treeze Ltd., Kanzleistrasse 4, CH-8610 Uster, www.treeze.ch

Life Cycle Inventories of Water Transport Services

Authors
Annika Messmer, Rolf Frischknecht

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Authors	Annika Messmer;Rolf Frischknecht treeze Ltd., fair life cycle thinking Kanzleistr. 4, CH-8610 Uster www.treeze.ch Phone +41 44 940 61 91, Fax +41 44 940 61 94 info@treeze.ch
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Abbreviations

a	year (annum)
BOD	biochemical oxygen demand
CH	Switzerland
CO	carbon monoxide
CO_2	carbon dioxide
COD	chemical oxygen demand
Cu	copper
Cr	chromium
d	day
DOC	dissolved organic carbon
dwt	deadweight tonnage
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
GLO	global average
Gt	gross ton
Gtkm	gross ton kilometre
HC	hydrocarbons
HCI	hydrochloric acid
HF	hydrogen fluoride
IMO	Institute for Marketecology
KBOB	Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren
kg	kilogram
km	kilometre
LCA	life cycle assessment
LCI	life cycle inventory analysis
LDT	light displacement tonnage
LPG	liquefied petroleum gas
mg	milligram
Mio	million
ng I-TEQ	nanogram international toxic equivalents
NMVOC	non-methane volatile organic compounds
N_2O	nitrous oxide / dinitrogen monoxide
NO_x	nitrogen oxides
OCE	Oceanic
pkm	passenger kilometre (transport unit)
PAH	polycyclic aromatic hydrocarbon
Pb	lead

PM	particulate matter (index gives size range in µm)
RER	Europe
Sn	tin
SO_2	sulphur dioxide
t	ton
tkm	ton kilometre (transport unit)
TOC	total organic carbon
TSP	total suspended particulate mattervkm vehicle kilometre (transport unit)
Zn	zink
ZSG	Schifffahrtsgesellschaft Zürichsee

Content

1 Introduction

1.1 Introduction

The update of the water transport life cycle inventory (LCI) data covers inland freight transport (bulk and tanker) and transoceanic freight transport (bulk, container and oil) and passenger inland water transport.

The structure of the existing datasets in KBOB life cycle inventory (LCI) data v2.2:2016 was adjusted to the new structure of ecoinvent data v3.1 datasets (no separate dataset on operation) and data on transport performance, vehicle travel distance and load factor were updated. No update was performed on the data of the manufacturing and maintenance of the vessels and of the port and canal infrastructure. However, data on the efforts and emissions of dismantling of ships were quantified for the first time.

2 Goal and Scope

2.1 Functional Unit

The functional unit of freight transport services is 1 ton kilometre (tkm), which corresponds to the transport of 1 ton of goods over a distance of 1 kilometre.

The functional unit of passenger transport services is 1 passenger kilometre (pkm), which corresponds to the transport of 1 person over a distance of 1 kilometre.

2.2 System Boundaries

The update of the water transport life cycle inventories includes the following four types of freight water transportation:

- transoceanic tanker (~ 150’000 dwt, new ~200’000 dwt)
- transoceanic bulk freight ship (~ 50’000 dwt dry bulk carrier, new ~100’000 dwt)
- barge tanker (average barge tanker operating on inland waterways)
- barge (average barge operating on inland waterways, i.e. rivers)

New processes are modelled for:

- transoceanic container freight ship (~ 65’000 dwt)
- passenger vessel for inland water transport on lakes

The life cycle inventories of the water transport processes include the following phases of the life cycle:

- Vessel production, maintenance, dismantling and disposal
- Operation of the vessel (including emissions, fuel supply)
- Port infrastructure construction, maintenance and disposal

2.3 Data Sources and Quality

Current data of the transport performance, fuel consumption as well as load factor and emission factors are based on recent literature and statistics (Psaraftis & Kontovas 2009, IMO 2014, Trozzi et al. 2013) and on information provided by manufacturers, and shipping companies. The updated and new process data compiled in this project are linked to the background data of KBOB LCI data v2.2:2016 (KBOB et al. 2016).

3 Life Cycle Inventories Transoceanic Transport

3.1 Key Characteristics

To update the transoceanic water transport processes, most common vessel sizes for transoceanic tanker, container ship and bulk freight ship were defined based on Psaraftis & Kontovas (Psaraftis & Kontovas 2009). The carrying capacity of the ships varies between 65’000 dwt (dead weight tons) of the container ship to 200’000 dwt of the oil tanker. The specific fuel consumption for the three ship types is derived from data published in Psaraftis & KontovasPsaraftis & Kontovas 2009) and varies between 3.82 g of heavy fuel oil per tkm (container ship) to 1.42 g/tkm (bulk freight ship). The specific fuel consumption of container ships is distinctly higher due to higher average speed and lower carrying capacity compared to freight ship and tanker.

Tab. 3.1 and present the key figures of the transoceanic water transport applied for the processes.

Tab. 3.1 Average transport performance and fuel consumption of the transoceanic transport of container ship, bulk freight ship and tanker of the world fleet (Psaraftis & Kontovas 2009)

	Unit	Container ship	Freight ship	Tanker
Yearly fuel consumption of the world fleet	t/a	85'000'218	47'642'790	33'526'464
Average yearly transport performance of the world fleet	tkm/a	22'245'695'722'569	30'898'058'364'163	23'545'396'683'431
Fuel consumption[1)]	g/tkm	3.82	1.54	1.42

[1)] Own calculation

	Unit	Container ship	Bulk freight ship	Tanker
Yearly fuel consumption of the world fleet	t/a	85'000'218	47'642'790	33'526'464
Average yearly transport performance of the world fleet	tkm/a	22'245'695'722'569	30'898'058'364'163	23'545'396'683'431
Fuel consumption[1)]	g/tkm	3.82	1.54	1.42

[1)] Own calculation

Tab. 3.2 Key figures of the transoceanic transport of container ship, bulk freight ship and tanker (Psaraftis & Kontovas 2009 and Spielmann et al. 2007)

	Unit	Container ship	Bulk freight ship	Tanker
Payload[1)]	t	52671	93548	197884
Carrying capacity[2)]	DWT	65'000	100'000	200'000
Light displacement tons[3)]	LDT	12'025	18'500	37'000
Yearly transport performance per vessel[4)]	tkm/a*ship	8'828'983'224	8'960'764'713	16'923'891'809
Life span[5)]	a	20	20	30
Transport performance per vehicle[6)]	tkm/vehicle	176'579'664'481.15	179'215'294'255	507'716'754'256
Ship demand [6)]	unit/tkm	7.1E-12	1.1E-11	2.0E-12
Maintenance [6)]	unit/tkm	7.1E-12	1.1E-11	2.0E-12
Wrecking[6)]	unit/tkm	5.7E-12	5.6E-12	2.0E-12

[1)] weighted average of the data published by Psaraftis & Kontovas (2009)

[2)] calculated using the relationship between payload and deadweight for the different ship types of the Clean Shipping Index: freight ship 0.9, container ship 0.8 and tanker 0.95

[3)] Weight of the empty ship (LDT), calculated based on the ratio: 0.185 LDT/DWT (SHIP BREAKING AND RECYCLING INDUSTRY IN BANGLADESH AND PAKISTAN, M. Sarraf, 2010)

[4)] interpolated based on the data published by Psaraftis & Kontovas (2009) for the different ship sizes

[5)] ecoinvent report 14 (Spielmann, 2007)

[6)] own calculation, ship demand and maintenanse scaled from ship size of ship manufacturing process in ecoinvent 2.2. to the new size of the ship

3.2 Airborne Gaseous Emissions

3.2.1 Fuel Content Dependent Emissions

The sulphur dioxide and CO_2 emissions are directly dependent on the sulphur and carbon-content of the marine bunker fuel. According to IMO (IMO 2014) the sulphur content is 2.7 % resulting in a sulphur dioxide emission factor of 52.8 g SO_2/kg fuel. The CO_2 emission factor was determined as 3’110 g/kg fuel (IMO 2014).

The emission factors for HCl and HF are adopted from KBOB LCI data v2.2:2016 as no more recent data are available (KBOB et al. 2016).

3.2.2 Combustion Process Dependent Emission

In Tab. 3.3 current data on emission factors of combustion process dependent pollutants are shown.

Tab. 3.3 Emission factors for heavy fuel oil engines, reported in g per kg heavy fuel oil (IMO 2014)

Specific Emission g/kg	
CO	2.77
N_2O	0.16
NO_x	93
NMVOC	3.08

For individual hydrocarbons no updated data was found. Therefore the hydrocarbons’ emission profile from the existing processes in KBOB LCI data v2.2:2016 was used with one exception (KBOB et al. 2016). The current emission factor of 0.06 g/kg for methane as published in the GHG report of IMO (IMO 2014) was applied.

3.2.3 Particulate matter emissions

In the EMEP/EEA emission inventory guidebook (Trozzi et al. 2013) recent data of PM10, PM2.5 and TSP emissions were published (see Tab. 3.4).

Tab. 3.4 Particulate matter emission factors of transoceanic vessels, reported in g per kg heavy fuel oil (Trozzi et al. 2013)

TSP	6.2	g/kg
PM10	6.2	g/kg
PM2.5	5.6	g/kg

3.2.4 Heavy Metal Emission

Current data on heavy metal emission factors from heavy fuel oil used in transoceanic transportation are available in the EMEP/EEA emission inventory guidebook 2013 (Trozzi et al. 2013). The emission factors are presented in Tab. 3.5.

Tab. 3.5 Heavy metal emission factors of transoceanic transport, reported in g per kg heavy fuel oil (EMEP/EEA Trozzi et al. 2013)

Lead	0.00018	g/kg
Cadmium	0.00002	g/kg
Copper	0.00125	g/kg
Chromium	0.00072	g/kg
Nickel	0.032	g/kg
Selenium	0.00021	g/kg
Zinc	0.0012	g/kg
Mercury	0.00002	g/kg
Arsenic	0.00068	g/kg

3.2.5 Persistent Organic Compounds

In Cooper & Gustafsson (2004) emission factors for four different PAHs are listed. For Benzo(a)pyrene an emission factor of 5.1 µg/kg fuel is reported. The emission factors of the other PAHs sum up to a total of 25.9 µg/kg.

For dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin equivalents, an emission factor of 0.47 ng I-TEQ/kg fuel is reported in the EMEP/EEA emission inventory guidebook 2013 (Trozzi et al. 2013).

3.2.6 Emissions to Water

In 2008 the International Convention on the Control of Harmful Anti-fouling Systems on Ships of the International Maritime Organization banned completely the use of tributyltin compounds as antifouling on ships. Therefore other products are now applied as antifouling on ships which mainly contain copper or other biocides.

The copper emissions from antifoulings to the sea are included. Kojima et al.(2014) observed an emission rate of 200 mg/m^2d of antifouling agent (copper). The total emission per ship was calculated multiplying the surface of the ship (calculated with the formula published by Cotteleer (2012) (8.75*Gross tonnage of the ship)^(2/3)) by the emission rate and the life span of the ship (in days). For the emission per tkm the total emission was divided by the tonnage transported of a single ship per lifetime.

Tab. 3.6 Average surface of the different ship and the total emission of antifoulants (Kojima et al. 2014, Spielmann et al. 2007)

		Container ship	Bulk freight ship	Tanker
Grosstonnage[1)]	Gt	52000	57000	110000
Surface (max)[2)]	m^2	12190	14367	22085
Life span	a	20	20	30
Transport performance per vehicle[2)]	tkm/vehicle	1.77E+11	1.79E+11	5.08E+11
Total emissionen of antifouling agent (copper)[2)]	kg/tkm	1.01E-07	1.17E-07	9.53E-08

[1)] estimated with information of the website www.marinetraffic.com, last visited 27. April 2016

[2)] own calculation

For the transport of crude oil in a tanker also oil emissions to the sea are included in the life cycle inventory. According to GESAMP (2007) the average oil pollution due to operational discharge was 19’000 t/a and due to accidents 60’300 t/a (based on data of the years 1988 to 1997). The average transport performance of oil tankers was 10’920 Mia tkm/a in this time period. This results in an oil emission of 3.23 mg/tkm. The emission factors of BOD, COD, TOC and DOC were derived from the oil emissions based on the relations as described in in the life cycle inventory of Spielmann et al. (2007).

3.2.7 Disposal Bilge Oil

Bilge oil occurs in the belly of the ships when sea water mixes with the fuel and lubricating oil of the engines. The shipping company Laisz in Germany reported in 2014 an amount of bilge oil of about 20 g per kg fuel. It is assumed that the bilge oil is burned in a hazardous waste incineration plant.

3.3 Port facilities Demand and Allocation

The demand for port facilities construction and operation and the allocation to freight, oil and container ship is quantified based on data describing the port of Rotterdam, Netherlands (Port of Rotterdam Authority 2014). With the total annual throughput at the port of Rotterdam of about 450 Mio. tons, an average shipping distance of 5’000 km (container ship and freight ship) and 8’800 km (tanker) and a assumed life time of the port (100 a) the demand of port facilities per tkm is calculated (see Tab. 3.7). The average shipping distances are adopted from Spielmann et al. (2007). A yearly maintenance is accounted to the ship transport. The demand of maintenance is calculated by multiplying the port demand per tkm by the life time of the port (100 a).

Tab. 3.7 Throughput at the port Rotterdam in 2014 and the specific demand of port infrastructure per tkm transportation (Port of Rotterdam Authority 2014)

	Unit	Container ship	Freight ship	Tanker
Total throughput Rotterdam port 2014	t	444733000		
Life span of the port[1)]	a	100		
Demand port per tonne	unit/t	4.50E-11		
Average distance [1)]	km	5000	5000	8800
Demand port per tkm	unit/tkm	8.99E-15	8.99E-15	5.11E-15

[1)] information from Spielmann et al. 2007

3.4 Unit process Life Cycle Inventory data

Tab. 3.8 Life cycle inventory data of transoceanic ship transport of freight

	Name	Location	InfrastructureProcess	Unit	transport, transoceanic freight ship	transport, transoceanic tanker	transport, transoceanic container ship	UncertaintyType	StandardDeviation95 %	GeneralComment
	Location				OCE	OCE	OCE			
	InfrastructureProcess				0	0	0			
	Unit				tkm	tkm	tkm			
product	transport, transoceanic freight ship	OCE	0	tkm	1	0	0			
product	transport, transoceanic tanker	OCE	0	tkm	0	1	0			
product	transport, transoceanic container ship	OCE	0	tkm	0	0	1			
technosphere	transoceanic freight ship	OCE	1	unit	1.08E-11		7.15E-12	1	3.06	(2,4,1,3,1,5,BU:3); scaled with the transport capacity (65'000dwt container ship; 100'000dwt freight ship); calculation based on the assumption of a life time of 20 years; CO2 Emission Statistics for the World Commercial Fleet, 2009
	transoceanic tanker	OCE	1	unit	0	1.97E-12	0	1	3.30	(3,4,1,3,4,5,BU:3); scaled for the assumed transport capacity 200'000dwt, calculated based on the assumption of a life time of 30 years; CO2 Emission Statistics for the World Commercial Fleet, 2009
	maintenance, transoceanic freight ship	RER	1	unit	1.08E-11	1.97E-12	7.15E-12	1	3.07	(3,4,1,3,1,5,BU:3); ;
	port facilities	RER	1	unit	8.99E-15	5.11E-15	8.99E-15	1	3.06	(2,4,1,3,1,5,BU:3); assumed throughput port Rotterdam in 2014: 444733000t/a; Yearly report of the port Rotterdam 2014
	operation, maintenance, port	RER	1	unit	8.99E-13	5.11E-13	8.99E-13	1	3.06	(2,4,1,3,1,5,BU:3); port facility multiplied by 100 a (life span of a port);
	heavy fuel oil, at regional storage	RER	0	kg	1.54E-3	1.42E-3	3.82E-3	1	1.24	(2,4,1,3,1,5,BU:1.05); ; CO2 Emission Statistics for the World Commercial Fleet, 2009
emission air, low population density	Benzene	-	-	kg	9.02E-8	8.33E-8	2.24E-7	1	3.34	(3,5,2,5,4,5,BU:3); emission factor of heavy fuel: 5.85E-2 g/kg heavy fuel; VOC profile from ecoinvent 2.2
	Methane, fossil	-	-	kg	9.25E-8	8.54E-8	2.29E-7	1	1.57	(2,3,1,3,1,5,BU:1.5); emission factor of heavy fuel: 6.00E-2 g/kg heavy fuel; IMO
	Carbon monoxide, fossil	-	-	kg	4.27E-6	3.94E-6	1.06E-5	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 2.77E+0 g/kg heavy fuel; IMO
	Carbon dioxide, fossil	-	-	kg	4.80E-3	4.43E-3	1.19E-2	1	1.22	(2,3,1,3,1,5,BU:1.05); emission factor of heavy fuel: 3.11E+3 g/kg heavy fuel; IMO
	Dinitrogen monoxide	-	-	kg	2.47E-7	2.28E-7	6.11E-7	1	1.57	(2,3,1,3,1,5,BU:1.5); emission factor of heavy fuel: 1.60E-1 g/kg heavy fuel; IMO
	Ammonia	-	-	kg	6.28E-7	5.80E-7	1.56E-6	1	1.70	(3,5,2,5,4,5,BU:1.2); emission factor of heavy fuel: 4.07E-1 g/kg heavy fuel; ecoinvent 2.2, heavy fuel oil burned in industrial furnance
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	4.58E-6	4.23E-6	1.14E-5	1	1.57	(2,3,1,3,1,5,BU:1.5); emission factor of heavy fuel: 2.97E+0 g/kg heavy fuel; IMO
	Nitrogen oxides	-	-	kg	1.43E-4	1.32E-4	3.55E-4	1	1.57	(2,3,1,3,1,5,BU:1.5); emission factor of heavy fuel: 9.30E+1 g/kg heavy fuel; IMO
	Sulfur dioxide	-	-	kg	8.14E-5	7.52E-5	2.02E-4	1	1.22	(2,3,1,3,1,5,BU:1.05); emission factor of heavy fuel: 5.28E+1 g/kg heavy fuel; IMO
	Toluene	-	-	kg	3.80E-8	3.51E-8	9.41E-8	1	1.90	(3,5,2,5,4,5,BU:1.5); emission factor of heavy fuel: 2.46E-2 g/kg heavy fuel; ecoinvent 2.2
	Xylene	-	-	kg	3.80E-8	3.51E-8	9.41E-8	1	1.90	(3,5,2,5,4,5,BU:1.5); emission factor of heavy fuel: 2.46E-2 g/kg heavy fuel; ecoivnent 2.2
	Particulates, > 10 um	-	-	kg	0	0	0	1	1.57	(2,3,1,3,1,5,BU:1.5); emission factor of heavy fuel: 0.00E+0 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
	Particulates, > 2.5 um, and < 10um	-	-	kg	9.25E-7	8.54E-7	2.29E-6	1	2.06	(2,3,1,3,1,5,BU:2); emission factor of heavy fuel: 6.00E-1 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
	Particulates, < 2.5 um	-	-	kg	8.63E-6	7.97E-6	2.14E-5	1	3.05	(2,3,1,3,1,5,BU:3); emission factor of heavy fuel: 5.60E+0 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
	Lead	-	-	kg	2.78E-10	2.56E-10	6.88E-10	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 1.80E-4 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
	Cadmium	-	-	kg	3.08E-11	2.85E-11	7.64E-11	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 2.00E-5 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
	Copper	-	-	kg	1.93E-9	1.78E-9	4.78E-9	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 1.25E-3 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
	Chromium	-	-	kg	1.11E-9	1.03E-9	2.75E-9	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 7.20E-4 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
	Nickel	-	-	kg	4.93E-8	4.56E-8	1.22E-7	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 3.20E-2 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
	Selenium	-	-	kg	3.24E-10	2.99E-10	8.02E-10	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 2.10E-4 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
	Zinc	-	-	kg	1.85E-9	1.71E-9	4.59E-9	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 1.20E-3 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
	Mercury	-	-	kg	3.08E-11	2.85E-11	7.64E-11	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 2.00E-5 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
	Arsenic	-	-	kg	1.05E-9	9.68E-10	2.60E-9	1	5.06	(2,3,1,3,1,5,BU:5); emission factor of heavy fuel: 6.80E-4 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013
	Hydrogen chloride	-	-	kg	8.88E-8	8.20E-8	2.20E-7	1	1.57	(2,3,1,3,1,5,BU:1.5); Cl content of heavy fuel, emission factor of heavy fuel: 5.76E-2 g/kg heavy fuel; Cl content of heavy fuel, ecoinvent 2.2
	Hydrogen fluoride	-	-	kg	8.88E-9	8.20E-9	2.20E-8	1	1.57	(2,3,1,3,1,5,BU:1.5); Fl content of heavy fuel, emission factor of heavy fuel: 5.76E-3 g/kg heavy fuel; F contant of heavy fuel, ecoinvent 2.2
	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	-	-	kg	1.54E-15	1.42E-15	3.82E-15	1	3.34	(3,5,2,5,4,5,BU:3); emission factor of heavy fuel: 4.70E-10 g/kg heavy fuel; EMEP/EEA emission inventory guidebook 2013, ecoinvent
	PAH, polycyclic aromatic hydrocarbons	-	-	kg	3.99E-11	3.69E-11	9.90E-11	1	3.05	(2,3,1,3,1,5,BU:3); emission factor of heavy fuel: 2.59E-5 g/kg heavy fuel; Cooper & Gustavson 2004

Tab. 3.8 Life cycle inventory data of transoceanic ship transport of freight (continued)

	Name	Location	InfrastructureProcess	Unit	transport, transoceanic freight ship	transport, transoceanic tanker	transport, transoceanic container ship	UncertaintyType	StandardDeviation95 %	GeneralComment
	Location				OCE	OCE	OCE			
	InfrastructureProcess				0	0	0			
	Unit				tkm	tkm	tkm			
product	transport, transoceanic freight ship	OCE	0	tkm	1	0	0			
product	transport, transoceanic tanker	OCE	0	tkm	0	1	0			
product	transport, transoceanic container ship	OCE	0	tkm	0	0	1			
	Benzo(a)pyrene	-	-	kg	7.86E-12	7.26E-12	1.95E-11	1	3.05	(2,3,1,3,1,5,BU:3); emission factor of heavy fuel: 5.10E-6 g/kg heavy fuel; Cooper & Gustavson 2004
	Heat, waste	-	-	MJ	6.35E-2	5.87E-2	1.57E-1	1	1.22	(2,3,1,3,1,5,BU:1.05); default value;
emission water, ocean	Copper, ion	-	-	kg	1.17E-7	9.53E-8	1.01E-7	1	3.05	(2,3,1,3,1,5,BU:3); leaching factor 200mg/m2d; Assessment leaching antifouling agent 2014
	Oils, unspecified	-	-	kg	0	1.64E-5	0	1	1.57	(2,3,1,3,1,5,BU:1.5); assumed oil spill between 1988-1999: 179'000t; GESAMP, 2007; UNCTAD 1988-1999
	BOD5, Biological Oxygen Demand	-	-	kg	0	5.17E-5	0	1	1.57	(2,3,1,3,1,5,BU:1.5); ; own calculation, according to quality guidelines, derived from emissions of oil.
	COD, Chemical Oxygen Demand	-	-	kg	0	5.17E-5	0	1	1.57	(2,3,1,3,1,5,BU:1.5); ; own calculation, according to quality guidelines, derived from emissions of oil.
	TOC, Total Organic Carbon	-	-	kg	0	1.42E-5	0	1	1.57	(2,3,1,3,1,5,BU:1.5); ; own calculation, according to quality guidelines, derived from emissions of oil.
	DOC, Dissolved Organic Carbon	-	-	kg	0	1.42E-5	0	1	1.57	(2,3,1,3,1,5,BU:1.5); ; own calculation, according to quality guidelines, derived from emissions of oil.
technosphere	disposal, bilge oil, 90% water, to hazardous waste incineration	CH	0	kg	3.08E-5	2.85E-5	7.64E-5	1	1.22	(2,3,1,3,1,5,BU:1.05); assumption 2% of the fuel; Reederei Laeisz 2014 Umweltbericht
	wrecking, transocean container ship	IN	0	unit			5.66E-12	1	2.06	(2,3,1,3,1,5,BU:2); assumed life time 20 years; CO2 Emission Statistics for the World Commercial Fleet, 2009
	wrecking, transocean ship	IN	0	unit	5.58E-12			1	2.06	(2,3,1,3,1,5,BU:2); assumed life time 20 years; CO2 Emission Statistics for the World Commercial Fleet, 2009
	wrecking, transocean tanker	IN	0	unit		1.97E-12		1	2.06	(2,3,1,3,1,5,BU:2); assumed life time 30 years; CO2 Emission Statistics for the World Commercial Fleet, 2009

3.5 Wrecking

Most of the oceangoing ships are transported after their use to wrecking yards in India. There the ships are dismantled and the usable material is separated. Deshpande et al. (2013) have published energy demand and emissions and waste occurring during the wrecking process of ships in Alang (India). For a ship with the size of 1000 LDT (Light Displacement Tonnage) 24000 km*mm cut is required, which results in a cut requirement of 24 km*mm per LDT. In Tab. 3.9 information on the energy demand, the amount of burned paint and the amount of deposited paint as well as the CO_2-emissions per km length and mm depth of the cut is displayed. Tab. 3.10 shows the heavy metal contents of the surface paint of ships and Tab. 3.11 shows the amounts of wastes incurring during the wrecking process depending on the type of ship.

Tab. 3.9 The fuel consumption and emission per km length and mm cut depth of the ship wrecking (Deshpande et al. 2013).

Fuel consumption	6.2	kg LPG/(km length * mm cut depth)
Oxygen consumed	28.5	kg oxygen/(km length * mm cut depth)
Molten steel lost	51.8	kg/(km length * mm cut depth)
CO_2 emissions	21.77	kg/(km length * mm cut depth)
Paint burnt	0.9	kg/(km length * mm cut depth)
Paint deposited	1.34	kg/(km length * mm cut depth)

Tab. 3.10 The composition of the surface paint to the ships (Deshpande et al. 2013)

Cu	4.08	%w/w
Zn	2.25	%w/w
Pb	0.49	%w/w
Sn	0.09	%w/w
Cr	0.06	%w/w

Tab. 3.11 The amount of wastes from wrecking of different ship types per LDT (light displacement tonnage) (Deshpande et al. 2013)

		Cargo ship	Oil & chemical tanker	Container Ship
Asbestos	kg/LDT	0.99	1.66	1.2
Glasswoll	kg/LDT	12.89	14.94	15.63
Other landfillable waste	kg/LDT	2.58	0.83	3.13
Total landfillable waste	kg/LDT	16.50	16.60	20.00
Incinerable waste	kg/LDT	2.70	3.30	3.00
Bilge water	kg/LDT	2.10	4.50	2.40
Waste total	kg/LDT	21.30	24.40	25.40

The waste, the energy consumption and the emission occurring from the wrecking of the ocean going tanker, container ship and freight ship are summarized in Tab. 3.12.

Tab. 3.12 The calculated emissions, energy consumption and wastes incurring during the ship wrecking process

		Cargo ship	Tanker	Container ship
Deadweight tonnage	DWT	100'000	200'000	65'000
Light Displacement Tonnage	LDT	18'500	37'000	12'025
Fuel consumption (LPG)	kg	27'528	55'056	17'893
Oxygen consumed	kg	126'540	253'080	82'251
Molten steel	kg	229'992	459'984	149'495
CO2-Emission	kg	96'659	193'318	62'828
Paint burned	kg	3'996	7'992	2'597
Paint deposited	kg	5'950	11'899	3'867
Emission from the paint				
Iron oxide, to soil	kg	1'487	2'975	967
Cu, to soil	kg	243	485	158
Zn, to soil	kg	134	268	87
Pb, to soil	kg	29	58	19
Sn, to soil	kg	5	11	3
Cr, to soil	kg	4	7	2
Cu, to air	kg	163	326	106
Zn, to air	kg	90	180	58
Pb, to air	kg	20	39	13
Sn, to air	kg	4	7	2
Cr , to air	kg	2	5	2
Iron, to air	kg	999	1'998	649
Waste				
Asbestos	kg	18'315	61'420	14'430
Glasswoll	kg	238'465	552'780	187'891
Other landfillable waste	kg	47'693	30'710	37'578
Total landfillable waste	kg	305'250	614'200	240'500
Incinerable waste	kg	49'950	122'100	36'075
Bilge Water	kg	38'850	166'500	28'860
Waste total	kg	394'050	902'800	305'435

3.6 Life cycle inventory data

Tab. 3.13 Life cycle inventory data of the wrecking process

	Name	Location	InfrastructureProcess	Unit	wrecking, transocean ship	wrecking, transocean tanker	wrecking, transocean container ship	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				IN	IN	IN			
	InfrastructureProcess				0	0	0			
	Unit				unit	unit	unit			
product	wrecking, transocean ship	IN	0	unit	1	0	0			
product	wrecking, transocean tanker	IN	0	unit	0	1	0			
product	wrecking, transocean container ship	IN	0	unit	0	0	1			
technosphere	liquefied petroleum gas, at service station	CH	0	kg	2.75E+4	5.51E+4	1.79E+4	1	1.36	(3,4,1,5,3,5,BU:1.05); ; Paritosh C. Deshpande, 2012
	oxygen, liquid, at plant	RER	0	kg	1.27E+5	2.53E+5	8.23E+4	1	1.36	(3,4,1,5,3,5,BU:1.05); ; Paritosh C. Deshpande, 2012
emission air, low population density	Carbon dioxide, fossil	-	-	kg	2.30E+5	4.60E+5	1.49E+5	1	1.36	(3,4,1,5,3,5,BU:1.05); ; Paritosh C. Deshpande, 2013
	Copper	-	-	kg	1.63E+2	3.26E+2	1.06E+2	1	5.15	(3,4,1,5,3,5,BU:5); ; Paritosh C. Deshpande, 2014
	Zinc	-	-	kg	8.99E+1	1.80E+2	5.84E+1	1	5.15	(3,4,1,5,3,5,BU:5); ; Paritosh C. Deshpande, 2015
	Lead	-	-	kg	1.96E+1	3.92E+1	1.27E+1	1	5.15	(3,4,1,5,3,5,BU:5); ; Paritosh C. Deshpande, 2016
	Tin	-	-	kg	3.60E+0	7.19E+0	2.34E+0	1	5.15	(3,4,1,5,3,5,BU:5); ; Paritosh C. Deshpande, 2017
	Chromium	-	-	kg	2.40E+0	4.80E+0	1.56E+0	1	5.15	(3,4,1,5,3,5,BU:5); ; Paritosh C. Deshpande, 2018
	Iron	-	-	kg	9.99E+2	2.00E+3	6.49E+2	1	5.15	(3,4,1,5,3,5,BU:5); ; Paritosh C. Deshpande, 2019
emission soil, unspecified	Iron	-	-	kg	2.30E+5	4.60E+5	1.49E+5	1	1.66	(3,4,1,5,3,5,BU:1.5); ; Paritosh C. Deshpande, 2012
	Iron	-	-	kg	1.49E+3	2.97E+3	9.67E+2	1	1.66	(3,4,1,5,3,5,BU:1.5); ; Paritosh C. Deshpande, 2012
	Copper	-	-	kg	2.43E+2	4.85E+2	1.58E+2	1	1.66	(3,4,1,5,3,5,BU:1.5); ; Paritosh C. Deshpande, 2012
	Zinc	-	-	kg	1.34E+2	2.68E+2	8.70E+1	1	1.66	(3,4,1,5,3,5,BU:1.5); ; Paritosh C. Deshpande, 2012
	Lead	-	-	kg	2.92E+1	5.83E+1	1.89E+1	1	1.66	(3,4,1,5,3,5,BU:1.5); ; Paritosh C. Deshpande, 2012
	Tin	-	-	kg	5.35E+0	1.07E+1	3.48E+0	1	1.66	(3,4,1,5,3,5,BU:1.5); ; Paritosh C. Deshpande, 2012
	Chromium	-	-	kg	3.57E+0	7.14E+0	2.32E+0	1	1.66	(3,4,1,5,3,5,BU:1.5); ; Paritosh C. Deshpande, 2012
technosphere	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	3.05E+5	6.14E+5	2.41E+5	1	1.36	(3,4,1,5,3,5,BU:1.05); ; Paritosh C. Deshpande, 2013
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	5.00E+4	1.22E+5	3.61E+4	1	1.36	(3,4,1,5,3,5,BU:1.05); ; Paritosh C. Deshpande, 2014
	disposal, bilge oil, 90% water, to hazardous waste incineration	CH	0	kg	3.89E+4	1.67E+5	2.89E+4	1	1.36	(3,4,1,5,3,5,BU:1.05); ; Paritosh C. Deshpande, 2015

4 Life Cycle Inventory Inland Water Transport

4.1 Key characteristics

For the update of the inland water transport processes the average vessel sizes and the fuel consumption for barge tanker and barge ship published by Knörr et al. (2013) were used. Tab. 4.1 presents updated key figures of the inland water transport processes. To determine the kilometric performance of a barge tanker and a barge ship the distance from Basel to Rotterdam (850 km) and 50 round trips a year were assumed. The yearly transport performance of a barge tanker and a barge ship was calculated by multiplying the kilometric performance by the average load. The life span of a barge tanker and barge ship are adopted from the KBOB LCI data v2.2:2016 as no more recent data are available (KBOB et al. 2016). One ship divided by the yearly transport performance and the life span results in the ship demand per tkm. The demand of the ship is adjusted by the new weight.

For the manufacturing of the barge tanker and the barge ship data sets from the KBOB LCI data v2.2:2016 were used.

Tab. 4.1 Key figures of the inland water transport for barge and barge tanker (Knörr et al. 2013)

	Unit	Barge	Barge tanker
Size (carring capacity)	dwt	1978	2164
Fuel consumption	g/tkm	8.00	9.70
Average load factor		57%	43%
Average load 1)	t	1127	931
Yearly kilometric performance 2)	vkm/a	85'000	85'000
Yearly transport performance	tkm/a	95'834'100	79'094'200
Life span 3)	a	46.5	32.5
Total kilometric performance per vehicle 1)	vkm/vehicle	3'952'500	2'762'500
Transport performance per vehicle 1)	tkm/vehicle	4'456'285'650	2'570'561'500
Demand ship 3)	unit/tkm	4.4E-10	2.2E-10
Maintenance	unit/tkm	4.4E-10	2.2E-10

1) own calculation

2) own calculation, assumed distance Basel-Rotterdam (850km), number of trips 50 a year

3) Ecoinvent report 14, Spielmann et al. 2007

3) demand of ship scaled from ship size of ship manufactory process in ecoinvent 2.2 to the new ship size

4.2 Airborne Gaseous Emissions

4.2.1 Fuel Content Dependent Emission

The sulphur dioxide and CO_2 emissions are dependent on the sulphur and C-content of the diesel fuel, predominantly used for inland water transport. According to Schweighofer et al. 2013 the sulphur content is 10 ppm resulting in a sulphur dioxide emission factor of 0.02 g SO_2/kg fuel. The CO_2 emission factor is 3'175 g/kg fuel (Schweighofer et al. 2013).

4.2.2 Combustion Process Dependent Emission

In Tab. 4.2 current data of combustion process dependent emission indices can be found. These emission factors are published in the non-road database (Notter & Schmied 2015).

Tab. 4.2 Emission factors of combustion dependent pollutants for diesel engines of barges (Notter & Schmied 2015)

Specific Emission g/kg	
NO_x	41.4
CO	20.4
CH_4	0.06
N_2O	0.09
HC	10.57
Benzene	0.02

Because no updated data on the HC species profile were found the HC species profile of lorry transport is used (Tab. 4.3).

Tab. 4.3 Profile of HC species (Notter & Schmied 2015;Ntziachristos et al. 2014)

	Fraction NMVOC (%)	g/kg fuel
Ethane	0.0%	0.003
Propane	0.1%	0.01
Butane	0.2%	0.02
Pentane	0.0006	0.01
Heptane	0.003	0.03
Toluene	0.0001	0.001
m-Xylene	0.0098	0.10
o-Xylene	0.004	0.04
Formaldehyde	0.084	0.89
Acetaldehyde	0.0457	0.48
Benzaldehyde	0.0137	0.14
Acrolein	0.0177	0.19
Styrene	0.0056	0.06

4.2.3 Particulate matter emissions

According to Schweighofer et al.(2013) the PM_{10} emission factor is 1.44 g/kg fuel. Information about the particle size distribution is not available. Therefore the same size distribution was applied as for heavy duty vehicles according to Spielmann et al. (2007).

Tab. 4.4 Particulate matter emission factors of barges, reported in g per kg fuel

PM10 emission factor [g/kg]	Fraction of PM10 with a diameter < 2.5 mm in (%)	Fraction of TSP with diameter < 10 mm in (%)	Fine Particles (PM2.5) (g/kg)	Coarse Particles (PM2.5-PM10) (g/kg)	Large Particles (TPM-PM10) (g/kg)
1.44	92.3	96.2	1.33	0.06	0.05

4.2.4 Heavy Metal and Persistent Organic Compounds Emissions

Heavy metal and persistent organic compounds emissions from diesel engines of barges are approximated with emission factors for heavy duty vehicles (Ntziachristos et al. 2014).

Tab. 4.5 Heavy metal emissions of heavy duty vehicles (Ntziachristos et al. 2014)

Cadmium	8.70E-09	kg/kg fuel
Chromium	3.00E-08	kg/kg fuel
Copper	2.12E-08	kg/kg fuel
Nickel	8.80E-09	kg/kg fuel
Selenium	1.00E-10	kg/kg fuel
Lead	5.21E-08	kg/kg fuel
Mercury	5.30E-09	kg/kg fuel
Zinc	1.74E-06	kg/kg fuel
Arsenic	1.00E-10	kg/kg fuel
Chromium VI	6.00E-11	kg/kg fuel

4.3 Port and Canal Infrastructure Demand

Inland ports are approximated with the infrastructure of the Port of Rotterdam, The Netherlands. Using the average shipping distance of 850 km, the demand of ports is calculated (see Tab. 4.6). To determine the yearly demand of port operation and maintenance the port demand was multiplied by the life span of the port (100 a).

Tab. 4.6 Throughput at the port Rotterdam in 2014 and the allocation

	Unit	Barge	Barge tanker
Total throughput Rotterdam port 2014	t	444'733'000	444'733'000
Demand port per tonne	unit/t	4.50E-11	4.50E-11
Average distance	km	850	850
Demand port per tkm	unit/tkm	5.29E-14	5.29E-14

According to ZKR (ZKR 2014) the transport performance on the river Rhine between Basel and Rotterdam is about 41’400’000’000 tkm a year. To determine the canal demand the distance between Basel and Rotterdam (850 km) was divided by the yearly transport performance on the river Rhine (41’400’000’000 km, ZKR 2014). This results in a canal demand of 2.05E-5 meter year per tkm. The demand of canal operation and maintenance is the same as the demand of canal construction.

4.4 Unit process Life Cycle Inventory Data

Tab. 4.7 Life cycle inventory data of inland water transport of freight

	Name	Location	InfrastructureProcess	Unit	transport, barge	transport, barge tanker	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER			
	InfrastructureProcess				0	0			
	Unit				tkm	tkm			
product	transport, barge	RER	0	tkm	1	0			
product	transport, barge tanker	RER	0	tkm	0	1			
technosphere	barge	RER	1	unit	4.44E-10		1	3.05	(2,3,1,3,1,5,BU:3); assumed transport distance: 850km, assuming 50 rides a year and a life time of 45 years; own assumption, ecoinvent report 14, Tremod 2012
technosphere	barge tanker	RER	1	unit		7.02E-10	1	3.05	(2,3,1,3,1,5,BU:3); assumed transport distance: 850km and 50 rides a year and a average life time of 33 years; own assumption, ecoinvent report 14, Tremod 2012
	maintenance, barge	RER	1	unit	4.44E-10	7.02E-10	1	3.09	(4,3,1,3,1,5,BU:3); ;
	port facilities	RER	1	unit	5.29E-14	5.29E-14	1	3.06	(2,4,1,3,1,5,BU:3); assumed throughput port in Rotterdam: 444733000t per year ; Yearly report, Port Rotterdam 2014
	operation, maintenance, port	RER	1	unit	5.29E-12	5.29E-12	1	3.06	(2,4,1,3,1,5,BU:3); assumed throughput port in Rotterdam: 44473300000t per year; Yearly report, Port Rotterdam 2014
	canal	RER	1	ma	2.05E-5	2.05E-5	1	3.33	(4,4,1,3,4,5,BU:3); calculated based on the total yearly transport performance on the Rhein: 41400000000tkm and a transport distance of 850km; Marktbeobachtung 2014 Binnenschifffahrt Europa
	maintenance, operation, canal	RER	1	ma	2.05E-5	2.05E-5	1	3.33	(4,4,1,3,4,5,BU:3); assumed total yearly transport performance on the Rhein: 41400000000tkm and a transport distance of 850km; 0
	diesel, at regional storage	RER	0	kg	8.00E-3	9.70E-3	1	1.24	(2,4,1,3,1,5,BU:1.05); assumed diesel consumption 8g/tkm for barge ship and 10g/tkm for barge tanker; Tremod 2012
emission air, low population density	Benzene	-	-	kg	1.33E-7	1.61E-7	1	3.15	(3,5,2,3,3,5,BU:3); emission factor of diesel: 1.66E-2 g/kg diesel; BAFU 2015: non road database
	Benzo(a)pyrene	-	-	kg	6.16E-11	7.47E-11	1	3.15	(3,5,2,3,3,5,BU:3); emission factor of diesel: 7.70E-6 g/kg diesel; ecoinvent report 14
	Carbon dioxide, fossil	-	-	kg	2.52E-2	3.06E-2	1	1.40	(3,5,2,3,3,5,BU:1.05); emission factor of diesel: 3.15E+3 g/kg diesel; BAFU 2015: non road database
	Carbon monoxide, fossil	-	-	kg	1.68E-4	2.03E-4	1	5.17	(3,5,2,3,3,5,BU:5); emission factor of diesel: 2.10E+1 g/kg diesel; BAFU 2015: non road database
	Dinitrogen monoxide	-	-	kg	1.23E-6	1.50E-6	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.54E-1 g/kg diesel; BAFU 2015: non road database
	Methane, fossil	-	-	kg	4.91E-7	5.95E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 6.14E-2 g/kg diesel; BAFU 2015: non road database
	Nitrogen oxides	-	-	kg	3.31E-4	4.01E-4	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 4.14E+1 g/kg diesel; BAFU 2015: non road database
	Sulfur dioxide	-	-	kg	1.60E-7	1.94E-7	1	1.40	(3,5,2,3,3,5,BU:1.05); emission factor of diesel: 2.00E-2 g/kg diesel; HBEFA 3.1.
	Particulates, < 2.5 um	-	-	kg	1.06E-5	1.29E-5	1	3.15	(3,5,2,3,3,5,BU:3); emission factor of diesel: 1.33E+0 g/kg diesel; BAFU 2015: non road database
	Particulates, > 10 um	-	-	kg	4.49E-7	5.45E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 5.62E-2 g/kg diesel;
	Particulates, > 2.5 um, and < 10um	-	-	kg	4.38E-7	5.31E-7	1	2.16	(3,5,2,3,3,5,BU:2); emission factor of diesel: 5.47E-2 g/kg diesel;
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	6.82E-5	8.26E-5	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 8.52E+0 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Ethane	-	-	kg	2.52E-8	3.05E-8	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 3.15E-3 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Propane	-	-	kg	8.39E-8	1.02E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.05E-2 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Butane	-	-	kg	1.26E-7	1.53E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.57E-2 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Pentane	-	-	kg	5.03E-8	6.10E-8	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 6.29E-3 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Heptane	-	-	kg	2.52E-7	3.05E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 3.15E-2 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Toluene	-	-	kg	8.39E-9	1.02E-8	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.05E-3 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	m-Xylene	-	-	kg	8.22E-7	9.97E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.03E-1 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	o-Xylene	-	-	kg	3.36E-7	4.07E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 4.19E-2 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Formaldehyde	-	-	kg	7.05E-6	8.55E-6	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 8.81E-1 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Acetaldehyde	-	-	kg	3.83E-6	4.65E-6	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 4.79E-1 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Benzaldehyde	-	-	kg	1.15E-6	1.39E-6	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.44E-1 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Acrolein	-	-	kg	1.48E-6	1.80E-6	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 1.86E-1 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Styrene	-	-	kg	4.70E-7	5.70E-7	1	1.69	(3,5,2,3,3,5,BU:1.5); emission factor of diesel: 5.87E-2 g/kg diesel; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Cadmium	-	-	kg	6.96E-11	8.44E-11	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 8.70E-9 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
	Chromium	-	-	kg	2.40E-10	2.91E-10	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 3.00E-8 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103

Tab. 4.7 Life cycle inventory data of inland water transport of freight (continued)

	Name	Location	InfrastructureProcess	Unit	transport, barge	transport, barge tanker	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER			
	InfrastructureProcess				0	0			
	Unit				tkm	tkm			
product	transport, barge	RER	0	tkm	1	0			
product	transport, barge tanker	RER	0	tkm	0	1			
	Copper	-	-	kg	1.70E-10	2.06E-10	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 2.12E-8 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
	Nickel	-	-	kg	7.04E-11	8.54E-11	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 8.80E-9 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
	Selenium	-	-	kg	8.00E-13	9.70E-13	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 1.00E-10 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
	Lead	-	-	kg	4.17E-10	5.05E-10	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 5.21E-8 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
	Mercury	-	-	kg	4.24E-11	5.14E-11	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 5.30E-9 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
	Zinc	-	-	kg	1.39E-8	1.69E-8	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 1.74E-6 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
	Arsenic	-	-	kg	8.00E-13	9.70E-13	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 1.00E-10 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
	Chromium VI	-	-	kg	4.80E-13	5.82E-13	1	5.16	(2,5,2,3,3,5,BU:5); emission factor of diesel: 6.00E-11 g/kg diesel; EMEP/EEA guidebook 2013, 1.A.3.b.i-iv, Tab. 3-103
	Heat, waste	-	-	MJ	3.30E-1	4.00E-1	1	1.38	(2,5,2,3,3,5,BU:1.05); devault value;

5 Life Cycle Inventory Passenger Water Transport

5.1 Key Characteristics

This chapter deals with passenger traffic on Swiss lakes. In Tab. 5.1 current key figures of the passenger inland water transport are presented. The average capacity and the average weight of a passenger vessel were calculated from data published by the Schifffahrtsgesellschaft of Zürich (ZSG). The kilometric performance and the transport performance of all passenger vessels in Switzerland per year were published from Bundesamt für Statistik (2014). The average load factor was calculated by dividing the transport performance by the kilometric performance. According to the statistic information of BFS are in Switzerland 147 passenger vessels in operation. The transport performance of the lifetime of a single vessel can therefore be calculated by dividing the transport performance of all vessels by the number of vessels and multiplying it with the life span. The life span of the passenger vessel is derived from the life span data of an inland barge vessel (Spielmann et al. 2007) and adjusted upwards to 50 years as no more recent data are available.

Tab. 5.1 Key figures of the passenger inland water transport (BFS 2014, ZSG 2008)

Average weight of a passenger vessel[1)]	t	149
Average passenger capacity[1)]	p	423
Kilometric transport performance per year[2)]	vkm/a	2257000
Transport performance per year[2)]	pkm/a	150200000
Average load factor[3)]		16%
Life span	a	50
Total transport performance per vessel[3)]	pkm	51088435
Demand ship per pkm[3)]	unit/pkm	2.0.E-08

[1)] Information from the yearly report of ZSG, 2008

[2)] Information from BFS, 2014

[3)] Own calculation

Most passenger vessels on the Swiss lakes are operated with diesel fuel. The average fuel consumption per pkm of the ship fleet on the lake of Zürich in 2014 was 38 g/pkm (ZSG 2014). This specific fuel consumption is considered representative for the specific diesel consumption on Swiss lakes.

5.2 Manufacturing and Maintenance of Passenger Vessels

Data on the passenger vessel manufacture were neither available from literature nor from shipyards. The construction effort per kg of a passenger vessel is approximated with 50 % construction effort of a regional train and 50 % construction effort for a barge vessel. The barge vessel has a weight of 300 tons (Spielmann et al. 2007). The dataset of the train and barge manufacturing was taken from KBOB LCI data v2.2:2016 (KBOB et al. 2016).

Tab. 5.2 Demand of a regional train/barge vessel to cover the demand of a passenger vessel

		Regional passenger train	Barge vessel
Weight	t	171	300
Share of a train/barge	%	0.435	0.248
Demand passenger vessel	unit/pkm	8.51E-09	4.85E-09

No specific data of passenger vessel maintenance are available. Therefore the expenses of the maintenance are assumed to be 5 % of the expenses of the vessel production.

5.3 Port

No information about the number of passenger using an average port in Switzerland is available. The port infrastructure is thus neglected.

5.4 Airborne Gaseous Emissions

No specific emission factors for airborne gaseous emissions of passenger vessels are available in literature. The emission factors per kg diesel of a diesel locomotive including particulate filter are used (Messmer & Frischknecht 2016).

5.5 Unit process Life Cycle Inventory data

Tab. 5.3 Life cycle inventory data of passenger ship transport

	Name	Location	InfrastructureProcess	Unit	transport, passenger ship	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				pkm			
product	transport, passenger ship	CH	0	pkm	1			
technosphere	regional train	CH	1	unit	8.93E-9	1	3.50	(5,3,1,3,4,5,BU:3); yearly kilometric transport performance of 2257000 vkm and a material composition of 50% regional train and 50% barge (extrapolated with the weight) ; BFS statistic, 2014
	barge	RER	1	unit	5.09E-9	1	3.50	(5,3,1,3,4,5,BU:3); yearly kilometric transport performance of 2257000 vkm and a material composition of 50% regional train and 50% barge (extrapolated with the weight) ; BFS statistic, 2014
	diesel, at regional storage	CH	0	kg	3.83E-2	1	1.24	(2,4,1,3,1,5,BU:1.05); average diesel consumption of 3.40 l/vkm; ZSG yearly report, 2014
emission air, unspecified	Benzene	-	-	kg	2.63E-7	1	3.29	(2,4,2,3,4,5,BU:3); emission factor (0.01 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: non road emission factor database
	Methane, fossil	-	-	kg	2.10E-6	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (0.05 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: non road emission factor database
	Carbon monoxide, fossil	-	-	kg	9.54E-4	1	5.33	(2,4,2,3,4,5,BU:5); emission factor (24.93 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: non road emission factor database
	Carbon dioxide, fossil	-	-	kg	1.21E-1	1	1.59	(2,4,2,3,4,5,BU:1.05); emission factor (3150.09 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: non road emission factor database
	Dinitrogen monoxide	-	-	kg	5.79E-6	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (0.15 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: non road emission factor database
	Ammonia	-	-	kg	3.83E-7	1	1.64	(2,4,2,3,4,5,BU:1.2); emission factor (0.01 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; EMEP/EEA guidebook 2013, 1.A.3.c, Tab. 3-3
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	1.59E-4	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (4.15 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; non road emission factor
	Ethane	-	-	kg	5.86E-8	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (0.00 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Propane	-	-	kg	1.95E-7	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (0.01 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Butane	-	-	kg	2.93E-7	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (0.01 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Pentane	-	-	kg	1.17E-7	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (0.00 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Heptane	-	-	kg	5.86E-7	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (0.02 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Benzene	-	-	kg	1.37E-7	1	3.29	(2,4,2,3,4,5,BU:3); emission factor (0.00 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	Toluene	-	-	kg	1.95E-8	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (5.11E-4 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	m-Xylene	-	-	kg	1.92E-6	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (0.05 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
	o-Xylene	-	-	kg	7.82E-7	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (0.02 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112

Tab. 5.3 Life cycle inventory data of passenger ship transport (continued)

Name	Location	InfrastructureProcess	Unit	transport, passenger ship	UncertaintyType	StandardDeviation95%	GeneralComment
Location				CH			
InfrastructureProcess				0			
Unit				pkm			
Formaldehyde	-	-	kg	1.64E-5	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (0.43 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Acetaldehyde	-	-	kg	8.93E-6	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (0.23 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Benzaldehyde	-	-	kg	2.68E-6	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (0.07 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Acrolein	-	-	kg	3.46E-6	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (0.09 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Styrene	-	-	kg	1.09E-6	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (0.03 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: Non-road database; EMEP/EEA guidebook 2013, Tab. 3-112
Nitrogen oxides	-	-	kg	1.73E-3	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (45.08 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: non road emission factor database
Particulates, > 10 um	-	-	kg	2.72E-7	1	1.84	(2,4,2,3,4,5,BU:1.5); emission factor (0.01 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: non road emission factor database
Particulates, > 2.5 um, and < 10um	-	-	kg	2.65E-7	1	2.30	(2,4,2,3,4,5,BU:2); emission factor (0.01 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: non road emission factor database
Particulates, < 2.5 um	-	-	kg	6.43E-6	1	3.29	(2,4,2,3,4,5,BU:3); emission factor (0.17 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; BAFU 2015: non road emission factor database
Sulfur dioxide	-	-	kg	7.65E-7	1	1.59	(2,4,2,3,4,5,BU:1.05); emission factor (0.02 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; HBEFA 3.1., CH
Benzo(a)pyrene	-	-	kg	1.15E-9	1	3.29	(2,4,2,3,4,5,BU:3); emission factor (3.00E-5 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; EMEP/EEA guidebook 2013, 1.A.2.f.ii, Tab. 3-1
PAH, polycyclic aromatic hydrocarbons	-	-	kg	1.26E-7	1	3.29	(2,4,2,3,4,5,BU:3); emission factor (3.29E-3 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; EMEP/EEA guidebook 2013, 1.A.2.f.ii, Tab. 3-1
Arsenic	-	-	kg	3.83E-12	1	5.33	(2,4,2,3,4,5,BU:5); emission factor (1.00E-7 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; EMEP/EEA guidebook 2013, 1.A.2.f.ii, Tab. 3-1
Selenium	-	-	kg	3.83E-10	1	5.33	(2,4,2,3,4,5,BU:5); emission factor (1.00E-5 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; EMEP/EEA guidebook 2013, 1.A.2.f.ii, Tab. 3-1
Zinc	-	-	kg	3.83E-8	1	5.33	(2,4,2,3,4,5,BU:5); emission factor (1.00E-3 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; EMEP/EEA guidebook 2013, 1.A.2.f.ii, Tab. 3-1
Copper	-	-	kg	6.51E-8	1	5.33	(2,4,2,3,4,5,BU:5); emission factor (1.70E-3 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; EMEP/EEA guidebook 2013, 1.A.2.f.ii, Tab. 3-1
Nickel	-	-	kg	2.68E-9	1	5.33	(2,4,2,3,4,5,BU:5); emission factor (7.00E-5 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; EMEP/EEA guidebook 2013, 1.A.2.f.ii, Tab. 3-1
Chromium	-	-	kg	1.91E-9	1	5.33	(2,4,2,3,4,5,BU:5); emission factor (5.00E-5 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; EMEP/EEA guidebook 2013, 1.A.2.f.ii, Tab. 3-1
Chromium VI	-	-	kg	3.83E-12	1	5.33	(2,4,2,3,4,5,BU:5); emission factor (1.00E-7 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; EMEP/EEA guidebook 2013, 1.A.2.f.ii, Tab. 3-1
Mercury	-	-	kg	2.03E-10	1	5.33	(2,4,2,3,4,5,BU:5); emission factor (5.30E-6 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; EMEP/EEA guidebook 2013, 1.A.2.f.ii, Tab. 3-1
Cadmium	-	-	kg	3.83E-10	1	5.33	(2,4,2,3,4,5,BU:5); emission factor (1.00E-5 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; EMEP/EEA guidebook 2013, 1.A.2.f.ii, Tab. 3-1
Lead	-	-	kg	1.99E-9	1	5.33	(2,4,2,3,4,5,BU:5); emission factor (5.20E-5 g/kg diesel) adapted from shunting emission of regional train, assuming the use of particle filter; EMEP/EEA guidebook 2013, 1.A.2.f.ii, Tab. 3-1
Heat, waste	-	-	MJ	1.64E+0	1	1.59	(2,4,2,3,4,5,BU:1.05); default value;

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