Life Cycle Assessment of freight transport in Belgium

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Abstract: *BRAIN-TRAINS is a project supported by the Belgian Federal Government that deals with the possible development of rail freight intermodality in Belgium, analysing the current situation of the intermodal freight transport from an interdisciplinary perspective. Life Cycle Assessment (LCA) methodology has been chosen to analyse the environmental impact of freight transport in Belgium. In a first stage we have carried out the LCA of rail freight transport, inland waterways transport and road freight transport independently. The purpose of this paper is to discuss the first results obtained from the study of the environmental impacts of inland freight transport using the LCA methodology.*

Keywords*:* "Environmental impact", "Life Cycle Assessment", "Freight transport".

1. Introduction

Transport plays a fundamental role in the economy and in society, but it also may have an adverse impact on the climate, the natural environment and the human health.

In Belgium, the transport sector was the main source of greenhouse gas (GHG) emissions in 2012, representing 35% of the total emissions. Half of the GHG transport emissions were caused by road transport (European Commission, 2014). Furthermore, transport represents an important source of air pollution. In Belgium, road transport was responsible for 49% of the total emissions of nitrogen oxides (NO_X) in 2012, accounting for 6% the other modes of transport. Moreover, transport was a major source of Non-Methane Volatile Organic Compounds (NMVOCs) with 9% of the total emissions from road transport and 1% from other modes of transport, sulphur dioxide (SO_2) with 2% of the total emissions, primary particulate matter of a diameter of 2.5 µm or less ($PM_{2.5}$) with 13% of the total emissions from road transport and 2% from other modes of transport and carbon monoxide (CO) with 17% of the total emissions from road transport and 1% from other modes of transport (EEA, 2014). The mentioned pollutants are produced during fuel combustion, but other non-exhaust emissions of particulate matter, including PM_{10} (particles with a diameter of 10 µm or less) and $PM_{2.5}$, are emitted from the wear of brakes, tyres and road surface in road transport and the abrasion of brakes, wheels and rails in rail transport.

Additionally, transport consumes a large amount of energy (in Belgium, the transport sector accounted for the 27% of the final energy consumption in 2012) (European Commission, 2014) and this, together with the use of other resources such as land and raw materials, could lead to problems of resource scarcity.

Therefore, the search for more environmentally and health friendly, energy-efficient and competitive transport systems becomes necessary. In this framework, intermodal freight transport represents an opportunity to achieve all this goals through the shifting of road freight transport in long distances to others modes of transport with improved environmental performance such as rail freight transport and inland waterways transport.

Environmental impact studies on freight transport show that rail freight transport is the land transport option that has the highest environmental performance compared to intermodal road-rail and all-road transport (Fries and Hellweg, 2014; Facanha and Horvath, 2006),

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especially when electrified railway is used (Spielmann and Scholz, 2005). Although inland waterways transport is the inland freight transport with highest energy-efficiency, it is strongly limited by geographical conditions. Nevertheless, road transport is more flexible with a more extended network and direct links, causing the dominant use of all-road or road-rail intermodal transport (Demir et al., 2015).

The glossary for transport statistics defines the intermodal freight transport as the transport of goods by at least two different modes of transport, in one and the same Intermodal Transport Unit (ITU) without handling the goods themselves when changing modes (ITF, Eurostat, UNECE, 2009). As shown in Figure 1, the major part of the journey is done by rail, inland waterway or sea (main haulage) while road transport is used for the shortest possible initial and final parts of the transport chain (pre- and post-haulage) (Tawfik and Limbourg, 2015). At the intermodal terminal, the ITUs (container, swap body or road vehicle) are transferred between modes of transport.

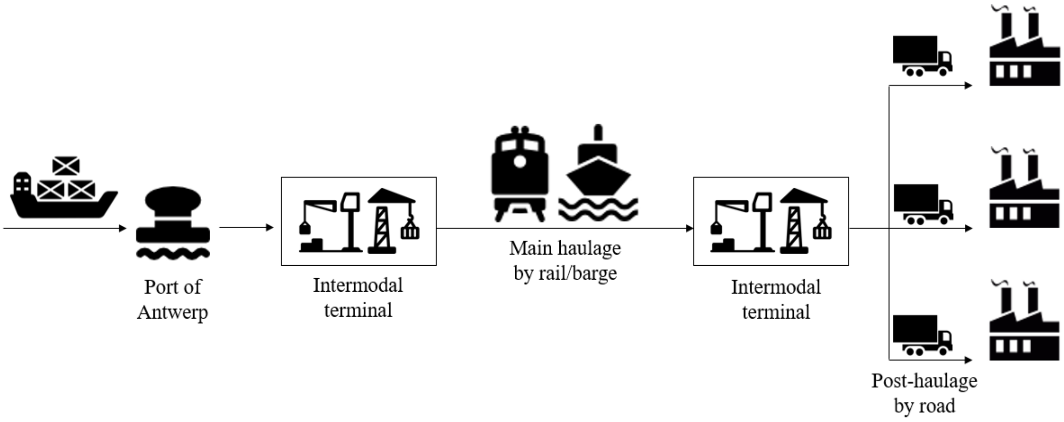


Figure 1 : Example of intermodal freight transport

Intermodal rail freight transport presents several strengths that can lead it to grow such as the reduced cost that can be obtained due to the high payload capacity of trains and the reduced externalities compared to road transport due to decrease of emissions and improvement of road safety (Crozet et al., 2014). The liberalization of the Belgian rail freight market started in 2005 could lead to an increase in the competitiveness of the railway sector, involving a modal shift from road transport to rail freight intermodality and enhancing the economy due to the relationship between transport and the GDP (improving transport activities causes GDP increases). Nevertheless, intermodal rail freight transport presents some weaknesses due to its dependence on rail infrastructure, resulting in missing direct rail links, weak access to the rail network or a lack of flexibility. Furthermore, rail equipment causes high operating costs or the need for high investments, leading to complex pricing strategies (Vanelslander et al., 2015).

The creation of a single European transport area promoted by the European Commission's White Paper on transport (2011) through the Trans-European Transport Network (TEN-T) is presented as an opportunity to increase the rail freight transport in Belgium, because it entails the standardization and interoperability of the intermodal rail freight transport on the European continent. The promotion of intermodal transport to consolidate freight flows and an increase in future road taxes could lead to consolidate the intermodal rail freight transport at European level. However, some threats impacting negatively on the intermodal rail freight transport have to be considered, such as the impossibility of consolidating freight leading to the increase of prices because the high fixed cost of rail freight transport, the cancellation of investments and subsides by European countries, the increase of passenger traffic receiving priority over freight transport and the possibility of a monopoly or duopoly by well-established companies (Vanelslander et al., 2015).

In order to increase the rail share in the modal split of freight transport in Belgium, the Belgian Federal Government has initiated the BRAIN-TRAINS project, which approaches the possible development of rail freight intermodality in Belgium from an interdisciplinary perspective, focusing on five main subjects: optimal corridors and hub development, macro-economic impact of intermodality, effective market regulation, governance and organization for a well-functioning intermodality, and environmental sustainability of intermodal rail freight transport. The objective of increasing the rail freight transport is linked to the European Commission's White Paper on transport (2011), which aims to shift the 30% of road freight over 300 km to other modes of transport more energy-efficient such as rail or waterborne transport by 2030. This shift of road freight transport may represent a challenging target to the rail freight sector due to the high amount of goods that this implies.

2. Methodology

The environmental impact of freight transport is determined using the Life Cycle Assessment (LCA) methodology. LCA is a structured, comprehensive and internationally standardised method by ISO Standards 14040 and 14044 (International Standardization Organization, 2006), and using the ILCD Handbook (European Commission, 2010) as a reference to perform an LCA.

The LCA methodology allows studying complex systems like intermodal transport, providing a system perspective analysis that allows assessing environmental impacts through all the stages of the intermodal freight transport system (transport operation, vehicle and infrastructure), from raw material extraction, through materials use, and finally disposal. Furthermore, LCA methodology allows quantifying all relevant emissions and consumptions, as well as the related environmental and health impacts and resource depletion issues that are associated with freight transport. Thus, through the application of the LCA methodology, the contribution of the pollutants emitted by freight transport can be analysed using midpoint environmental impact categories, such as climate change, resource depletion, acidification, human toxicity or ecotoxicity for example. Then, as can be seen in Figure 2, the influence of these midpoint categories to endpoint categories such as damage to human health, damage to ecosystem diversity and resource scarcity can be evaluated. These endpoint categories are related to the areas of protection of human health, natural environment and natural resources, respectively (European Commission, 2010).

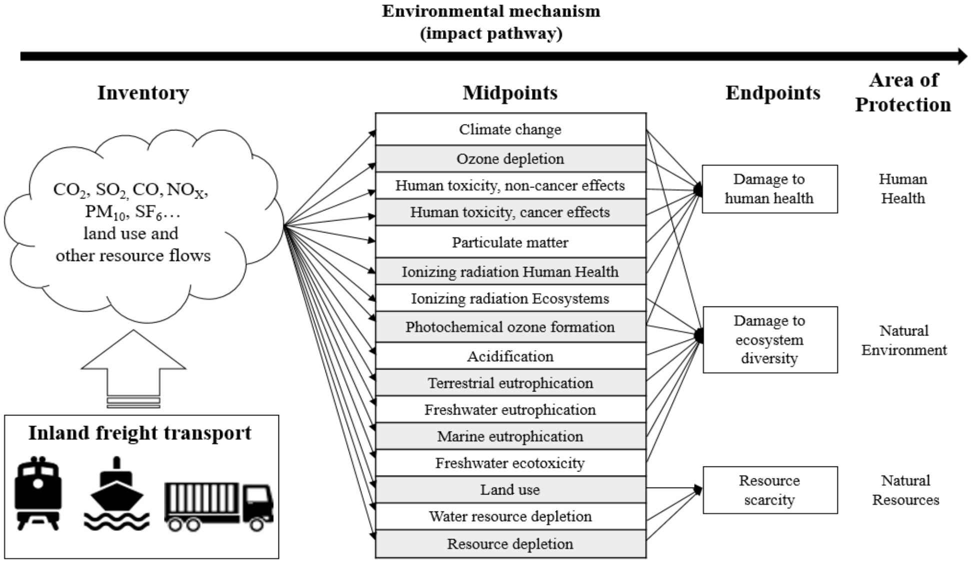
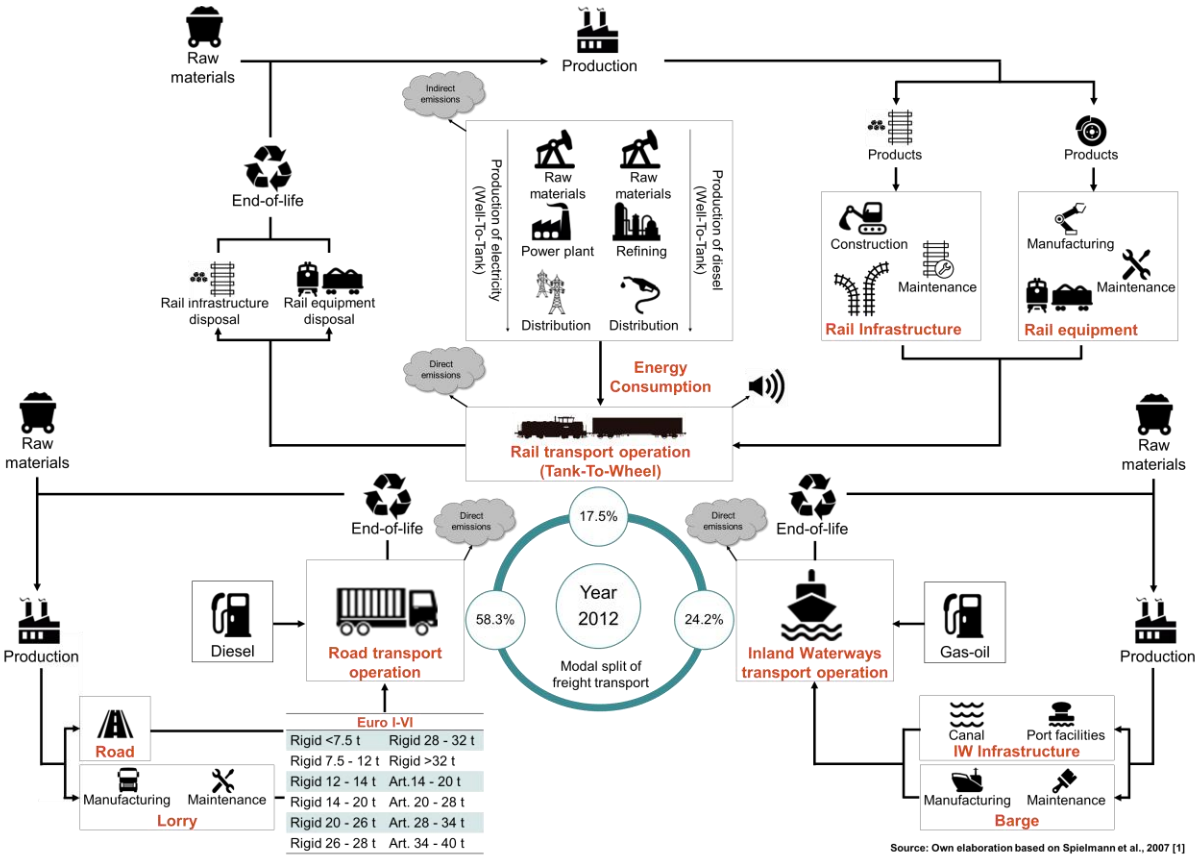


Figure 2 : Diagram of the Life cycle Impact assessment methodology applied on inland freight transport. Source: European Commission, 2010

Figure 3 presents the stages considered in our study for the rail freight transport, inland waterways transport and road freight transport. In Belgium, road transport was responsible for 58.3% of the total inland freight expressed in tonne-kilometres in 2012, representing the dominant mode of the three major inland transport modes. Inland waterways accounts for 24.3% and rail transport for 17.5% (Eurostat, 2015).

A detailed study of the rail freight transport has been conducted, collecting data directly from Infrabel (the Belgian railway infrastructure manager) and B-Logistics, which is the main rail freight operator in Belgium with a market share of 86.62% of tkm in 2012 (Van de Voorde and Vanelslander, 2014). The rail freight system is divided in three sub-systems: rail transport operation, rail infrastructure and rail equipment (locomotives and wagons). The specific energy consumption of electric and diesel trains has been determined separately. Upstream emissions related to the production and distribution of the energy to the traction unit and the direct emissions during the rail transport activity (exhaust emissions to air related to the diesel combustion in locomotives, emissions to soil from abrasion of brake linings, wheels, rails and overhead contact lines and the sulphur hexafluoride (SF_6) emitted during conversion at traction substations related to electricity consumption) have been determined. In order to adjust as closely as possible the environmental impact related to the yearly electricity consumption, and since the electricity supply mix varies widely over the years, our LCA study uses the electricity supply mix in Belgium corresponding to the appropriate year. The life cycle phases of construction, maintenance and disposal of rail infrastructure and manufacturing, maintenance and disposal of rail equipment are analysed.



Source: Own elaboration based on Spielmann et al., 2007 [1]

Figure 3: Inland freight transport system boundaries. Source: Own elaboration based on Spielmann et al., 2007

In the case of both inland waterways transport and road transport in Belgium, the Ecoinvent v3 database has been used as a model (Weidema et al., 2013). Information relative to the total annual freight moved by inland waterways transport in Belgium by barge type, fuel consumption in the vessel transport operation and waterways infrastructure characteristics for several years have been collected. Similarly, information relative to the total annual freight moved by road transport in Belgium by weight classification and heavy duty vehicle technology type, fuel consumption in the road transport operation and road infrastructure characteristics for several years have been collected.

A division of the processes related to the energy consumption in transport can be made. On the one hand, Well-To-Tank (WTT) processes such as primary energy consumption and indirect emissions are produced at the upstream energy processes, which start with the raw materials extraction, continue with the diesel refining or electricity production and end with the energy distribution to the traction unit (locomotive, barge or lorry in our study). On the other hand, the Tank-to-Wheel (TTW) processes such as the final energy consumption and the exhaust emissions are produced during the transport activity. Finally, the Well-To-Wheel (WTW) processes are the sum of the WTT processes and the TTW processes.

In our study, the LCA approach have been used, taking into consideration the overall life cycle of the energy carrier. LCA methodology can provide complete information of the environmental impacts related to a process, and not only providing information on energy consumption and emissions produced but also on raw materials consumption. Furthermore, the application of LCA methodology on transport allows analysing not only the transport emissions related to the energy consumption during the transport operation, but also the emissions related to the construction of rail infrastructure, inland waterways infrastructure and road infrastructure and the manufacturing of vehicles, such as locomotives, wagons, barges or lorries for example. Moreover, the maintenance and disposal of both infrastructure and vehicles is also considered (Spielmann et al., 2007).

Table 1 compares direct and indirect energy consumptions between the different modes of inland freight transport extracted from Messagie et al. (2004). For rail transport, the TTW stage is only responsible for 19% of the total energy consumption while WTT stage accounts for 50%. These proportions represent a European average with a mixed use of mainly electricity and the remaining part of diesel. The manufacture, maintenance and disposal of the rail equipment accounts for 12% and the construction, maintenance and disposal of the rail infrastructure accounts for 19% of the total energy consumption. Concerning inland waterways transport, in the case of a M4 barge on CEMT VI waterway in Belgium, barge operation is responsible for 67%, WTT stage for 20%, manufacture, maintenance and disposal of the M4 barge for 2% and construction, maintenance and disposal of the CEMT VI waterway for 11% of the total energy consumption. For road transport, the TTW stage accounts, on average, for 75% of the total energy consumption, 11% for fuel production, 6% for manufacture, maintenance and disposal of the lorry and 8% for the construction, maintenance and disposal of the road infrastructure (Messagie et al., 2014). While the shares of energy consumption showed in table 1 are only indicative and dependent on specific assumptions, they highlight the importance of all the stages of transport in the total energy consumption of freight transport.

Table 1 : Direct and indirect energy consumptions in different modes of transport. [1]Spielmann and Scholz, 2005; [2]van Lier and Macharis, 2014. Source: Messagie et al., 2014

Average energy consumption	WTT	TTW	Vehicle	Infrastructure
Rail transport[1]	50%	19%	12%	19%
Inland waterways transport[2]	20%	67%	2%	11%
Road transport[1]	11%	75%	6%	8%

3. Results

3.1. Rail freight transport in Belgium

The specific energy consumption during the rail transport activity of electric and diesel trains has been determined separately on the basis of the total annual energy consumption of electricity and diesel and the total annual rail freight moved by each energy traction from the period 2006 to 2012, using the data in table 2. The data from SNCB include the energy consumed by trains, such as the empty returns, shunting activity, maintenance of trains, as well as electrical losses in catenary (SNCB, 2009; SNCB, 2013 and SNCB, 2015). The Belgian high voltage network has distribution losses of 5% and the railway network has transmission losses of 7% (Infrabel, 2014).

Table 2 : Rail freight transport performance and energy consumption in Belgium. Sources: SNCB, 2009; SNCB, 2013 and SNCB, 2015

Year	2006	2007	2008	2009	2010	2011	2012
Rail freight (millions tkm)	8442	8148	7882	5439	5729	5913	5220
Electric traction consumption (TJ)	3489	3261	3382	2472	2092	2248	1922
Diesel traction consumption (TJ)	1449	1339	1282	739	721	582	465
Total consumption (TJ)	4939	4600	4664	3211	2813	2830	2387
Energy consumption (kJ/tkm)	585	565	592	590	491	479	457

The energy consumption for the Belgian rail freight transport has been calculated as 457 kJ/tkm in 2012. However, no differentiation can be made between electric and diesel traction. The rail freight traction share in table 3 has been used to calculate the rail freight moved by electric and diesel traction, enabling to determine the specific energy consumption of electric and diesel trains separately. The data are obtained from the Flemish Environment Agency (VMM) and they are calculated only for the Flemish region, but this value can be considered as representative for Belgium in general. The rail freight traction share of years 2006 and 2010 have been calculated using linear interpolation. It should be noted that the use of diesel traction is decreasing in Belgium, which means that only a small part of the rail freight produces exhaust emissions.

Table 3 : Electric and diesel rail freight traction share in Flanders (Belgium). Sources: Flemish Environment Agency (VMM, 2008, 2009, 2010, 2012, 2013)

Year	2006	2007	2008	2009	2010	2011	2012
Electric traction	76.33%	76%	78.2%	83.1%	83.45%	83.8%	86.3%
Diesel traction	23.67%	24%	21.8%	16.9%	16.55%	16.2%	13.7%

Table 4 shows the values of energy consumption of electric and diesel trains calculated in our study from the period 2006 to 2012. If we take year 2012 as an example, 86.3% of the 5220 million tkm of rail freight in Belgium were moved with electric traction, resulting in 4505 million tkm. The total electricity consumed in 2012 was 1922 TJ, therefore the specific energy consumption of electric trains was 427 kJ/tkm. Similarly, 13.7% of the 5,220 million tkm of rail freight in Belgium were moved with diesel traction, resulting in 715 million tkm. The total diesel consumed in 2012 was 465 TJ, including the diesel consumption of the shunting activity, therefore the specific energy consumption of diesel trains was 650 kJ/tkm.

Table 4 : Energy consumption of rail freight transport in Belgium

Year	2006	2007	2008	2009	2010	2011	2012
Energy consumption of electric trains (kJ/tkm)	541	527	549	547	438	454	427
Energy consumption of diesel trains (kJ/tkm)	725	685	746	804	760	608	650

EcoTransIT (2008) uses as energy consumptions for the year 2005 the values of 456 kJ/tkm for electric traction and 530 kJ/tkm for diesel traction, representing the European average energy consumptions for cargo transport within Europe. Moreover, these values comprise both the final energy consumption during transport operation and the energy consumption of the generation of diesel and electricity (EcoTransIT, 2008). By comparing the values used in EcoTransIT (2008) with the energy consumptions obtained in our study for the year 2006, our results for Belgium show higher energy consumptions with 541 kJ/tkm and 725 kJ/tkm of electricity and diesel consumed (including shunting activity), respectively.

The final electricity and diesel consumed for goods transport in table 5 is calculated using the energy consumption of electric and diesel trains (see table 4) and the electric and diesel traction share (see table 3). The results of our study show that, in 2012, 368 kJ of electricity and 89 kJ of diesel (including shunting activity) were needed to move 1 tkm in Belgium. According to Ecoinvent v3 data in 2014, a consumption of 260 kJ of electricity and 157 kJ of diesel were required to move 1 tkm of rail freight in Belgium. As in our study, the values of energy consumption extracted from the Ecoinvent v3 database represent the final energy consumption during transport operation. The results of final electricity consumption from our study are always higher than the value used by Ecoinvent v3. However, since the year 2009, the final diesel consumption from our study shows values lower than the value from Ecoinvent v3. The discrepancies between the values of our study and those of Ecoinvent v3 should be highlighted, since they point out a need for updating the Ecoinvent v3 database.

Table 5 : Final electricity and diesel consumption of rail freight transport in Belgium

Year	2006	2007	2008	2009	2010	2011	2012
Final electricity consumption (kJ/tkm)	413	400	429	454	365	380	368
Final diesel consumption (kJ/tkm)	172	164	163	136	126	98	89

The emission factors of Spielmann et al. (2007) have been used to calculate direct emissions. The diesel consumption has been used to obtain the exhaust emissions of diesel trains. The SF_6 emissions to air produced during conversion of electricity at traction substations have been calculated using the electricity consumption. To determine particle emissions, it is necessary to add the particles produced by the abrasion to those produced by the combustion of diesel.

The emissions of SO_2 are dependent on the sulphur concentration in the diesel. B-Logistics uses conventional road-transport diesel, which is regulated by Directive 2003/17/EC, establishing a low sulphur content with a maximum limit of 10 ppm sulphur by mass from 2009. However, diesel in Belgium has an average sulphur content of 8 ppm since 2008. The sulphur content in diesel in Belgium was 24 ppm and 9 ppm for the years 2006 and 2007, respectively (Twisse and Scott, 2012).

3.2. Inland waterways transport in Belgium

The average energy consumption during the inland waterways transport activity by barge has been determined using the class specific fuel consumption of barges in Wallonia (Service Public de Wallonie, 2014). It has been aggregated using the total carrying capacity of each vessel class by year from the period 2006 to 2012 (see table 6) as allocation factor.

Table 6 : Tonnage (t/year) of dry bulk barges in Belgium by vessel class. Sources: ITB, 2012

Vessel class	2006	2007	2008	2009	2010	2011	2012
< 250 t	2 448	3 947	4 176	3 323	2 871	3 446	3 595
251 t – 450 t	115 068	103 812	96 513	91 662	87 596	78 726	72 071
451 t – 650 t	85 909	80 693	72 066	72 836	68 222	63 551	63 193
651 t – 850 t	77 600	71 358	64 625	61 135	58 988	54 852	50 646
851 t – 1000 t	72 450	65 900	65 486	58 151	55 850	48 416	41 895
1001 t – 1500 t	320 440	325 035	317 936	296 911	280 938	268 805	263 778
1501 t- 2000 t	132 898	138 658	131 161	129 578	134 418	118 650	110 414
2001 t – 2500 t	160 131	144527	141 009	138 400	136 363	128 367	137 369
2501 t – 3000 t	278 908	260 489	224 229	227 298	229 233	228 739	222 872
> 3000 t	265 451	321 592	393 622	445 115	498 284	510 206	511 032
TOTAL	1 511 303	1 516 011	1 510 823	1 524 409	1 552 763	1 503 758	1 476 865

Table 7 shows the methodology used to calculate the average fuel consumption of inland waterways transport by weighted arithmetic mean each year taking as an example the year 2012. The average fuel consumption of 2012 for dry bulk cargo was 6.73 g/tkm.

Table 7 : Average fuel consumption of dry bulk barges in Belgium in 2012. Sources: [1]ITB, 2012 and [2]Service Public de Wallonie, 2014

Vessel class	Tonnage (t)[1]	Share	Class specific fuel consumption in canals (g/tkm)[2]	Contribution to average fuel consumption (g/tkm)
< 250 t	3 595	0.24%	10.248	0.02
251 t – 450 t	72 071	5%	10.248	0.50
451 t – 650 t	63 193	4%	9.492	0.41
651 t – 850 t	50 646	3%	8.736	0.30
851 t – 1000 t	41 895	3%	8.736	0.25
1001 t – 1500 t	263 778	18%	8.064	1.44
1501 t- 2000 t	110 414	7%	7.392	0.55
2001 t – 2500 t	137 369	9%	7.392	0.69
2501t – 3000 t	222 872	15%	7.392	1.12
> 3000 t	511 032	35%	4.200	1.45
TOTAL	1 476 865	100%	-	6.73

Table 8 shows the average fuel consumption of inland waterways transport calculated from the period 2006 to 2012. The values used in EcoTransIT (2008) for the year 2005 are 438 kJ/tkm and 727 kJ/tkm for inland waterways transport downstream and upstream, respectively. These values include both the final energy consumption during transport operation and the energy consumption of the generation of fuel (EcoTransIT, 2008).

In the case of Ecoinvent v3 database, the energy consumption for inland waterways transport for the year 2014 is 402 kJ/tkm. This value represents the final energy consumption during transport operation. By comparing the values obtained in our study with the values from EcoTransIT (2008) and Ecoinvent v3 database, our results show lower energy consumptions. It should be noted that the reference values represent European averages, whereas our results represent a Belgian average.

Table 8 : Average fuel consumption of inland waterways transport of dry bulk in Belgium. [1]Considering that diesel net calories are 42.8 MJ/kg

Year	2006	2007	2008	2009	2010	2011	2012
Average fuel consumption (g/tkm)	7.45	7.30	7.11	6.97	6.85	6.77	6.73
Average energy consumption (kJ/tkm)[1]	319	312	304	299	293	290	288

The exhaust emissions produced during the TTW stage of inland waterways transport have been calculated using the emission factors of Spielmann et al. (2007) and the calculated fuel consumption. As mentioned above, the emissions of SO_2 are dependent on the sulphur content in diesel. The gas-oil used in barges has been regulated by several European Directives, such as the Directive 93/12/EC, establishing a sulphur content of gas-oil used in inland waterways transport of 2000 ppm from 1994; Directive 1999/32/EC establishing a sulphur content of gas-oil of 1000 ppm from 2008; and Directive 2009/30/EC establishing a sulphur content of gas-oil of 10 ppm from 2011.

3.3. Road freight transport in Belgium

The average fuel consumption during the road freight transport activity has been determined using the average diesel consumption in Belgium from the TRACCS database (Papadimitriou et al., 2013) showed in table 9 and the actual payload of each lorry class calculated from the period 2005 to 2010 (see table 10). The data from the TRACCS project have been converted from g/km to g/tkm dividing by the actual payload of each lorry gross vehicle weight (GVW) class. It should be noted that in the same year, on the one hand, the fuel consumption in g/km increases with the size of the lorry (from 109 g/km to 254 g/km in 2005), but on the other hand, the fuel consumption in g/tkm decreases with the size of the lorry (from 231 g/tkm to 43 g/tkm in 2005). This is due to increased payload (see table 10) with the GVW category. Furthermore, in the same GVW category, the fuel consumption (in g/tkm) increases over the years as a result of a decrease in the load factor (from 23.3% in 2005 to 17.4% in 2010), which entails a decrease in the actual payload.

Table 9 : Fuel consumption of road transport in Belgium. Source: [1]Papadimitriou et al., 2013

Heavy Duty Lorry	Fuel Consumption[1] (g/km)						Fuel Consumption (g/tkm)					
	2005	2006	2007	2008	2009	2010	2005	2006	2007	2008	2009	2010
Rigid <7.5 t	109	109	109	109	109	109	231	241	252	288	293	312
Rigid 7.5 - 12 t	146	146	145	146	146	146	124	129	135	155	157	167
Rigid 12 - 14 t	153	154	154	154	154	154	94	98	102	117	118	126
Rigid 14 - 20 t	179	179	178	178	178	178	79	82	86	98	99	106
Rigid 20 - 26 t	215	214	213	213	213	213	67	70	73	83	84	89
Rigid 26 - 28 t	226	226	226	225	225	225	59	62	65	73	74	79
Rigid 28 - 32 t	260	260	260	260	260	260	61	63	66	75	77	81
Rigid >32 t	255	254	253	253	253	253	55	58	60	69	69	74
Art. 14 - 20 t	172	171	170	170	170	170	58	60	63	72	73	77
Art. 20 - 28 t	215	213	212	212	212	212	54	56	58	66	67	72
Art. 28 - 34 t	225	223	222	222	222	222	45	46	48	55	56	59
Art. 34 - 40 t	254	253	252	252	252	251	43	45	47	53	54	57

Table 10 presents the methodology used to calculate the actual payload of each lorry GVW class using the maximum payload and the load factor for each year.

Table 10 : Actual payload calculated after maximum payload and load factor. Source: [1]Papadimitriou et al., 2013

Heavy Duty Lorry	Maximum Payload (t/vehicle) [1]	Load Factor (%) [1]						Actual Payload (t/vehicle)					
		2005	2006	2007	2008	2009	2010	2005	2006	2007	2008	2009	2010
Rigid <7.5 t	2	23.3%	22.4%	21.4%	18.7%	18.5%	17.4%	0.47	0.45	0.43	0.38	0.37	0.35
Rigid 7.5 - 12 t	5							1.17	1.12	1.07	0.94	0.93	0.87
Rigid 12 - 14 t	7							1.64	1.57	1.50	1.32	1.30	1.22
Rigid 14 - 20 t	9.7							2.26	2.17	2.07	1.82	1.79	1.68
Rigid 20 - 26 t	13.7							3.20	3.07	2.93	2.57	2.53	2.38
Rigid 26 - 28 t	16.4							3.82	3.67	3.50	3.07	3.03	2.84
Rigid 28 - 32 t	18.4							4.29	4.11	3.93	3.44	3.40	3.19
Rigid >32 t	19.7							4.60	4.41	4.21	3.69	3.64	3.42
Art. 14 - 20 t	12.6							2.95	2.83	2.70	2.37	2.34	2.19
Art. 20 - 28 t	17.1							3.99	3.82	3.65	3.20	3.16	2.96
Art. 28 - 34 t	21.5							5.02	4.82	4.60	4.03	3.98	3.74
Art. 34 - 40 t	25.3							5.91	5.67	5.41	4.75	4.68	4.40

In order to do an average energy consumption for every year, the tonne-kilometers moved by each lorry GVW category have been used to calculate a weighted arithmetic mean. Table 11 shows the methodology used to calculate the average fuel consumption of road freight transport each year taking as an example the year 2010. The average fuel consumption of 2010 for road freight transport in Belgium was 66.47 g/tkm.

Table 11 : Average fuel consumption of road freight transport in Belgium in 2010

Heavy Duty Lorry	Freight transport performance (million tkm)						Share of tkm	Contribution to average fuel consumption (g/tkm)
	2005	2006	2007	2008	2009	2010	2010	2010
Rigid <7.5 t	259	240	224	240	229	212	0.65%	2.01
Rigid 7.5 - 12 t	774	736	702	654	639	599	1.83%	3.05
Rigid 12 - 14 t	142	125	110	97	87	77	0.23%	0.30
Rigid 14 - 20 t	1435	1347	1268	1172	1129	1048	3.20%	3.38
Rigid 20 - 26 t	1963	1888	1820	1727	1716	1628	4.97%	4.44
Rigid 26 - 28 t	15	47	75	9	7	8	0.03%	0.02
Rigid 28 - 32 t	460	458	456	423	434	421	1.28%	1.05
Rigid >32 t	4796	4484	4204	4256	4042	3762	11.48%	8.49
Art. 14 - 20 t	128	111	96	97	90	82	0.25%	0.19
Art. 20 - 28 t	98	83	69	76	68	61	0.19%	0.13
Art. 28 - 34 t	117	98	81	92	82	148	0.45%	0.27
Art. 34 - 40 t	30511	29042	27769	28056	26455	24737	75.45%	43.13
TOTAL	40700	38660	36873	36898	34979	32784	100%	66.47

Table 12 shows the average fuel consumption of road freight transport calculated from the period 2005 to 2010 in Belgium. It should be noted that the lorry GVW category “articulated 34-40 t” represents approximately 75% of the road freight transport performance every year in Belgium. Therefore, this lorry GVW category have been used to compare the different inland freight transport modes because it is representative.

Table 12 : Average fuel consumption of road freight transport of dry bulk in Belgium. [1]Considering that diesel net calories are 42.8 MJ/kg

	2005	2006	2007	2008	2009	2010
Average fuel consumption (g/tkm)	50.05	52.00	54.27	61.54	62.50	66.47
Average energy consumption (kJ/tkm)[1]	2142	2225	2323	2634	2675	2845
Road transport Art. 34 - 40 t (kJ/tkm)	1837	1910	1996	2273	2301	2447

The value used in EcoTransIT (2008) for an articulated lorry of 34–40 t for the year 2005 is 1082 kJ/tkm. This value includes both the final energy consumption during transport operation and the energy consumption of the generation of diesel (EcoTransIT, 2008). In the case of Ecoinvent v3 database, the energy consumption for a lorry of >32 t for the year 2014 is 739 kJ/tkm. This value represents the final energy consumption during transport operation. It should be noted that the reference values represent European averages, whereas our results represent a Belgian average. By comparing the values obtained in our study with the values from EcoTransIT (2008) and Ecoinvent v3 database, our results show higher energy consumptions due to the lowest load factor considered in our study.

The exhaust emissions produced during the TTW stage of road freight transport have been determined using the calculated diesel consumption and the emissions factors from two sources. For fuel dependent emissions such as CO_2 and heavy metals, the emission factors of Spielmann et al. (2007) have been used. For other pollutant emissions dependent on the engine emission technology have been used the tier 2 emission factors from EMEP/EEA air pollutant emission inventory guidebook 2013 (Ntziachristos et al., 2014).

The road transport emissions dependent on the engine are delimited by the “Euro” emission standards, which are regulated by several European policies, such as the Directive 91/542/EEC (Euro I and Euro II), the Directive 1999/96/EC (Euro III, Euro IV and Euro V) and the EC Regulation 595/2009 (Euro VI). The emission engine technologies presents in our study are the following: Conventional, Euro I, Euro II, Euro III, Euro IV and Euro V. The emission engine technology Euro IV appears in the year 2006 in the Belgian heavy duty vehicle market, and the Euro V in the year 2009. The emission engine technology Euro VI appears in the year 2014, thus it is not included in our study.

3.4. Intermodal terminals in Belgium

Intermodal terminals are essential in freight transport, working as a point of collection, sorting, transhipment and distribution of goods (ITF, Eurostat, UNECE, 2009). In order to transfer the merchandise between modes of transport, cargo handling equipment such as gantry cranes or reach stackers are used in intermodal terminals. Messagie et al. (2014) estimate an energy consumption in the transhipment processes of 16560 kJ per TEU, 1440 kJ/t for bulk transport and 4680 kJ/t for other goods.

Focusing on rail freight transport, the shunting activity plays a key role in intermodal transport. It includes the processes of parking and selecting wagons to assemble new trains, being performed in a marshalling yard, which can be part of an intermodal terminal. In Belgium, shunting activity is particularly significant because Belgium is mainly an exporter and importer of goods rather than a transit country. Moreover, since the shunting activity in Belgium is performed by diesel locomotives, it might result in a high negative impact. Therefore, a thorough analysis is presented hereunder.

B-Logistics uses 110 locomotives of the class HLD 77 with an energy consumption of 25 L/hour of diesel for shunting activity. Considering that the shunting service of every locomotive last 8 hour/day and it is performed every day of the year, it results in 8030000 litres of diesel per year. The density of diesel is 0.84 kg/L and the diesel net calories are 42.8

MJ/kg (Frischknecht et al., 2007), resulting in a diesel consumption of the shunting activity of 288.69 TJ per year.

As showed in table 13, a diesel consumption for shunting activity from 49.74 kJ/tkm to 55.31 kJ/tkm is obtained from the year 2006 to 2012, respectively. In table 13, we have made two assumptions: we consider an energy consumption for shunting activity of 288.69 TJ for the year 2012 (last year with available rail freight transport performance), and we assume that the shunting activity increases at a rate of 75% of the increase in rail freight transport performance. The last assumption is justified by the fact that the increase in freight transport is realized with more direct train connections than shunting activity, resulting in improved efficiency and therefore lower need for shunting activity (Vanherle et al., 2007).

Spielmann et al. (2007) estimate a diesel consumption of the shunting activity of 29.104 kJ/tkm, which is always lower than our estimations. Moreover, the energy consumption for shunting activity represents from 8.50% to 12.09% of the total energy consumption from the year 2006 to 2012, respectively. Vanherle et al. (2007) estimate that an 8.8% of the total energy consumed in rail freight transport is destined to shunting activity, which is approximate to our estimations from 2006 to 2009. While the results of energy consumption of the shunting activity showed in table 13 are only indicative, they bring out the importance of the shunting activity in the total energy consumption of rail freight transport.

Table 13 : Energy consumption of the shunting activity

Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Rail freight (millions tkm)	8442	8148	7882	5439	5729	5913	5220
Total energy consumption (TJ)	4939	4600	4664	3211	2813	2830	2387
Shunting activity (TJ)	419.89	408.83	398.74	298.26	310.03	317.44	288.69
Shunting activity (kJ/tkm)	49.74	50.18	50.59	54.84	54.12	53.69	55.31
Share of shunting activity in total energy consumption	8.50%	8.89%	8.55%	9.29%	11.02%	11.22%	12.09%

An improvement in the environmental impact of both cargo handling equipment and locomotives used in shunting activity in the intermodal terminals can be reached. For example, through the use of cleaner energy sources such as electricity or biodiesel and the control of direct emissions using cleaner engine technologies such as filters and catalysts. Furthermore, a greater energy efficiency could be achieved by optimizing the management systems in the intermodal terminals, which would allow lower waiting times for transport vehicles such as barges or lorries and more efficient in the transhipment processes using cargo handling equipment for example.

A strategic target to improve the rail market share in Belgium are ports. For example, in the port of Antwerp road transport was the main mode of transport for containers in 2015 with a 58% of the share, a 35% of container were transported by barge and a 7% by train (Antwerp Port Authority, 2016). It should be noted that inland waterways transport has been clearly chosen over rail. However, a shift from road to rail transport could be encouraged with the implementation of measures to promote the rail freight transport. Furthermore, a greater integration of the different transport modes, especially road-rail intermodal transport, would lead to an increase of the rail market share. The strong presence and competiveness of the inland waterways transport in Belgium makes it an alternative to road and rail freight transport.

3.5. Life Cycle Assessment of inland freight transport modes in Belgium

A LCA study comprises four stages. First, the goal and scope definition, which in this deliverable is to compare the environmental impacts of the different inland freight transport modes in Belgium (see figure 3). The functional unit chosen is "one tonne-kilometre of freight transported". The second stage of a LCA is the inventory analysis, collecting data directly from Infrabel and B-Logistics in the case of rail freight transport and complementing the information using the Ecoinvent V3.1 database. The model used in Ecoinvent V3.1 has been adapted to the Belgian situation in the case of both inland waterways transport and road transport (using the calculated transport parameters of tonne-kilometres, load factor, payload, number of vehicles, and characteristics of infrastructures for example). **The information collected from Infrabel and B-Logistics has not been fully modelled, therefore the results on LCA presented in this paper are subject to a degree of uncertainty**. Therefore, a more detailed study of impact assessment will be carry out in the future. The third stage is the impact assessment. All calculations were made with the SimaPro 8.0.5 software using the Life Cycle Impact Assessment (LCIA) method "ILCD 2011 Midpoint+" (version V1.06 / EU27 2010), which is the method recommended by the European Commission (European Commission, 2010). "ILCD 2011 Midpoint+" is a midpoint method including 16 environmental impact indicators. The fourth stage is the assessment of the results obtained in the previous stage.

Figure 4 compares the results on LCIA of different modes of rail freight transport in Belgium (year 2012) and the reference values from Ecoinvent v3 (year 2014). Since each environmental impact indicator is expressed in different units, and to facilitate the interpretation of the LCIA results, all the scores of an indicator have been divided by the highest score of the indicator, which represents the maximum impact of the indicator. Therefore, the lowest value represents de mode of transport with less impact and the highest value represents the maximum impact.

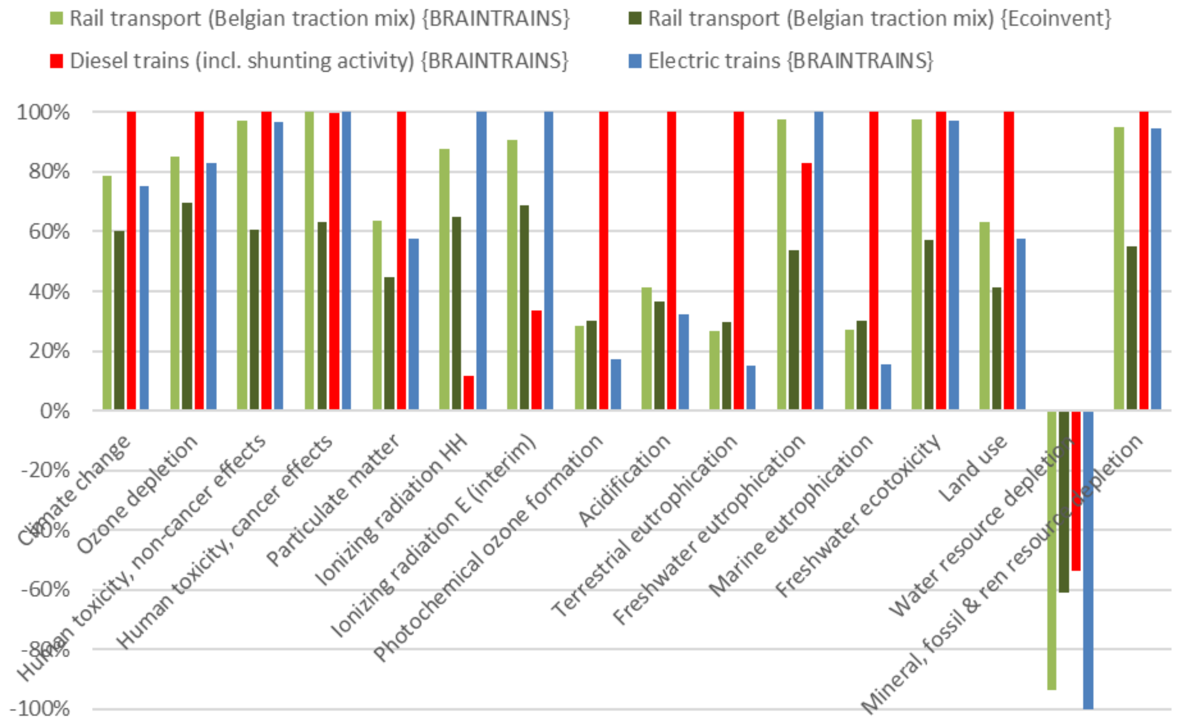


Figure 4 : LCIA of rail freight transport in Belgium in 2012

Diesel trains (including shunting activity) present the maximum impact in 11 indicators. It should be noted the high difference in comparison with the other rail freight transport modes due to the exhaust emissions produced in the diesel locomotives in the following indicators: photochemical ozone formation, acidification and terrestrial and marine eutrophication.

For the indicator climate change, diesel trains present the maximum impact due to the exhaust emissions during the transport activity. Even if the electric traction emits SF_6 during electricity conversion at traction substations, the main greenhouse gas emissions are produced in the electricity generation, especially in the natural gas power plants.

Electric trains present the maximum impact in the indicators related with the radiation due to the use of a 42% of nuclear power in the electricity production in Belgium in 2012 (Eurostat, 2015). The indicator "Human toxicity, cancer effects" shows similar values in the three rail freight transport modes studied due to the similar steel demand in the railway construction.

The negative score in the indicator water resource depletion indicates that water has been emitted or returned to the environment, becoming a positive impact. The emission of water to the environment is produced in the electricity generation at the natural gas power plant. However, this results should be interpreted with caution due to the uncertainty of the methodology.

Figure 5 shows a comparison of the results on LCIA of different modes of inland freight transport in Belgium (year 2010) and the reference values from Ecoinvent v3 (year 2014).

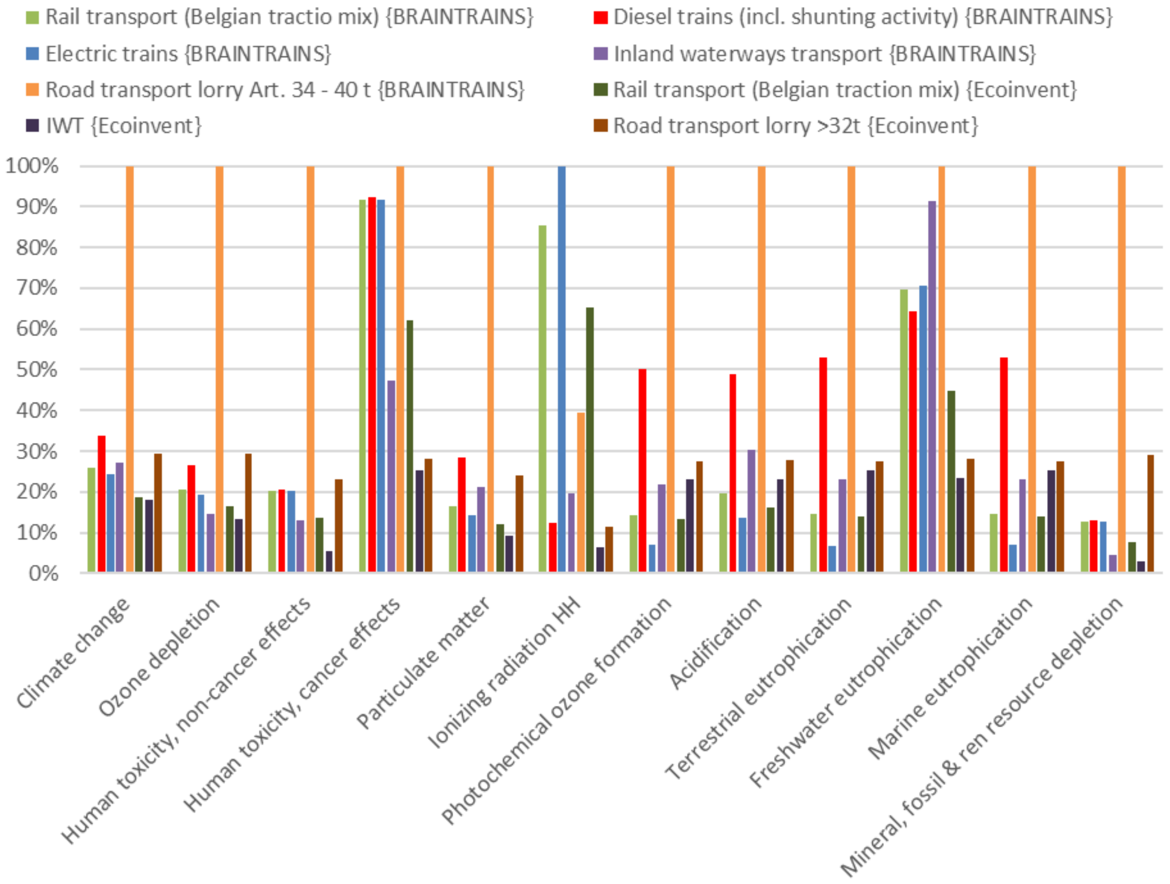


Figure 5 : LCIA of inland freight transport in Belgium in 2010

Road transport presents the maximum impact in all the indicators except the indicator ionizing radiation. The electric trains present the maximum impact in this indicator due to the use of nuclear power in the electricity generation in Belgium.

The exhaust emissions calculated during the road transport activity have caused the high difference in comparison with the other transport modes in the following indicators: climate change, photochemical ozone formation, acidification and terrestrial and marine eutrophication. Road transport presents an elevated fuel consumption and this, together the low load factor, has caused the high exhaust emissions of road freight transport.

For the indicator particulate matter, the direct emissions in the road transport activity of tire wear, break wear and road wear have a strong influence in the result of the indicator.

Focusing on the inland waterways transport, it presents a high impact in the indicators human toxicity, cancer effects and freshwater eutrophication. This is the result of the infrastructure demand of canals and port facilities.

4. Conclusion

The aim of the BRAIN-TRAINS project is to analyse the current situation of intermodal transport in Belgium to allow policymakers to take decisions for the development of intermodal transport. Some relevant factors that might influence the possible development of rail transport are the improvement of both rail infrastructure and interoperability between rail networks of different countries acting on the infrastructure, signalling, traffic management and rolling stock that lead to higher speed of rail freight transport. Alternatively, policy measures that promote a modal shift from road transport to rail transport such as subsidies for rail transport, road pricing or environmental zoning could be applied. Particularly, all this measures could allow a development of rail freight transport in long distances (Den Boer et al., 2011).

The energy efficiency in the railway sector, and therefore its competiveness, will improve in the future. Some points to improve the efficiency of the rail freight transport will be the weight reduction through new materials of locomotives and wagons. This would allow the saving of the energy consumed during transport activity, but also energy consumed in the manufacture and disposal of rail vehicles. Moreover, the development of new engines for locomotives more energy-efficient and with more restrictive emissions standards, the energy recovery systems from braking, the energy-efficient driving through the control of speed and improved aerodynamics in rolling stock, will lead to a reduction in the energy consumption.

The use of cleaner energy such as electricity from renewable sources or replacing diesel by other sources of cleaner energy as biodiesel, will lead to the reduction of environmental impacts. It should be noted that the use of biodiesel produces advantages in terms of CO_2 emissions, but analysing the life cycle of the biodiesel the pollution could be transferred from air when combustion to soil and water during crop production. Therefore, the environmental advantages of the use of biodiesel depend on the specific type and source of the biodiesel.

Inland waterways transport is the most energy-efficient mode of inland freight transport. It represents the least energy consuming mode of transport in our study, but also in both the EcoTransIT (2008) and Ecoinvent databases. Within rail freight transport, electric traction has the lowest energy consumption, while diesel traction has the highest. The Belgian traction mix, which includes a combination of electric and diesel traction, achieves an intermediate consumption, but closer at the energy consumption of the electric traction due to its highest share of the Belgian traction mix. As mentioned above, the values of energy consumption in road transport of our study are much higher than the reference values, because the load factors considered in our study are lower. In order to improve the results of our study, we will proceed to collect data from road freight operators involved in intermodal transport and use sensitivity analysis. Moreover, the methodology will be improved in the future with the inclusion in the model of information relative to the Belgian railway infrastructure and the rail equipment used in Belgium.

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