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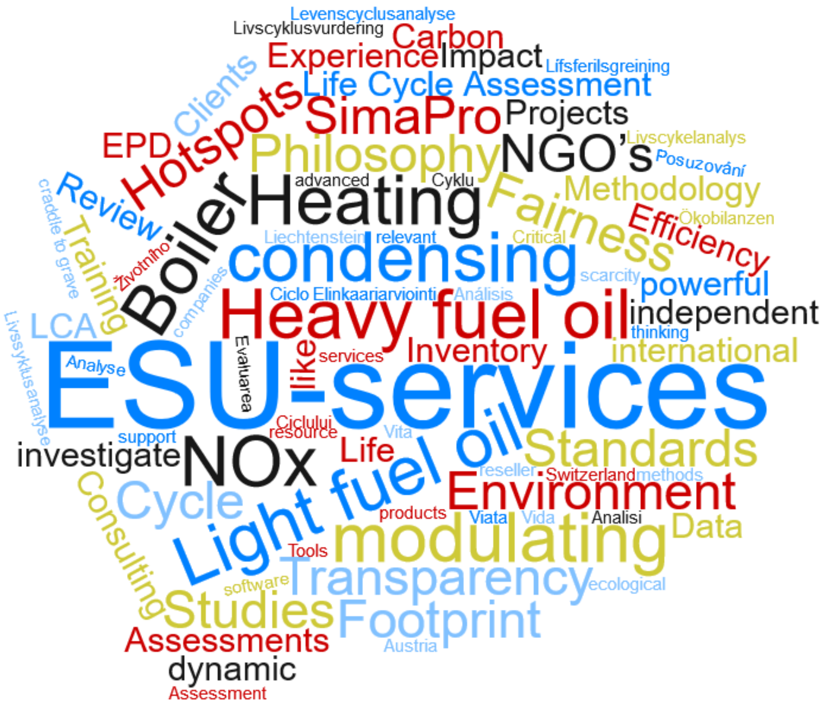
Life cycle inventories of oil heating systems



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Life cycle inventories of oil heating systems

Final report

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Abbreviations

a	year (annum)
API	American Petroleum Institute
AZ	Azerbaijan
BAFU	Bundesamt für Umwelt
B(a)P	Benzo(a)Pyren
BAT	Best available Technologies
bbl	Barrel
bcm	billion cubic meters
bld	below limit of detection
bn	Billion
BEW	Bundesamt für Energiewirtschaft (Federal office for the energy industry)
BFE	Bundesamt für Energie
BOD5	Biochemical oxygen demand for 5 days of microbial degardation
BOOS	Burner Out Of Service
BTU	British Thermal Unit (1 BTU = 1055 J)
BTX	Benzene, Toluene, and Xylenes
Bq	Becquerel
BUWAL	Bundesamt für Umwelt, Wald und Landschaft; (Federal offices for environment, forest and landscape
CEL	Central European Pipeline
cf	Cubic Feet
CH4	Methane
CHP	Combined Heat and Power
Ci	Curie
CIS	Commonwealth of Independent States
CMC	Carboxymethyl Cellulose
CO	Carbon monoxide
CO2	Carbon dioxide
COD	Chemical oxygen demand
Concawe	Conservation of Clean Air and Water in Europe (the oil companies' European organization for environmental and health protection, established in 1963)
d	day
DeNOx	Dentirification method (general)
DGMK	Deutsche Wissenschaftliche Gesellschaft für Erdöl, Erdgas und Kohle e.V. (German scientific assosciation for oil, natural gas and coal)
DM	Dry matter
DoE	Department of Energy, US
dwt	Dead weight tons
E5/10/15/85•	Petrol with 5%/10%/15%/85% ethanol
EdF	Electricité de France
EdP	Electricidade de Portugal S.A.
EMPA	Swiss federal material testing institute
ENEA	Italian National Agency for New Technology, Energy and the Environment
EOR	Enhanced Oil Recovery

EOS SA	l'Energie de l'Ouest-Suisse
EPA	Environmental Protection Agency, US
FGD	Flue Gas Desulphurisation system
GGFR	Global Gas Flaring Reduction Partnership
GRT	Gross Registered Tonne
GWP	Global Warming Potential
HC	Hydro carbons
HEC	Hydroxyethyle cellulose
I.f.	insignificant fraction
IEA	International Energy Agency
IMO	International Maritime Organization
IPCC	International Panel on Climate Change
IQ	Iraq
J	Joule
KBOB	Koordinationsgremium der Bauorgane des Bundes
KZ	Kazakhstan
LCI	Life cycle inventory analysis
LCIA	Life cycle impact assessment
LRV	Luftreinhalte-Verordnung (Swiss Clean Air Act)
MEEPD	Ministry of the Environment, Environmental Protection Department
M.	Million
MJ	Megajoule
Mt	Megaton = 1 million tons
MTBE	Methyl tert-butyl ether
MW	Megawatt
MX	Mexico
NCI	Nelson complexity index
NDP	Norvegian Petroleum Directorate
NG	Nigeria
NGL	Natural Gas Liquids
NL	Netherlands
Nm3	Normal-cubic metre (for gases)
NMVOC	Non-Methane-Volatile Organic Compounds
NO	Norway
NOAA	National Oceanic and Atmospheric Administration
NORM	Naturally-Occuring Radioactive Materials
NOX	Nitrogen oxides
NR	Not Reported
Ns	not specified
OBM	Oil Based Mud,
OE	Oil equivalent
OECD	Organisation for Economic Cooperation and Development
OFA	Over Firing Air
PAH	Polycyclic Aromatic Hydrocarbons
PARCOM	Paris Commission
PC	Personal Communication
PM	Particulate Matter

PRTR	Pollutant Release and Transfer Register
RMPE	Royal Ministry of Petroleum and Energy Norway
Rn	Radon
RODP	Relative Ozone Depletion Potential
RSO	Raffinerie du Sud-Ouest SA
RU	Russia
SA	Saudi-Arabia
SEPL	South European Pipeline
SMA	Schweizerische Meteorologische Anstalt (Swiss Meterological Institute)
SN	Smoke number
SNCR	Selective-Non-Catalytic-Reduction
SPCA	State Pollution Control Authority
SPSE	Société du pipeline sud-européen (South European Pipeline)
SRE	Société Romande d'Electricité
SRI	Sustainable Recycling Industries
TDS	Total Dissolved Solids
TEL	Tetraethyl lead
toe	Ton Oil Equivalent
TSP	Total Suspended Particulates
TSS	Total Suspended Solids
UBA	Umweltbundesamt (Federal Office for the Environment)
UCTE	Union for the Co-ordination of Transmission of Electricity
ULCC	Ultra Large Crude Carrier
ULS	Ultra low sulphur
UNEP	United Nations Environment Programme
Unipede	International Union of Producers and Distributors of Electrical Energy
US (A)	United States of America
UVEK	Federal Department for Environment, Transport, Energy and Communications
VDEW	Vereinigung Deutscher Elektrizitätswerke e.V. (Union of German Electricity Works)
VEÖ	Verband der Elektrizitätswerke Österreichs (Association of Austrian Electricity Works)
VFWL	Verein zur Förderung der Wasser- und Lufthygiene (Society to Support Water and Air Hygiene)
VLCC	Very Large Crude Carrier
VOC	Volatile Organic Compounds
VVS	Verordnung über den Verkehr mit Sonderabfällen, (Regulation on handling of hazardous wastes)
WBM	Water Based Mud,
WEC	World Energy Council

Indices

e	electric
End	End energy
In	Input, related to a energy converter (end energy)
Nutz	useful energy
Out	Output, related to an energy converter (useful energy or end energy)
therm	thermal

1 Introduction

1.1 Overview

This document describes the update of data from version v2.0 of the ecoinvent database (Jungbluth 2007). The German report has been translated in 2012 by Franziska Peter, PSI for the ecoinvent centre. This English translation forms the starting point for updating the data with the reference year 2016.

The goal of the report is to report data as they are investigated with this update for the reference year 2016. Thus, the reader should have a full overview about the data sets as they are now provided for the KBOB database.

In general, subchapters on process steps that are assessed as relevant in the final LCIA results (ecological scarcity 2013) were kept or updated in this report.

If the numbers did not change considerably or no new numbers were available, the former text was kept for this report to provide this relevant information.

Technical descriptions in the former report often were elaborated for the 1996 version of the data (Frischknecht et al. 1996). They often seemed to be outdated and such descriptions which are not relevant for the estimates have been deleted.

Parts of the text which are not relevant (anymore) for the final estimation of the life cycle inventory have been removed to improve the readability of the new report and shorten the amount of documentation. This concerns e.g. long literature lists of data sources dating back to the 80ies if up-to-date data were available. This concerns also annexes with long documentation of data which finally were not used for a new estimation in this report. If no current information was available only the final estimation is documented to improve the readability. The documentation focuses on aspects which are relevant for the updated life cycle inventories presented in this report.

To keep this report readable outdated and old information has been removed partly. If LCI data are still based on such very old information they are cited as (Jungbluth 2007) which means they often have been published before the year 2000.

Changes made to ecoinvent v2.0 data and implemented in ecoinvent v3 between 2007 and 2017 are NOT part of this report. Therefore, the content of this document does not reflect the LCI data of ecoinvent v3.

The report contains information on furnaces that are operated with fossil oil fuels. Because of the variety of systems (burner technique, performance classes, application), as examples, the following systems are assessed. Three classes of boiler are distinguished according to the rated power of heat supply in kW. Thereby, information on performance should be understood as order of magnitude:

- Low-temperature boiler 10 and 100-kW, light fuel oil (condensing, modulating) - new
- Low-temperature boiler 10 and 100-kW, light fuel oil (average) – new dataset, average of boilers installed in 2016 in Switzerland
- Industrial furnace 1 MW, light fuel oil, CH, Europe
- Industrial furnace 1 MW, heavy fuel oil, CH, Europe

The update focuses on these inputs and outputs which are known to be relevant for assessment using the three LCIA methods CED, GWP and environmental scarcity method 2013. For many other issues older data have not been systematically updated.

Research has not yielded much current information e.g. about the emission of boilers. It was found that there is limited scientific interest in comprehensive monitoring of such boilers. Only the most important air pollutants like CO and NOx are frequently reported.

For boilers a complete material inventory was created for which data are taken from the previous study (Jungbluth 2007). Some components are extrapolated using analogies from the 10 kW boilers. For boiler production, energy cost and wastes are assessed, for tank and other components; data on construction costs is not available. Transport of semi-finished products to the production site and of heating components to the place of installation is summarised.

For house furnaces (condensing boiler) an optimal design of the heating plant is presumed. With the performance (10 and 100 kW respectively), the expected running time of the burner per year and the lifetime of the plant, material input and construction costs were related to the amount of energy input. Demand for auxiliary energy (electricity) is determined.

Emission factors used here are based on condensing boilers as they are sold in 2017. This means that as far as possible and if relevant, only blue flame burner technology is considered. For industrial furnaces often, average emission factors are used. For the multitude of VOC components, VOC profiles are used as standard values. They were created based on an evaluation of several exhaust analyses in the context of a European Inventory of Atmospheric Air Pollutants called CORINAIR. The present measurement series of case studies resulted in atypical values for these pollutants and are partially based on burner techniques that are outdated in Switzerland. For condensing boilers, for some pollutants embedding into the condensate is considered (sulphur, chlorine, fluorine) and for industrial furnaces operated with heavy fuel oil, an installation rate of flue gas cyclones is assumed.

For condensing boilers of the performance class 10 and 100 kW, additionally emissions due to condensate discharge into the canalisation is considered. The 10 kW condensing boiler is equipped with a cleaning based on an ion-exchange resin, which filters 98% of metals and salt ions. Pollutants then accrue as hazardous waste during periodical regeneration of the ion-exchange resin.

Wastes which are generated during the operation of the plant are considered. Next to hazardous wastes from condensing boilers with lower performance; during the periodical cleansing of the tank, oil sludge accrues. The disposal of the installation is assessed under material input.

Datasets related to the combustion of a specific amount of fuel cannot be found in the present ecoinvent data v3.4 (ecoinvent Centre 2017). Only data for the provision of heat are shown there. In this context, it must be noted that the efficiency of furnaces always depends on the working conditions and especially the temperature level of the heat supply. Thus, data for heat at the furnace are just meant as examples. The efficiency can easily be adapted in case studies where the real efficiency is known. If the amount of fuel burned is known, it is recommended to apply datasets related to this fuel input and not the datasets related to the amount of heat provided.

1.2 Updates

During the update of the life cycle inventory data, the following main sources of information have been used.

Sippula et al. (2007) performed some measurements of a heavy fuel oil furnace in Finland 2005. One 4 MW furnace and one 7 MW furnace with no filtration technology were investigated. Data on fine particle emissions can be taken from this study.

Struschka (2008) estimated average emission factors for furnace in German households, in the trade-, industry-, service- and in the military-sector. These factors are not based on measurements, but they are derived from older literature studies dating back partly to 2005.

The same main author measured actual emissions in a 18 kW low-temperature boiler with oil burner which were modern in Germany in 2010 (Struschka et al. 2010). CO_2, CO, COC, NO_x and particles were measured.

Particle emissions in two 4 MW furnaces and one 7 MW industrial furnace for heavy fuel oil have been reported in an article by Sippula et al. (2009) in Finland. The furnaces used for the measurements were 'fire-tube boilers and equipped with oil burners with pressurized atomizers' not including any particle filtration systems. They were from 3 to 5 years old in 2009.

Some actual emissions for a large light fuel oil furnace have been investigated for a district heating in the City of Zurich (Flury & Jungbluth 2011).

Furthermore, there are emission factors for light and heavy fuel oil published in Kaivosoja et al. (2013). The emission factors for light fuel oil are based on measurements made for a 20 kW burner and the ones for heavy fuel oil refer to a 5.2 MW burner taking place in Finland. No filtration is done.

The Swiss 'Federal Department of the Environment, Transport, Energy and Communications' (DETEC) and the Federal Office for the Environment (FOEN) report average emission factors for light fuel oil and natural gas based on 200'000 official measurements in Switzerland in the years 2010 and 2011 (UVEK & BAFU 2015). Furthermore, the emission factors for modern furnaces using standard or low sulphur content oil are given. These data are based on 200 measurements taking place in 2009 and 2010. According to this study modern furnaces are condensing low-NOx-fan-burners. This is considered the most reliable source of information for the small furnaces.

The following two types of furnaces have not been updated as they are not relevant for the new selling in the market in 2016. They can be replaced with the average boiler investigated for this study (or used further if the inventories refer to the assessment for old production routes).

- LowNOx-boiler 10 and 100 kW, light fuel oil
- Condensing boiler 10 and 100 kW, light fuel oil

2 Material input and construction costs for infrastructure

Here, material input for oil heating is inventoried. Distribution of the heat within the building and the therefore required components are not considered. This means, e.g. pumps and pipes for distribution as well as hot water storage are excluded. No major updates have been commissioned to this section. Therefore most information is taken from the former study (Jungbluth 2007).

2.1 Boiler and burner

2.1.1 Materials

From information by the Swiss boiler manufacturers (Heizung 1993a, b) and from literature, for the manufacturing of oil boilers and gas boilers, the specific data shown in Tab. 2.1 are reported. Material demand per kW is between 5 and 13 kg/kW.

Tab. 2.1 Material demand in kg/piece for boilers of different performances

	10 – 20 kW 1)		100 kW 1)		1'000 kW 1)		18-21 kW	9 kW 5)
	Steel 2)	Cast 3)	Steel 2)	Cast 3)	steel 2)	cast 3)	steel 4)	cast 5)
Steel unalloyed	120	0	510	0	200	0	98	114
Steel high alloy	0	0	0	0	0	0	10	4.6
Cast iron	0	140	0	400	4'420	2'000	25	0
Aluminium, cast	0	0	0	0	0	0	7.5	0
Chamotte	0	0	0	0	70	0	0	36
Mineral wool	8	5	19	15	40	30	12	12
Copper	3	0	25	0	ns	0	0.2	kA
Plastics	0	0	0	0	0	0	0.8	2.7
Corrosion protection	0.25	0	ns	0	ns	0	ns	ns
Covering paint	1	0.2	2	0.4	4	0.6	ns	ns
Total	132	145	560	415	4'740	2'030	154	169

1) Without Burner, 2) (Heizung 1993a), 3) (Heizung 1993b), 4) (Wagner et al. 1989b), 5): (Hofstetter et al. 1991)

For house furnaces, a steel boiler is assumed, for industrial furnaces a cast boiler. This leads to the material demand used in this study, which is shown in Tab. 2.2 (corrosion protection is allocated to the covering colour). The total material demand and weight has been compared with actual boiler specifications in 2017 and was found to be about the same.

Tab. 2.2 Specific material demand of boilers of different performances used in this study

	10 kW	100 kW	1 MW
	kg/piece	kg/piece	kg/piece
Steel unalloyed	115	485	190
Steel high alloy 1)	5	25	230
Cast iron	0	0	4'200
Aluminium, cast	7.5	15 2)	30 2)
Chamotte	0	0	70
Mineral wool	8	19	40
Copper	3	25	0
Covering paint 3)	1.25	2.5	5
total	**140**	**570**	**4'765**

1): assumption 5 % Steel high alloy, 2): Assumption (burner case), 3): incl. 20 % by weight corrosion protection (Heizung 1993a)

2.1.2 Energy demand production

Information in Tab. 2.3 on energy demand for production of boilers comes from Swiss boiler manufacturers. Energy carrier, amount of energy and type of firing per produced unit are shown. The relatively big difference between the two plants cannot be explained satisfactorily. It is assumed that for cast boiler manufacturing, heating of the production halls is not considered.

Tab. 2.3 Specific energy demand for boiler fabrication

	10 - 20 kW		100 kW		1 MW
	Steel	Cast	Steel	Cast	Cast
	MJ/boiler	MJ/boiler	MJ/boiler	MJ/boiler	MJ/boiler
Natural gas in industrial furnace	2.5E+3	0	3.2E+3	0	0

Light fuel oil in industrial furnace CH	0	42.7	0	0.1E+3	0.15E+3
Electricity CH	0.14E+3	0.3E+3	0.22E+3	0.86E+3	4.3E+3
	(Heizung 1993a)	(Heizung 1993b)	(Heizung 1993a)	(Heizung 1993b)	(Heizung 1993b)

From the environmental report by Viessmann (1998), costs per kg raw material input can be determined (Tab. 2.4). The values calculated from this are much higher than those shown above. These values are multiplied by the weight of the different boilers from Tab. 2.2 for this study.

Tab. 2.4 Specific energy demand for boiler fabrication (Viessmann 1998)

		Demand per kg of raw material processing
Electricity	kWh	**0.59**
Fuel oil	MJ	**1.78**
Natural gas	MJ	**3.37**

2.1.3 Operating materials

For boiler manufacture, welding anodes and water (pressure test) are needed (cf. Tab. 2.5). The amounts are indicated per production unit. Viessmann (1998) states a water demand of 2.7 kg/kg raw material. However, in Viessmann (2002) the figure proposes a much lower amount of 1.3 kg/kg raw material. This value is multiplied here by the weight of the boiler from Tab. 2.2. From this, 83% are assumed to be disposed as wastewater.

Tab. 2.5 Specific demand for operating materials for the fabrication of boilers with different performances

	10 kW	100 kW	1000 kW	source
	kg/boiler	kg/boiler	kg/boiler	
Welding anodes 1)	**4**	**6**	-	(Heizung 1993a)
Water	**182**	**741**	**6'188**	(Viessmann 2002)

1): assessed as hard solder, free of cadmium

2.1.4 Packaging

As packaging materials, PE foils and cardboard are used for smaller units as shown in Tab. 2.6 (Heizung 1993a).

Tab. 2.6 Specific material demand for packaging of boilers with different performances (Heizung 1993a)

	10 kW	100 kW	1000 kW
	kg/boiler	kg/boiler	kg/boiler
PE-foil	0.5	1	-
cardboard	5	10	-

2.1.5 Wastes

Next to the actual boiler and its materials, welding dust and packaging materials accrue as wastes. Steel and aluminium parts go into scrap trade (Heizung 1993a) and are thus not assessed further.

Tab. 2.7 Specific amounts of waste generated during production, distribution and disposal of boilers with different performances

		10 kW	100 kW	1000 kW
		kg/boiler	kg/boiler	kg/boiler
Boiler	-Chamotte 1)	0	0	70
	-Mineral wool 1)	8	19	40
	-Copper 1)	3	25	-
	-Cover paint 2)	1.25	2.5	5
Packaging and production	- PE-foil in incineration plant	0.5	1	-
	- cardboard in incineration plant	5	10	-
	- Welding dust 3)	0.2	0.3	-

1): to inert materials landfill, 2): to steel recycling, 3): to treatment of hazardous waste

2.2 Fuel oil tank and receiving equipment

Furthermore, tanks and receiving equipment is needed. Possible materials for tanks are plastics (e.g. HD-PE) and steel. Plastic tanks are available in standard sizes between 800 and 2000 litres and are used mainly in single family houses. Steel tanks can be constructed according to the individual settings. Tanks are either in a concrete basin with a protective coating or in a separate receiving container. Separate receiving basins are, among others, fabricated out of polyester, reinforced by glass-fibres (Hofstetter et al. 1991).

Tank volume varies between demands for 1/3 to 3 heating periods. Here, a stockpiling of 1.5 years is assumed and a steel tank with primary walling of concrete is charged.

For a steel tank with a useful content of 3000 l, specific steel demand is 150 kg/$m^3_{crude\ oil}$ (Wagner et al. 1989b). Additionally, for a steel tank, 10 kg plastic lining is required and 6 kg of paint (Wagner et al. 1989b).

Furthermore, a primary walling made of concrete of 3*0.5*0.15m is assumed, which leads to a concrete demand of 0.225 m^3 for a 10-kW furnace. Values used in this study are listed in Tab. 2.8.

Tab. 2.8 Specific material demand for oil tank and reception basins / concrete primary walling as well as material demand for this study, related to a lifetime of the boiler of 20 years.

		Steel 1)	10 kW	100 kW 4)	1 MW 7)
		Piece	Furnace	Furnace	Furnace
HD-PE 2)	kg	10			
Steel unalloyed	kg	450			
paint 3)	kg	6			
concrete 5)	m 3	0.225			
Volume	l	3000	2000	8000	40'000

1): 3'000 Litre (Wagner et al. 1989b), 2): plastic lining assumed as HD-PE, 3): assumed: plastic powder (See covering paint boiler), 4): assumption factor 4 compared to 10 kW heating, 5): Primary walling, 6): Factor 2 (assumption), 7): separate tank room, Factor 20 compared to 10 kW heating

2.3 Chimney

Chimneys for single family houses (performance ranges 10-35 kW) are distinguished from those for apartment buildings (performance up to 100 kW). Assessed are three-layer chimney building blocks. They consist – from the inside to the outside – out of a concrete chamotte pipe, an insulation of mineral fibres and a coat of brick debris concrete. Total weight is 95 kg/m for 10-35 kW and 135 kg/m for 100 kW (Reimann 1993). The insulation constitutes an estimated 0.5% by weight (see Tab. 2.9). For the calculation 95 kg/m is used. Height of the chimney is assumed with 8 m for a two-storey single family house and 18 m for a five-storey apartment building and 50 m for a 1 MW furnace. Lifetime is estimated with 40 years, corresponding to half the lifetime of the building. Concrete chamotte and brick debris concrete are inventoried as fireclay. Amounts of material also accrue as wastes to the inert materials landfill.

For modern oil heating (conditions in 2017) a two-way chimney is necessary. Combustion air is aspirated via the chimney for pre-warming and thus reducing the heat loss. Therefore, plastic or steel pipes are installed into the existing chimney. In this study the weight is assumed with 5.9 kg of stainless steel per m.[1]

Tab. 2.9 Specific material demand for chimneys of different performances

Material		10 kW	100 kW
		m	m
Refractory, fireclay	kg	95	135
Mineral fibre	kg	0.5	0.5
Stainless steel	kg	5.9	5.9
Height	m	8	18
lifetime	a	80	80

2.4 Remaining components

Information on materials which concern the remaining components is from Wagner et al. (1989b). These components are inventoried either in the process “oil storage” or “oil boiler” as shown in Tab. 2.10. The components for heat distribution in the house (e.g. pump) are not considered in this study. Construction costs for further components are not considered due to a lack of information.

Tab. 2.10 Specific material demand for remaining components of a 15 kW-boiler (Wagner et al. 1989b)

Material	Mixing valve	Oil pipe	Control
	kg/piece	kg/m	kg/piece
Steel unalloyed	1.3	0.02	0.03
Cast iron	6	0	0
brass	1.4 1)	0	0.05
copper	0.1	2	0.03
plastics 2)	0.1	0.005	0.4
Demand pieces	1	10 m	1
Inventory in	Oil tank	Oil tank	burner

1): incl. non-iron metals, 2): incl. rubber

1 https://www.schornsteinmarkt.de/schornsteinrohr-edelstahl-1080-mm-doppelwandig-eka-com-plex-d-25/product/208/1/9/52, 24.01.2018

2.5 Transports

A standard transport distance for all semi-finished products and resources of 50 km by lorry and 600 km by rail is assumed. For smaller boilers (10 and 100 kW) additionally 50 km by delivery van are inventoried.

2.6 Land occupation

Infras (1981) reports a space demand for storage of fuel oil of 0.3 to 0.4 m^3/kW. For a cubic tank, this corresponds to an area demand of 0.45 to 0.55 m^2/kW. According to the amount of energy which is converted, this corresponds to a land occupation of 60 to 71 m^2a/TJ_{in}. This order of magnitude is confirmed by Jensch (1988) with 0.2 m^2/MWh filling size. For an oil tank of 3000 l, a specific land occupation of 80 m^2a/TJ_{in} results.

In this study, area demand of heating systems is not considered, because this area is located exclusively within buildings and therefore is already charged to buildings.

3 Reference unit, energy demand and losses

3.1 Heating period and energy delivery

No new information on lifetime of boilers has been found. The lifetime of the boilers is estimated with 20 years (Jungbluth 2007).

Thus, for burner turn-on times of 2'100h per heating period and a lifetime of 20 years, for house furnaces of 10 kW, 0.69 boilers/TJ_{in} are required and for 100 kW 0.069 boiler/TJ_{in}, for industrial furnaces with an annual load factor of 5000 h and 20 years lifetime it is 0.0026 boiler/TJ_{in}.

3.2 Demand for auxiliary electricity

Oil heating needs auxiliary energy for the control of the heating, burner control, the mixing valve and the blower (Jungbluth 2007).

The demand for electric auxiliary energy is between 0.3 and 1.04% of the consumed fuel oil, according to the compilation in Tab. 3.1 which is based on technical data sheets of different producers. The difference can be explained because different running times were considered for the burner on the one side and for pump as well as control on the other side.

Tab. 3.1 Auxiliary energy demand of small boilers according to technical data sheets published in 2017

Brand	Performance	Auxiliary electricity demand		Auxiliary electricity demand
	kW	W		Wh/MJ_{In}
Schuett	10.6 – 18	272	1.90%	3.89
Viessmann	10 – 18.7	106	0.74%	2.05
Viessmann	10 – 22.9	154	0.96%	2.69
Viessmann	12.5 – 28.1	128	0.63%	1.75
Intercal	12 – 30	252	1.20%	3.33
Buderus	18	220	1.22%	3.40
Intercal	30 – 45	268	0.63%	1.99
Average			1.04%	2.73

The data about the auxiliary electricity demand for 100 kW and 1 MW boilers is taken from the previous study since no current information could be found (Jungbluth 2007). Tab. 3.2 summarizes the figures taken for this study.

Tab. 3.2 Relative performance demand (electric) to fuel oil consumption (calorific value) of the peripheral devices of boilers

		10 kW	100 kW	1000 kW
Total	%	1.04%	0.63	0.3
Total	Wh/MJ	2.73	1.7	0.8

If insignificant fraction

3.3 Efficiencies used to calculate the heat supply

For each type of heating an example dataset for "heat, at …" is investigated. This calculates the amount of heat provided to the user and therefore uses the efficiency of the boiler. These datasets better allow a direct comparison of different heating devices. But, in most cases, if the amount of used fuel is known, using the dataset for fuel oil burned in a specific type of boiler is more appropriate.

During heat generation, there are various losses. Regarding losses through exhaust gas, unburnt parts, sensible heat and latent heat can be distinguished. Radiation during operation of the burner and during downtime of the burner as well as inner cooling adds up to stand-by losses. This leads to the annual efficiency factor of the boiler (see Fig. 3.1) which indicates the relation of energy within the fuel (calorific value) to the energy fed into the distribution grid. The annual use efficiency additionally considers losses by distribution (SIA 1988).

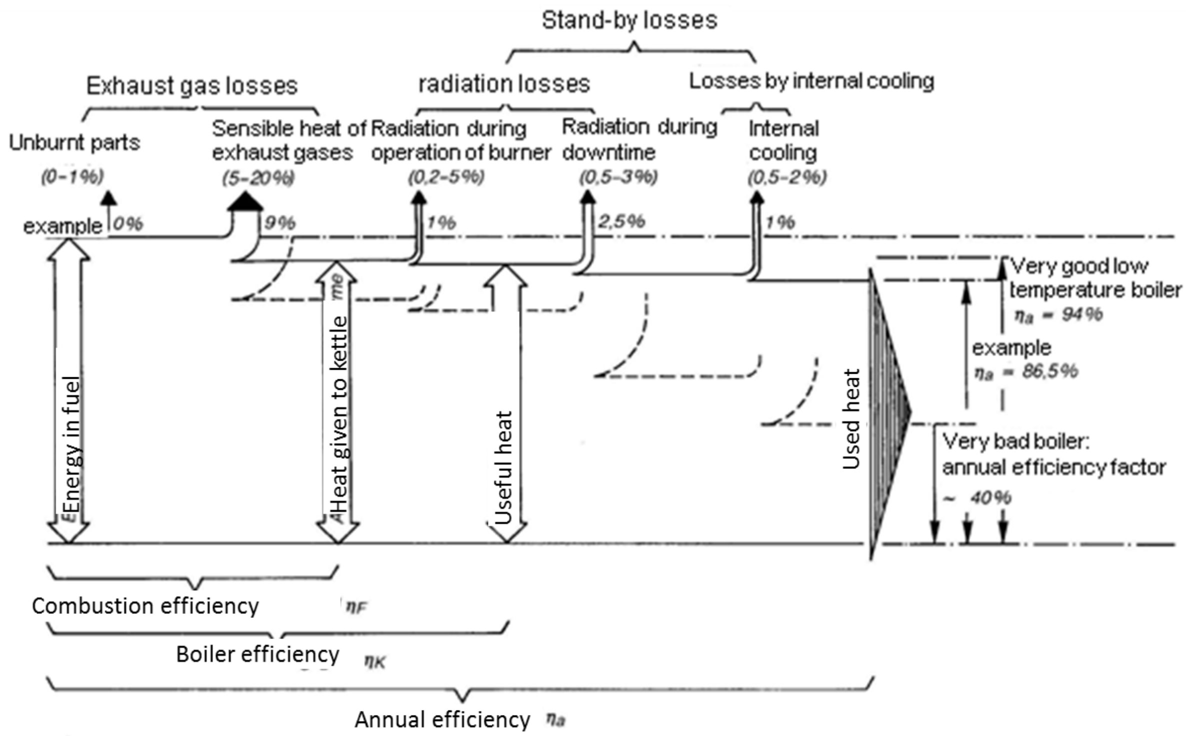

Fig. 3.1 Losses and efficiency factors of boilers (BfK 1986)

The efficiencies of furnaces are dependent on the output temperature during operation. Heating for houses normally provide warm water with temperatures of about 40°C to 60°C. The tendency in modern houses is to plan the heating for lower temperatures and thus achieve higher operation efficiencies of the boilers. Larger furnaces in industry have to provide higher output temperatures (even for pressurized steam with above 100°C) and thus reach lower efficiencies.

EV (2002) specifies annual use efficiencies of renovated plants of 90% for normal boilers and 98% for condensing boilers. EV (2002) specifies annual use efficiencies of renovated plants of 90% for normal boilers and 98% for condensing boilers. Technical data sheets by Hoval, Buderus and Brötje report average norm use efficiencies of modern 10 and 100 kW oil boilers of 103.6 and 104.6% (lower heating value), respectively (Brötje 2017; Hoval 2015). Jakob et al. (2002) estimated annual use efficiency including losses by distribution for 2000 with 89%. Buderus (2002) reports norm utilisation level of condensing boilers of 102-103%. Other boilers are in the range of 93-96.5%.

Bigger furnaces (over 1000 kW) tend to reach lower values mainly because the delivered temperatures are normally higher (Hoval 2015). The average norm use efficiency of industrial furnaces amounts to 95% (Hoval 2015).

Distribution losses in the house (unheated rooms) are not considered in the inventory for furnaces.

For each size of furnace, the efficiency is considered according to Tab. 3.3.

Per heating season or year, respectively, the following amounts of energy are required/delivered (Tab. 2.1). The efficiencies of 10- and 100-kW boilers refer to 30% partial load.

As efficiencies depend largely on operating conditions and less on size or type of heating, the efficiencies should be adapted to known values if datasets for “heat, at …” are used in a life cycle inventory.

For house furnaces the value for proper dimension without hot water heating at inside air temperature of 20°C is used. This corresponds to a relative turn-on time of just less than 40%, related to the duration of the heating period. The burner running time per operation cycle is between 2 and 6 minutes for conventional heating systems, while modern systems reach burner running times of up to 10 min, among others thanks to the higher volume of water of the boiler (Viessmann 1992; Struschka et al. 1988). Applicable to the average of the residential houses in the region Mittelland, the annual burner running time is 2100 h (BfK 1982).

Tab. 3.3 Annual energy conversion in boilers for heating of buildings (without hot water heating) and in industrial boilers. Average use efficiency (without distribution, partial load)

Performance	Running time	Input	Average boiler	modulating, condensing	non-modulating	condensing, non-modulating
kW (delivered heat)	h	GJ_{In}	η	η	η	η
10	2'100	75.6	1.034	1.042	0.94	1.000
100	2'100	756	1.046	1.050	0.940	1.000
1'000	5'000	18000	0.951			

4 Emissions to air

4.1 General

According to permanent tests by Struschka et al. (1988) with fuel oils of different qualities (density, viscosity, boiling point) only the pollutants CO and the smoke number were dependent from the fuel. Unburnt hydrocarbons, CO_2 and NO_x were relatively stable within the measurement accuracy. However, this only applies for constant nitrogen content of the fuel, which mostly amounts approximately 40 ppm regarding the standard light fuel oil (Struschka et al. 2010).

The content of trace elements in the fuel is used to determine the emissions of trace elements.

4.2 Carbon dioxide (CO_2)

The emission factors for CO_2 are calculated according to the fuel quality documented in the report on refineries (Jungbluth et al. 2018).

4.3 Carbon monoxide (CO)

CO-content serves, next to smoke number and VOC, as reliable indicator of complete combustion. As shown above, emission factors depend on temperature in the combustion chamber, the combination of burner-boiler and the frequency of operation. Tab. 4.1 shows the compiled emission factors of different types of furnaces.

The CO emission factors for this study are marked in bold. Due to the big fluctuation range, basis uncertainty is estimated with 3.

Tab. 4.1 CO-emission factors according to different sources

	CO	Source
	mg/MJIn	
Average furnace in households (2008)	15	(Struschka et al. 2008)
Average furnace in trade, industry and services (2008)	12	(Struschka et al. 2008)
Average furnace in military sector (2008)	14	(Struschka et al. 2008)
Low-temperature boiler with oil burner	1.94	(Struschka et al. 2010)
Official limit 500 ppm	10.9	(Bundesverband des Schornsteinfegerhandwerks 2017)
Small furnaces, 10kW	9	(Jungbluth 2007)
Big furnaces, 100kW	7.5	(Jungbluth 2007)
Boiler	2.8 – 8.3	(Buderus 2001)
District heating plant 628 kW (Zürich)	**2.5**	(Flury & Jungbluth 2011)
4MW industrial furnace, heavy fuel oil	2.5 – 6.2 (**5**)	(Sippula et al. 2009)
Industrial furnaces	10	(Swedish EPA 2000)
Industrial furnaces	20	(IPPC 2001;Richardson 1999)
Industrial furnaces	2.6 / 5.5	Fuel oil / heavy oil in Germany (Rentz et al. 2002)
light fuel oil, burned at boiler <50kW, average	**13**	UVEK & BAFU 2015
light fuel oil, burned at boiler 50-350 kW, average	**7**	UVEK & BAFU 2015
light fuel oil, burned at boiler <50kW, modern, low sulphur content	**3**	UVEK & BAFU 2015
light fuel oil, burned at boiler 50-350kW, modern, low sulphur content	**1**	UVEK & BAFU 2015

4.4 Sulphur dioxide (SO_2)

According to the study of Struschka (2008), 1 MJ light fuel oil burned in an average furnace in a household causes 59 mg SO_2. The same amount burned in the trade, industry and service sector causes 60 mg SO_2 whereas the emission factor in the military sector is 77 mg SO_2/MJ.

The emission factor of 12 mg/MJin for light fuel oil boilers is based on actual measurements (UVEK & BAFU 2015). For modern boilers with low sulphur fuel the emissions might be as low as 1.3 mg/MJin (UVEK & BAFU 2015).

Since the sulphur content of the fuels did not change significantly the values of the previous study are taken for heavy fuel oil boilers (Tab. 4.2, Jungbluth 2007). As these emissions depend on the sulphur content of the fuel (which might be quite variable) and the waste gas treatment at the specific boiler, it is recommended to adapt the emission factors for case studies dealing with a specific combustion unit.

Tab. 4.2 Sulphur dioxide emission factors (Jungbluth 2007)

Boiler kW	**This study**
	mg/MJIn
Heavy fuel oil, CH	**394**
Heavy fuel oil, EU	**400**

4.5 Nitrogen oxides (NO_x)

The NO_x-emissions applied for this study are shown in Tab. 4.3. For modern 10kW low-temperature boilers with oil burner an average value of 22.2 mg NO_2/MJ_{In} is measured (Struschka et al. 2010).

For average low-temperature boilers (10kW) a value of 27.8 mg NO_2/MJ_{In} is derived from different sources (Buderus 2015; Jungbluth 2007; Struschka et al. 2008).

For 100 kW boilers emission factors of 36 and 28 mg NO_2/MJ_{In} are found for average and modern technology respectively (UVEK & BAFU 2015).

For light fuel oil burned in industrial furnaces an emission factor of 29 mg NO_2/MJ_{In} is derived from a study on district heating in Zurich and other Swiss measurements (Flury & Jungbluth 2011; UVEK & BAFU 2015).

No newer data referring to heavy fuel oil furnaces in Europe were found. The previous factor of 100 mg/MJin (Jungbluth 2007) has been reduced to 50 mg/MJin in order to reflect the development seen for this type of furnaces in Switzerland.

Tab. 4.3 NOx-emission factors used in this study

	NO_X as NO_2
	mg/MJ_{In}
light fuel oil, 10 kW, average	27.8
light fuel oil, 10 kW, modern	22.2
light fuel oil, 100 kW, average	36
light fuel oil, 100 kW, modern	28
Industrial furnaces, light fuel oil	29
Industrial furnaces, heavy fuel oil	50

4.6 Nitrous oxide (N_2O)

Emission factors for burning extra light fuel oil in average furnaces are stated to be 0.55 mg/MJ in households and 0.56 mg/MJ in trade, industry and military sector (Struschka et al. 2008). Regarding industrial furnaces using heavy oil, data are taken from the previous study for Switzerland (Jungbluth 2007).

Tab. 4.4 N2O-emission factors for this study

	N_2O
	mg/MJ_{In}
Small furnaces	0.55
Medium furnace	0.56
Industrial furnaces, light fuel oil	0.6
Industrial furnaces, heavy fuel oil	0.8

4.7 Particles (dust and soot)

The overall particle emissions of average furnaces are reported to amount 0.87 mg/MJ in households, 1.3 for the sectors of trade, industry and services and 1.8 for the military sector. Struschka (2010) reports condensable particle emissions of 0.375 mg/MJ_{In} and additional total suspended particulates (TSP) of 0.017 mg/MJ_{In} for low-temperature boilers with oil burner.

The TSP emissions from burning oil in condensing furnaces amount 0.39 mg/MJ light fuel oil (Struschka et al. 2010). Other data is based on the previous study (Jungbluth 2007).

For heavy fuel oil for Swiss as well as for European conditions the mean value is taken as it can be found in Tab. 4.5 (Happonen et al. 2013; Kasurinen et al. 2014; Sippula et al. 2007, 2009).

The data for industrial furnaces using light fuel oil is taken from the previous study (Jungbluth 2007).

Tab. 4.5 Emission factors for particles from fuel oil furnaces

	PM2.5	PM10	TSP
	mg/MJ_{In}	mg/MJ_{In}	mg/MJ_{In}
Condensing - furnace	0.39	0.39	0.39
Industrial furnace, light fuel oil	0.5	0.5	0.5
Industrial furnace, heavy fuel oil	7.6	9.6	12

4.8 Ammonia (NH_3)

Ammonia emissions are specified as 0.01 mg/MJ for heavy oil and 0.01-2.68 mg/MJ for fuel oil. Here, 0.01 and 0.15 mg/MJ, respectively, are used (Richardson 1999).

4.9 Volatile organic compounds

The composition of volatile organic compounds depends on the fuel and the conditions during combustion. Because of the rather small proportion of combustion-related VOC emissions to the total load, information on their composition is rare (Veldt et al. 1992). For liquid fuels break down NMVOC emissions, namely for smaller plants as well as for large plants, operated with light fuel oil and heavy fuel oil are listed in Tab. 4.6 (Veldt, 1991 & 1992). The few data which serve as basis for the VOC profiles have quite big fluctuations. For this reason and particularly for the profiles A and B described in Tab. 4.6, corrections were done. It concerns emissions of aromatic hydrocarbons, which are completely absent in profile B and in profile A, they are underestimated because of the used background information (Veldt et al. 1992). The VOC profile D was created based on extensive measurements of a blue flame burner (35 kW). It only has informative character.

For this study the VOC profiles A to C in the Tab. 4.6 are combined to derive a generic VOC emission rate used for all investigated processes in this study.

Some emission factors for individual VOC are published, which correspond in their order of magnitude approximately with the values used here (Pfeiffer et al. 2000). Big differences exist between (Veldt et al. 1992) and Braun et al. (1991), because for the measurement values by Braun et al. (1991), the aromatics form the biggest part of VOC emissions with over 80% by weight. The part of aldehydes and alcohols is strikingly higher in plants fired with oil residues than in plants run by light fuel oil. Also, the proportion of methane in the emissions varies between 20 and 50% by weight concerning VOC.

VOC emission factors taken from literature (Struschka et al. 2008) come to 1.7 mg/MJ for the average furnace in households, 2.6 mg/MJ for the trade, industry and service sector and 2.8 mg/MJ for the military sector, each refers to one MJ of light fuel oil. The amount of NMVOCs per MJ light fuel oil is given by the same number for each sector, respectively.

Data for methane is named by 0.046 mg/MJ for households, 0.026 mg/MJ for trade, industry and services and 0.017 mg/MJ for military (Struschka et al. 2008).

However, according to UVEK in Switzerland the methane emission factor is equal to 1mg/MJ and the NMVOC factor equal to 6mgNMVOC/MJ for small and medium furnaces in households and 2mgNMVOC/MJ for industrial furnaces (UVEK & BAFU 2015). Therefore, to be consistent with this study, a

Tab. 4.6 VOC-Profile of liquid fuels, from literature and used in this study

Pollutant, % by weight	A	B	C	D	**This study, furnaces in households**	**This study, furnaces in industry**
Acetaldehyde	2.5	0	ns	ns	**2.0**	**1.6**
Acetic acid	10	0	0	8.5	**2.0**	**1.6**
Acetone	2.5	0	5	ns	**5.0**	**3.9**
Acetylene	0	0	1	0	**1.0**	**0.8**
Alkane C6+	10	16	25	0	**25.0**	**19.4**
Alkene C4+	0.5	0	2	0	**0.0**	**0.0**
Benzene	0.5	1 2)	2	80	**2.0**	**1.6**
Ethane	0	0	2	0	**2.0**	**1.6**
Ethanol	5	0	ns	ns	**1.0**	**0.8**
Ethylene	0	0	5	1.2	**5.0**	**3.9**
Formaldehyde	7.5	30 2)	ns	0.2	**0.6**	**0.5**
Methane	50	33.3	20	3	**14.3**	**33.3**
Methanol	8.5 1)	0	ns	ns	**0.0**	**0.0**
n-,i-Butane	0	10.5 2)	15	0	**15.0**	**11.7**
n-,i-Pentane	0	7.0 2)	10	0	**10.0**	**7.8**
other Aldehydes	ns	ns	5	1.4	**5.0**	**3.9**
Other aromatics	2.5	1 2)	2	0	**1.7**	**1.3**
Propane	0.5	0.67	3	0	**3.0**	**2.3**
Propionic acid	ns	ns	0	3.6	**2.0**	**1.6**
Propylene	0	0	2	0	**2.0**	**1.6**
Toluene	0	0.5 2)	1	2.4	**1.4**	**1.1**
Total	**100**	**100**	**100**	**100**	**100**	**100.0**

A: Industrial furnaces, heavy oil/ oil residues, B: industrial furnaces, light fuel oil (distillate oil) C: smaller furnaces, A&B: Veldt (1991), C: Veldt et al (1992), D: Compilation of results of an investigation with blue flame burner 35 kW (Braun et al. 1991)
1) incl. Non-identifiable NMVOC, 2): analogy conclusions based on information by Veldt et al. (1992) and Veldt (1991)

4.9.1 Paraffin and olefins

Higher concentrations of paraffin and olefins only occur in oil furnaces during setting testing. Regarding CH_4 OECD (1991b) specifies 2.9 mg/MJ_{in} for industrial furnaces operated with heavy oil. For house furnaces it is 0.6 mg/MJ_{in}. Because of the stationary measuring settings, values by Braun et al. (1991) are not considered. Emission factors for this study are thus evident from the respective VOC profiles (cf. Tab. 4.6).

No newer data have been found for the update in 2018.

Tab. 4.7 Paraffin- und Olefin-emission factors from blue flame burners and yellow flame burners (Braun et al. 1991)

Pollutant	Yellow flame burner	Blue flame burner	Blue flame burner 1)
	mg/MJ_{In}	mg/MJ_{In}	mg/MJ_{In}
Methane	bld – 0.63	0.02 – 0.1	0.05
Ethylene	bld – 0.18	bld	0.02
Acetylene	bld – 0.39	bld	bld
Propane/ Propene	bld – 0.06	bld	bld
Sum P. & O.	-	-	0.07

1): standard setting of blue flame burner

4.9.2 Monocyclic aromatic hydrocarbons

Regarding monocyclic aromatic hydrocarbons, for furnaces equipped with blue flame burners, virtually only benzene and toluene are important. Ratios of mean emission factors of benzene, toluene and others to total hydrocarbon emissions by Struschka et al. (1988) are a bit lower than proportions in Veldt et al. (1992) see appendix table A.25 (Jungbluth 2007).

The values measured by Braun sometimes vary greatly due to setting testing and they are comparatively high. Tab. 4.8 shows values which were measured during standard settings of the furnace. Thereby, only benzene and toluene were detected. The high emission factor for benzene is noticeable.

Struschka et al. (2008) list benzene emission factors for average furnaces for households (0.014 mg/MJ), for the trade, industry and service sector (0.018 mg/MJ) and for the military sector (0.019 mg/MJ), regarding light fuel oil.

Emission factors for this study are apparent from the according VOC profiles (cf. Tab. 4.6). Emission factor for aromatics is between 0 and 0.2 mg/MJ_{in}.

Tab. 4.8 Benzene emission factors from literature

	Benzene	Literature
	mg/MJ_{In}	
10kW boiler, light fuel oil	0.014	(Struschka et al. 2008)
100 kW boiler, light fuel oil	0.018 – 0.019 (0.019)[1]	(Struschka et al. 2008)
1 MW industrial furnace, light fuel oil	0.015	(Jungbluth 2007)
1 MW industrial furnace, heavy fuel oil	0.015	(Jungbluth 2007) for light fuel oil

1): mean value in brackets

4.9.3 Polycyclic aromatic hydrocarbons (PAH)

Polycyclic aromatic hydrocarbons are detected only in low amounts in oil furnaces (see appendix A.26, Jungbluth 2007). Based on the big differences of the available information, only benzo(a)pyrene and total PAH are assessed. For yellow flame burners in stationary state and smoke number 0, emissions are higher by one order of magnitude than those of a blue flame burner. Intermittent operation of yellow flame burners generally leads to lower emissions (Struschka et al. 1988). In total, emissions of fluoranthene and pyrene measured by Struschka are very high compared to those in Braun et al. (1991). However, the trend towards higher PAH emissions for yellow flame burners is confirmed by measurements from Braun et al. (1991). The values published in Smith (1984) for atmospheric and fan burners clearly show the big advantage of a fan burner regarding PAH emissions (see table A.26, Jungbluth 2007). For standard settings, Braun et al. (1991) detected the substances listed in Tab. 4.9. For industrial furnaces and house furnaces ("commercial boiler") there are the following emission factors, but there is no information on fuel and furnace technique (Smith 1984).

Emission factors for PAH are 0.0012 mg/MJ light fuel oil for average furnace in household, 0.00021 mg/MJ for average in the trade, industry and service sector and 0.00014 mg/MJ for average in the military sector (Struschka et al. 2008).

Tab. 4.9 PAH-emission factors of blue flame burners and yellow flame burners under standard settings; industrial furnaces and commercial furnaces; emission factors for this study

Pollutant	Blue flame burner	Yellow flame burner	House furnace	Industrial furnace
	g/TJ_{In} 1)	g/TJ_{In}	g/TJ_{In}	g/TJ_{In}
Acenaphthylene	0.2	bld		
Acenaphthene	0.03	bld		
Fluorene	0.06	bld		
Phenantrene	0.06	0.02		
Fluoranthene	0.085	0.02		
Pyrene	0.02	bld		
Benzo(a)Pyrene	**bld (0)**	bld	1.0	**0.028**
Sum PAH	**0.455**	0.04	1.2	**0.18**
	(Braun et al. 1991)	(Braun et al. 1991)	(Struschka et al. 2008)	(Struschka et al. 2008)

1): typical value

4.9.4 Aldehydes

During normal operation of furnaces investigated by Braun et al. (1991), aldehyde emissions were generally below 0.010 mg/MJ_{in}. During setting testing, few values of over 0.4 mg/MJ_{in} (acetaldehyde, yellow flame burner) were measured (Braun et al. 1991). According to Gerold et al. (1980), aldehyde emissions (as formaldehyde) of furnaces over 1 MW performance, are between 33 and 48 % by weight of the VOC emissions. Between 3 and 6.5 mg/MJ_{in} aldehydes are specified. Thus, these factors are 2 to 4 times higher than those calculated with the VOC profiles.

Emission factors for this study are evident from the respective VOC profiles (between 0.2 and 1 $mg/MJ_{in,}$ cf. Tab. 4.6). For smaller furnaces the proportions of single aldehydes from Braun et al. (1991) (Tab. 4.10) are applied to the total share of aldehydes (Tab. 4.6).

No newer data have been found for the update in 2018.

Tab. 4.10 Aldehyde-emission factors of blue flame burners and yellow flame burners (Braun et al. 1991; Braun 1992), conversion with the help of fuel data by Braun et al. (1991)

Pollutant	Yellow flame burner	Blue flame burner	Blue flame burner 1)	Fraction
	mg/MJ_{In}	mg/MJ_{In}	mg/MJ_{In}	% 2)
Formaldehyde	0.003 – 0.14	0.003 – 0.006	0.003	**12**
Acetaldehyde	0.006 – 0.23	0.011 – 0.02	0.0011	**41**
Acrolein	0.006 – 0.085	0.006 – 0.014	0.006	**23**
Propionic aldehyde	0.003 – 0.085	0.003 – 0.006	0.003	**12**
Benz aldehyde	0.003 – 0.085	0.003 – 0.006	0.003	**12**
Sum Aldehydes	-	-	0.026	**100**

1): for standard settings, 2): Profile for house furnaces in this study

4.9.5 Acids

Braun et al. (1991) detected acetic acid and propionic acid in exhaust gas. Emission factor of the 70 kW (yellow flame burner) and 35 kW furnaces are between 0.03 and 0.35 mg/MJ$_{in}$. There was no significant difference detectable between yellow flame burners and blue flame burners.

No newer data have been found for the update in 2018.

Tab. 4.11 Emission factors of aromatic compounds based on field testing with standard setting (Braun et al. 1991); conversion with the help of fuel data by Braun et al. (1991).

Pollutant	Yellow flame burner	Blue flame burner
	mg/MJ$_{In}$	mg/MJ$_{In}$
Acetic acid (CH_3COOH)	0.115 – 0.37	0.14 – 0.37
Propionic acid (C_2H_5COOH)	0.03 – 0.115	0.06 – 0.085

Emission factors for this study are evident from the according VOC profiles (0.6 mg/MJ$_{in}$ for industrial furnaces fired with heavy oil, cf. Tab. 4.6). The values by Braun et al. (1991) are not used on. It is assumed that in household furnaces, aldehydes are rather emitted than acids.

4.10 Dioxins and furans

Detailed dioxin measurements were carried out by Braun et al. (1992). Thereby, emissions of a blue flame burner (35 kW) and a yellow flame burner (70 kW) were determined. Chlorine content of the fuel was 3 ppm by weight. In total it was shown that dioxin and furan emissions of a blue flame burner are rather present in the condensate fraction and the absorbate fraction; for the yellow flame burner they are primarily in the dust fraction. Only total emissions are indicated as toxicity equivalents (dust-, condensate-, and absorbate fraction). For emission measurements by Bröker et al. (1992) of a 46 kW and a 56-kW fan burner (yellow flame burner) with on/off cycles and an oxygen content of 14-16% by volume (excess air number ca. 4) TCDD equivalents were measured (minimal values) in the order of magnitude of those by Braun et al. (1992). For Germany in 1995, an emission factor of 2500 ng/TJ (without specifications) was mentioned (Pfeiffer et al. 2000). Due to unrealistic measurement cycles in Bröker et al. (1992) the values by Braun are used.

For oil furnaces, official bodies (BUWAL 1993) did not conduct dioxin measurements. Chlorine content in heavy oil, however, in principle enables the formation of dioxin but the simultaneous presence of sulphurs has a hampering effect (Hasler 1993).

Struschka et al. (2008) report PCDD/F emission factors that amount 0.0022 mg/MJ light fuel oil for average furnace in households, 0.0027 mg/MJ for the trade, industry and services sector and 0.0028 mg/MJ for the military sector. It was not possible to interpret these factors in terms of TCDD equivalents. Therefore, the same values are used as in the former study (Jungbluth 2007).

Tab. 4.12 Dioxin- und Furan-emission factors of blue flame burners and yellow flame burners (Braun et al. 1992), conversion with the help of fuel data in Braun et al. (1991), PCDD/F emission factors according to Struschka et al. (2008)

Pollutant in mg/TJin	Bröker et al. 1992	Braun et al. 1992	
	Yellow flame burner	Yellow flame burner	Blue flame burner
H7CDD	ns	22	0.850
- 1,2,3,4,6,7,8-HpCDD	ns	18	0.850
O8CDD	ns	29	bld
Sum PCDD	ns	51	0.85
H7CDF	ns	21	4.5
- 1,2,3,4,6,7,8-HpCDF	ns	20	4.5
O8CDF	ns	24	4.5
Sum PCDF	ns	52	9.1
PCDD + PCDF	ns	103	9.9
TCDD-equivalents	0.480/ 2.650 1)	**0.450** 2)	**0.057** 3)

1): Min. / Max., 2): emission factor for industrial furnaces for this study, 3): emission factor condensing furnaces, this study

4.11 Trace elements and halogens

Light fuel oil is poor in trace elements compared to other heavier oil products, such as heavy fuel oil or bitumen. A mercury content of 20 µg/kg is assumed.

Through contact with metals in the tanks, pipes etc. fuel oil absorbs traces of metals such as aluminium, copper, zinc or chromium. This leads to the following emission factors. No newer data have been found for the update in 2018.

Tab. 4.13 Emission factors of trace elements for light fuel oil and heavy fuel oil

Pollutant	fuel	Gross calorific value	Heavy fuel oil
	µg/kg	ng/MJIn	ng/MJIn
Chlorine (as HCl)	4'000 1)	**0 4)**	**1'440**
Fluorine (as HF)	400 1)	**4.5 7)**	**144**
Copper	30 2)	**0.4 5)**	**-**
Mercury	20 3)	**0.5**	**-**
Zinc	30 2)	**0.5 6)**	**-**

1): (BUWAL 1993), 2): (DGMK 1987a), 3): see chapter 3.7, 4): removal rate 100%, 5): removal rate 43 %, 6): Removal rate: 29 %; 7): removal rate 50 % assumed; concerning removal rate see chapter 11.5

Tab. 4.14 provides the data used for this study. Except for Molybdenum (Mo) all emission factors are assumed similar for Switzerland and Europe. By quantity, mainly nickel, vanadium and sodium (the latter one from deposit water and sea water) as well as the corrosion product iron are of importance. For chromium VI a proportion of 1% for industrial furnaces is estimated with a basis uncertainty of 10 (Katz 1994).

Tab. 4.14 Emission factors of trace elements for heavy fuel oil, CH and Europe (in brackets if different) for this study

	Emission-factor	Source
	ng/MJIn	
Al	14	(Sippula et al. 2007, Sippula et al. 2009)
As	1.6	(Sippula et al. 2007, Sippula et al. 2009, Happonen et al. 2013)
Ba	4	(Happonen et al. 2013)
Ca	117	(Kasurinen et al. 2014)
Cd	2.5	Undated internet document Statistics Norway[2]
Co	4.8	(Sippula et al. 2007, Sippula et al. 2009, Happonen et al. 2013)
Cr	5	(Jungbluth 2007)
Cu	2	(Sippula et al. 2007, Sippula et al. 2009, Happonen et al. 2013)
Fe	174	(Sippula et al. 2007, Sippula et al. 2009, Happonen et al. 2013, Kaivosoja et al. 2013)
Hg	0.15	(Jungbluth 2007)
K	92	(Sippula et al. 2007, Sippula et al. 2009, Happonen et al. 2013)
Mg	27	(Sippula et al. 2007, Sippula et al. 2009, Happonen et al. 2013)
Mn	2.5	(Sippula et al. 2007, Sippula et al. 2009, Happonen et al. 2013)
Mo	8 (16)	(Jungbluth 2007)
Na	150	(Sippula et al. 2007, Sippula et al. 2009, Kasurinen et al. 2014)
Ni	175	(Sippula et al. 2007, Sippula et al. 2009, Happonen et al. 2013)
Pb	1.4	(Sippula et al. 2007, Sippula et al. 2009, Happonen et al. 2013, Kaivosoja et al. 2013)
Sb	0.56	(Sippula et al. 2007, Sippula et al. 2009)
Se	12	(Jungbluth 2007)
V	219	(Sippula et al. 2007, Sippula et al. 2009, Happonen et al. 2013, Kaivosoja et al. 2013)
Zn	8	(Sippula et al. 2007, Sippula et al. 2009, Happonen et al. 2013, Kaivosoja et al. 2013)

4.12 Waste heat

According to the annual use efficiency of the considered furnaces, waste heat accrues. The gross calorific value is used as input. Additionally, there is waste heat from electricity input.

5 Condensate emissions to water

For condensing boilers, between 0.3 and 0.65 kg condensate is generated per $kg_{fuel\ oil}$ (for 12 and 14 $\%_{vol}$ CO_2, respectively) (DGMK 1987a). From other investigations, the temperature dependent amount of condensate can be determined (see Tab. 5.1). Practical experiences with a low temperature heating (460 kW) showed for a minimal back flow temperature of 35 °C, a specific amount of condensate of just less than 0.3 kg/kg_{oil} (Schmid 1992). Thereby, the combustion-technical efficiency factor was 101.2%.

No newer data have been found for the update in 2018.

[2] https://www.ssb.no/_attachment/291696/binary/95503?_version=547186

Tab. 5.1 Average amount of exhaust gas condensate and combustion technical efficiency factor of condensing boilers as a function of return flow temperature (DGMK 1987a)

Return flow temperature °C	Condensate	Combustion technical efficiency factor
	kg/kg_{oil}	%
46	0	98.1
43/ 44	0.14	97.9
36	0.58	98.5
26/ 27	0.77	98.9
24/ 25	0.85	98.7

Per MJ_{in}, thus between 3'300 and just under 20'000 mg of condensate accrue. In this study a mean condensate production of 10'000 mg/MJ_{in} is assumed. With around 420 l/t_{oil} the amount of wastewater is in the same order of magnitude as in refineries. Condensate composition assumed to go to wastewater treatment is documented in (Doka 2009)

6 Wastes and tank residues

During storage of fuel oil at the customer, over a period of 10 years (interval of tank revisions) depending on the size of the tank, 50 to 100 l oil sludge is formed. Related to the turn-over of fuel oil in 10 years this is 66 l/TJ_{in} for a 10-kW furnace with 4000 l tank (50 l oil sludge), for the 100-kW furnace it is around 13 l/TJ_{in} and for a 1 MW industrial furnace it is 0.4 l/TJin.

No newer data have been found for the update in 2018.

Tab. 6.1 Average amount of oil sludge (hazardous waste, code 1472 (VVS 1989)) in tanks (Tarag 1992) and specific values for this study, maintenance interval of 10 years.

	Oil sludge	Heating	Oil sludge
l	l	kW	l/TJ_{In}
5'000	50	10	66
10'000	60	100	13
> 10'000	100	1'000 1)	0.4

1): industrial furnace

Oil sludge is declared as hazardous waste (code 1472, VVS 1989), it is dried to 5-10% by weight, filtered (filter residue ca. 0.5% of the filtered amount for light fuel oil) and in Switzerland it is used in the cement industry as alternative fuel (Minder 1993). Possible filter residues are disposed to waste incineration or if chlorine content is too high, to an incineration plant for hazardous wastes (high temperature incineration).

The use in cement works means that tank residue is regarded as recyclate and thus is not assessed within furnaces. For the sake of completeness, quality information on the residues is shown in Tab. 6.2.

Tab. 6.2 Information on quality of tank residues for different fuels (Minder 1993)

	Unit	Light fuel oil	Heavy fuel oil 1)
Water content	% by weight	< 10	1 - 90
Calorific value	MJ/kg	> 37	-1)
Chlorine	% by weight	< 0.1	< 0.5
Sulphur	% by weight	-	0.5 - 5

1): depending on water content

7 Summary of life cycle inventory data

In this chapter the life cycle inventories for the newly modelled and updated processes are presented. All data are provided as unit process raw data in the EcoSpold v1 format (unit process in SimaPro). The electronic data is including full EcoSpold v1 documentation.

For each investigated process, two types of tables (X-Process and X-Exchange) are provided in this report. Tab. 7.1 contains Meta-information about the newly modelled and updated processes. Tab. 7.2 until Tab. 7.6 show the full life cycle inventory data for the newly modelled and updated processes.

Tab. 7.1 Meta information for the investigated life cycle inventories, part 1

Name	oil boiler 10kW	oil boiler 100kW	industrial furnace 1MW, oil	chimney
Location	CH	CH	CH	CH
InfrastructureProcess	1	1	1	1
Unit	unit	unit	unit	m
IncludedProcesses	Infrastructure of the boiler, including electric equipment. Energy use for the production. Disposal of the facilities.	Infrastructure of the boiler, including electric equipment. Energy use for the production. Disposal of the facilities.	Infrastructure of the furnace, including electric equipment. Energy use for the production. Disposal of the facilities.	Materials for a chimney used for small heating. Disposal of the facilities. Not including energy use for construction.
GeneralComment	Inventory for an oil boiler with a life time of 20 years a 2100 h/a.	Inventory for an oil boiler with a life time of 20 years a 2100 h/a.	Inventory for a furnace with a life time of 20 years and 5000 h/a.	Inventory for a chimney with a life time of 40 years.
InfrastructureIncluded	1	1	1	1
Category	oil	oil	oil	oil
SubCategory	heating systems	heating systems	heating systems	heating systems
LocalCategory	Erdöl	Erdöl	Erdöl	Erdöl
LocalSubCategory	Heizungssysteme	Heizungssysteme	Heizungssysteme	Heizungssysteme
StartDate	2000	2000	2000	2000
EndDate	2003	2003	2003	2016
DataValidForEntirePeriod	1	1	1	1
OtherPeriodText	Materials investigated in 1993. Energy use estimated based on environmental report from 1998.	Materials investigated in 1993. Energy use estimated based on environmental report from 1998.	Materials investigated in 1993. Energy use estimated based on environmental report from 1998.	Materials investigated in 1993. Additional inlay added in 2016 for modern heating.
Text	Data for Swiss and German producers.	Data for Swiss and German producers.	Data for Swiss and German producers.	Data for Swiss producers.
Text	Oil boiler used in one-family house.	Oil boiler used in multiple family dwelling.	Oil furnace used in industrial production facilities.	Chimney used for oil heating in small houses.
Percent ProductionVolume	Not known	Not known	Not known	Not known
SamplingProcedure	Data provided by manufacturers.	Data provided by manufacturers.	Data provided by manufacturers.	Data provided by manufacturers.
Extrapolations	Data for Germany used with assumptions for Swiss energy supply.	Data for Germany used with assumptions for Swiss energy supply.	Data for Germany used with assumptions for Swiss energy supply.	none

Meta information for the investigated life cycle inventories, part 2

Name	oil storage 3000l	light fuel oil, burned in boiler 10kW, condensing, modulating	light fuel oil, burned in boiler 100kW, condensing, modulating	heat, light fuel oil, at boiler 10kW, condensing, modulating	heat, light fuel oil, at boiler 100kW, condensing, modulating
Location	CH	CH	CH	CH	CH
InfrastructureProcess	1	0	0	0	0
Unit	unit	MJ	MJ	MJ	MJ
IncludedProcesses	Infrastructure of an oil tank, including oil pipes and valves used for small oil heating. Disposal of the facilities. Not including energy use for the production.	Direct air emissions from combustion, waste, effluents and auxiliary electricity use, input of fuel oil. Infrastructure is included.	Direct air emissions from combustion, waste, effluents and auxiliary electricity use, input of fuel oil. Infrastructure is included.	Heat delivered by the boiler not including losses and electricity demand for heat circulation in the house.	Heat delivered by the boiler not including losses and electricity demand for heat circulation in the house.
GeneralComment	Inventory for an oil storage with a life time of 20 years.	Inventory for the operation of a modern condensing, modulating low-temperature oil boiler for one-family houses, data related to fuel input.	Inventory for the operation of a modern condensing, modulating low-temperature oil boiler for one-family houses, data related to fuel input.	Inventory for heat delivery. Efficiency depends on use patterns such as input and output temperature and is here estimated at partial load (30% load) with efficiency 1.042	Inventory for heat delivery. Efficiency depends on use patterns such as input and output temperature and is here estimated at partial load (30% load) with efficiency 1.05
InfrastructureIncluded	1	1	1	1	1
Category	oil	oil	oil	oil	oil
SubCategory	heating systems	heating systems	heating systems	heating systems	heating systems
LocalCategory	Erdöl	Erdöl	Erdöl	Erdöl	Erdöl
LocalSubCategory	Heizungssysteme	Heizungssysteme	Heizungssysteme	Heizungssysteme	Heizungssysteme
StartDate	2000	2010	2010	2015	2015
EndDate	2003	2016	2016	2016	2016
DataValidForEntirePeriod	1	1	1	1	1
OtherPeriodText	Materials investigated in 1993.	Estimation for regulated emissions investigated in 2016. Data for subsidiary regulated emissions are partly based on older literature data.	Estimation for regulated emissions investigated in 2016. Data for subsidiary regulated emissions are partly based on older literature data.	Estimation for efficiency of boilers sold in 2016.	Estimation for efficiency of boilers sold in 2016.
Text	Data for Swiss producers.	Assumption for operation in Switzerland.	Assumption for operation in Switzerland.	Assumption for operation in Switzerland.	Assumption for operation in Switzerland.
Text	Oil storage 3000l used for oil heating.	Average modulating, condensing boiler used in 2016.	Average modulating, condensing boiler used in 2016.	Average modulating, condensing boiler used in 2016.	Average modulating, condensing boiler used in 2016.
Percent					
ProductionVolume	Not known	Not known	Not known	Not known	Not known
SamplingProcedure	Data provided by manufacturers.	Data published in literature based on measurements and technical data sheets.	Data published in literature based on measurements and technical data sheets.	Data published in technical data sheets.	Data published in technical data sheets.
Extrapolations	none	Some information from other European countries has been used to determine the emission factors.	Some information from other European countries has been used to determine the emission factors.	none	none

Meta information for the investigated life cycle inventories, part3

Name	heat, light fuel oil, at industrial furnace 1MW	heat, light fuel oil, at industrial furnace 1MW	heat, heavy fuel oil, at industrial furnace 1MW	heat, heavy fuel oil, at industrial furnace 1MW	light fuel oil, burned in boiler 10kW, average	light fuel oil, burned in boiler 100kW, average
Location	CH	RER	CH	RER	CH	CH
InfrastructureProcess	0	0	0	0	0	0
Unit	MJ	MJ	MJ	MJ	MJ	MJ
IncludedProcesses	Heat delivered by the furnace not including losses during distribution in the factory.	Heat delivered by the furnace not including losses during distribution in the factory.	Heat delivered by the furnace not including losses during distribution in the factory.	Heat delivered by the furnace not including losses during distribution in the factory.	Direct air emissions from combustion, waste, effluents and auxiliary electricity use, input of fuel oil. Infrastructure is included.	Direct air emissions from combustion, waste, effluents and auxiliary electricity use, input of fuel oil. Infrastructure is included.
GeneralComment	Inventory for heat delivery. Efficiency depends on use patterns such as input and output temperature and is here estimated with (Hu) 0.951272727272727	Inventory for heat delivery. Efficiency depends on use patterns such as input and output temperature and is here estimated with (Hu) 0.951272727272727	Inventory for heat delivery. Efficiency depends on use patterns such as input and output temperature and is here estimated with (Hu) 0.951272727272727	Inventory for heat delivery. Efficiency depends on use patterns such as input and output temperature and is here estimated with (Hu) 0.951272727272727	Inventory for the operation of an average condensing, modulating low-temperature oil boiler for one-family houses, data related to fuel input.	Inventory for the operation of an average oil boiler, data related to fuel input. Refers to boilers used in multiple dwellings.
InfrastructureIncluded	1	1	1	1	1	1
Category	oil	oil	oil	oil	oil	oil
SubCategory	heating systems	heating systems	heating systems	heating systems	heating systems	heating systems
LocalCategory	Erdöl	Erdöl	Erdöl	Erdöl	Erdöl	Erdöl
LocalSubCategory	Heizungssysteme	Heizungssysteme	Heizungssysteme	Heizungssysteme	Heizungssysteme	Heizungssysteme
StartDate	2000	2000	2000	2000	2008	2008
EndDate	2016	2016	2016	2016	2016	2016
DataValidForEntirePeriod	1	1	1	1	1	1
OtherPeriodText	Estimation for efficiency of furnaces used in 2016.	Estimation for efficiency of furnaces used in 2016.	Estimation for efficiency of furnaces used in 2016.	Estimation for efficiency of furnaces used in 2016.	Estimation for regulated air pollutants measured in 2016. Data for subsidiary regulated emissions are partly based on older literature data.	Estimation for regulated air pollutants measured in 2016. Data for subsidiary regulated emissions are partly based on older literature data.
Text	Assumption for operation in Switzerland.	Assumption for operation in Europe.	Assumption for operation in Switzerland.	Assumption for operation in Switzerland.	Assumption for operation in Switzerland.	Assumption for operation in Switzerland.
Text	Non-modulating furnace.	Non-modulating furnace.	Average furnace used in 2016.	Average furnace used in 2016.	Average modulating, condensing boiler used in 2016.	Average modulating, condensing boiler used in 2016.
Percent						
ProductionVolume	Not known	Not known	Not known	Not known	Not known	Not known
SamplingProcedure	Data published in literature	Data published in literature	Data published in technical data sheets.	Data published in technical data sheets.	Data published in literature based on measurements and technical data sheets.	Data published in literature based on measurements and technical data sheets.
Extrapolations	none	none	none	none	Some information from other European countries has been used to determine the emission factors.	Some information from other European countries has been used to determine the emission factors.

Meta information for the investigated life cycle inventories, part4

Name	heat, light fuel oil, at boiler 10kW, average	heat, light fuel oil, at boiler 100kW, average	light fuel oil, burned in industrial furnace 1MW, non-modulating	light fuel oil, burned in industrial furnace 1MW, non-modulating	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	heavy fuel oil, burned in industrial furnace 1MW, non-modulating
Location	CH	CH	CH	RER	CH	RER
InfrastructureProcess	0	0	0	0	0	0
Unit	MJ	MJ	MJ	MJ	MJ	MJ
IncludedProcesses	Heat delivered by the boiler not including losses and electricity demand for heat circulation in the house.	Heat delivered by the boiler not including losses and electricity demand for heat circulation in the house.	Direct air emissions from combustion, including infrastructure, fuel consumption, waste and auxiliary electricity use.	Direct air emissions from combustion, including infrastructure, fuel consumption, waste and auxiliary electricity use.	Direct air emissions from combustion, including infrastructure, fuel consumption, waste and auxiliary electricity use.	Direct air emissions from combustion, including infrastructure, fuel consumption, waste and auxiliary electricity use.
GeneralComment	Inventory for heat delivery. Efficiency depends on use patterns such as input and output temperature and is here estimated at partial load (30% load) for Hu with 1.0344	Inventory for heat delivery. Efficiency depends on use patterns such as input and output temperature and is here estimated at partial load (30% load) for Hu with 1.046	Inventory for the operation of an oil boiler, data related to fuel input. NOx and CO emissions derived from measurements conducted (ERZ Zurich). 5*000 hours of usage estimated per year.	Inventory for the operation of an oil boiler, data related to fuel input. 5*000 hours of usage estimated per year.	Inventory for the operation of an oil boiler, data related to fuel input. 5*000 hours of usage estimated per year.	Inventory for the operation of an oil boiler, data related to fuel input. 5*000 hours of usage estimated per year.
InfrastructureIncluded	1	1	1	1	1	1
Category	oil	oil	oil	oil	oil	oil
SubCategory	heating systems	heating systems	heating systems	heating systems	heating systems	heating systems
LocalCategory	Erdöl	Erdöl	Erdöl	Erdöl	Erdöl	Erdöl
LocalSubCategory	Heizungssysteme	Heizungssysteme	Heizungssysteme	Heizungssysteme	Heizungssysteme	Heizungssysteme
StartDate	2015	2015	2000	2000	2000	2000
EndDate	2016	2016	2016	2016	2016	2016
DataValidForEntirePeriod	1	1	1	1	1	1
OtherPeriodText	Estimation for efficiency of boilers used in 2016.	Estimation for efficiency of boilers used in 2016.	New data for regulated emissions like NOx, particles, other figures are partly based on older literature data.	New data for regulated emissions like NOx, particles, other figures are partly based on older literature data.	New data for regulated emissions like NOx, particles, other figures are partly based on older literature data.	New data for regulated emissions like NOx, particles, other figures are partly based on older literature data.
Text	Assumption for operation in Switzerland.	Assumption for operation in Switzerland.	Assumption for operation in Switzerland.	Assumption for operation in Europe.	Assumption for operation in Switzerland.	Assumption for operation in Europe.
Text	Average modulating, condensing boiler used in 2016.	Average modulating, condensing boiler used in 2016.	Average non-modulating, non-condensing furnace used in 2016.	Average non-modulating, non-condensing furnace used in 2016.	Average non-modulating, non-condensing furnace used in 2016.	Average non-modulating, non-condensing furnace used in 2016.
Percent ProductionVolume	Not known	Not known	Not known	Not known	Not known	Not known
SamplingProcedure	Data published in technical data sheets.	Data published in technical data sheets.	Data published in literature based on measurements.	Data published in literature based on measurements.	Data published in literature based on measurements.	Data published in literature based on measurements.
Extrapolations	none	none	Some information from other European countries has been used to determine the emission factors.	none	Some information from other European countries has been used to determine the emission factors.	none

Tab. 7.2 Unit process raw data of the oil boiler, industrial furnace, chimney and oil storage

	Name	Location	Infrastructur	Unit	oil boiler 10kW	oil boiler 100kW	industrial furnace 1MW, oil	chimney	oil storage 3000l	Uncertainty Type	StandardDeviation95%	GeneralComment
	Location				CH	CH	CH	CH	CH			
	InfrastructureProcess				1	1	1	1	1			
	Unit				unit	unit	unit	m	unit			
energy	electricity, medium voltage, at grid	CH	0	kWh	1.13E+2	3.69E+2	2.84E+3	-	-	1	3.24	(2,4,5,3,1,na); Calculation: raw material times factor from Viessmann 1998
	natural gas, burned in industrial furnace low-NOx >100kW	RER	0	MJ	6.44E+2	2.11E+3	1.62E+4	-	-	1	3.24	(2,4,5,3,1,na); Calculation: raw material times factor from Viessmann 1999
	light fuel oil, burned in industrial furnace 1MW, non-modulating	CH	0	MJ	3.40E+2	1.11E+3	8.57E+3	-	-	1	3.24	(2,4,5,3,1,na); Calculation: raw material times factor from Viessmann 2000
	tap water, unspecified natural origin CH, at user	CH	0	kg	182	741	6'188	-	-	1	3.24	(2,4,5,3,1,na); Viessmann 2002
materials	concrete, normal, at plant	CH	0	m3	-	-	-	-	2.25E-1	1	3.28	(2,3,5,1,3,na); Literature
	refractory, fireclay, packed, at plant	DE	0	kg	-	-	-	9.50E+1		1	3.24	(3,3,5,1,1,na); Literature
	alkyd paint, white, 60% in solvent, at plant	RER	0	kg	1.25E+0	2.50E+0	5.00E+0		6.00E+0	1	3.24	(3,3,5,1,1,na); Literature
	aluminium, production mix, cast alloy, at plant	RER	0	kg	7.50E+0	1.50E+1	3.00E+1	-	-	1	3.24	(3,3,5,1,1,na); Literature
	brass, at plant	CH	0	kg	5.00E-2	5.00E-2	5.00E-2	-	1.40E+0	1	3.24	(3,3,5,1,1,na); Literature, mixing valve
	brazing solder, cadmium free, at plant	RER	0	kg	4.00E+0	6.00E+0	-	-	-	1	3.47	(3,3,5,1,4,na); Approximation for welding anodes
	cast iron, at plant	RER	0	kg	-	-	4.20E+3	-	6.00E+0	1	3.24	(3,3,5,1,1,na); Literature
	chromium steel 18/8, at plant	RER	0	kg	5.00E+0	2.50E+1	2.30E+2	5.90E+0	-	1	3.24	(3,3,5,1,1,na); Literature, assumption for steel, high alloy
	copper, at regional storage	RER	0	kg	3.03E+0	2.50E+1	3.00E-2	-	2.01E+1	1	3.24	(3,3,5,1,1,na); Literature
	refractory, fireclay, packed, at plant	DE	0	kg	-	-	7.00E+1	-	-	1	3.24	(3,3,5,1,1,na); Literature, assumption for chamotte
	polyethylene, HDPE, granulate, at plant	RER	0	kg	4.00E-1	4.00E-1	4.00E-1	-	5.50E-1	1	3.24	(3,3,5,1,1,na); Literature
	rock wool, packed, at plant	CH	0	kg	8.00E+0	1.90E+1	4.00E+1	5.00E-1	-	1	3.24	(3,3,5,1,1,na); Literature
	steel, low-alloyed, at plant	RER	0	kg	1.15E+2	4.85E+2	1.90E+2	-	4.52E+2	1	3.24	(3,3,5,1,1,na); Literature
packaging	corrugated board, mixed fibre, single wall, at plant	RER	0	kg	5.00E+0	1.00E+1		-	-	1	3.24	(3,3,5,1,1,na); Literature
	polyethylene, HDPE, granulate, at plant	RER	0	kg	5.00E-1	1.00E+0		-		1	3.24	(3,3,5,1,1,na); Literature
manufacturing	drawing of pipes, steel	RER	0	kg	-	-	-	5.90E+0	-	1	3.24	(3,3,5,1,1,na); Inlay for modern heatings
transport	transport, van <3.5t	RER	0	tkm	7.46E+0	2.94E+1	-	3.20E-1	2.43E+1	1	4.01	(3,5,5,3,3,na); 50km delivery distance, excl. concrete
	transport, lorry 20-28t, fleet average	CH	0	tkm	7.46E+0	2.94E+1	2.38E+2	5.07E+0	3.42E+1	1	4.01	(3,5,5,3,3,na); Standard distance 50km
	transport, freight, rail	RER	0	tkm	8.96E+1	3.53E+2	2.86E+3	3.84E+0	2.91E+2	1	4.01	(3,5,5,3,3,na); Standard distance 600km
disposal	disposal, concrete, 5% water, to inert material landfill	CH	0	kg	-	-	7.00E+1	9.50E+1	4.95E+2	1	3.25	(3,4,5,1,1,na); Estimation for disposal
	disposal, packaging cardboard, 19.6% water, to municipal incineration	CH	0	kg	5.00E+0	1.00E+1	-	-	-	1	3.25	(3,4,5,1,1,na); Estimation for disposal
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	4.00E-1	4.00E-1	4.00E-1	-	5.50E-1	1	3.25	(3,4,5,1,1,na); Estimation for disposal
	disposal, mineral wool, 0% water, to inert material landfill	CH	0	kg	8.00E+0	1.90E+1	4.00E+1	5.00E-1	-	1	3.25	(3,4,5,1,1,na); Estimation for disposal
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	4.00E+0	6.00E+0	-	-	-	1	3.25	(3,4,5,1,1,na); Estimation for disposal
	treatment, pig iron production effluent, to wastewater treatment, class 3	CH	0	m3	1.51E-1	6.15E-1	5.14E+0	-	-	1	5.00	(2,4,5,3,1,na); Environmental report, 83% of water use, basic uncertainty estimated = 3
emission air, high population density	Heat, waste	-	-	MJ	4.06E+2	1.33E+3	1.02E+4	-	-	1	3.25	(3,4,5,1,1,na); Literature
weight	total			kg	1.91E+2	6.25E+2	4.81E+3	157	981			

Tab. 7.3 Unit process raw data of light fuel oil burned in 10 and 100 kW boiler, part 1

	Name	InfrastructureProcess	Unit	light fuel oil, burned in boiler 10kW, average	light fuel oil, burned in boiler 10kW, condensing, modulating	light fuel oil, burned in boiler 100kW, average	light fuel oil, burned in boiler 100kW, condensing, modulating	light fuel oil, burned in boiler 10kW, non-modulating	light fuel oil, burned in boiler 10kW condensing, non-modulating	light fuel oil, burned in boiler 100kW, non-modulating	light fuel oil, burned in boiler 100kW condensing, non-modulating	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			CH	CH	CH	CH	CH	CH	CH	CH			
	InfrastructureProcess			0	0	0	0	0	0	0	0			
	Unit			MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ			
technosphere	light fuel oil, at regional storage	0	kg	2.33E-2	2.33E-2	2.33E-2	2.33E-2	2.33E-2	2.33E-2	2.33E-2	2.33E-2	1	1.12	(3,3,1,1,1,na); Literature
	electricity, low voltage, at grid	0	kWh	2.73E-3	2.73E-3	1.66E-3	1.66E-3	3.59E-3	3.59E-3	1.66E-3	1.66E-3	1	1.53	(3,3,5,1,1,na); Literature
	oil boiler 10kW	1	unit	6.84E-7	6.84E-7	0	0	6.61E-7	6.61E-7	0	0	1	3.03	(3,3,3,1,1,na); Estimation 2100h use per year
	oil boiler 100kW	1	unit	0	0	6.92E-8	6.92E-8	0	0	6.61E-8	6.61E-8	1	3.03	(3,3,3,1,1,na); Estimation 2100h use per year
	chimney	1	m	2.65E-6	2.65E-6	5.95E-7	5.95E-7	2.65E-6	2.65E-6	5.95E-7	5.95E-7	1	3.24	(3,3,5,1,1,na); Calculated
	oil storage 3000l	1	unit	4.41E-7	4.41E-7	1.76E-7	1.76E-7	4.41E-7	4.41E-7	1.76E-7	1.76E-7	1	3.24	(3,3,5,1,1,na); Calculated
	treatment, condensate from light oil boiler, to wastewater treatment, class 2	0	m3	9.79E-6	9.79E-6	9.79E-6	9.79E-6	0	9.79E-6	0	9.79E-6	1	3.24	(3,3,5,1,1,na); Literature, basic uncertainity = 3
	disposal, hazardous waste, 25% water, to hazardous waste incineration	0	kg	4.15E-6	4.15E-6	4.15E-6	4.15E-6	0	4.15E-6	0	4.15E-6	1	1.53	(3,3,5,1,1,na); Literature
emission air, high population density	Heat, waste	-	MJ	1.06E+0	1.06E+0	1.06E+0	1.06E+0	1.07E+0	1.07E+0	1.06E+0	1.06E+0	1	1.53	(3,3,5,1,1,na); Literature
	Acetaldehyde	-	kg	1.40E-7	1.40E-7	1.40E-7	1.40E-7	2.05E-8	2.05E-8	2.05E-8	2.05E-8	1	1.52	(3,3,1,1,1,na); Literature
	Aldehydes, unspecified	-	kg	3.50E-7	3.50E-7	3.50E-7	3.50E-7	0	0	0	0	1	1.52	(3,3,1,1,1,na); Literature
	Acetic acid	-	kg	1.40E-7	1.40E-7	1.40E-7	1.40E-7	0	0	0	0	1	1.52	(3,3,1,1,1,na); Literature
	Acetone	-	kg	3.50E-7	3.50E-7	3.50E-7	3.50E-7	5.00E-8	5.00E-8	5.00E-8	5.00E-8	1	1.52	(3,3,1,1,1,na); Literature
	Acetylene, dichloro-	-	kg	7.00E-8	7.00E-8	7.00E-8	7.00E-8	0	0	0	0	1	1.52	(3,3,1,1,1,na); Literature
	Acrolein	-	kg	1.15E-8	1.15E-8	1.15E-8	1.15E-8	1.15E-8	1.15E-8	1.15E-8	1.15E-8	1	1.52	(3,3,1,1,1,na); Literature
	Hydrocarbons, aliphatic, alkanes, unspecified	-	kg	1.75E-6	1.75E-6	1.75E-6	1.75E-6	2.50E-7	2.50E-7	2.50E-7	2.50E-7	1	1.52	(3,3,1,1,1,na); Literature
	Hydrocarbons, aliphatic, unsaturated	-	kg	2.00E-8	2.00E-8	2.00E-8	2.00E-8	2.00E-8	2.00E-8	2.00E-8	2.00E-8	1	1.52	(3,3,1,1,1,na); Literature
	Hydrocarbons, aromatic	-	kg	1.19E-7	1.19E-7	1.19E-7	1.19E-7	2.00E-8	2.00E-8	2.00E-8	2.00E-8	1	1.52	(3,3,1,1,1,na); Literature
	Benzaldehyde	-	kg	6.00E-9	6.00E-9	6.00E-9	6.00E-9	6.00E-9	6.00E-9	6.00E-9	6.00E-9	1	1.52	(3,3,1,1,1,na); Literature
	Benzene	-	kg	1.40E-7	1.40E-7	1.40E-7	1.40E-7	2.00E-8	2.00E-8	2.00E-8	2.00E-8	1	3.02	(3,3,1,1,1,na); Literature
	Butane	-	kg	1.05E-6	1.05E-6	1.05E-6	1.05E-6	1.50E-7	1.50E-7	1.50E-7	1.50E-7	1	1.52	(3,3,1,1,1,na); Literature
	Ethane	-	kg	1.40E-7	1.40E-7	1.40E-7	1.40E-7	2.00E-8	2.00E-8	2.00E-8	2.00E-8	1	1.52	(3,3,1,1,1,na); Literature
	Ethanol	-	kg	7.00E-8	7.00E-8	7.00E-8	7.00E-8	0	0	0	0	1	1.52	(3,3,1,1,1,na); Literature
	Ethene	-	kg	5.00E-8	5.00E-8	5.00E-8	5.00E-8	5.00E-8	5.00E-8	5.00E-8	5.00E-8	1	1.52	(3,3,1,1,1,na); Literature
	Ethylene diamine	-	kg	3.50E-7	3.50E-7	3.50E-7	3.50E-7	0	0	0	0	1	1.52	(3,3,1,1,1,na); Literature

Unit process raw data of light fuel oil burned in 10 and 100 kW boiler, part 2

	Name	InfrastructureProcess	Unit	light fuel oil, burned in boiler 10kW, average	light fuel oil, burned in boiler 10kW, condensing, modulating	light fuel oil, burned in boiler 100kW, average	light fuel oil, burned in boiler 100kW, condensing, modulating	light fuel oil, burned in boiler 10kW, non-modulating	light fuel oil, burned in boiler 10kW condensing, non-modulating	light fuel oil, burned in boiler 100kW, non-modulating	light fuel oil, burned in boiler 100kW condensing, non-modulating	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			CH	CH	CH	CH	CH	CH	CH	CH			
	InfrastructureProcess			0	0	0	0	0	0	0	0			
	Unit			MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ			
emission air, high population density	Ethyne	-	kg	1.00E-8	1.00E-8	1.00E-8	1.00E-8	1.00E-8	1.00E-8	1.00E-8	1.00E-8	1	1.52	(3,3,1,1,1,na); Literature
	Formaldehyde	-	kg	4.20E-8	4.20E-8	4.20E-8	4.20E-8	6.00E-9	6.00E-9	6.00E-9	6.00E-9	1	1.52	(3,3,1,1,1,na); Literature
	Methane, fossil	-	kg	1.00E-6	1.00E-6	1.00E-6	1.00E-6	2.00E-7	2.00E-7	2.00E-7	2.00E-7	1	1.52	(3,3,1,1,1,na); Literature
	Pentane	-	kg	7.00E-7	7.00E-7	7.00E-7	7.00E-7	1.00E-7	1.00E-7	1.00E-7	1.00E-7	1	1.52	(3,3,1,1,1,na); Literature
	Propane	-	kg	2.10E-7	2.10E-7	2.10E-7	2.10E-7	3.00E-8	3.00E-8	3.00E-8	3.00E-8	1	1.52	(3,3,1,1,1,na); Literature
	Propene	-	kg	2.00E-8	2.00E-8	2.00E-8	2.00E-8	2.00E-8	2.00E-8	2.00E-8	2.00E-8	1	1.52	(3,3,1,1,1,na); Literature
	Propionic acid	-	kg	1.40E-7	1.40E-7	1.40E-7	1.40E-7	0	0	0	0	1	1.52	(3,3,1,1,1,na); Literature
	Propanal	-	kg	6.00E-9	6.00E-9	6.00E-9	6.00E-9	6.00E-9	6.00E-9	6.00E-9	6.00E-9	1	1.52	(3,3,1,1,1,na); Literature
	Propylene oxide	-	kg	1.40E-7	1.40E-7	1.40E-7	1.40E-7	0	0	0	0	1	1.52	(3,3,1,1,1,na); Literature
	Toluene	-	kg	9.87E-8	9.87E-8	9.87E-8	9.87E-8	1.00E-8	1.00E-8	1.00E-8	1.00E-8	1	1.52	(3,3,1,1,1,na); Literature
	Carbon monoxide, fossil	-	kg	1.30E-5	3.00E-6	7.00E-6	1.00E-6	9.00E-6	9.00E-6	7.50E-6	7.50E-6	1	5.02	(3,3,1,1,1,na); Literature
	Carbon dioxide, fossil	-	kg	7.37E-2	7.37E-2	7.37E-2	7.37E-2	7.37E-2	7.37E-2	7.37E-2	7.37E-2	1	1.12	(3,3,1,1,1,na); Literature
	Copper	-	kg	4.00E-10	4.00E-10	4.00E-10	4.00E-10	7.00E-10	4.00E-10	7.00E-10	4.00E-10	1	5.02	(3,3,1,1,1,na); Literature
	Hydrogen chloride	-	kg	9.40E-8	9.40E-8	9.40E-8	9.40E-8	9.40E-8	9.40E-8	9.40E-8	9.40E-8	1	1.52	(3,3,1,1,1,na); Literature
	Hydrogen fluoride	-	kg	4.50E-9	4.50E-9	4.50E-9	4.50E-9	9.00E-9	4.50E-9	9.00E-9	4.50E-9	1	1.52	(3,3,1,1,1,na); Literature
	Lead	-	kg	1.17E-7	1.17E-7	1.17E-7	1.17E-7	1.17E-7	1.17E-7	1.17E-7	1.17E-7	1	5.02	(3,3,1,1,1,na); Product properties
	Mercury	-	kg	4.66E-10	4.66E-10	4.66E-10	4.66E-10	4.66E-10	4.66E-10	4.66E-10	4.66E-10	1	5.02	(3,3,1,1,1,na); Product properties
	Nickel	-	kg	1.17E-7	1.17E-7	1.17E-7	1.17E-7	1.17E-7	1.17E-7	1.17E-7	1.17E-7	1	5.02	(3,3,1,1,1,na); Product properties
	Dinitrogen monoxide	-	kg	5.50E-7	5.50E-7	5.60E-7	5.60E-7	7.00E-7	7.00E-7	7.00E-7	7.00E-7	1	4.03	(3,3,3,1,1,na); Struschka 2008 basic uncertainty estimated = 4
	Nitrogen oxides	-	kg	2.78E-5	2.22E-5	3.60E-5	2.88E-5	2.75E-5	2.75E-5	2.75E-5	2.75E-5	1	1.50	(2,1,1,1,1,na); Literature
	PAH, polycyclic aromatic hydrocarbons	-	kg	4.60E-10	4.60E-10	1.90E-10	1.90E-10	4.60E-10	4.60E-10	4.60E-10	4.60E-10	1	3.03	(3,3,3,1,1,na); Literature
	Particulates, < 2.5 um	-	kg	3.92E-7	3.92E-7	5.00E-7	5.00E-7	5.00E-7	5.00E-7	5.00E-7	5.00E-7	1	3.03	(3,3,3,1,1,na); Literature, basic uncertainty estimated = 3
	Sulfur dioxide	-	kg	1.20E-5	1.30E-6	1.20E-5	1.30E-6	4.66E-5	4.55E-5	4.66E-5	4.55E-5	1	1.16	(3,3,3,1,1,na); Calculated
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	-	kg	5.70E-17	5.70E-17	5.70E-17	5.70E-17	5.70E-17	5.70E-17	5.70E-17	5.70E-17	1	3.03	(3,3,3,1,1,na); Literature
	Zinc	-	kg	5.00E-10	5.00E-10	5.00E-10	5.00E-10	7.00E-10	5.00E-10	7.00E-10	5.00E-10	1	5.03	(3,3,3,1,1,na); Literature
	VOC			7.12E-6	7.12E-6	7.12E-6	7.12E-6	1.00E-6	1.00E-6	1.00E-6	1.00E-6	1	6.03	(3,3,3,1,1,na); UVEK 2015, basic uncertainty estimated = 6

Tab. 7.4 Unit process raw data of heat from light fuel oil of 10 and 100 kW boiler (average and “condensing, modulating”)

	Name	Location	InfrastructureProc	Unit	heat, light fuel oil, at boiler 10kW, average	heat, light fuel oil, at boiler 100kW, average	heat, light fuel oil, at boiler 10kW, condensing, modulating	heat, light fuel oil, at boiler 100kW, condensing, modulating	heat, light fuel oil, at boiler 10kW, non-modulating	heat, light fuel oil, at boiler 10kW condensing, non-modulating	heat, light fuel oil, at boiler 100kW, non-modulating	heat, light fuel oil, at boiler 100kW condensing, non-modulating	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				CH	CH	CH	CH	CH	CH	CH	CH			
	InfrastructureProcess				0	0	0	0	0	0	0	0			
	Unit				MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ			
technosphere	light fuel oil, burned in boiler 10kW, non-modulating	CH	0	MJ	0	0	0	0	1.06E+0	0	0	0	1	1.53	(3,3,5,1,1,na); Literature
	light fuel oil, burned in boiler 10kW condensing, non-modulating	CH	0	MJ	0	0	0	0	0	1.00E+0	0	0	1	1.53	(3,3,5,1,1,na); Literature
	light fuel oil, burned in boiler 100kW, non-modulating	CH	0	MJ	0	0	0	0	0	0	1.06E+0	0	1	1.53	(3,3,5,1,1,na); Literature
	light fuel oil, burned in boiler 100kW condensing, non-modulating	CH	0	MJ	0	0	0	0	0	0	0	1.00E+0	1	1.53	(3,3,5,1,1,na); Literature
	light fuel oil, burned in boiler 10kW, average	CH	0	MJ	9.67E-1	0	0	0	0	0	0	0	1	1.12	(3,3,1,1,1,na); Literature
	light fuel oil, burned in boiler 100kW, average	CH	0	MJ	0	9.56E-1	0	0	0	0	0	0	1	1.12	(3,3,1,1,1,na); Literature
	light fuel oil, burned in boiler 10kW, condensing, modulating	CH	0	MJ	0	0	9.60E-1	0	0	0	0	0	1	1.12	(3,3,1,1,1,na); Literature
	light fuel oil, burned in boiler 100kW, condensing, modulating	CH	0	MJ	0	0	0	9.52E-1	0	0	0	0	1	1.12	(3,3,1,1,1,na); Literature

Tab. 7.5 Unit process raw data of light and heavy fuel oil burned in 1 MW boiler, part 1

	Name	Location	InfrastructureProcess	Unit	light fuel oil, burned in industrial furnace 1MW, non-modulating	light fuel oil, burned in industrial furnace 1MW, non-modulating	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH	RER	CH	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				MJ	MJ	MJ	MJ			
technosphere	light fuel oil, at regional storage	CH	0	kg	2.33E-2	0	0	0	1	1.09	(2,3,2,1,1,na); Literature
	light fuel oil, at regional storage	RER	0	kg	0	2.33E-2	0	0	1	1.09	(2,3,2,1,1,na); Literature
	heavy fuel oil, at regional storage	CH	0	kg	0	0	2.43E-2	0	1	1.09	(2,3,2,1,1,na); Literature
	heavy fuel oil, at regional storage	RER	0	kg	0	0	0	2.43E-2	1	1.09	(2,3,2,1,1,na); Literature
	electricity, low voltage, at grid	CH	0	kWh	8.31E-4	0	8.31E-4	0	1	1.53	(3,3,5,1,1,na); Literature
	electricity, low voltage, production ENTSO, at grid	ENTSO	0	kWh	0	8.31E-4	0	8.31E-4	1	1.53	(3,3,5,1,1,na); Literature
	industrial furnace 1MW, oil	CH	1	unit	2.78E-9	2.78E-9	2.78E-9	2.78E-9	1	3.24	(3,3,5,1,1,na); Estimation 5000h use per year
	chimney	CH	1	m	3.47E-8	3.47E-8	3.47E-8	3.47E-8	1	3.24	(3,3,5,1,1,na); Calculated
	oil storage 3000l	CH	1	unit	3.70E-8	3.70E-8	3.70E-8	3.70E-8	1	3.24	(3,3,5,1,1,na); Calculated
emission air, high population density	Heat, waste	-	-	MJ	1.06E+0	1.06E+0	1.08E+0	1.10E+0	1	1.53	(3,3,5,1,1,na); Calculated
	Carbon monoxide, fossil	-	-	kg	2.50E-6	2.50E-6	4.97E-6	4.97E-6	1	5.02	(3,3,2,1,1,na); Literature
	Carbon dioxide, fossil	-	-	kg	7.37E-2	7.37E-2	7.70E-2	7.70E-2	1	1.13	(3,3,2,1,1,na); Literature
	Acetaldehyde	-	-	kg	4.67E-8	4.67E-8	1.50E-7	1.50E-7	1	1.79	(3,3,5,1,1,na); Literature
	Acetic acid	-	-	kg	4.67E-8	4.67E-8	6.00E-7	6.00E-7	1	1.79	(3,3,5,1,1,na); Literature
	Acetone	-	-	kg	1.17E-7	1.17E-7	1.50E-7	1.50E-7	1	1.79	(3,3,5,1,1,na); Literature
	Acetylene, dichloro-	-	-	kg	2.33E-8	2.33E-8	0	0	1	1.79	(3,3,5,1,1,na); Literature
	Hydrocarbons, aliphatic, alkanes, unspecified	-	-	kg	5.83E-7	5.83E-7	6.00E-7	6.00E-7	1	1.79	(3,3,5,1,1,na); Literature
	Benzene	-	-	kg	4.67E-8	4.67E-8	1.50E-8	1.50E-8	1	3.24	(3,3,5,1,1,na); Literature
	Ethane	-	-	kg	4.67E-8	4.67E-8	0	0	1	1.79	(3,3,5,1,1,na); Literature
	Ethanol	-	-	kg	2.33E-8	2.33E-8	3.00E-7	3.00E-7	1	1.79	(3,3,5,1,1,na); Literature
	Ethylene diamine	-	-	kg	1.17E-7	1.17E-7	0	0	1	1.79	(3,3,5,1,1,na); Literature
	Formaldehyde	-	-	kg	1.40E-8	1.40E-8	4.50E-7	4.50E-7	1	1.79	(3,3,5,1,1,na); Literature
	Butane	-	-	kg	3.50E-7	3.50E-7	0	0	1	1.79	(3,3,5,1,1,na); Literature
	Pentane	-	-	kg	2.33E-7	2.33E-7	0	0	1	1.79	(3,3,5,1,1,na); Literature
	Aldehydes, unspecified	-	-	kg	1.17E-7	1.17E-7	0	0	1	1.79	(3,3,5,1,1,na); Literature
	Hydrocarbons, aromatic	-	-	kg	3.97E-8	3.97E-8	1.50E-7	1.50E-7	1	1.79	(3,3,5,1,1,na); Literature

Unit process raw data of light and heavy fuel oil burned in 1 MW boiler, part 2

	Name	Location	InfrastructureProcess	Unit	light fuel oil, burned in industrial furnace 1MW, non-modulating	light fuel oil, burned in industrial furnace 1MW, non-modulating	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH	RER	CH	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				MJ	MJ	MJ	MJ			
emission air, high population density	Propane	-	-	kg	7.00E-8	7.00E-8	3.00E-8	3.00E-8	1	1.79	(3,3,5,1,1,na); Literature
	Propionic acid	-	-	kg	4.67E-8	4.67E-8	0	0	1	1.79	(3,3,5,1,1,na); Literature
	Propylene oxide	-	-	kg	4.67E-8	4.67E-8	0	0	1	1.79	(3,3,5,1,1,na); Literature
	Toluene	-	-	kg	3.29E-8	3.29E-8	3.00E-8	3.00E-8	1	1.79	(3,3,5,1,1,na); Literature
	Methanol	-	-	kg	0	0	5.10E-7	5.10E-7	1	1.79	(3,3,5,1,1,na); Literature
	Methane, fossil	-	-	kg	1.00E-6	1.00E-6	3.00E-6	3.00E-6	1	1.79	(3,3,5,1,1,na); Literature
	Benzo(a)pyrene	-	-	kg	2.50E-11	2.50E-11	2.80E-11	2.80E-11	1	3.24	(3,3,5,1,1,na); Literature
	PAH, polycyclic aromatic hydrocarbons	-	-	kg	5.80E-10	5.80E-10	5.80E-10	5.80E-10	1	3.24	(3,3,5,1,1,na); Literature
	Hydrocarbons, aliphatic, unsaturated	-	-	kg	0	0	3.00E-8	3.00E-8	1	1.79	(3,3,5,1,1,na); Literature
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	-	-	kg	4.50E-16	4.50E-16	4.50E-16	4.50E-16	1	3.24	(3,3,5,1,1,na); Literature
	Ammonia	-	-	kg	1.50E-7	1.50E-7	1.00E-8	1.00E-8	1	1.58	(3,3,5,1,1,na); Literature
	Hydrogen chloride	-	-	kg	9.40E-8	9.40E-8	1.44E-6	1.44E-6	1	1.79	(3,3,5,1,1,na); Literature
	Hydrogen fluoride	-	-	kg	9.00E-9	9.00E-9	4.80E-8	1.44E-7	1	1.79	(3,3,5,1,1,na); Literature
	Nitrate	-	-	kg	8.10E-11	8.10E-11	4.87E-9	4.87E-9	1	1.52	(3,3,2,1,1,na); Literature
	Dinitrogen monoxide	-	-	kg	6.00E-7	6.00E-7	8.00E-7	8.00E-7	1	1.79	(3,3,5,1,1,na); Literature
	Nitrogen oxides	-	-	kg	2.90E-5	2.90E-5	5.00E-5	5.00E-5	1	1.52	(3,3,2,1,1,na); Estimation based on literature data
	Sulfur dioxide	-	-	kg	1.20E-5	1.20E-5	3.94E-4	4.00E-4	1	1.13	(3,3,2,1,1,na);
	Aluminium	-	-	kg	0	0	1.40E-8	1.40E-8	1	5.02	(3,3,2,1,1,na); Literature
	Arsenic	-	-	kg	0	0	1.59E-9	1.59E-9	1	5.02	(3,3,2,1,1,na); Literature
	Barium	-	-	kg	0	0	4.01E-9	4.01E-9	1	5.02	(3,3,2,1,1,na); Literature
	Calcium	-	-	kg	5.10E-10	5.10E-10	1.17E-7	1.17E-7	1	5.02	(3,3,2,1,1,na); Literature
	Cadmium	-	-	kg	0	0	2.50E-9	2.50E-9	1	5.28	(3,3,5,1,1,na); Literature
	Cobalt	-	-	kg	0	0	4.78E-9	4.78E-9	1	5.02	(3,3,2,1,1,na); Literature
	Chromium	-	-	kg	0	0	4.95E-9	1.58E-8	1	5.02	(3,3,2,1,1,na); Literature

Unit process raw data of light and heavy fuel oil burned in 1 MW boiler, part3

	Name	Location	InfrastructureProcess	Unit	light fuel oil, burned in industrial furnace 1MW, non-modulating	light fuel oil, burned in industrial furnace 1MW, non-modulating	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH	RER	CH	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				MJ	MJ	MJ	MJ			
emission air, high population density	Chromium VI	-	-	kg	0	0	5.00E-11	1.60E-10	1	5.28	(3,3,5,1,1,na); Literature, estimation 1% Cr VI of Cr
	Copper	-	-	kg	6.99E-10	6.99E-10	1.97E-9	1.97E-9	1	5.02	(3,3,2,1,1,na); Literature
	Iron	-	-	kg	0	0	1.74E-7	1.74E-7	1	5.02	(3,3,2,1,1,na); Literature
	Mercury	-	-	kg	4.66E-10	4.66E-10	1.46E-10	1.46E-10	1	5.28	(3,3,5,1,1,na); Literature
	Potassium	-	-	kg	7.90E-10	7.90E-10	9.17E-8	9.17E-8	1	5.02	(3,3,2,1,1,na); Literature
	Magnesium	-	-	kg	0	0	3.81E-8	2.68E-8	1	5.02	(3,3,2,1,1,na); Literature
	Manganese	-	-	kg	0	0	2.54E-9	2.54E-9	1	5.02	(3,3,2,1,1,na); Literature
	Molybdenum	-	-	kg	0	0	8.00E-9	1.60E-8	1	5.28	(3,3,5,1,1,na); Literature
	Sodium	-	-	kg	0	0	1.50E-7	1.50E-7	1	5.02	(3,3,2,1,1,na); Literature
	Nickel	-	-	kg	1.60E-11	1.60E-11	1.75E-7	1.75E-7	1	5.02	(3,3,2,1,1,na); Literature
	Lead	-	-	kg	0	0	1.41E-9	1.41E-9	1	5.02	(3,3,2,1,1,na); Literature
	Antimony	-	-	kg	0	0	5.60E-10	5.60E-10	1	5.02	(3,3,2,1,1,na); Literature
	Selenium	-	-	kg	0	0	1.20E-8	1.20E-8	1	5.28	(3,3,5,1,1,na); Literature
	Vanadium	-	-	kg	0	0	2.19E-7	2.19E-7	1	5.02	(3,3,2,1,1,na); Literature
	Zinc	-	-	kg	1.56E-10	1.56E-10	7.98E-9	7.98E-9	1	5.02	(3,3,2,1,1,na); Literature
	Particulates, < 2.5 um	-	-	kg	1.00E-7	1.00E-7	7.60E-6	7.60E-6	1	3.02	(3,3,2,1,1,na); Literature
	Particulates, > 2.5 um, and < 10um	-	-	kg	0	0	1.20E-6	5.00E-6	1	2.25	(3,3,5,1,1,na); Literature
	Particulates, > 10 um	-	-	kg	0	0	2.40E-6	1.00E-5	1	1.79	(3,3,5,1,1,na); Literature

Tab. 7.6 Unit process raw data of heat from light and heavy fuel oil at industrial furnace (1 MW)

	Name	Location	Unit	heat, light fuel oil, at industrial furnace 1MW	heat, light fuel oil, at industrial furnace 1MW	heat, heavy fuel oil, at industrial furnace 1MW	heat, heavy fuel oil, at industrial furnace 1MW	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			CH	RER	CH	RER			
	InfrastructureProcess			0	0	0	0			
	Unit			MJ	MJ	MJ	MJ			
technosphere	light fuel oil, burned in industrial furnace 1MW, non-modulating	CH	MJ	1.05E+0	0	0	0	1	1.13	(3,3,2,1,1,na); Literature
	light fuel oil, burned in industrial furnace 1MW, non-modulating	RER	MJ	0	1.05E+0	0	0	1	1.13	(3,3,2,1,1,na); Literature
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	CH	MJ	0	0	1.05E+0	0	1	1.13	(3,3,2,1,1,na); Literature
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	MJ	0	0	0	1.05E+0	1	1.13	(3,3,2,1,1,na); Literature

8 Datasets to be replaced in KBOB database

It is recommended to first change the name of the most used datasets to the name of the new average dataset before importing data.

The following two types of furnaces have not been updated as they are not relevant for the new selling in the market in 2017. They can be replaced with the average boiler investigated for this study (or used further if the inventories refer to the assessment for old production routes).

- LowNOx-boiler 10 and 100 kW, light fuel oil
- Condensing boiler 10 and 100 kW, light fuel oil

9 Data quality

The data quality is general very good. Emission factors for the main air pollutants and the efficiency could be updated for this study. No newer data were found for the specific NMVOC profile, but the total emission factor was updated. This shows the trend to investigate and publish only data for the main air pollutants, but not for a long list of very specific substances.

Other inputs and outputs which have not been updated during this study are normally of very low relevance for the calculated environmental impacts.

10 Life cycle impact assessment

Tab. 10.1 shows the key indicator results for the processes investigating the combustion of fuel oil.

Larger furnaces show a slightly better performance for the CED when burning heavy fuel oil. This is due to the lower electricity use and/or different electricity mixes (CH and RER). The GWP is similar for all options. For the ecological scarcity results some improvements can be seen for modern appliances, but the results are similar for all options burning light fuel oil.

Tab. 10.1 Key indicator results for the updated processes investigating **oil burned in** heating devices (red marks highest and green lowest values per column of special interest)

technology	reference value	primary energy factor, total [MJ-eq]	primary energy factor,fossil [MJ-eq]	primary energy factor, nuklear [MJ-eq]	primary energy factor, renewable [MJ-eq]	CO equivalents [kg CO2-eq]	eco-points [eco-points 2013]
light fuel oil, 10kW, non-modulating	MJ	1.357	1.289	0.054	0.015	0.095	73.431
light fuel oil, 10kW condensing, non-modulating	MJ	1.358	1.289	0.054	0.015	0.095	73.579
light fuel oil, 10kW, condensing, modulating	MJ	1.348	1.288	0.047	0.013	0.095	72.407
light fuel oil, 10kW, average	MJ	1.348	1.288	0.047	0.013	0.095	72.857
light fuel oil, 100kW, non-modulating	MJ	1.324	1.276	0.038	0.011	0.094	71.233
light fuel oil, 100kW condensing, non-modulating	MJ	1.324	1.276	0.038	0.011	0.094	71.382
light fuel oil, 100kW, condensing, modulating	MJ	1.324	1.276	0.038	0.011	0.094	70.771
light fuel oil, 100kW, average	MJ	1.324	1.276	0.038	0.011	0.094	71.280
light fuel oil, 1MW, CH	MJ	1.310	1.271	0.031	0.009	0.094	67.045
light fuel oil, 1MW, RER	MJ	1.308	1.278	0.022	0.007	0.094	66.760
heavy fuel oil, 1MW, CH	MJ	1.292	1.252	0.032	0.009	0.096	79.363
heavy fuel oil, 1MW, RER	MJ	1.286	1.255	0.024	0.008	0.096	79.051

Tab. 10.2 show the key indicator results for the processes providing heat. Here the differences between different options are larger due to the change in efficiencies.

Tab. 10.2 Key indicator results for the updated processes investigating **heat delivered** by oil heating devices (red marks highest and green lowest values per column of special interest)

technology	reference value	primary energy factor, total [MJ-eq]	primary energy factor,fossil [MJ-eq]	primary energy factor, nuklear [MJ-eq]	primary energy factor, renewable [MJ-eq]	CO equivalents [kg CO2-eq]	eco-points [eco-points 2013]
light fuel oil, 10kW, non-modulating	MJ	1.444	1.371	0.058	0.016	0.101	78.116
light fuel oil, 10kW condensing, non-modulating	MJ	1.358	1.289	0.054	0.015	0.095	73.579
light fuel oil, 10kW, condensing, modulating	MJ	1.294	1.236	0.046	0.013	0.091	69.488
light fuel oil, 10kW, average	MJ	1.304	1.245	0.046	0.013	0.092	70.434
light fuel oil, 100kW, non-modulating	MJ	1.408	1.357	0.040	0.011	0.100	75.778
light fuel oil, 100kW condensing, non-modulating	MJ	1.324	1.276	0.038	0.011	0.094	71.382
light fuel oil, 100kW, condensing, modulating	MJ	1.261	1.215	0.036	0.010	0.090	67.400
light fuel oil, 100kW, average	MJ	1.266	1.220	0.036	0.010	0.090	68.145
light fuel oil, 1MW, CH	MJ	1.377	1.336	0.032	0.009	0.099	70.478
light fuel oil,1MW, RER	MJ	1.375	1.343	0.024	0.008	0.099	70.178
heavy fuel oil, 1MW, CH	MJ	1.358	1.316	0.033	0.009	0.101	83.427
heavy fuel oil, 1MW, RER	MJ	1.352	1.319	0.025	0.008	0.101	83.098

Tab. 10.3 and Tab. 10.4 show a comparison of the life cycle impact assessment with data investigated in the former study (Jungbluth 2007). As seen there, the largest difference regarding eco-points is found for heavy fuel oil burned in (and heat delivered by) an industrial furnace in Europe. This is mainly due to lowered air emission factors and to a smaller extent to reduced emissions in the heavy fuel oil production. The increase in GWP is mainly due to higher venting rates found for crude oil extraction.

No major update has been made for the non-modulating and condensing non-modulating datasets for small heating as these technologies are outdated. But, there are changes in the supply of fuel which have also some importance for the final results at this stage.

Tab. 10.3 LCIA-comparison of updated and former datasets for **oil burned in** heating devices

technology	reference value	primary energy factor, total		eco-points		CO2 equivalents	
		MJ-eq		eco-points		kg CO2-equivalents	
light fuel oil, 10kW, non-modulating	MJ	1.34	1.36	71.5	73.4	0.090	0.095
light fuel oil, 10kW condensing, non-modulating	MJ	1.34	1.36	71.7	73.6	0.090	0.095
light fuel oil, 100kW, non-modulating	MJ	1.31	1.32	69.6	71.2	0.090	0.094
light fuel oil, 100kW condensing, non-modulating	MJ	1.31	1.32	69.8	71.4	0.090	0.094
light fuel oil, 1MW, CH	MJ	1.30	1.31	73.5	67.0	0.089	0.094
light fuel oil, 1MW, RER	MJ	1.30	1.31	75.7	66.8	0.090	0.094
heavy fuel oil, 1MW, CH	MJ	1.32	1.29	81.7	79.4	0.093	0.096
heavy fuel oil, 1MW, RER	MJ	1.36	1.29	106.1	79.1	0.093	0.096
Source		KBOB v2.2: 2016	This study	KBOB v2.2: 2016	This study	KBOB v2.2: 2016	This study

Tab. 10.4 LCIA-comparison of updated and former datasets for **heat delivered** by oil heating devices

technology	reference value	primary energy factor, total		eco-points		CO2 equivalents	
		MJ-eq		eco-points		kg CO2-equivalents	
light fuel oil, 10kW, non-modulating	MJ	1.42	1.44	75.8	78.1	0.096	0.101
light fuel oil, 10kW condensing, non-modulating	MJ	1.34	1.36	71.7	73.6	0.090	0.095
light fuel oil, 100kW, non-modulating	MJ	1.39	1.41	73.8	75.8	0.095	0.100
light fuel oil, 100kW condensing, non-modulating	MJ	1.31	1.32	69.8	71.4	0.090	0.094
light fuel oil, 1MW, CH	MJ	1.36	1.38	77.2	70.5	0.094	0.099
light fuel oil,1MW, RER	MJ	1.37	1.37	79.5	70.2	0.094	0.099
heavy fuel oil, 1MW, CH	MJ	1.39	1.36	85.8	83.4	0.098	0.101
heavy fuel oil, 1MW, RER	MJ	1.43	1.35	111.4	83.1	0.098	0.101
Source		KBOB v2.2: 2016	This study	KBOB v2.2: 2016	This study	KBOB v2.2: 2016	This study

11 Outlook

The LCIA of the different heating systems shows only very small differences for the datasets covering “light fuel oil, burned in” for 10kw and 100kW and different technologies. Thus, for the next revision it might be considered to provide only one average option for this dataset that covers heating in dwellings.

Instead it would be recommended to provide also a European dataset for the combustion of light fuel oil for room heating.

More differences can be encountered for the datasets in relation to the heat provided. It would be recommended to provide more options for different levels of output temperatures which have a direct influence on the efficiency of the heating devices.

12 References

This report builds on a translation of the report for the ecoinvent data v2.0. In this translation automatic references were not included. Thus, the reference section is split in a part for references added for the present version and references already cited in the previous version.

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