.4 (Tab. 2.6) are applied here. Since the data in chapter 2.4 is based on "kilogram material input" it has to be recalculated to be based on the "kilogram material removed" using the average removal rate mentioned in chapter 2.3.3.

Tab. 8.1: Electricity consumption per kg material removed of conventional and CNC drilling of different types of metals

	Conventional Drilling kWh/kg	CNC Drilling kWh/kg
Steel	0.181	0.542
Chromium Steel	0.250	0.750
Aluminium	0.076	0.229
Cast Iron	0.056	0.167
Brass	0.021	0.063
Source	(Barnes 1976)	(Barnes 1976) and (Degner & Wolfram 1990)

Tab. 8.2: Unit process raw data of the datasets "drilling, conventional"

	Name	Location	InfrastructureProcess	Unit	drilling, conventional, steel	drilling, conventional, chromium steel	drilling, conventional, aluminium	drilling, conventional, cast iron	drilling, conventional, brass	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0	0			
	Unit				kg	kg	kg	kg	kg			
product	drilling, conventional, steel	RER	0	kg	1							
product	drilling, conventional, chromium steel	RER	0	kg		1						
product	drilling, conventional, aluminium	RER	0	kg			1					
product	drilling, conventional, cast iron	RER	0	kg				1				
product	drilling, conventional, brass	RER	0	kg					1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	1.81E-1	2.50E-1	7.64E-2	5.56E-2	2.08E-2	1	1.24	(1,3,2,1,3,4); estimated from literature
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3	0	0	0	0	0	1	1.80	(5,3,2,1,4,4); estimated
	lubricating oil, at plant	RER	0	kg						1	1.80	(5,3,2,1,4,4); estimated
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg						1	1.80	(5,3,2,1,4,4); estimated disposal pathway
	metal working machine, unspecified, at plant	RER	1	kg	3.95E-5	3.95E-5	3.95E-5	3.95E-5	3.95E-5	1	1.80	(5,3,2,1,4,4); estimated
	metal working factory	RER	1	unit	2.02E-9	2.02E-9	2.02E-9	2.02E-9	2.02E-9	1	1.80	(5,3,2,1,4,4); estimated
	operation, metal working factory, average heat energy	RER	0	kg	4.41E+0	4.41E+0	4.41E+0	4.41E+0	4.41E+0	1	1.80	(5,3,2,1,4,4); estimated
	steel, low-alloyed, at plant	RER	0	kg	1.00E+0					1	1.05	(1,1,1,1,1,1); material removed
	chromium steel 18/8, at plant	RER	0	kg		1.00E+0				1	1.05	(1,1,1,1,1,1); material removed
	aluminium, production mix, at plant	RER	0	kg			1.00E+0			1	1.05	(1,1,1,1,1,1); material removed
	cast iron, at plant	RER	0	kg				1.00E+0		1	1.05	(1,1,1,1,1,1); material removed
	brass, at plant	CH	0	kg					1.00E+0	1	1.05	(1,1,1,1,1,1); material removed
emission air, high population density	Heat, waste	-	-	MJ	6.50E-1	9.00E-1	2.75E-1	2.00E-1	7.50E-2	1	1.24	(1,3,2,1,3,4); due to electricity consumption

Tab. 8.3: Unit process raw data of the datasets “drilling, CNC”

	Name	Location	InfrastructureProcess	Unit	drilling, CNC, steel	drilling, CNC, chromium steel	drilling, CNC, aluminium	drilling, CNC, cast iron	drilling, CNC, brass	UncertaintyType	StandardDeviation95%	GeneralComment
	Location InfrastructureProcess Unit				RER 0 kg	RER 0 kg	RER 0 kg	RER 0 kg	RER 0 kg			
product	drilling, CNC, steel	RER	0	kg	1							
product	drilling, CNC, chromium steel	RER	0	kg		1						
product	drilling, CNC, aluminium	RER	0	kg			1					
product	drilling, CNC, cast iron	RER	0	kg				1				
product	drilling, CNC, brass	RER	0	kg					1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	5.42E-1	7.50E-1	2.29E-1	1.67E-1	6.25E-2	1	1.24	(1,3,2,1,3,4); estimated from literature
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3	1.28E+0	1.28E+0	1.28E+0	1.28E+0	1.28E+0	1	1.48	(3,5,4,5,3,5); estimated
	lubricating oil, at plant	RER	0	kg	3.82E-3	3.82E-3	3.82E-3	3.82E-3	3.82E-3	1	1.48	(3,5,4,5,3,5); estimated
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	3.82E-3	3.82E-3	3.82E-3	3.82E-3	3.82E-3	1	1.48	(3,5,4,5,3,5); estimated disposal pathway
	metal working machine, unspecified, at plant	RER	1	kg	3.95E-5	3.95E-5	3.95E-5	3.95E-5	3.95E-5	1	1.48	(3,5,4,5,3,5); estimated
	metal working factory	RER	1	unit	2.02E-9	2.02E-9	2.02E-9	2.02E-9	2.02E-9	1	1.48	(3,5,4,5,3,5); estimated
	operation, metal working factory, average heat energy	RER	0	kg	4.41E+0	4.41E+0	4.41E+0	4.41E+0	4.41E+0	1	1.48	(3,5,4,5,3,5); estimated
	steel, low-alloyed, at plant	RER	0	kg	1.00E+0					1	1.05	(1,1,1,1,1,1); material removed
	chromium steel 18/8, at plant	RER	0	kg		1.00E+0				1	1.05	(1,1,1,1,1,1); material removed
	aluminium, production mix, at plant	RER	0	kg			1.00E+0			1	1.05	(1,1,1,1,1,1); material removed
	cast iron, at plant	RER	0	kg				1.00E+0		1	1.05	(1,1,1,1,1,1); material removed
	brass, at plant	CH	0	kg					1.00E+0	1	1.05	(1,1,1,1,1,1); material removed
emission air, high population density	Heat, waste	-	-	MJ	1.95E+0	2.70E+0	8.25E-1	6.00E-1	2.25E-1	1	1.24	(1,3,2,1,3,4); due to electricity consumption

Tab. 8.4: Metainformation of the datasets "drilling" (all datasets contain the same information, therefore, only one is shown here)

ReferenceFunction	Name	drilling, conventional, steel
Geography	Location	RER
ReferenceFunction	InfrastructureProcess	0
ReferenceFunction	Unit	kg
	IncludedProcesses	This dataset encompasses the direct electricity consumption of the machine. Furthermore, the metal removed is already included. Machine as well as factory infrastructure and operation are considered as well. The metal removed is assumed to be recycled. Maintenance and tool (bit) replacements are not included.
	Amount	1
	LocalName	Bohren, konventionell, Stahl
	Synonyms	
	GeneralComment	The reference for drilling is 1 kg of metal removed by drilling. As there is a large variation from factory to factory with regard to the LCI, it is advised that in case this dataset becomes important in the results, it has to be investigated further if the rough estimations made are applicable or not.
	InfrastructureIncluded	1
	Category	metals
	SubCategory	chipping
	LocalCategory	Metalle
	LocalSubCategory	Spanende Bearbeitung
	Formula	
	StatisticalClassification	
	CASNumber	
TimePeriod	StartDate	2006
	EndDate	2007
	DataValidForEntirePeriod	1
	OtherPeriodText	
Geography	Text	Geographical coverage encompasses the industrialised countries.
Technology	Text	Average technology
Representativeness	Percent	0
	ProductionVolume	unknown
	SamplingProcedure	unknown
	Extrapolations	none
	UncertaintyAdjustments	none

8.6 Selected cumulative results and interpretation

8.6.1 Introduction

Selected LCI results and values for the cumulative energy demand are presented and discussed in this chapter. Please note that only a small part of the about 1000 elementary flows is presented here. The selection of the elementary flows shown in the tables is not based on their environmental relevance. It rather allows to show by examples the contributions of the different life cycle phases, or specific inputs from the technosphere to the selected elementary flows. Please refer to the ecoinvent database for the complete LCIs.

The shown selection is not suitable for a life cycle assessment of the analysed processes and products. Please use the data from the database for your own calculations, also because of possible minor deviations between the presented results and the database due to corrections and changes in background data used as inputs in the dataset of interest.

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

8.6.2 Results

The results are strongly dependent on the material drilled but much less on the type of process (conventional or CNC). The general energy supply to operate a metal working factory is much more important (and considered equal in both types of drilling operations) than the specific electricity consumption during drilling.

The non renewable cumulative energy demand varies between 41 MJ-eq and 135 MJ-eq per kg of material removed. The fossil CO_2 emissions vary between 2.6 and 8.3 kg per kg material removed (cast iron and aluminium, respectively).

Tab. 8.5: Selected LCI results and cumulative energy demand of conventional drilling

	Name		drilling, conventional, steel	drilling, conventional, chromium steel	drilling, conventional, aluminium	drilling, conventional, cast iron	drilling, conventional, brass
	Location		RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0
	Infrastructure		kg	kg	kg	kg	kg
CED	fossil	MJ-Eq	39.3	81.4	104.6	36.0	44.3
CED	nuclear	MJ-Eq	6.3	18.3	25.2	5.0	8.9
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	0.7	1.3	1.1	0.7	1.0
CED	geothermal, converted	MJ-Eq	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	1.2	6.1	23.2	0.7	5.6
CED	kinetic (in wind), converted	MJ-Eq	0.1	0.3	0.1	0.1	0.1
land occupation	resource	m2a	3.0E-1	4.1E-1	3.7E-1	2.5E-1	8.4E-1
CO2, fossil	air	kg	3.0E+0	6.3E+0	8.0E+0	2.6E+0	3.5E+0
NMVOC	air	kg	1.9E-3	3.2E-3	3.4E-3	1.4E-3	4.3E-3
nitrogen oxides	air	kg	6.5E-3	1.5E-2	1.6E-2	5.3E-3	2.1E-2
sulphur dioxide	air	kg	5.9E-3	1.9E-2	2.8E-2	4.9E-3	8.3E-2
particulates, <2.5 um	air	kg	2.1E-3	1.0E-2	3.6E-3	1.1E-3	8.2E-3
BOD	water	kg	9.0E-3	1.8E-2	2.1E-2	8.2E-3	1.1E-2
cadmium	soil	kg	2.6E-9	3.3E-9	2.9E-9	2.5E-9	2.9E-9

Tab. 8.6: Selected LCI results and cumulative energy demand of CNC drilling

	Name		drilling, CNC, steel	drilling, CNC, chromium steel	drilling, CNC, aluminium	drilling, CNC, cast iron	drilling, CNC, brass
	Location		RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0
	Infrastructure		kg	kg	kg	kg	kg
CED	fossil	MJ-Eq	44.0	87.1	107.8	38.9	46.7
CED	nuclear	MJ-Eq	9.2	21.8	27.1	6.8	10.3
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	0.8	1.5	1.2	0.7	1.0
CED	geothermal, converted	MJ-Eq	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	1.6	6.5	23.5	0.9	5.7
CED	kinetic (in wind), converted	MJ-Eq	0.2	0.4	0.2	0.1	0.1
land occupation	resource	m2a	3.1E-1	4.2E-1	3.7E-1	2.6E-1	8.5E-1
CO2, fossil	air	kg	3.3E+0	6.8E+0	8.3E+0	2.9E+0	3.7E+0
NMVOC	air	kg	2.1E-3	3.4E-3	3.5E-3	1.5E-3	4.4E-3
nitrogen oxides	air	kg	7.2E-3	1.5E-2	1.6E-2	5.7E-3	2.2E-2
sulphur dioxide	air	kg	7.1E-3	2.1E-2	2.9E-2	5.7E-3	8.4E-2
particulates, <2.5 um	air	kg	2.1E-3	1.0E-2	3.7E-3	1.2E-3	8.2E-3
BOD	water	kg	9.3E-3	1.8E-2	2.1E-2	8.4E-3	1.1E-2
cadmium	soil	kg	2.8E-9	3.5E-9	3.0E-9	2.6E-9	2.9E-9

8.7 Data Quality

The life cycle inventory is based on one source reporting electricity consumption for drilling different types of metals. All other inputs (compressed air, infrastructure and factory operation) were taken from the average machining datasets. The literature source, as well as the use of average data, cause a certain uncertainty.

The main data gap concerns possible air emissions as no data was available. The extent and exact composition is dependent on process conditions as well as the material processed.

9 Laser Machining of Metals

9.1 Introduction

Laser can be used to either cut, drill, weld or engrave (Steen 2003). The most relevant types of lasers for machining are Nd:YAG (neodymium-doped yttrium aluminium garnet) and CO_2 lasers. Both types emit light in the infrared. While YAG-lasers cover the lower end of beam energy between about 0.04 and 600 W, the CO_2-lasers can deliver up to 25'000 W. YAG, as well as CO_2 lasers, are suitable for cutting, welding and engraving since the laser power can normally be adjusted to the requirements. CO_2-lasers are typically used in high productivity machining since their high laser power allows for fast processing in automated machines.

Laser machining is not very energy efficient as most of the energy input is lost as heat and typically less than 20% of the energy input is converted into usable laser energy. Therefore, water cooling units are common for lasers used in machining.

Nd:YAG lasers belong to the group of solid state lasers. The laser beam is produced by exciting a solid media. In this case, Nd:YAG is used as the solid media and excited with flash lamps. It is possible to produce either a pulsed or a continuous laser beam.

A CO_2-laser is actually a gas discharge lamp, i.e. the gas is excited by high-voltage to produce a laser beam in the infrared light spectrum. The gas mixture used typically consists of CO_2, N_2, H_2 or Xe and He. CO_2-lasers can be operated in pulsed or continuous mode.

Laser cutting is primarily used on sheets of metals although cutting of non-flat objects is also possible. The energy from the laser beam results in melting, burning or vaporizing of the material being processed leaving a cut with a high quality surface finish. The process of laser cutting can be similar to traditional milling. Advantages of laser cutting are precision (due to the absence of physical contact and wear) and a small heat-affected area.

Laser beam welding can be used to weld aluminium, titanium and carbon steel as well as stainless steel. The laser beam is used as a concentrated heat source that allows work pieces to be joined. The welding speed is high but only narrow welds are possible. Sometimes laser-hybrid welding is applied to combine the advantages of the laser with gas metal arc welding. In that case the latter provides molten metal to fill the gap between the welded pieces.

9.2 Data Sources and Quality

There is very little information on environmental data of laser machining in the scientific literature. Degner & Wolfram (1990) mentions energy consumption for laser cutting on a per volume basis which is thought to be an inadequate unit for a life cycle inventory since the volume removed by laser cutting is rarely known.

The manufacturers of laser machining machines sometimes indicate the typical power consumption during full or part load operation. Although it can be assumed that the values stated assume ideal conditions, they can be used as a first indication. In order to have a consistent set of data for laser machining one of the major producers of such machines (Trumpf) is chosen.

9.3 System Boundaries

The dataset is based on a complete system (work piece feeder, laser system as well as cooling and control systems). Any additional equipment such as possibly necessary ventilation or additional security installations are not included. Furthermore, it is not possible to relate factory infrastructure and operation to laser machining and, thus, is excluded.

9.4 Life Cycle Inventory

The inventory considers the two most common types of lasers. This is the YAG and the CO_2 based lasers. As the reference (functional unit) one hour of operation at full laser power is assumed. The assumptions on operating times are summarised in Tab. 9.1 and based on findings in Bongard & Jufer (1992) concerning the share of time a machine is in operation.

It is not possible to apply the average factory operation and infrastructure demand derived in chapter 2.6 and 2.7 to laser machining. There are no industrial data available on how much material is on average processed by laser machining in a given time period. Therefore, the mass based average factors are not related to the time based laser machining.

Tab. 9.1: Assumptions on operating times of YAG and CO_2 laser systems

	YAG-Laser Systems		CO_2-Laser Systems	
Life Span (a)	15	Assumption	15	Assumption
In Operation (h/d)	2	Assuming 25% operation time in 1 shift	12	Assuming 50% operation time in 2 shifts
Total Operation Time (s)	2.81E+07	Assuming 5 working days a week	1.68E+08	Assuming 5 working days a week
Infrastructure Need (unit/s)	3.56E-08		5.94E-09	

The YAG laser covers the lower end of the laser power range. It is assumed that this type of laser is used for a semi-automatic machine processing 2D or 3D work pieces typically used for small to medium batch sizes. Although it is possible to have one laser used on multiple machines simultaneously, it is assumed here that one laser supplies one single machine.

Tab. 9.2: Inventory data of YAG laser machining (Trumpf 2004a; Trumpf 2004b)

Laser (HL series)								
	HL22P	**HL32P**	**HL54P**	**HL62P**	**HL124P**	**HL204P**	**HL304P**	**HL506P**
Power (W)	30	40	50	60	120	200	330	500
Laser Type	YAG	YAG	YAG	YAG	YAG	YAG	YAG	YAG
Weight (kg)	175	175	220	380	380	480	900	900
Cooling water (m^3/h)			0.2	0.25	0.4	0.5	1	1
Power Consumption at 100% (kW)	2	2	2.5	3	5.5	9	18	18
Processing Machine (Lasma 584R)								
Weight (kg)	1900	1900	1900	1900	1900	1900	1900	1900
Power Consumption (kW)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Complete System								
Weight (kg)	2075	2075	2120	2280	2280	2380	2800	2800
Cooling water (m^3/h)			0.2	0.25	0.4	0.5	1	1
Power Consumption at 100% (kW)	4.5	4.5	5	5.5	8	11.5	20.5	20.5

The CO_2-lasers are more commonly used in high productivity applications. Therefore, the machines are significantly larger (and heavier) but are operated fully automatic. The 2D TruLaser Series (Trumpf 2006) has been chosen as a typical representative.

Tab. 9.3: Inventory data of CO_2-laser machining based on TruFlow laser TruLaser processing machine (Trumpf 2006)

Laser						
TruFlow Series	2000	2700	3200	4000	5000	6000
Laser Power (W) *Laser Type*	2000 CO_2	2700 CO_2	3200 CO_2	4000 CO_2	5000 CO_2	6000 CO_2
Helium (l/h) *N_2 (l/h)* *CO_2 (l/h)*	13 6 1	13 6 1	13 6 1	13 6 1	13 6 1	13 6 1
Processing Machine						
TruLaser Series	3030	3030	3030	3030	5030	5030
Complete System						
Power Consumption at 100% (kW)	40	50	53	65	72	76
Weight (kg)	11'500	11'500	11'500	11'500	12'000	12'000

Tab. 9.4: Density values of gases used for the conversion of from litre to kilogram

	Density **kg/m^3**	**Remark**
Helium (He) *Nitrogen (N_2)* *Carbon Dioxide (CO_2)*	0.16 1.14 1.80	calculation based on 1 atm and 25 °C

As cutting and welding of metals by a laser beam leads to vaporisation of the metal, there is a significant amount of particulates formed. Furthermore, NO_x and ozone are produced due to the irradiation energy of the laser beam. The nature of the particulates is closely related to the composition of the material processed, while the amount of particulates, NO_x and ozone emitted is a result of the processing conditions and parameters (Puester & Nygren ; Schröder et al. 1995).

Transport service requirements are calculated with the weight of the three gases listed in Tab. 9.4 and standard transport distances (200km lorry and 100km railway).

Tab. 9.5 summarises emission factors from three literature sources. "Total Fume" is interpreted as total particulate matter. Appropriate emission control measures for laser machining of metals is filtration. Reduction measures for NO_x and ozone are not needed (Puester & Nygren). According to Orza et al. (1995) the distribution of the particle size is as follows: about 50% of the particles are smaller than 1 µm and about 80% smaller than 10 µm. It is assumed that after filtration only particles smaller than 2.5 µm (PM2.5) remain in the exhaust air since filtration removes larger particles more efficiently than small ones. The average of all values reported (after emission control) is used in this study for a 5 kW laser (Tab. 9.6).

There is a factor of about ten between the lowest and highest factor of each substance (Tab. 9.5). This difference can not be related to the differences in the laser power as the laser with the lower power produces the higher emissions in absolute terms. Nevertheless, it is thought that the amount emitted per second must be related to the laser power. The specific emission values are, therefore, interpolated based on laser power. The average values mentioned in Tab. 9.6 are assumed to represent a 5 kW laser system.

Tab. 9.5: Air emissions of fume, NOx and ozone due to laser machining of steel according to literature sources

		Air Emissions					
		Min	**Max**	**Min**	**Max**	**Min**	**Max**
Total Fume	mg/s			18.91	18.91	2.5	10
NO_x	mg/s	0.860	1.707	0.013	0.091		
Ozone	mg/s	0.233	0.420			0.036	0.107
Remark		Welding of steel sheet with a 3.5kW CO_2-laser		Welding and cutting of steel		Welding of steel with CO_2-lasers between 5 and 10kW	
Source		(Schröder et al. 1995)		(Løhde-Hansen & Olsen 1993)		(Hurup & Hansen 1995)	

Tab. 9.6: Air emissions of fume, NOx and ozone used in this study

		Average	**Removal by Emission Control**		**This Study (5 kW laser)**
Total Fume	mg/s	12.58	99%	Filtration	0.126
NO_x	mg/s	0.668	0%	no emission control	0.668
Ozone	mg/s	0.199	0%	no emission control	0.199

Tab. 9.7: Unit process raw data of the datasets "laser machining, metal, with YAG-laser"

	Name	Location	InfrastructureProc	Unit	laser machining, metal, with YAG-laser, 30W power	laser machining, metal, with YAG-laser, 40W power	laser machining, metal, with YAG-laser, 50W power	laser machining, metal, with YAG-laser, 60W power	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				h	h	h	h			
product	laser machining, metal, with YAG-laser, 30W power	RER	0	h	1						
product	laser machining, metal, with YAG-laser, 40W power	RER	0	h		1					
product	laser machining, metal, with YAG-laser, 50W power	RER	0	h			1				
product	laser machining, metal, with YAG-laser, 60W power	RER	0	h				1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	4.50E+0	4.50E+0	5.00E+0	5.50E+0	1	1.22	(1,3,1,1,1,5); manufacturer data
	tap water, at user	RER	0	kg	0	0	2.00E+2	2.50E+2	1	1.22	(1,3,1,1,1,5); manufacturer data
	metal working machine, unspecified, at plant	RER	1	kg	2.66E-1	2.66E-1	2.72E-1	2.92E-1	1	1.63	(4,3,2,1,4,5); estimated
emission air, high population density	Particulates, < 2.5 um	-	-	kg	2.72E-6	3.62E-6	4.53E-6	5.43E-6	1	3.11	(2,3,3,3,3,5); estimated air emissions
	Nitrogen oxides	-	-	kg	1.44E-5	1.92E-5	2.40E-5	2.87E-5	1	1.64	(2,3,3,3,3,5); estimated air emissions
	Ozone	-	-	kg	4.23E-6	5.64E-6	7.06E-6	8.47E-6	1	1.64	(2,3,3,3,3,5); estimated air emissions
	Heat, waste	-	-	MJ	1.62E+1	1.62E+1	1.80E+1	1.98E+1	1	1.63	(4,3,2,1,4,5); due to electricity consumption

Tab. 9.7: (continued)

	Name	Location	InfrastructureProcess	Unit	laser machining, metal, with YAG-laser, 120W power	laser machining, metal, with YAG-laser, 200W power	laser machining, metal, with YAG-laser, 330W power	laser machining, metal, with YAG-laser, 500W power	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				h	h	h	h			
product	laser machining, metal, with YAG-laser, 120W power	RER	0	h	1						
product	laser machining, metal, with YAG-laser, 200W power	RER	0	h		1					
product	laser machining, metal, with YAG-laser, 330W power	RER	0	h			1				
product	laser machining, metal, with YAG-laser, 500W power	RER	0	h				1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	8.00E+0	1.15E+1	2.05E+1	2.05E+1	1	1.22	(1,3,1,1,1,5); manufacturer data
	tap water, at user	RER	0	kg	4.00E+2	5.00E+2	1.00E+3	1.00E+3	1	1.22	(1,3,1,1,1,5); manufacturer data
	metal working machine, unspecified, at plant	RER	1	kg	2.92E-1	3.05E-1	3.59E-1	3.59E-1	1	1.63	(4,3,2,1,4,5); estimated
emission air, high population density	Particulates, < 2.5 um	-	-	kg	1.09E-5	1.81E-5	2.99E-5	4.53E-5	1	3.11	(2,3,3,3,3,5); estimated air emissions
	Nitrogen oxides	-	-	kg	5.75E-5	9.58E-5	1.58E-4	2.40E-4	1	1.64	(2,3,3,3,3,5); estimated air emissions
	Ozone	-	-	kg	1.69E-5	2.82E-5	4.66E-5	7.06E-5	1	1.64	(2,3,3,3,3,5); estimated air emissions
	Heat, waste	-	-	MJ	2.88E+1	4.14E+1	7.38E+1	7.38E+1	1	1.63	(4,3,2,1,4,5); due to electricity consumption

Tab. 9.8: Unit process raw data of the datasets "laser machining, metal, with CO2-laser"

	Name	Location	InfrastructureProcess	Unit	laser machining, metal, with CO2-laser, 2000W power	laser machining, metal, with CO2-laser, 2700W power	laser machining, metal, with CO2-laser, 3200W power	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				h	h	h			
product	laser machining, metal, with CO2-laser, 2000W power	RER	0	h	1					
product	laser machining, metal, with CO2-laser, 2700W power	RER	0	h		1				
product	laser machining, metal, with CO2-laser, 3200W power	RER	0	h			1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	4.00E+1	5.00E+1	5.30E+1	1	1.22	(1,3,1,1,1,5); manufacturer data
	helium, at plant	GLO	0	kg	2.12E-3	2.12E-3	2.12E-3	1	1.22	(1,3,1,1,1,5); manufacturer data
	nitrogen, liquid, at plant	RER	0	kg	6.86E-3	6.86E-3	6.86E-3	1	1.22	(1,3,1,1,1,5); manufacturer data
	carbon dioxide liquid, at plant	RER	0	kg	1.80E-3	1.80E-3	1.80E-3	1	1.22	(1,3,1,1,1,5); manufacturer data
	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3	0	0	0	1	1.63	(4,3,2,1,4,5); estimated
	lubricating oil, at plant	RER	0	kg	0	0	0	1	1.63	(4,3,2,1,4,5); estimated
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	0	0	0	1	1.63	(4,3,2,1,4,5); estimated disposal pathway
	metal working machine, unspecified, at plant	RER	1	kg	2.46E-1	2.46E-1	2.46E-1	1	1.63	(4,3,2,1,4,5); estimated
	metal working factory	RER	1	unit				1	1.63	(4,3,2,1,4,5); estimated
	metal working factory operation, average heat energy	RER	0	kg				1	1.63	(4,3,2,1,4,5); estimated
	transport, lorry 32t	RER	0	tkm	2.16E-3	2.16E-3	2.16E-3	1	2.33	(4,3,2,1,4,5); standard distance
	transport, freight, rail	RER	0	tkm	1.08E-3	1.08E-3	1.08E-3	1	2.33	(4,3,2,1,4,5); standard distance
emission air, high population density	Particulates, < 2.5 um	-	-	kg	1.81E-4	2.45E-4	2.90E-4	1	3.11	(2,3,3,3,3,5); estimated air emissions
	Nitrogen oxides	-	-	kg	9.58E-4	1.29E-3	1.53E-3	1	1.64	(2,3,3,3,3,5); estimated air emissions
	Ozone	-	-	kg	2.82E-4	3.81E-4	4.52E-4	1	1.64	(2,3,3,3,3,5); estimated air emissions
	Helium	-	-	kg	2.12E-3	2.12E-3	2.12E-3	1	1.56	(1,3,1,1,1,5); due to gas input
	Carbon dioxide, fossil	-	-	kg	1.80E-3	1.80E-3	1.80E-3	1	1.22	(1,3,1,1,1,5); due to gas input
	Heat, waste	-	-	MJ	1.44E+2	1.80E+2	1.91E+2	1	1.22	(1,3,1,1,1,5); due to electricity consumption

Tab. 9.8: (continued)

	Name	Location	InfrastructureP	Unit	laser machining, metal, with CO2-laser, 4000W power	laser machining, metal, with CO2-laser, 5000W power	laser machining, metal, with CO2-laser, 6000W power	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				h	h	h			
product	laser machining, metal, with CO2-laser, 4000W power	RER	0	h	1					
product	laser machining, metal, with CO2-laser, 5000W power	RER	0	h		1				
product	laser machining, metal, with CO2-laser, 6000W power	RER	0	h			1			
technosphere	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	6.50E+1	7.20E+1	7.60E+1	1	1.22	(1,3,1,1,1,5); manufacturer data
	helium, at plant	GLO	0	kg	2.12E-3	2.12E-3	2.12E-3	1	1.22	(1,3,1,1,1,5); manufacturer data
	nitrogen, liquid, at plant	RER	0	kg	6.86E-3	6.86E-3	6.86E-3	1	1.22	(1,3,1,1,1,5); manufacturer data
	carbon dioxide liquid, at plant	RER	0	kg	1.80E-3	1.80E-3	1.80E-3	1	1.22	(1,3,1,1,1,5); manufacturer data
	metal working machine, unspecified, at plant	RER	1	kg	2.46E-1	2.56E-1	2.56E-1	1	1.63	(4,3,2,1,4,5); estimated
	transport, lorry 32t	RER	0	tkm	2.16E-3	2.16E-3	2.16E-3	1	2.33	(4,3,2,1,4,5); standard distance
	transport, freight, rail	RER	0	tkm	1.08E-3	1.08E-3	1.08E-3	1	2.33	(4,3,2,1,4,5); standard distance
emission air, high population density	Particulates, < 2.5 um	-	-	kg	3.62E-4	4.53E-4	5.43E-4	1	3.11	(2,3,3,3,3,5); estimated air emissions
	Nitrogen oxides	-	-	kg	1.92E-3	2.40E-3	2.87E-3	1	1.64	(2,3,3,3,3,5); estimated air emissions
	Ozone	-	-	kg	5.64E-4	7.06E-4	8.47E-4	1	1.64	(2,3,3,3,3,5); estimated air emissions
	Helium	-	-	kg	2.12E-3	2.12E-3	2.12E-3	1	1.56	(1,3,1,1,1,5); due to gas input
	Carbon dioxide, fossil	-	-	kg	1.80E-3	1.80E-3	1.80E-3	1	1.22	(1,3,1,1,1,5); due to gas input
	Heat, waste	-	-	MJ	2.34E+2	2.59E+2	2.74E+2	1	1.22	(1,3,1,1,1,5); due to electricity consumption

Tab. 9.9: Metainformation of the datasets "laser machining" (all datasets contain the same information, therefore, only one is shown here)

Name	laser machining, metal, with YAG-laser, 30W power
Location	RER
InfrastructureProcess	0
Unit	h
IncludedProcesses	This dataset includes work piece feeder, laser system, cooling and control system. Any additional equipment such as possibly necessary ventilation or additional security installations are not included. It includes the input of energy, of cooling water (where needed) and of the laser equipment. Further factory infrastructure (halls, buildings) are not included. The dataset includes process specific air emissions.
Amount	1
LocalName	Laserbearbeitung, Metall, mit YAG-Laser, 30W Leistung
Synonyms	
GeneralComment	The reference for laser machining is its operation at 100% power for 1 hour. It does not include the input of the material processed. This need to be added separately. The dataset can be used when metals are treated with a YAG laser of the capacity indicated. Factory infrastructure needs to be added. Data are based on manufacturers' data (weight and power consumption) and literature (air emissions).
InfrastructureIncluded	1
Category	metals
SubCategory	chipless shaping
LocalCategory	Metalle
LocalSubCategory	Spanlose Bearbeitung
Formula	
StatisticalClassification	
CASNumber	
StartDate	2006
EndDate	2007
DataValidForEntirePeriod	1
OtherPeriodText	
Text	Geographical coverage encompasses the industrialised countries.
Text	HL series of YAG Lasers and Lasma 584R processing machine
Percent	0
ProductionVolume	unknown
SamplingProcedure	unknown
Extrapolations	none
UncertaintyAdjustments	none

9.5 Selected cumulative results and interpretation

9.5.1 Introduction

Selected LCI results and values for the cumulative energy demand are presented and discussed in this chapter. Please note that only a small part of the about 1000 elementary flows is presented here. The selection of the elementary flows shown in the tables is not based on their environmental relevance. It rather allows to show by examples the contributions of the different life cycle phases, or specific inputs from the technosphere to the selected elementary flows. Please refer to the ecoinvent database for the complete LCIs.

The shown selection is not suitable for a life cycle assessment of the analysed processes and products. Please use the data from the database for your own calculations, also because of possible minor deviations between the presented results and the database due to corrections and changes in background data used as inputs in the dataset of interest.

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

9.5.2 Results

The results are shown per hour of operation of lasers of different power (from a 30 W to 6 kW) and different technology (YAG and CO_2). The non renewable cumulative enery demand is very much dependent on the power and varies between 74 and more than 560 MJ-eq per hour. On a per Wh basis (hour of operation times power of the laser), the values decrease from 2.5 MJ-eq to 1.5 MJ-eq from the smallest YAG to the largest CO_2 laser. This equals to an energy efficiency of 0.15 to 0.25 %.

The technology shows a much smaller influence as compared to the power of the laser. The emissions show a similar behaviour like the non renewable cumulative energy demand.

Tab. 9.10: Selected LCI results and cumulative energy demand of CO_2 laser machining

	Name		laser machining, metal, with CO2-laser, 2000W power	laser machining, metal, with CO2-laser, 2700W power	laser machining, metal, with CO2-laser, 3200W power	laser machining, metal, with CO2-laser, 4000W power	laser machining, metal, with CO2-laser, 5000W power	laser machining, metal, with CO2-laser, 6000W power
	Location		RER	RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0	0
	Infrastructure		h	h	h	h	h	h
CED	fossil	MJ-Eq	304.2	376.5	398.2	484.9	536.1	565.1
CED	nuclear	MJ-Eq	192.9	240.3	254.5	311.4	344.7	363.6
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	6.8	8.4	8.9	10.9	12.0	12.7
CED	geothermal, converted	MJ-Eq	-	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.1	0.1	0.1	0.1	0.1	0.1
CED	potential (in barrage water), converted	MJ-Eq	22.4	27.7	29.3	35.8	39.6	41.7
CED	kinetic (in wind), converted	MJ-Eq	3.6	4.4	4.7	5.8	6.4	6.7
land occupation	resource	m2a	5.6E-1	6.9E-1	7.3E-1	8.8E-1	9.7E-1	1.0E+0
CO2, fossil	air	kg	2.4E+1	2.9E+1	3.1E+1	3.8E+1	4.2E+1	4.4E+1
NMVOC	air	kg	5.5E-3	6.7E-3	7.1E-3	8.5E-3	9.3E-3	9.8E-3
nitrogen oxides	air	kg	4.3E-2	5.3E-2	5.7E-2	6.9E-2	7.6E-2	8.1E-2
sulphur dioxide	air	kg	8.4E-2	1.0E-1	1.1E-1	1.3E-1	1.5E-1	1.5E-1
particulates, <2.5 um	air	kg	7.2E-3	8.7E-3	9.2E-3	1.1E-2	1.2E-2	1.3E-2
BOD	water	kg	1.1E-2	1.4E-2	1.4E-2	1.7E-2	1.9E-2	2.0E-2
cadmium	soil	kg	1.0E-8	1.3E-8	1.4E-8	1.7E-8	1.9E-8	2.0E-8

Tab. 9.11: Selected LCI results and cumulative energy demand of YAG laser machining

	Name		laser machining, metal, with YAG-laser, 30W power	laser machining, metal, with YAG-laser, 40W power	laser machining, metal, with YAG-laser, 50W power	laser machining, metal, with YAG-laser, 60W power	laser machining, metal, with YAG-laser, 120W power	laser machining, metal, with YAG-laser, 200W power	laser machining, metal, with YAG-laser, 330W power	laser machining, metal, with YAG-laser, 500W power
	Location		RER	RER	RER	RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0	0	0	0
	Infrastructure		h	h	h	h	h	h	h	h
CED	fossil	MJ-Eq	48.6	48.6	53.3	58.3	76.9	103.4	173.5	173.5
CED	nuclear	MJ-Eq	25.0	25.0	27.9	30.6	42.8	59.7	104.1	104.1
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	1.0	1.0	1.1	1.2	1.7	2.3	4.0	4.0
CED	geothermal, converted	MJ-Eq	-	-	-	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	3.4	3.4	3.7	4.1	5.5	7.4	12.6	12.6
CED	kinetic (in wind), converted	MJ-Eq	0.5	0.5	0.5	0.6	0.8	1.1	1.9	1.9
land occupation	resource	m2a	1.3E-1	1.3E-1	1.4E-1	1.6E-1	1.9E-1	2.4E-1	3.9E-1	3.9E-1
CO2, fossil	air	kg	3.7E+0	3.7E+0	4.0E+0	4.4E+0	5.9E+0	7.9E+0	1.3E+1	1.3E+1
NMVOC	air	kg	1.4E-3	1.4E-3	1.5E-3	1.6E-3	1.9E-3	2.4E-3	3.7E-3	3.7E-3
nitrogen oxides	air	kg	7.3E-3	7.3E-3	8.0E-3	8.7E-3	1.1E-2	1.5E-2	2.5E-2	2.5E-2
sulphur dioxide	air	kg	1.4E-2	1.4E-2	1.6E-2	1.7E-2	2.2E-2	2.9E-2	4.9E-2	4.9E-2
particulates, <2.5 um	air	kg	1.9E-3	1.9E-3	2.1E-3	2.2E-3	2.6E-3	3.2E-3	4.8E-3	4.8E-3
BOD	water	kg	3.2E-3	3.2E-3	3.4E-3	3.7E-3	4.3E-3	5.2E-3	7.9E-3	7.9E-3
cadmium	soil	kg	1.5E-9	1.5E-9	1.6E-9	1.8E-9	2.5E-9	3.4E-9	5.8E-9	5.8E-9

9.6 Data Quality

The data source provides reliable data for electricity and gas (CO_2-laser) consumption. However, it was not possible to relate factory infrastructure and operation data to laser machining hours. This is a data gap leading to a certain underestimation. Furthermore, only a limited number of air emissions are included. Since the composition is dependent on the material processed it is difficult to include in a general dataset.

10 Compressed Air Supply

10.1 Introduction

Compressed air is used for a large number of production processes in small workshops up to large factories and plants. It is used to operate simple compressed air pistols, manual machining tools as well as in automated machining centres.

A typical compressed air supply system encompasses the following components:

- compressor
- compressed air storage container (optional)
- dryer (optional)
- filter (optional)
- pipe network for distribution
- consumer devices

The pressure level of an average supply network of a larger installation is typically adjusted to a value between 6 and 8 bar gauge. Small installations have pressure levels that are typically 2 bar higher. Besides these standard pressure levels, there are applications like varnishing pistols that can be operated at low pressure networks with a pressure level of about 2 bar gauge.

The single largest cost factor in the production of compressed air is the electricity consumption of the compressors. Additional equipment like dryers and filters adds only a small percentage to this. In one example of a large installation this amounts to about 3% (BFE 2005b), for a smaller installation to about 5% (BFE 2002). The main factors for differences in electricity consumption per Nm^3 of compressed air are (roughly ordered according to relevance):

- leakage rate
- pressure level (the higher the pressure level the more energy is needed for compression)
- appropriateness of the control settings (i.e. complete shut down at week ends/during the night, compressors operate mainly in their most efficient state)
- size of the compressor (larger compressors are generally more efficient and the maintenance is conducted more professionally)

The leakage rate is considered by providing datasets representing average and optimised installations. The datasets are further differentiated according to pressure level. Finally, the size aspect of the installation is included as well by considering small and large scale installations separately.

Market analysis shows that most of the compressors in operation are smaller than 3 kW, but most of the electricity is consumed by large compressors (Tab. 10.1). As a consequence of this, the separation in small and large scale installations is set to 30 kW (two 15 kW compressors).

Tab. 10.1: Estimated installed compressors for compressed air systems in Switzerland and their electricity consumption according to BFE (2000).

	Power in kW				
	<3	**3-15**	**18-90**	**>90**	**Total**
Installed Compressors (units)	110'000 *74%*	30'000 *20%*	8'000 *5%*	800 *1%*	148'800
Electricity Consumption (GWh)	11 *1%*	150 *20%*	400 *53%*	200 *26%*	761

10.2 System Boundaries

10.2.1 Compressor Infrastructure

The datasets include all materials needed to produce a compressor. The final disposal is also accounted for (assuming metals to recycling, plastics to incineration). Furthermore, the transports of the materials to the manufacturer are considered.

10.2.2 Compressed Air at Compressor

This dataset includes the compressor, operating materials (lubricating oil), the electricity consumption as well as the transports of the compressor and the lubricant to the installation site. The installation at the site is not included.

10.2.3 Compressed Air at Consumer

This dataset includes compressed air at compressor, the pipe network for distribution as well as losses of air by leaks. The transport of the pipe network to the installation site is accounted for. End user devices consuming compressed air are not included.

10.3 Life Cycle Inventory

10.3.1 Compressor

The configuration of the compressor used in the large system is based on the indications in BFE (2005b). The configuration of the small system is based on a pre-built package consisting of a compressor and an oil separator as mentioned in LFU (2004). The configurations are summarised in Tab. 10.2. The weight of electronics translates into an PWB area of about 0.25 m^2 per kg (Hischier et al. 2007).

An international company of the compressed air supply industry provided detailed data on two sizes of air-cooled screw compressors (Tab. 10.3). They are used as the compressors in the large air supply system (300 kW) and the small system (4 kW) respectively.

Transport service requirements are calculated with the weight of the materials and/or components and standard transport distances (100km lorry and 200km railway).

Tab. 10.2: Configuration and life span of the 4 kW and 300 kW compressors as mentioned in the literature for a carpentry and a chemical plant

	Amount	Unit	Remark	Source
4 kW Compressor				
Configuration	2	units	Data for Carpentry	(LFU 2004)
Power of a Unit	4	kW	Data for Carpentry	(LFU 2004)
Life Span	15	a	Average	(BFE 2000)
300 kW Compressor				
Configuration	4	units		(BFE 2005b)
Power of a Unit	300	kW	Average value of the compressors	(BFE 2005b)
Life Span	15	a	Average	(BFE 2000)

Tab. 10.3: Summary of the materials of a 4 kW and a 300 kW screw compressor and the consumption of lubricating oil during operation (data from an international compressor manufacturer).

		Compressor Power	
		4 kW	300 kW
Machine Weight	kg	140	4'600
Materials			
High-alloy Steel	kg	16	250
Low-alloy Steel	kg	40	2'100
Unalloyed Steel	kg	30	1'700
Copper	kg	20	300
Aluminium	kg	20	220
Plastics (PS)	kg	10	20
Electronics (PWB)	kg	1	1
Rubber	kg	3	9
Operating Materials			
Mineral Oil	kg/Nm^3	1.0E-05	2.1E-06

10.3.2 Infrastructure Demand

The amount of compressed air produced per compressor not only varies between companies but is also dependent on the leakage rate when assuming the same amount of compressed air at the consuming devices. Therefore, the compressed air production of a single compressor is calculated separately for average, optimised and best installations as well as for small and large scale installations (Tab. 10.11). The average compressor operates during 750 hours per year (BFE 2000). Hence, the compressor runs 11'250 hours during its service life.

Tab. 10.4: Calculation of the amount of compressed air produced by a single unit of compressor over the whole life span

		<30 kW network (Carpentry)		>30 kW network (Chemical Plant A)		
Leakage		Average	Optimised	Average	Optimised	Best
Leakage Rate		50%	5%	30%	15%	10%
Compressors	Units	2	2	4	4	4
Compressed Air at Compressors	Nm^3/h	2.15	1.13	5641	4646	4387
Compressed Air per Compressor	Nm^3/life of unit	1.21E+04	6.37E+03	1.59E+07	1.31E+07	1.23E+07
Compressor Demand	**unit/Nm^3**	8.26E-05	1.57E-04	6.30E-08	7.65E-08	8.10E-08

The layout of the pipe network is based on the large network presented in BFE (2005b). Due to the lack of more accurate data on small systems these data are also applied on a per volume of air basis to the small system. Carbon steel, stainless steel, copper and aluminium as well as different types of plastic are used as piping material. For larger diameters (i.e. installations) steel is most commonly used (stainless steel if corrosion resistance is needed). For smaller diameters copper, aluminium or stainless steel are used (eCompressedair 2007).

Stainless steel and copper are rather expensive options and probably only used when absolutely necessary. Therefore, steel is used for the piping in the large installations (>30 kW) and aluminium in the small installations (<30 kW).

Tab. 10.5: Estimation on the material need for the pipe network based on a large installation (BFE 2005b)

	Amount	Unit	Remark	Source
Pipe Network				
Pipe Diameter DN	100	mm	Estimation mentioned in the literature source	(BFE 2005b)
Inner Diameter d_{in}	97.2	mm		(Legris 2005)
Outer Diameter d_{out}	101.8	mm		(Legris 2005)
Network Length	4'500	m	Estimation mentioned in the literature source	(BFE 2005b)
Material Volume	3.24	m^3	Calculated material use for complete network	
Life Span of pipe Network	15	a	Assumed to be identical to the life span of the compressors	
Aluminium	3.35E-05	kg/Nm^3	Pipe Network Demand	
Steel	9.79E-05	kg/Nm^3	Pipe Network Demand	

10.3.3 Operation of a Compressed Air Supply Network

According to Bierbaum et al. (2004) an economically tolerable leakage rate (i.e. cost of finding and repairing the leaks vs. the cost of compressed air loss) is 15% or lower (Tab. 10.6). However, real life system can show significantly higher values. LFU (2002b) discovered a leakage rate of more than 50% in a large system, while for a small system the highest value found exceeded 90%.

Tab. 10.6: Maximum leakage rate that is economically tolerable according to Bierbaum et al. (2004)

	Max. Tolerable Leakage Rate
small network	5%
medium network	7%
large network	10%
very large networks	15%

Electricity Consumption and Leakage Rate in Medium to Large Scale (>30 kW) Installations

In order to arrive at average data on the operation of a compressed air supply system, a number of Swiss and German installations are evaluated. The electricity consumption as well as the leakage rate of most of them were measured before (Tab. 10.7) and after the implementation of optimisation measures (Tab. 10.8). Based on this, a value for average and optimised installations can easily be calculated (Tab. 10.9). Furthermore, data on a "best installation" is derived.

The range of pressure level for larger installations seems to be between 6 and 8 bar gauge. The average of the considered systems is at about 7 bar gauge. A change in pressure level by 1 bar leads to a change of about 7% in electricity consumption (BFE 2006). This value is used to deduce the datasets for 8 and 6 bar gauge.

Tab. 10.7: Industry data of compressed air installations >30kW in Switzerland and Germany (average installation standard).

Average Industry Values		**Chemical Plant A**	**Chemical Plant B**	**Packaging Factory**
Installed Compressor Power	kW	1285	725	525
Pressure Level	bar gauge	7.3	6	6 and 8
Compressed Air at Compressor	Nm^3/h	4646	2838	928
Leakage Rate		15%	30%	13.3%
Compressed Air at Consumer	Nm^3/h	3949	1987	805
Electricity Consumption	kWh/h	743	258	224
Electricity Consumption per air volume at compressor	kWh/m^3	0.160	0.091	0.242
Remarks		Leakage rate assumed according to values given in Bierbaum et al. (2004)		Badly structured distribution network before optimisation
Source		(BFE 2005b, p.26)	(BFE 2005a, p.35)	(BFE 1999)

Tab. 10.7 (continued)

Average Industry Values		**Machine Industry Plant**	**Plastics Processing Plant**	**Food Production Plant**
Installed Compressor Power	kW	295	756	74
Pressure Level	bar gauge	6.9	7	8
Compressed Air at Compressor	Nm^3/h	774	1341	6
Leakage Rate		51.7%	26.9%	20%
Compressed Air at Consumer	Nm^3/h	374	981	4.79
Electricity Consumption	kWh/h	111	147.5	33.8
Electricity Consumption per air volume at compressor	kWh/m^3	0.143	0.110	(5.64)
Remarks				Not considered in average - abnormally high electricity consumption is due to mistaken control settings
Source		(LFU 2002b)	(LFU 2002a)	(LFU 2001)

Tab. 10.8: Industry data of compressed air installations >30kW in Switzerland and Germany (optimised installation standard).

Optimised Industry Values		**Chemical Plant A**	**Chemical Plant B**	**Packaging Industry**	**Machine Industry**
Installed Compressor Power	kW	1285	725	525	295
Pressure Level	bar gauge	7.3	6	6 and 8	6.9
Compressed Air at Compressor	Nm^3/h	4646	2503	829	914
Leakage Rate		15%	21%	2.9%	12%
Compressed Air at Consumer	Nm^3/h	3949	1987	805	374
Electricity Consumption	kWh/h	579	227	150	49
Electricity Consumption per air volume at compressor	kWh/m^3	0.125	0.091	0.180	0.116
Remarks		Optimisation by new compressors and control system	Optimisation potential of several measures: reduction in electricity consumption by 11.8%	Optimised by leakage reduction and new control system	Optimised by leakage reduction measures and partial compressor replacement
Source		(BFE 2005b, p.26)	(BFE 2005a, p.35)	(BFE 1999)	(LFU 2002b, p.41/42)

Tab. 10.9: Electricity consumption and leakage rate used in this study for compressed air installations >30kW

Installations with >30kW		This Study at 6 bar gauge	This Study at 7 bar gauge	This Study at 8 bar gauge
Average Industry Values				
Leakage Rate	%	30%	30%	30%
Electricity Consumption per air volume at compressor	kWh/m^3	0.139	0.149	0.159
Remarks		Deduced from the 7 bar pressure level assuming a reduction of 7%/bar	Average value of five plants (Tab. 10.7). The food production plant is excluded.	Deduced from the 7 bar pressure level assuming an increase of 7%/bar
Optimised Industry Values				
Leakage Rate	%	15%	15%	15%
Electricity Consumption per air volume at compressor	kWh/m3	0.119	0.128	0.137
Remarks		Deduced from the 7 bar pressure level assuming a reduction of 7%/bar	Average value of four plants (Tab. 10.8).	Deduced from the 7 bar pressure level assuming an increase of 7%/bar
Best Industry Values				
Leakage Rate	%	10%	10%	10%
Electricity Consumption per air volume at compressor	kWh/m3	0.091	0.097	0.104
Remarks		Chemical Plant B from Tab. 10.8 with tolerable leakage rate according to Tab. 10.6; electricity demand adjusted by the amount of compressed air produced	Deduced from the 6 bar pressure level assuming an increase of 7%/bar	Deduced from the 6 bar pressure level assuming an increase of 7%/bar

Electricity Consumption and Leakage Rate in Small Scale (<30 kW) Installations

The data is derived from a German study evaluating different types of small scale compressed air consumers. The electricity consumption of two of them were measured before (Tab. 10.10) and after the implementation of optimisation measures (Tab. 10.11). Furthermore, it is assumed that the optimisation leads to an economically tolerable leakage rate according to Tab. 10.6. From this a value of average and optimised installations is calculated (Tab. 10.12).

The range of pressure level for small installations seems to be between 8 and 14 bar gauge. The average of the considered systems is at about 10 bar gauge. A change in pressure level by 1 bar leads to a change of about 7% in electricity consumption (BFE 2006). This value is used to derive the datasets for 8 and 12 bar gauge.

Tab. 10.10: Industry data of compressed air installations <30kW in Switzerland and Germany (average installation standard).

Average Industry Values for <30kW		**Garage for cars**	**Carpentry**	**Garage for lorries and building machines**	**Bicycle shop**
Installed Compressor Power	kW	11.5	8	5.5	3
Pressure Level	bar gauge	8 and 9.75	14	13	8.4
Compressed Air at Compressor	Nm^3/h	0.88	1.33	0.47	0.075
Leakage Rate		21%	19%	76%	93%
Electricity Consumption	kWh/h	0.16	0.26	0.09	0.012
Electricity Consumption per air volume at compressor	kWh/m^3	0.177	0.197	0.193	0.159
Remarks					
Source		(LFU 2004)	(LFU 2004)	(LFU 2004)	(LFU 2004)

Tab. 10.11: Industry data of compressed air installations <30kW in Switzerland and Germany (optimised installation standard).

Optimised Industry Values for <30kW		**Carpentry**	**Garage for lorries and building machines**
Installed Compressor Power	kW	8	5.5
Pressure Level	bar gauge	10	11
Compressed Air at Compressor	Nm^3/h	1.13	0.12
Leakage Rate		5%	5%
Electricity Consumption	kWh/h	0.17	0.02
Electricity Consumption per air volume at compressor	kWh/m^3	0.148	0.154
Remarks		Econ. tolerable leakage (Tab. 10.6) and optimised pressure level	Econ. tolerable leakage (Tab. 10.6) and optimised pressure level
Source		(LFU 2004)	(LFU 2004)

Tab. 10.12: Electricity consumption and leakage rate used in this study for compressed air installations <30kW

Installations with <30kW		This Study at 8 bar gauge	This Study at 10 bar gauge	This Study at 12 bar gauge
Average Industry Values				
Leakage Rate	%	50%	50%	50%
Electricity Consumption per air volume at compressor	kWh/m^3	0.157	0.181	0.207
Remarks		Deduced from the 10 bar pressure level assuming a reduction of 7%/bar	Average value of four installations (Tab. 10.10)	Deduced from the 10 bar pressure level assuming an increase of 7%/bar
Optimised Industry Values				
Leakage Rate	%	5%	5%	5%
Electricity Consumption per air volume at compressor	kWh/m^3	0.131	0.151	0.173
Remarks		Deduced from the 10 bar pressure level assuming a reduction of 7%/bar	Average value of two installations (Tab. 10.11)	Deduced from the 10 bar pressure level assuming an increase of 7%/bar

10.3.4 LCI Input Data

Tab. 10.13: Unit process raw data of the datasets "air compressor, screw type compressor""

	Name	Location	InfrastructureProcess	Unit	air compressor, screw-type compressor, 4 kW, at plant	air compressor, screw-type compressor, 300 kW, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER			
	InfrastructureProcess				1	1			
	Unit				unit	unit			
product	air compressor, screw-type compressor, 4 kW, at plant	RER	1	unit	1				
product	air compressor, screw-type compressor, 300 kW, at plant	RER	1	unit		1			
technosphere	chromium steel 18/8, at plant	RER	0	kg	1.60E+1	2.50E+2	1	1.24	(1,4,1,3,1,5); manufacturer data
	steel, low-alloyed, at plant	RER	0	kg	4.00E+1	2.10E+3	1	1.24	(1,4,1,3,1,5); manufacturer data
	cast iron, at plant	RER	0	kg	3.00E+1	1.70E+3	1	1.24	(1,4,1,3,1,5); manufacturer data
	copper, at regional storage	RER	0	kg	2.00E+1	3.00E+2	1	1.24	(1,4,1,3,1,5); manufacturer data
	aluminium, production mix, at plant	RER	0	kg	2.00E+1	2.20E+2	1	1.24	(1,4,1,3,1,5); manufacturer data
	polystyrene, high impact, HIPS, at plant	RER	0	kg	1.00E+1	2.00E+1	1	1.24	(1,4,1,3,1,5); manufacturer data
	printed wiring board, surface mount, at plant	GLO	0	m2	2.51E-1	2.51E-1	1	1.24	(1,4,1,3,1,5); manufacturer data
	synthetic rubber, at plant	RER	0	kg	3.00E+0	9.00E+0	1	1.24	(1,4,1,3,1,5); manufacturer data
	sheet rolling, chromium steel	RER	0	kg	1.60E+1	2.50E+2	1	1.24	(1,4,1,3,1,5); manufacturer data
	sheet rolling, steel	RER	0	kg	4.00E+1	2.10E+3	1	1.24	(1,4,1,3,1,5); manufacturer data
	sheet rolling, aluminium	RER	0	kg	2.00E+1	2.20E+2	1	1.24	(4,3,2,1,1,4); estimation
	wire drawing, copper	RER	0	kg	2.00E+1	3.00E+2	1	1.24	(4,3,2,1,1,4); estimation
	injection moulding	RER	0	kg	1.00E+1	2.00E+1	1	1.24	(4,3,2,1,1,4); estimation
	disposal, polystyrene, 0.2% water, to municipal incineration	CH	0	kg	1.00E+1	2.00E+1	1	1.24	(4,3,2,1,1,4); assumption
	disposal, rubber, unspecified, 0% water, to municipal incineration	CH	0	kg	3.00E+0	9.00E+0	1	1.24	(4,3,2,1,1,4); assumption
	transport, lorry 32t	RER	0	tkm	1.40E+1	4.60E+2	1	2.14	(4,5,1,1,1,5); Standard distance to for materials to manufacturer
	transport, freight, rail	RER	0	tkm	2.80E+1	9.20E+2	1	2.14	(4,5,1,1,1,5); Standard distance to for materials to manufacturer

Tab. 10.14: Unit process raw data of the datasets "compressed air, average generation, <30kW, at compressor "

	Name	Location	InfrastructureProcess	Unit	compressed air, average generation, <30kW, 8 bar gauge, at compressor	compressed air, average generation, <30kW, 10 bar gauge, at compressor	compressed air, average generation, <30kW, 12 bar gauge, at compressor	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				m3	m3	m3			
product	compressed air, average generation, <30kW, 8 bar gauge, at compressor	RER	0	m3	1					
product	compressed air, average generation, <30kW, 10 bar gauge, at compressor	RER	0	m3		1				
product	compressed air, average generation, <30kW, 12 bar gauge, at compressor	RER	0	m3			1			
technosphere	air compressor, screw-type compressor, 4 kW, at plant	RER	1	unit	8.26E-5	8.26E-5	8.26E-5	1	3.06	(2,4,2,1,1,5); manufacturer value
	lubricating oil, at plant	RER	0	kg	1.00E-5	1.00E-5	1.00E-5	1	1.24	(1,4,1,1,1,5); manufacturer value
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.00E-5	1.00E-5	1.00E-5	1	1.24	(1,4,1,1,1,5); manufacturer value
	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	1.57E-1	1.81E-1	2.07E-1	1	1.13	(1,3,2,1,1,4); average value
	transport, lorry >16t, fleet average	RER	0	tkm	1.16E-3	1.16E-3	1.16E-3	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of compressor and lubricating oil
	transport, freight, rail	RER	0	tkm	2.31E-3	2.31E-3	2.31E-3	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of compressor and lubricating oil
emission air, high population density	Heat, waste	-	-	MJ	5.64E-1	6.52E-1	7.46E-1	1	1.13	(1,3,2,1,1,4);

Tab. 10.15: Unit process raw data of the datasets "compressed air, optimised generation, <30kW, at compressor "

	Name	Location	InfrastructureProcess	Unit	compressed air, optimised generation, <30kW, 8 bar gauge, at compressor	compressed air, optimised generation, <30kW, 10 bar gauge, at compressor	compressed air, optimised generation, <30kW, 12 bar gauge, at compressor	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				m3	m3	m3			
product	compressed air, optimised generation, <30kW, 8 bar gauge, at compressor	RER	0	m3	1					
product	compressed air, optimised generation, <30kW, 10 bar gauge, at compressor	RER	0	m3		1				
product	compressed air, optimised generation, <30kW, 12 bar gauge, at compressor	RER	0	m3			1			
technosphere	air compressor, screw-type compressor, 4 kW, at plant	RER	1	unit	1.57E-4	1.57E-4	1.57E-4	1	3.06	(2,4,2,1,1,5); manufacturer value
	lubricating oil, at plant	RER	0	kg	1.00E-5	1.00E-5	1.00E-5	1	1.24	(1,4,1,1,1,5); manufacturer value
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.00E-5	1.00E-5	1.00E-5	1	1.24	(1,4,1,1,1,5); manufacturer value
	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	1.31E-1	1.51E-1	1.73E-1	1	1.13	(1,3,2,1,1,4); average value
	transport, lorry >16t, fleet average	RER	0	tkm	2.20E-3	2.20E-3	2.20E-3	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of compressor and lubricating oil
	transport, freight, rail	RER	0	tkm	4.39E-3	4.39E-3	4.39E-3	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of compressor and lubricating oil
emission air, high population density	Heat, waste	-	-	MJ	4.70E-1	5.44E-1	6.22E-1	1	1.13	(1,3,2,1,1,4);

Tab. 10.16: Unit process raw data of the datasets "compressed air, average generation, >30kW, at compressor "

	Name	Location	InfrastructureProcess	Unit	compressed air, average generation, >30kW, 6 bar gauge, at compressor	compressed air, average generation, >30kW, 7 bar gauge, at compressor	compressed air, average generation, >30kW, 8 bar gauge, at compressor	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				m3	m3	m3			
product	compressed air, average generation, >30kW, 6 bar gauge, at compressor	RER	0	m3	1					
product	compressed air, average generation, >30kW, 7 bar gauge, at compressor	RER	0	m3		1				
product	compressed air, average generation, >30kW, 8 bar gauge, at compressor	RER	0	m3			1			
technosphere	air compressor, screw-type compressor, 300 kW, at plant	RER	1	unit	6.30E-8	6.30E-8	6.30E-8	1	3.06	(1,4,1,1,1,5); manufacturer value
	lubricating oil, at plant	RER	0	kg	2.08E-6	2.08E-6	2.08E-6	1	1.24	(1,4,1,1,1,5); manufacturer value
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	2.08E-6	2.08E-6	2.08E-6	1	1.24	(1,4,1,1,1,5); manufacturer value
	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	1.39E-1	1.49E-1	1.59E-1	1	1.13	(1,3,2,1,1,4); average value
	transport, lorry >16t, fleet average	RER	0	tkm	2.90E-5	2.90E-5	2.90E-5	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of compressor and lubricating oil
	transport, freight, rail	RER	0	tkm	5.80E-5	5.80E-5	5.80E-5	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of compressor and lubricating oil
emission air, high population density	Heat, waste	-	-	MJ	4.99E-1	5.36E-1	5.74E-1	1	1.13	(1,3,2,1,1,4); from electricity

Tab. 10.17: Unit process raw data of the datasets “compressed air, optimised generation, >30kW, at compressor ”

	Name	Location	InfrastructureProcess	Unit	compressed air, optimised generation, >30kW, 6 bar gauge, at compressor	compressed air, optimised generation, >30kW, 7 bar gauge, at compressor	compressed air, optimised generation, >30kW, 8 bar gauge, at compressor	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				m3	m3	m3			
product	compressed air, optimised generation, >30kW, 6 bar gauge, at compressor	RER	0	m3	1					
product	compressed air, optimised generation, >30kW, 7 bar gauge, at compressor	RER	0	m3		1				
product	compressed air, optimised generation, >30kW, 8 bar gauge, at compressor	RER	0	m3			1			
technosphere	air compressor, screw-type compressor, 300 kW, at plant	RER	1	unit	7.65E-8	7.65E-8	7.65E-8	1	3.06	(1,4,1,1,1,5); manufacturer value
	lubricating oil, at plant	RER	0	kg	2.08E-6	2.08E-6	2.08E-6	1	1.24	(1,4,1,1,1,5); manufacturer value
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	2.08E-6	2.08E-6	2.08E-6	1	1.24	(1,4,1,1,1,5); manufacturer value
	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	1.19E-1	1.28E-1	1.37E-1	1	1.13	(1,3,2,1,1,4); average value
	transport, lorry >16t, fleet average	RER	0	tkm	3.52E-5	3.52E-5	3.52E-5	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of compressor and lubricating oil
	transport, freight, rail	RER	0	tkm	7.04E-5	7.04E-5	7.04E-5	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of compressor and lubricating oil
emission air, high population density	Heat, waste	-	-	MJ	4.29E-1	4.61E-1	4.93E-1	1	1.13	(1,3,2,1,1,4); from electricity

Tab. 10.18: Unit process raw data of the datasets “compressed air, best generation, >30kW, at compressor”

	Name	Location	InfrastructureProcess	Unit	compressed air, best generation, >30kW, 6 bar gauge, at compressor	compressed air, best generation, >30kW, 7 bar gauge, at compressor	compressed air, best generation, >30kW, 8 bar gauge, at compressor	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				m3	m3	m3			
product	compressed air, best generation, >30kW, 6 bar gauge, at compressor	RER	0	m3	1					
product	compressed air, best generation, >30kW, 7 bar gauge, at compressor	RER	0	m3		1				
product	compressed air, best generation, >30kW, 8 bar gauge, at compressor	RER	0	m3			1			
technosphere	air compressor, screw-type compressor, 300 kW, at plant	RER	1	unit	8.10E-8	8.10E-8	8.10E-8	1	3.06	(1,4,1,1,1,5); manufacturer value
	lubricating oil, at plant	RER	0	kg	2.08E-6	2.08E-6	2.08E-6	1	1.24	(1,4,1,1,1,5); manufacturer value
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	2.08E-6	2.08E-6	2.08E-6	1	1.24	(1,4,1,1,1,5); manufacturer value
	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh	9.10E-2	9.74E-2	1.04E-1	1	1.13	(1,3,2,1,1,4); average value
	transport, lorry >16t, fleet average	RER	0	tkm	3.73E-5	3.73E-5	3.73E-5	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of compressor and lubricating oil
	transport, freight, rail	RER	0	tkm	7.46E-5	7.46E-5	7.46E-5	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of compressor and lubricating oil
emission air, high population density	Heat, waste	-	-	MJ	3.28E-1	3.51E-1	3.75E-1	1	1.13	(1,3,2,1,1,4); from electricity

Tab. 10.19: Unit process raw data of the datasets “compressed air, average installation, <30kW, at supply network ”

	Name	Location	InfrastructureProcess	Unit	compressed air, average installation, <30kW, 8 bar gauge, at supply network	compressed air, average installation, <30kW, 10 bar gauge, at supply network	compressed air, average installation, <30kW, 12 bar gauge, at supply network	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				m3	m3	m3			
product	compressed air, average installation, <30kW, 8 bar gauge, at supply network	RER	0	m3	1					
product	compressed air, average installation, <30kW, 10 bar gauge, at supply network	RER	0	m3		1				
product	compressed air, average installation, <30kW, 12 bar gauge, at supply network	RER	0	m3			1			
technosphere	aluminium, production mix, at plant	RER	0	kg	3.35E-5	3.35E-5	3.35E-5	1	1.31	(4,3,2,1,1,5); average value of one distribution network
	section bar extrusion, aluminium	RER	0	kg	3.35E-5	3.35E-5	3.35E-5	1	1.31	(4,3,2,1,1,5); average value of one distribution network
	transport, lorry >16t, fleet average	RER	0	tkm	3.35E-6	3.35E-6	3.35E-6	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of pipe network
	transport, freight, rail	RER	0	tkm	6.69E-6	6.69E-6	6.69E-6	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of pipe network
	compressed air, average generation, <30kW, 8 bar gauge, at compressor	RER	0	m3	1.50E+0			1	1.13	(1,3,2,1,1,4); average value for Swiss and German installations
	compressed air, average generation, <30kW, 10 bar gauge, at compressor	RER	0	m3		1.50E+0		1	1.13	(1,3,2,1,1,4); average value for Swiss and German installations
	compressed air, average generation, <30kW, 12 bar gauge, at compressor	RER	0	m3			1.50E+0	1	1.13	(1,3,2,1,1,4); average value for Swiss and German installations

Tab. 10.20: Unit process raw data of the datasets “compressed air, optimised installation, <30kW, at supply network”

	Name	Location	InfrastructureProcess	Unit	compressed air, optimised installation, <30kW, 8 bar gauge, at supply network	compressed air, optimised installation, <30kW, 10 bar gauge, at supply network	compressed air, optimised installation, <30kW, 12 bar gauge, at supply network	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				m3	m3	m3			
product	compressed air, optimised installation, <30kW, 8 bar gauge, at supply network	RER	0	m3	1					
product	compressed air, optimised installation, <30kW, 10 bar gauge, at supply network	RER	0	m3		1				
product	compressed air, optimised installation, <30kW, 12 bar gauge, at supply network	RER	0	m3			1			
technosphere	aluminium, production mix, at plant	RER	0	kg	3.35E-5	3.35E-5	3.35E-5	1	1.31	(4,3,2,1,1,5); average value of one distribution network
	section bar extrusion, aluminium	RER	0	kg	3.35E-5	3.35E-5	3.35E-5	1	1.31	(4,3,2,1,1,5); average value of one distribution network
	transport, lorry >16t, fleet average	RER	0	tkm	3.35E-6	3.35E-6	3.35E-6	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of pipe network
	transport, freight, rail	RER	0	tkm	6.69E-6	6.69E-6	6.69E-6	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of pipe network
	compressed air, optimised generation, <30kW, 8 bar gauge, at compressor	RER	0	m3	1.05E+0			1	1.13	(1,3,2,1,1,4); optimised value for Swiss and German installations
	compressed air, optimised generation, <30kW, 10 bar gauge, at compressor	RER	0	m3		1.05E+0		1	1.13	(1,3,2,1,1,4); optimised value for Swiss and German installations
	compressed air, optimised generation, <30kW, 12 bar gauge, at compressor	RER	0	m3			1.05E+0	1	1.13	(1,3,2,1,1,4); optimised value for Swiss and German installations

Tab. 10.21: Unit process raw data of the datasets “compressed air, average installation, >30kW, at supply network ”

	Name	Location	InfrastructureProcess	Unit	compressed air, average installation, >30kW, 6 bar gauge, at supply network	compressed air, average installation, >30kW, 7 bar gauge, at supply network	compressed air, average installation, >30kW, 8 bar gauge, at supply network	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				m3	m3	m3			
product	compressed air, average installation, >30kW, 6 bar gauge, at supply network	RER	0	m3	1					
product	compressed air, average installation, >30kW, 7 bar gauge, at supply network	RER	0	m3		1				
product	compressed air, average installation, >30kW, 8 bar gauge, at supply network	RER	0	m3			1			
technosphere	steel, low-alloyed, at plant	RER	0	kg	9.79E-5	9.79E-5	9.79E-5	1	1.31	(4,3,2,1,1,5); average value of one distribution network
	section bar rolling, steel	RER	0	kg	9.79E-5	9.79E-5	9.79E-5	1	1.31	(4,3,2,1,1,5); average value of one distribution network
	transport, lorry >16t, fleet average	RER	0	tkm	9.79E-6	9.79E-6	9.79E-6	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of pipe network
	transport, freight, rail	RER	0	tkm	1.96E-5	1.96E-5	1.96E-5	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of pipe network
	compressed air, average generation, >30kW, 6 bar gauge, at compressor	RER	0	m3	1.30E+0			1	1.13	(1,3,2,1,1,4); average value for Swiss and German installations
	compressed air, average generation, >30kW, 7 bar gauge, at compressor	RER	0	m3		1.30E+0		1	1.13	(1,3,2,1,1,4); average value for Swiss and German installations
	compressed air, average generation, >30kW, 8 bar gauge, at compressor	RER	0	m3			1.30E+0	1	1.13	(1,3,2,1,1,4); average value for Swiss and German installations

Tab. 10.22: Unit process raw data of the datasets “compressed air, optimised installation, >30kW, at supply network”

	Name	Location	InfrastructureProcess	Unit	compressed air, optimised installation, >30kW, 6 bar gauge, at supply network	compressed air, optimised installation, >30kW, 7 bar gauge, at supply network	compressed air, optimised installation, >30kW, 8 bar gauge, at supply network	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				m3	m3	m3			
product	compressed air, optimised installation, >30kW, 6 bar gauge, at supply network	RER	0	m3	1					
product	compressed air, optimised installation, >30kW, 7 bar gauge, at supply network	RER	0	m3		1				
product	compressed air, optimised installation, >30kW, 8 bar gauge, at supply network	RER	0	m3			1			
technosphere	steel, low-alloyed, at plant	RER	0	kg	9.79E-5	9.79E-5	9.79E-5	1	1.31	(4,3,2,1,1,5); average value of one distribution network
	section bar rolling, steel	RER	0	kg	9.79E-5	9.79E-5	9.79E-5	1	1.31	(4,3,2,1,1,5); average value of one distribution network
	transport, lorry >16t, fleet average	RER	0	tkm	9.79E-6	9.79E-6	9.79E-6	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of pipe network
	transport, freight, rail	RER	0	tkm	1.96E-5	1.96E-5	1.96E-5	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of pipe network
	compressed air, optimised generation, >30kW, 6 bar gauge, at compressor	RER	0	m3	1.15E+0			1	1.13	(1,3,2,1,1,4); optimised value for Swiss and German installations
	compressed air, optimised generation, >30kW, 7 bar gauge, at compressor	RER	0	m3		1.15E+0		1	1.13	(1,3,2,1,1,4); optimised value for Swiss and German installations
	compressed air, optimised generation, >30kW, 8 bar gauge, at compressor	RER	0	m3			1.15E+0	1	1.13	(1,3,2,1,1,4); optimised value for Swiss and German installations

Tab. 10.23: Unit process raw data of the datasets “compressed air, best installation, >30kW, at supply network”

	Name	Location	InfrastructureProcess	Unit	compressed air, best installation, >30kW, 6 bar gauge, at supply network	compressed air, best installation, >30kW, 7 bar gauge, at supply network	compressed air, best installation, >30kW, 8 bar gauge, at supply network	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				m3	m3	m3			
product	compressed air, best installation, >30kW, 6 bar gauge, at supply network	RER	0	m3	1					
product	compressed air, best installation, >30kW, 7 bar gauge, at supply network	RER	0	m3		1				
product	compressed air, best installation, >30kW, 8 bar gauge, at supply network	RER	0	m3			1			
technosphere	steel, low-alloyed, at plant	RER	0	kg	9.79E-5	9.79E-5	9.79E-5	1	1.31	(4,3,2,1,1,5); average value of one distribution network
	section bar rolling, steel	RER	0	kg	9.79E-5	9.79E-5	9.79E-5	1	1.31	(4,3,2,1,1,5); average value of one distribution network
	transport, lorry >16t, fleet average	RER	0	tkm	9.79E-6	9.79E-6	9.79E-6	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of pipe network
	transport, freight, rail	RER	0	tkm	1.96E-5	1.96E-5	1.96E-5	1	2.14	(4,5,1,1,1,5); assuming 100km lorry, 200km train for transport of pipe network
	compressed air, best generation, >30kW, 6 bar gauge, at compressor	RER	0	m3	1.10E+0			1	1.13	(1,3,2,1,1,4); best value for Swiss and German installations
	compressed air, best generation, >30kW, 7 bar gauge, at compressor	RER	0	m3		1.10E+0		1	1.13	(1,3,2,1,1,4); best value for Swiss and German installations
	compressed air, best generation, >30kW, 8 bar gauge, at compressor	RER	0	m3			1.10E+0	1	1.13	(1,3,2,1,1,4); best value for Swiss and German installations

Tab. 10.24: Metainformation of the datasets "compressed air at compressor" and "compressed air at supply network" (all similar datasets contain the same information, therefore, only one of each is shown here) as well as for the two "compressor" datasets

ReferenceFunction	Name	compressed air, average generation, >30kW, 6 bar gauge, at compressor	compressed air, average installation, >30kW, 6 bar gauge, at supply network	air compressor, screw-type compressor, 4 kW, at plant	air compressor, screw-type compressor, 300 kW, at plant
Geography	Location	RER	RER	RER	RER
ReferenceFunction	InfrastructureProcess	0	0	1	1
ReferenceFunction	Unit	m3	m3	unit	unit
	IncludedProcesses	This dataset includes the compressor, operating materials (lubricating oil), the electricity consumption as well as the transports of the compressor and the lubricant to the installation site. The installation at the site is not included.	This dataset includes the compressor, operating materials (lubricating oil), the electricity consumption as well as the transports of the compressor and the lubricant to the installation site. Furthermore, the distribution network and its leakage is considered. The installation at the site is not included.	This dataset includes the materials and machining processes needed to produce a compressor. The disposal is also included.	This dataset includes the materials and machining processes needed to produce a compressor. The disposal is also included.
	Amount	1	1	1	1
	LocalName	Druckluft, durchschnittliche Erzeugung, >30kW, 6 bar, ab Kompressor	Druckluft, durchschnittliche Anlage, >30kW, 6 bar, ab Verteilnetz	Druckluftkompressor, Schraubenverdichter, 4 kW, ab Werk	Druckluftkompressor, Schraubenverdichter, 300 kW, ab Werk
	Synonyms				
	GeneralComment	As there is some variation from factory to factory with regard to the LCI, it is advised that in case this dataset becomes important in the results, it is recommended to investigated further if the assumptions made for this dataset are applicable or not.	As there is some variation from factory to factory with regard to the LCI, it is advised that in case this dataset becomes important in the results, it is recommended to investigated further if the assumptions made for this dataset are applicable or not.	The weight of the compressor is 140 kg	The weight of the compressor is 4600 kg
	InfrastructureIncluded	1	1	1	1
	Category	mechanical engineering	mechanical engineering	mechanical engineering	mechanical engineering
	SubCategory	compressed air generation	compressed air supply	compressed air equipment	compressed air equipment
	LocalCategory	Fertigungsprozesse	Fertigungsprozesse	Fertigungsprozesse	Fertigungsprozesse
	LocalSubCategory	Druckluftproduktion	Druckluftversorgung	Drucklufteinrichtungen	Drucklufteinrichtungen
	Formula				
	StatisticalClassification				
	CASNumber				
TimePeriod	StartDate	2006	2006	2006	2006
	EndDate	2007	2007	2007	2007
	DataValidForEntirePeriod	1	1	1	1
	OtherPeriodText				
Geography	Text	Geographical coverage encompasses the industrialised countries.	Geographical coverage encompasses the industrialised countries.	Geographical coverage encompasses the industrialised countries.	Geographical coverage encompasses the industrialised countries.
Technology	Text	Average technology	Average technology	Average technology	Average technology
Representativeness	Percent	0	0	0	0
	ProductionVolume	unknown	unknown	unknown	unknown
	SamplingProcedure	unknown	unknown	unknown	unknown
	Extrapolations	none	none	none	none
	UncertaintyAdjustments	none	none	none	none

10.4 Selected cumulative results and interpretation

10.4.1 Introduction

Selected LCI results and values for the cumulative energy demand are presented and discussed in this chapter. Please note that only a small part of the about 1000 elementary flows is presented here. The selection of the elementary flows shown in the tables is not based on their environmental relevance. It rather allows to show by examples the contributions of the different life cycle phases, or specific inputs from the technosphere to the selected elementary flows. Please refer to the ecoinvent database for the complete LCIs.

The shown selection is not suitable for a life cycle assessment of the analysed processes and products. Please use the data from the database for your own calculations, also because of possible minor deviations between the presented results and the database due to corrections and changes in background data used as inputs in the dataset of interest.

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

10.4.2 Results

The results are shown per m^3 compressed air supplied with average, optimal and best installations, further differentiating between the size of the compressor and various pressure levels. The cumulative results are highest for small units with and average performance and a high pressure level. The cumulative non renewable energy demand may be as high as 5 MJ-eq/m^3 (average installation, < 30kW, 12 bar gauge) or as low as 1.2 MJ-eq/m^3 (best installation, > 30kW, 6 bar gauge), which makes more than a factor 4 difference.

The variation in results due to differences in pressure level is minor compared to the differences due to the size and also compared to the leakage rate (average, optimised, best) of the compressed air network. The emissions of fossil CO_2 vary with the cumulative energy demand between 250 and less than 60 g per m^3 compressed air supplied.

Tab. 10.25: Selected LCI results and cumulative energy demand of compressed air supply, average

	Name		compressed air, average installation, <30kW, 12 bar gauge, at supply network	compressed air, average installation, <30kW, 10 bar gauge, at supply network	compressed air, average installation, <30kW, 8 bar gauge, at supply network	compressed air, average installation, >30kW, 8 bar gauge, at supply network	compressed air, average installation, >30kW, 7 bar gauge, at supply network	compressed air, average installation, >30kW, 6 bar gauge, at supply network
	Location		RER	RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0	0
	Infrastructure		m3	m3	m3	m3	m3	m3
CED	fossil	MJ-Eq	3.3	3.0	2.7	1.5	1.4	1.3
CED	nuclear	MJ-Eq	1.7	1.5	1.4	1.0	0.9	0.9
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	0.1	0.1	0.1	0.0	0.0	0.0
CED	geothermal, converted	MJ-Eq	-	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	0.3	0.2	0.2	0.1	0.1	0.1
CED	kinetic (in wind), converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
land occupation	resource	m2a	8.4E-3	7.9E-3	7.4E-3	2.6E-3	2.5E-3	2.3E-3
CO2, fossil	air	kg	2.5E-1	2.3E-1	2.1E-1	1.2E-1	1.1E-1	1.0E-1
NMVOC	air	kg	8.4E-5	7.9E-5	7.5E-5	2.5E-5	2.4E-5	2.2E-5
nitrogen oxides	air	kg	5.0E-4	4.6E-4	4.3E-4	2.1E-4	1.9E-4	1.8E-4
sulphur dioxide	air	kg	1.1E-3	1.0E-3	9.4E-4	4.1E-4	3.8E-4	3.6E-4
particulates, <2.5 um	air	kg	1.2E-4	1.1E-4	1.1E-4	3.1E-5	2.9E-5	2.8E-5
BOD	water	kg	2.2E-4	2.1E-4	2.0E-4	5.0E-5	4.7E-5	4.4E-5
cadmium	soil	kg	9.5E-11	8.5E-11	7.6E-11	5.2E-11	4.9E-11	4.6E-11

Tab. 10.26: Selected LCI results and cumulative energy demand of compressed air supply, optimised

	Name		compressed air, optimised installation, <30kW, 12 bar gauge, at supply network	compressed air, optimised installation, <30kW, 10 bar gauge, at supply network	compressed air, optimised installation, <30kW, 8 bar gauge, at supply network	compressed air, optimised installation, >30kW, 8 bar gauge, at supply network	compressed air, optimised installation, >30kW, 7 bar gauge, at supply network	compressed air, optimised installation, >30kW, 6 bar gauge, at supply network
	Location		RER	RER	RER	RER	RER	RER
	Unit	Unit	0	0	0	0	0	0
	Infrastructure		m3	m3	m3	m3	m3	m3
CED	fossil	MJ-Eq	2.7	2.5	2.4	1.2	1.1	1.0
CED	nuclear	MJ-Eq	1.2	1.1	1.0	0.7	0.7	0.7
CED	primary forest	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
CED	biomass	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
CED	geothermal, converted	MJ-Eq	-	-	-	-	-	-
CED	solar, converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
CED	potential (in barrage water), converted	MJ-Eq	0.2	0.2	0.2	0.1	0.1	0.1
CED	kinetic (in wind), converted	MJ-Eq	0.0	0.0	0.0	0.0	0.0	0.0
land occupation	resource	m2a	8.3E-3	8.0E-3	7.7E-3	2.0E-3	1.9E-3	1.8E-3
CO2, fossil	air	kg	2.0E-1	1.9E-1	1.7E-1	9.0E-2	8.4E-2	7.8E-2
NMVOC	air	kg	8.4E-5	8.1E-5	7.9E-5	1.9E-5	1.8E-5	1.7E-5
nitrogen oxides	air	kg	4.4E-4	4.2E-4	3.9E-4	1.6E-4	1.5E-4	1.4E-4
sulphur dioxide	air	kg	9.9E-4	9.4E-4	9.0E-4	3.1E-4	2.9E-4	2.7E-4
particulates, <2.5 um	air	kg	1.3E-4	1.2E-4	1.2E-4	2.4E-5	2.3E-5	2.1E-5
BOD	water	kg	2.4E-4	2.3E-4	2.3E-4	3.9E-5	3.6E-5	3.4E-5
cadmium	soil	kg	6.8E-11	6.2E-11	5.6E-11	4.0E-11	3.7E-11	3.5E-11

Tab. 10.27: Selected LCI results and cumulative energy demand of compressed air supply, best

	Name		compressed air, best installation, >30kW, 8 bar gauge, at supply network	compressed air, best installation, >30kW, 7 bar gauge, at supply network	compressed air, best installation, >30kW, 6 bar gauge, at supply network
	Location		RER	RER	RER
	Unit	Unit	0	0	0
	Infrastructure		m3	m3	m3
CED	fossil	MJ-Eq	0.84	0.79	0.74
CED	nuclear	MJ-Eq	0.55	0.51	0.48
CED	primary forest	MJ-Eq	0.00	0.00	0.00
CED	biomass	MJ-Eq	0.02	0.02	0.02
CED	geothermal, converted	MJ-Eq	-	-	-
CED	solar, converted	MJ-Eq	0.00	0.00	0.00
CED	potential (in barrage water), converted	MJ-Eq	0.06	0.06	0.05
CED	kinetic (in wind), converted	MJ-Eq	0.01	0.01	0.01
land occupation	resource	m2a	1.5E-3	1.4E-3	1.3E-3
CO2, fossil	air	kg	6.5E-2	6.1E-2	5.7E-2
NMVOC	air	kg	1.4E-5	1.3E-5	1.3E-5
nitrogen oxides	air	kg	1.2E-4	1.1E-4	1.0E-4
sulphur dioxide	air	kg	2.3E-4	2.2E-4	2.0E-4
particulates, <2.5 um	air	kg	1.8E-5	1.7E-5	1.6E-5
BOD	water	kg	2.9E-5	2.7E-5	2.5E-5
cadmium	soil	kg	2.9E-11	2.7E-11	2.5E-11

10.5 Data Quality

The data quality of all dataset is considered to be high, since there is industry data for the compressor infrastructure as well as a range of literature sources concerning measuring campains regarding electricity consumption and losses in factories operating a large variety of compressed air networks.

A small uncertainty is introduced by using a simplified approach to adjust electricity consumption to different pressure levels. However, it is thought that providing this extension will increase the accuracy of upstream dataset since the data collector can choose the best-fitting pressure level.

Data gaps concern possible air emissions (e.g. oil) in the compressor room as well as condensation water that can contain contaminations (mainly oil).

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