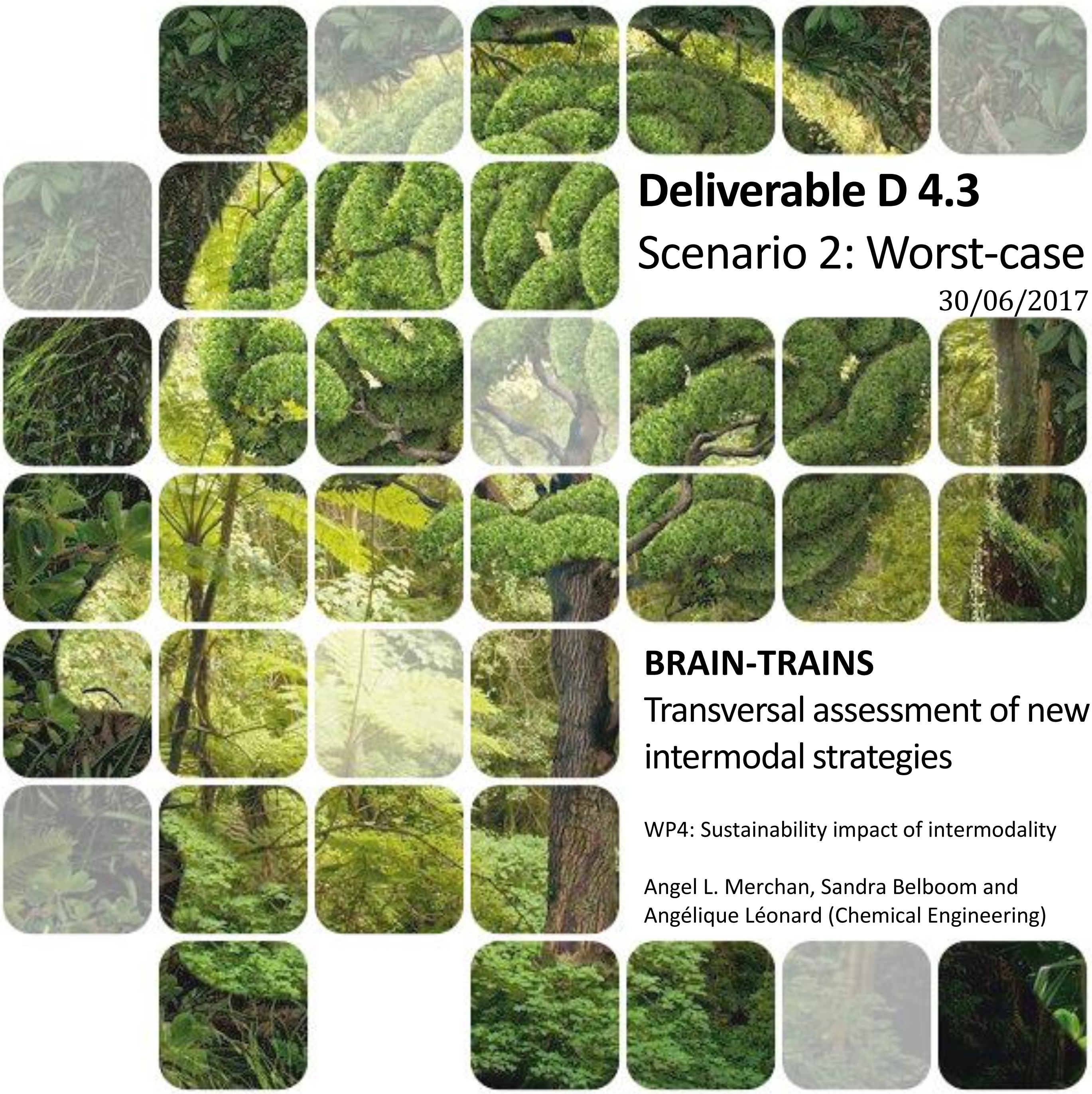
BRAINTRAINS

LIÈGE université 2000 · University of Antwerp

Belgian Science Policy Office

belspo

BELGIAN RESEARCH ACTION THROUGH INTERDISCIPLINARY NETWORKS



Deliverable D 4.3

Scenario 2: Worst-case

30/06/2017

BRAIN-TRAINS

Transversal assessment of new intermodal strategies

WP4: Sustainability impact of intermodality

Angel L. Merchan, Sandra Belboom and Angélique Léonard (Chemical Engineering)

CONTENTS

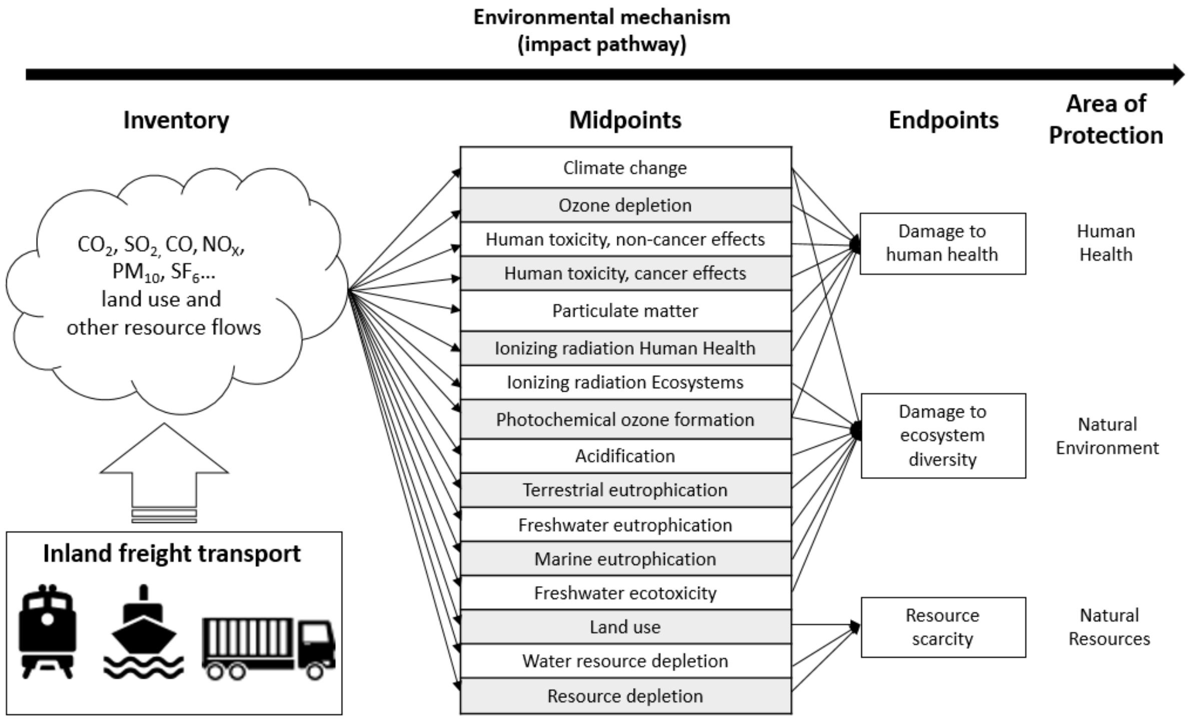
1. INTRODUCTION

Within the framework of the BRAIN-TRAINS project, a SWOT analysis was performed to identify the current state of the intermodal rail freight transport in Belgium. A final selection of 17 SWOT elements according to the impact and likelihood of happening in the future has been achieved (Vanelslander et al., 2015). Furthermore, three divergent Belgian scenarios with a time frame set in the year 2030 have been built for further analysis. These scenarios are directly linked to the third strategic goal of the European Commission's White Paper on transport (2011), which aims to shift the 30% of road freight over 300 km to other modes such as rail transport by 2030. As a result, a best, worst and medium case scenarios have been developed, depending on whether the 30% shift will have been successfully accomplished, the status quo will have been maintained or the goal will not have been completely reached by 2030, respectively (Troch et al., 2015).

The 17 SWOT elements have been translated into clear and measurable parameters for the scenario development, defining for every parameter an input value to quantify the scenarios. Moreover, all processes are analysed in the same unit of measurement, chosen as "tonne-kilometre (tkm)", which represents the transport of one tonne of goods over a distance of one kilometre. One of the selected elements from the SWOT analysis is the "strength of rail transport to reduce costs and externalities". This element contains five measurable parameters, four being related to the environmental aspect of the rail freight transport: transport emissions (CO_2 emissions and other emissions), energy consumption and noise exposure (Vanelslander et al., 2015).

The Life Cycle Assessment (LCA) methodology has been chosen to analyse the environmental impact of the inland freight transport in Belgium, including rail freight transport, inland waterways transport and road transport. The LCA methodology allows studying complex systems like freight 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, the LCA methodology allows modelling in a quantitative and multi-criteria way the environmental impacts of all relevant pollutant emissions and energy and material consumptions in numerous midpoint environmental impact categories, such as climate change, resource depletion, acidification, human toxicity or ecotoxicity for example. Then, as can be seen in figure 1, 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 1. DIAGRAM OF THE LIFE CYCLE IMPACT ASSESSMENT METHODOLOGY APPLIED ON RAIL TRANSPORT

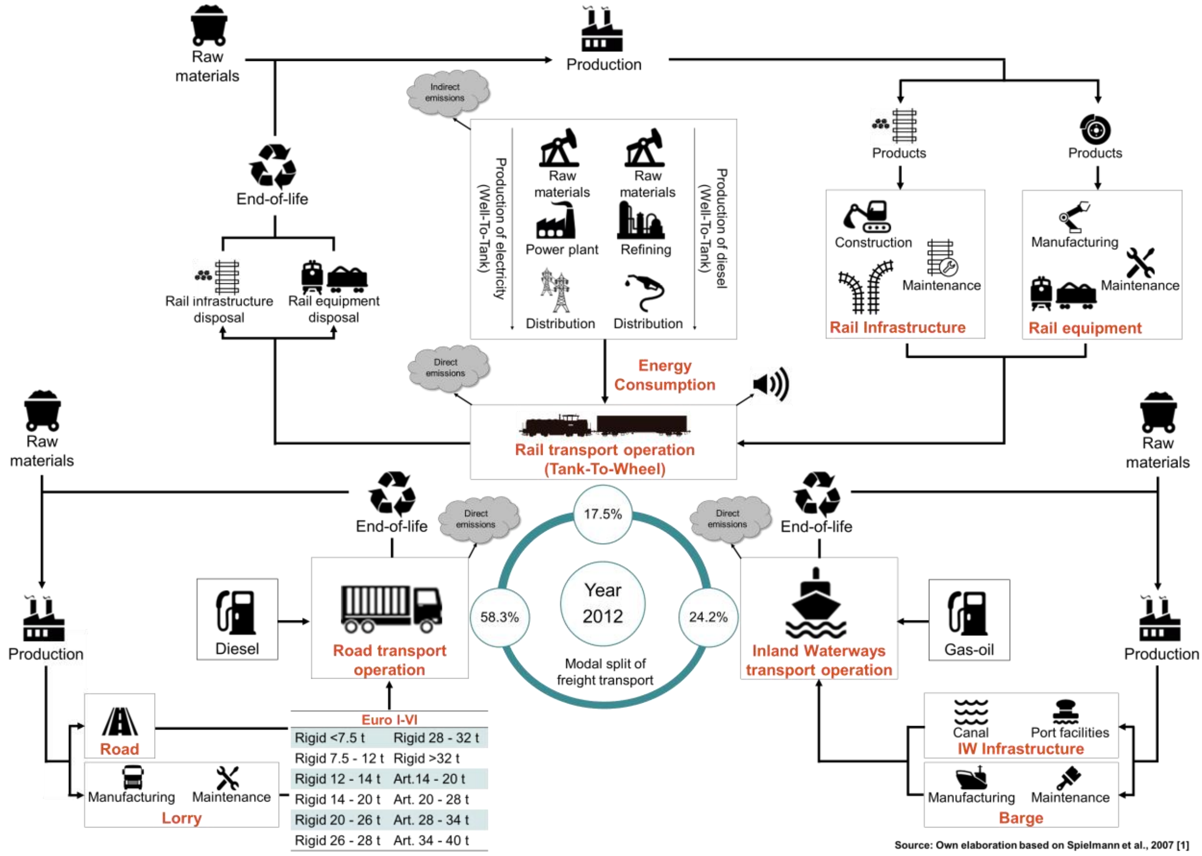


SOURCES: EUROPEAN COMMISSION, 2010 AND SALA ET AL., 2012

Figure 2 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. 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.

FIGURE 2. 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.

In a first stage we have analysed the environmental impacts of rail freight transport, inland waterways transport and road freight transport independently. Furthermore, a comparison between the environmental impacts of these inland freight transport modes has been performed. The first results in energy consumption, direct emissions and impact assessment have been explained in the deliverable D.4.2 of the BRAIN-TRAINS project (Merchan et al., 2017). In the present deliverable, the results in rail freight transport and road freight transport from the deliverable D.4.2 have been revised. This is because the information collected from Infrabel on railway infrastructure has been fully modelled, and the values of energy consumption in road transport have been updated (the load factors have been increased, causing a decrease in energy consumption).Since the BRAIN-TRAINS project deals with the possible development of intermodal rail freight transport in Belgium, in a second stage we have carried out a study of the environmental impacts related to intermodal rail freight transport. For this, we have analysed two consolidated intermodal rail-road routes in Belgium from the Port of Antwerp to the Port of Zeebrugge and Kortrijk. Moreover, a third intermodal route has been analysed. In collaboration with Terminal Container Athus, we have collected data of the intermodal rail-road route from the Port of Antwerp to Terminal Container Athus. Furthermore, detailed information on energy consumption for the handling of containers in the intermodal terminal of Terminal Container Athus has been collected as well.

The purpose of this deliverable is twofold: to discuss the updated results in rail freight transport and road freight transport from the deliverable D.4.2, and to analyse the results obtained from the study of the environmental impacts of the three intermodal routes using the LCA methodology.

2. INLAND FREIGHT TRANSPORT IN BELGIUM

2.1. Rail freight transport

The methodology to calculate the energy consumption of the rail freight transport in Belgium has been explained in the deliverable D.4.2 of the BRAIN-TRAINS project (Merchan et al., 2017).

The specific energy consumption during the rail transport activity of electric and diesel trains has been determined using data from the National Railway Company of Belgium (SNCB) such as 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. This data includes the energy consumed by trains, such as the empty returns, shunting activity, maintenance of trains, as well as electrical losses in the catenary system (SNCB, 2009; SNCB, 2013 and SNCB, 2015). Moreover, information on the rail freight traction share from the Flemish Environment Agency (VMM, 2005, 2006, 2007, 2008, 2009, 2010, 2012, 2013 and 2014) 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.

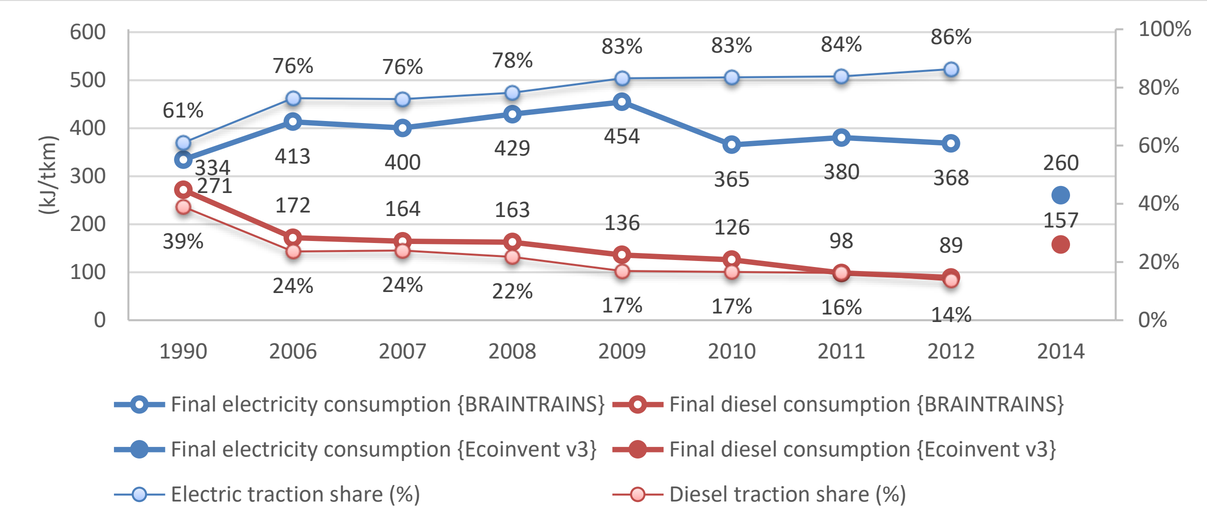
Table 1 shows the values of energy consumption of electric and diesel trains calculated in our study from the period 2006 to 2012. By comparing the reference values used in EcoTransIT (2008) of 456 kJ/tkm for electric traction and 530 kJ/tkm for diesel traction with the energy consumptions obtained in our study, for the year 2006 (which is the year with available data closest to EcoTransIT study) our results for Belgium show higher energy consumptions with 541 kJ/tkm and 725 kJ/tkm of electricity and diesel (including shunting activity) consumed, respectively. It should be noted that the reference values represent European averages, whereas our results represent a Belgian average. Moreover, the values of energy consumption from EcoTransIT comprise both the final energy consumption during transport operation and the energy consumption of the generation of diesel and electricity (EcoTransIT, 2008).

TABLE 1 : 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

The final electricity and diesel consumed for goods transport in figure 3 is calculated using the specific energy consumption of electric and diesel trains (see table 1) and the electric and diesel traction share from the Flemish Environment Agency (VMM). 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. The results of our study show that, in 2012, 368 kJ of electricity and 89 kJ of diesel 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. 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.

FIGURE 3. FINAL ELECTRICITY AND DIESEL CONSUMPTION OF RAIL FREIGHT TRANSPORT IN BELGIUM

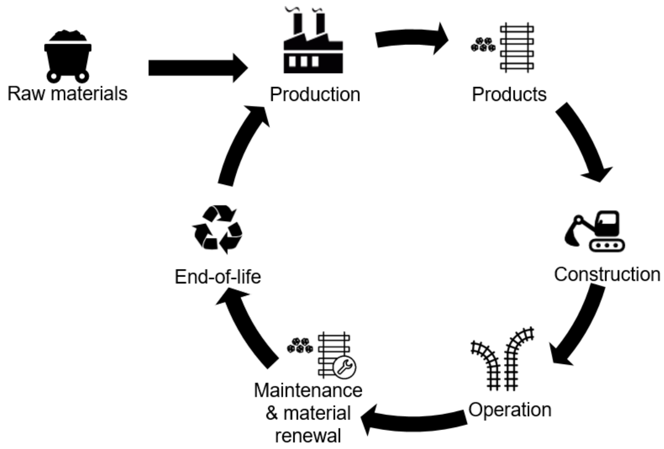


Three types of direct emissions produced during the rail transport operation can be distinguished: the exhaust emissions to air related to the diesel combustion in locomotives, the direct emissions to soil from abrasion of brake linings, wheels and rails and the sulphur hexafluoride (SF_6) emissions to air during conversion of electricity at traction substations. These direct emissions have been calculated using the emission factors of Spielmann et al. (2007). Therefore, the exhaust emissions of diesel trains and the SF_6 emissions of electric trains have been obtained using the diesel and electricity consumption, respectively. To determine particle emissions, it is necessary to add the particles produced by the abrasion of wheels and rails to those produced by the combustion of diesel. The direct emissions of rail freight transport (Belgian traction mix of diesel and electric traction), diesel trains and electric trains are in APPENDIX I.

2.1.1. Railway infrastructure

A detailed analysis of the Belgian railway infrastructure has been carried out. As showed in figure 4, the subsystem rail infrastructure includes the processes that are connected with the construction, maintenance and disposal of the railway infrastructure.

FIGURE 4. LIFE CYCLE ASSESSMENT OF THE RAILWAY INFRASTRUCTURE



We have collected data from Infrabel and literature sources relative to the Belgian railway infrastructure. This comprises information on the materials and energy used in the construction of the railway network (including track, tunnels and bridges) such as rails, sleepers, fastening systems, switches and crossings, track bedding or overhead contact system for example.

The maintenance of the Belgian railway infrastructure has been analysed as well. Therefore, the maintenance works such as rail grinding, rail renewal, sleeper and fastening system renewal, switches and crossing renewal, ballast tamping, ballast renewal, ballast cleaning and weed control are taken into account. We have considered in the maintenance of railway infrastructure both the fuel consumption and exhaust emissions from the machinery used in the maintenance and the new materials used in the track renewal.

We have also included in our study the end-of-life of the railway infrastructure and the land use in the Belgian railway network. Most of the elements are recycled such as the ballast that is reused as material for backfill and the wooden sleepers that are incinerated with energy recovery

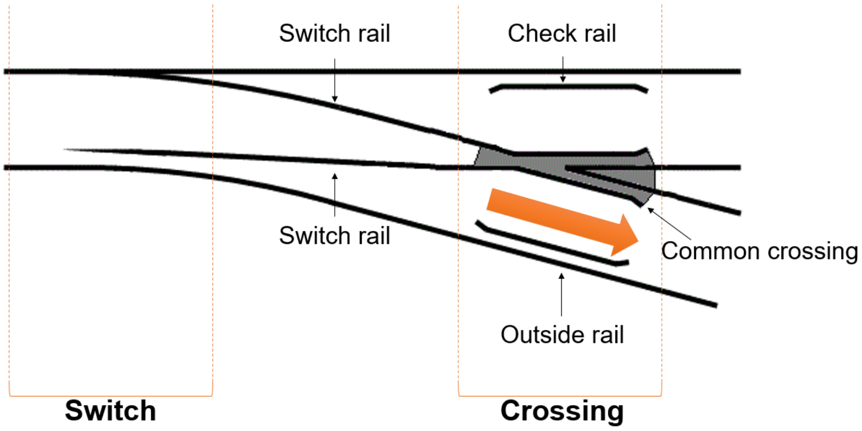
Since the railway infrastructure is shared between passenger and freight transport, an allocation of the environmental impacts related with the construction, maintenance and disposal of infrastructure has to be performed. On the one hand, the allocation of construction and disposal of the rail infrastructure has been calculated using the transport performance (tkm) and operating performance (Gtkm) for goods and passenger transport in Belgium. It should be noted that data on traction performance (GGtkm) is not available. On the other hand, the allocation of operation and maintenance of the rail infrastructure has been calculated using the transport performance (tkm) and kilometric performance (train-km) for goods and passengers transport in Belgium.

The Belgian railway network has 132 tunnels and 4800 bridges. The material demand from tunnel and bridge construction in the Belgian railway network has been calculated multiplying the share of tunnels and bridges by the obtained material demand of tunnel and bridge construction.

We have considered two main types of rails profiles in our study, the rail 50E2 and the rail 60E1. The distance between sleepers stated by Infrabel for the Belgian railway network in continuous welded rails 50E2 and 60E1 in main lines is 0.6 m, thus an average of 1.67 sleepers per metre is used. For continuous welded rails 50E2 in side lines, the sleepers are installed at 0.75 m spacing, thus an average 1.3 sleeper per metre is used (Infrabel, 2007). The Belgian railway network presented in the year 2010 a ratio between wooden and concrete sleepers in the main tracks of 21% and 79%, respectively. For side tracks, the rate was a 65% of wooden sleepers and a 35 % of concrete sleepers. In the switches, the distribution was a 95% of wooden sleepers and a 5% of concrete sleepers (UIC, 2013). The greater use of wooden sleepers in the switches is due to the flexibility of wooden sleepers to create custom-made sleepers (IBGE, 2011). Infrabel uses several techniques to fix the rails to the sleepers. The most representative elements of the fastening system have been identified for every method, such as clips for attachment, bolts, screw spikes and base plates for wooden sleepers, and rubber pad for concrete sleepers.

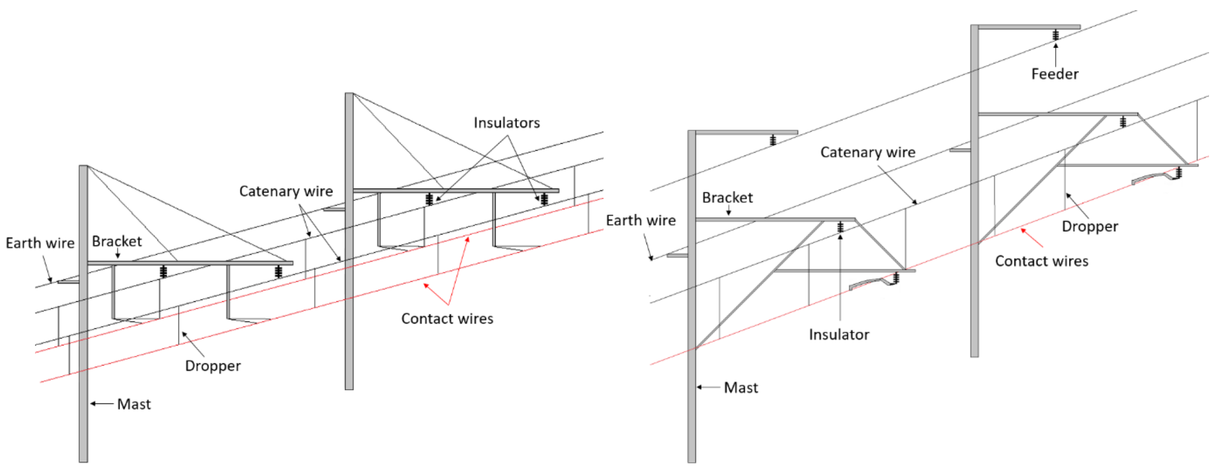
The switch and crossing systems play a key role in the connections between different tracks, establishing a railway network that allows the rail transport. The most relevant parts of the switch and crossing system considered in our study are showed in figure 5.

FIGURE 5. SWITCH AND CROSSING SYSTEM



Three main types of overhead contact line systems have been identified in the Belgian railway network. The main overhead contact lines have a power supply of 3 kV DC, which includes the type compound and the type R3. The overhead high speed contact lines have a power supply of 25 kV AC. The most relevant parts of the overhead contact lines considered in our study are showed in figure 6.

FIGURE 6. EXAMPLES OF OVERHEAD COMPOUND LINES (LEFT) AND OVERHEAD R3 LINES (RIGHT)



2.2. Inland waterways transport

The methodology to calculate the energy consumption of the inland waterways transport in Belgium has been explained in the deliverable D.4.2 of the BRAIN-TRAINS project (Merchan et al., 2017).

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 Wallonie, 2014). It has been aggregated using the total carrying capacity of each vessel class by year (ITB - Instituut voor het Transport langs de Binnenwateren / Institut pour le Transport par Batellerie) from the period 2006 to 2012 as allocation factor.

Table 2 shows the average fuel consumption of inland waterways transport calculated from the period 2006 to 2012. If we compare the energy consumptions for inland waterways transport obtained in our study with the reference values extracted from EcoTransIT (2008) and Ecoinvent v3 database, our results show lower energy consumptions. Thereby, 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. In the case of Ecoinvent v3 database, the energy consumption for inland waterways transport for the year 2014 is 402 kJ/tkm. It should be noted that the reference values represent European averages, whereas our results represent a Belgian average.

TABLE 2. AVERAGE FUEL CONSUMPTION OF INLAND WATERWAYS TRANSPORT OF DRY BULK IN BELGIUM

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

[1]CONSIDERING THAT DIESEL NET CALORIES ARE 42.8 MJ/KG

The exhaust emissions produced by the combustion of the gas-oil in the barges have been calculated using the emission factors of Spielmann et al. (2007) and the calculated fuel consumption. The direct emissions of inland waterways transport are in APPENDIX I.

2.3. Road transport

The methodology to calculate the energy consumption of road transport in Belgium has been explained in the deliverable D.4.2 of the BRAIN-TRAINS project (Merchan et al., 2017). However, the values of energy consumption in road transport obtained in our study were much higher than the reference values of EcoTransIT (2008) and Ecoinvent v3 database, because the load factors considered in our study were lower. The load factors used from the TRACCS database (Papadimitriou et al., 2013) ranged from 23.3% in 2005 to 17.4% in 2010. Thereby, an average energy consumption from 2142 kJ/tkm in 2005 to 2845 kJ/tkm in 2010 was obtained for road transport, and from 1837 kJ/tkm in 2005 to 2447 kJ/tkm in 2010 for an articulated lorry of 34-40 t. In order to address this issue, we have decided to use the load factor for an average cargo in road transport including empty trips of 50% from EcoTransIT (2008). As a result, the energy consumption of road transport has decreased.

The average fuel consumption during the road freight transport activity has been determined using the average diesel consumption (g/km) in Belgium and the maximum payload from the TRACCS database (Papadimitriou et al., 2013) showed in table 3.

TABLE 3. FUEL CONSUMPTION (G/KM) OF ROAD FREIGHT TRANSPORT IN BELGIUM

Heavy Duty Lorry	Fuel Consumption (g/km)						Maximum Payload (t/vehicle)
	2005	2006	2007	2008	2009	2010	
Rigid <7.5 t	109	109	109	109	109	109	2
Rigid 7.5 - 12 t	146	146	145	146	146	146	5
Rigid 12 - 14 t	153	154	154	154	154	154	7
Rigid 14 - 20 t	179	179	178	178	178	178	9.7
Rigid 20 - 26 t	215	214	213	213	213	213	13.7
Rigid 26 - 28 t	226	226	226	225	225	225	16.4
Rigid 28 - 32 t	260	260	260	260	260	260	18.4
Rigid >32 t	255	254	253	253	253	253	19.7
Art. 14 - 20 t	172	171	170	170	170	170	12.6
Art. 20 - 28 t	215	213	212	212	212	212	17.1
Art. 28 - 34 t	225	223	222	222	222	222	21.5
Art. 34 - 40 t	254	253	252	252	252	251	25.3

SOURCE: TRACCS DATABASE (PAPADIMITRIOU ET AL., 2013)

The energy consumption from the TRACCS database have been converted from g/km to g/tkm dividing by the actual payload of each lorry gross vehicle weight (GVW) class (see table 4). The actual payload of each lorry GVW class has been calculated multiplying the maximum payload by a load factor. Three scenarios with different load factors of 50%, 60% and 85% have been studied. It should be noted that the fuel consumption in g/km increases with the size of the lorry, but in g/tkm decreases with the size of the lorry. This is due to increased payload with the GVW category.

TABLE 4. ACTUAL PAYLOAD AND FUEL CONSUMPTION (G/TKM) OF ROAD TRANSPORT USING THE LOAD FACTORS (LF) OF 50%, 60% AND 85%

Heavy Duty Lorry	Actual Payload (t/vehicle)			Fuel consumption (g/tkm)		
	LF 50%	LF 60%	LF 85%	LF 50%	LF 60%	LF 85%
Rigid <7.5 t	1.01	1.21	1.72	108	90	64
Rigid 7.5 - 12 t	2.51	3.01	4.27	58	48	34
Rigid 12 - 14 t	3.51	4.22	5.97	44	36	26
Rigid 14 - 20 t	4.85	5.82	8.24	37	31	22
Rigid 20 - 26 t	6.85	8.22	11.65	31	26	18
Rigid 26 - 28 t	8.19	9.83	13.92	28	23	16
Rigid 28 - 32 t	9.19	11.03	15.62	28	24	17
Rigid >32 t	9.86	11.83	16.76	26	22	15
Art. 14 - 20 t	6.32	7.58	10.74	27	23	16
Art. 20 - 28 t	8.54	10.25	14.52	25	21	15
Art. 28 - 34 t	10.76	12.91	18.29	21	17	12
Art. 34 - 40 t	12.66	15.20	21.53	20	17	12

In order to do an average energy consumption for every year, the tonne-kilometres moved by each lorry GVW category have been used to calculate a weighted arithmetic mean. Table 5 shows the average energy 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 will be used to compare the different inland freight transport modes because it is representative.

TABLE 5. AVERAGE ENERGY CONSUMPTION OF ROAD FREIGHT TRANSPORT IN BELGIUM

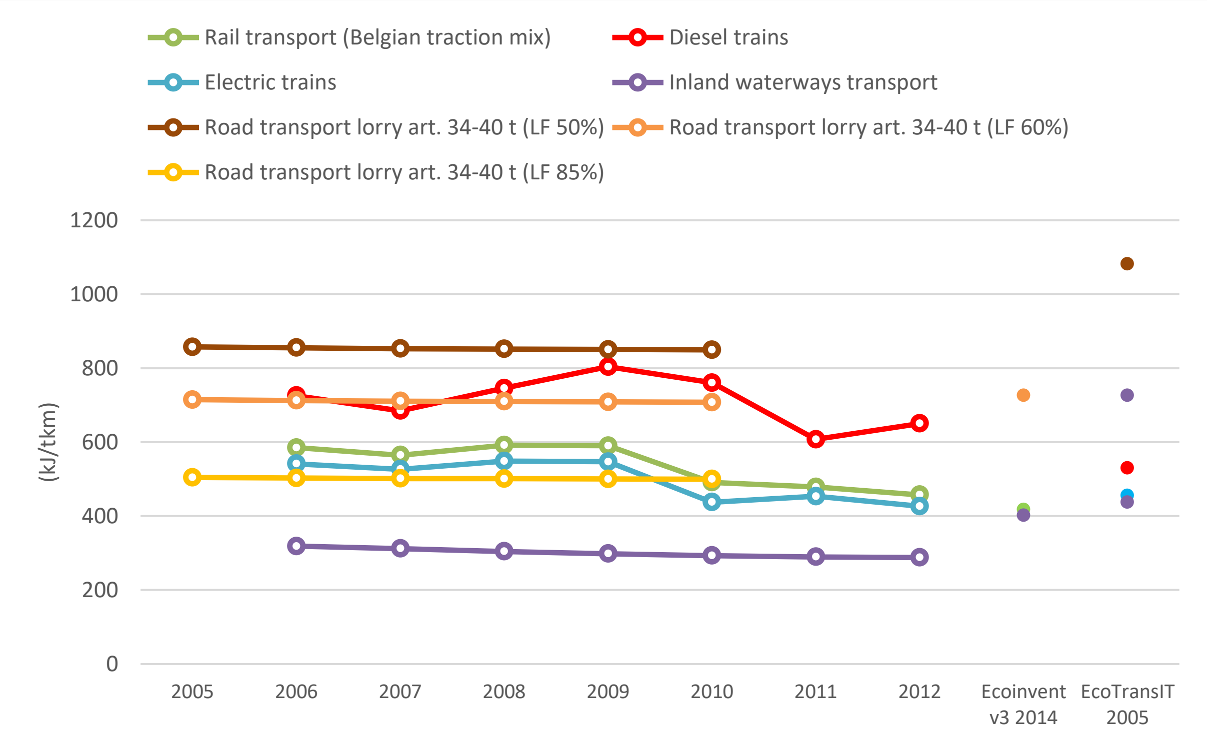
		Unit	2005	2006	2007	2008	2009	2010
Average road transport	Load factor 50%	(g/tkm)	23.37	23.28	23.19	23.07	23.10	23.08
		(kJ/tkm)	1000	996	993	987	989	988
	Load factor 60%	(g/tkm)	19.47	19.40	19.32	19.22	19.25	19.23
		(kJ/tkm)	833	830	827	823	824	823
	Load factor 85%	(g/tkm)	13.75	13.69	13.64	13.57	13.59	13.58
		(kJ/tkm)	588	586	584	581	582	581
Articulated lorry of 34-40 t	Load factor 50%	(g/tkm)	20.04	19.98	19.93	19.90	19.87	19.85
		(kJ/tkm)	858	855	853	852	850	849
	Load factor 60%	(g/tkm)	16.70	16.65	16.61	1659	16.56	16.54
		(kJ/tkm)	715	713	711	710	709	708
	Load factor 85%	(g/tkm)	11.79	11.75	11.72	11.71	11.69	11.68
		(kJ/tkm)	504	503	502	501	500	500

If we compare the energy consumptions for an articulated lorry of 34-40 t obtained in our study with the reference values extracted from EcoTransIT (2008), our results show lower energy consumptions. Thereby, the values used in EcoTransIT (2008) for an articulated lorry of 34-40 t for the year 2005 is 1082 kJ/tkm. In the case of Ecoinvent v3 database the energy consumption for a lorry of >32t Euro VI for the year 2014 is 727 kJ/tkm, which is between our results for and average road transport with a load factor of 60% and 85%. It should be noted that the reference values represent European averages, whereas our results represent a Belgian average.

Figure 7 shows a comparison of the energy consumptions obtained in the BRAIN-TRAINS project including the new results from road transport and the reference values from EcoTransIT (2008) and Ecoinvent v3 (years 2005 and 2014 respectively). As shown in figure 7, 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 database. 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.

Focusing on road transport, an articulated lorry of 34-40 t with a load factor of 50% presents the highest energy consumption among the different transport modes. However, with a load factor of 60%, it achieves a lower energy consumption than diesel trains for several years. Moreover, it shows similar values of energy consumption than Ecoinvent v3 database for a lorry of >32t Euro VI. An articulated lorry of 34-40 t with an 85% of load factor presents lower energy consumption than diesel trains. Furthermore, it presents a lower energy consumption than freight trains (Belgian traction mix) and electric trains until the year 2010, when an improvement in the energy efficiency of the electric trains occurs.

FIGURE 7. ENERGY CONSUMPTIONS (KJ/TKM) OF INLAND FREIGHT TRANSPORT MODES IN BELGIUM



The exhaust emissions produced during the road transport operation have been determined using the calculated diesel consumption and the emission 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 (CO, NMVOC, NO_x, N_2O, NH_3 and $PM_{2.5}$ for example) have been used the tier 2 emission factors from EMEP/EEA air pollutant emission inventory guidebook 2013 (Ntziachristos et al., 2014). The direct emissions of road transport are in APPENDIX I.

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.

Since the emissions related to the engine technology are dependent on the lorry GVW category as well, 48 different types of lorries have been considered in the year 2005 (12 lorry GVW categories split in 4 emission engine technologies), 60 different types of lorries have been taken into account in the years from 2006 to 2008 and 72 different types of lorries have been included in the years 2009 and 2010. In order to determine an average emission for every year, the tonne-kilometres moved by each lorry GVW category and emission engine technology have been used to calculate a weighted arithmetic mean. The methodology is the same as the one used in the energy consumption.

2.4. Life Cycle Assessment of inland freight transport 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 2). 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 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.

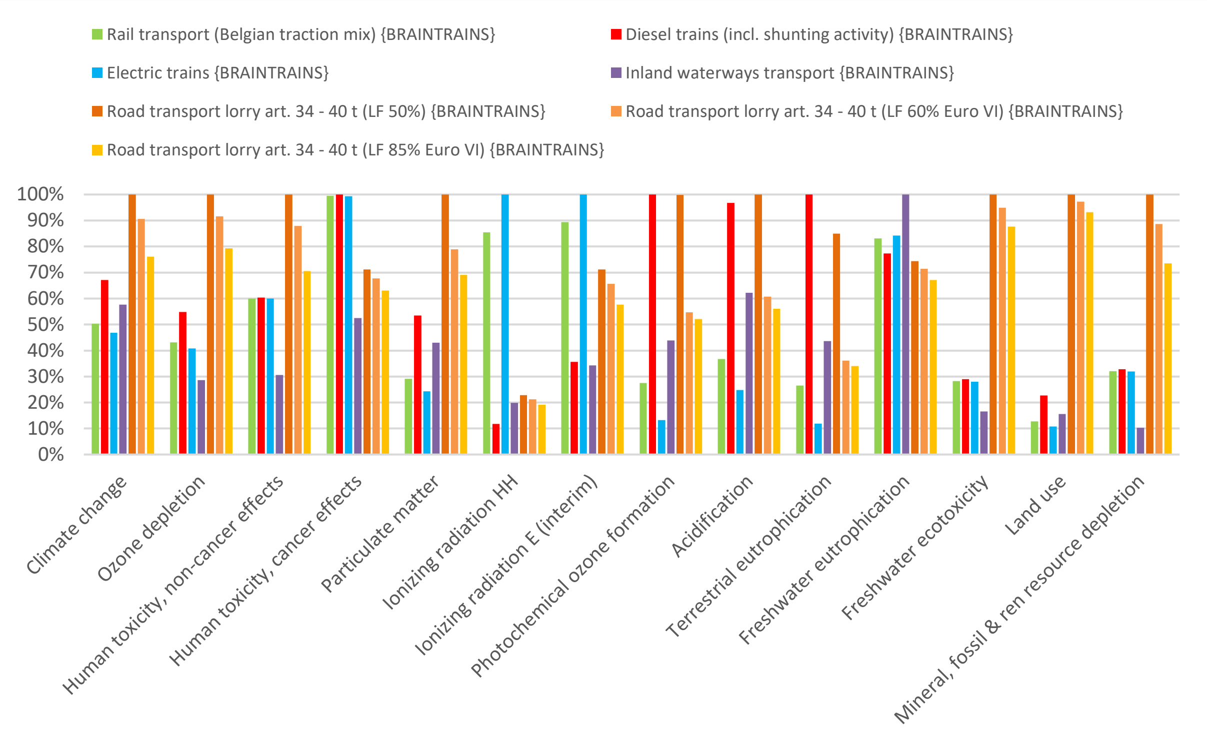
The results with the current LCIA of the different rail freight transport modes are in APPENDIX II. For the LCIA of the Belgian rail freight transport, all life cycle phases of rail freight transport operation (including the calculated electricity supply mix in Belgium corresponding to the appropriate year), the current analysis of the Belgian railway infrastructure, and the rail equipment are taken into account. Similarly, for the LCIA of inland waterways transport, all life cycle phases of inland waterways transport operation, inland waterways infrastructures (including canals and port facilities), and manufacturing and maintenance of the barge are included. For the LCIA of road transport, all life cycle phases of road transport operation, road infrastructure, and manufacturing and maintenance of the lorry are included.

Figure 8 shows a comparison of the results obtained in the LCIA of different modes of inland freight transport in Belgium in 2010. 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.

Even if the emission engine technology Euro VI for lorries has not been included in our study because of it appears in the year 2014 in the Belgian heavy duty vehicle market, we have decided that it would be interesting to compare an articulated lorry of 34-40 t with an emission engine technology Euro VI with the other transport modes, including an average articulated lorry of 34-40 t. Moreover, the articulated lorry of 34-40 t Euro VI with the load factors of 60% and 85% will be used in the environmental impact assessment of the intermodal routes in section 3.

The articulated lorry of 34-40 t Euro VI has been developed using all the parameters of an articulated lorry of 34-40 t in the year 2010 but using the emission factors for an engine technology Euro VI for the pollutant emissions dependent on the engine emission technology. Within the articulated lorries of 34-40 t in Belgium in the year 2010, the lorries with an emission engine technology conventional represented the 13% of the Belgian market, the Euro I a 7%, the Euro II a 17%, the Euro III a 24%, the Euro IV a 23% and the Euro V a 16%.

FIGURE 8. LCIA OF INLAND FREIGHT TRANSPORT IN BELGIUM



Diesel trains present the maximum impact in the indicators photochemical ozone formation and terrestrial eutrophication due to the exhaust emissions produced in the diesel locomotives. Moreover, diesel trains show the maximum impact in the indicator “Human toxicity, cancer effects”, but with similar values than the other rail freight transport modes studied due to the similar steel demand in the railway infrastructure. Electric trains present the maximum impact in the two indicators related with the radiation due to the use of nuclear power in the electricity production in Belgium. Inland waterways transport presents the maximum impact in the indicator freshwater eutrophication due to the infrastructure demand of canals and port facilities.

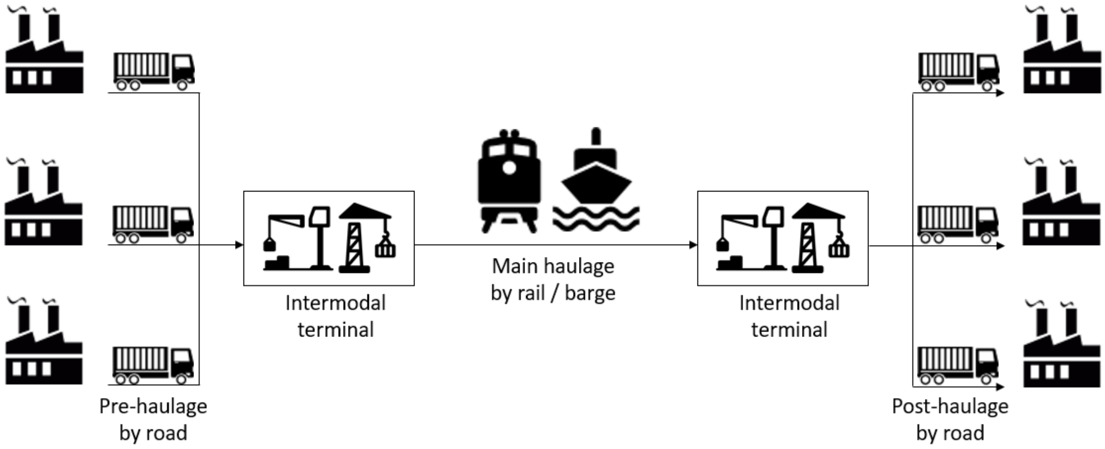
For the indicator climate change, road transport presents the maximum impact due to the exhaust emissions during the transport activity. Although with an 85% of load factor, road transport is near the diesel trains. Electric trains emits SF_6 during electricity conversion at traction substations, but the main greenhouse gas emissions are produced in the electricity generation, especially in the natural gas power plants.

The lorries Euro VI present a lower impact than the average road transport on the indicator particulate matter due to the lower exhaust emissions on $PM_{2.5}$ of the lorries Euro VI in comparison with the other engine technologies. Furthermore, 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. Similarly, for the indicator photochemical ozone formation, the lorries Euro VI present a lower impact than the average road transport due to the lower exhaust emissions on NMVOC of the lorries Euro VI. Moreover, for the indicators acidification and terrestrial eutrophication, the lorries Euro VI present a lower impact than the average road transport due to the lower exhaust emissions on NO_x of the lorries Euro VI.

3. INTERMODAL ROUTES IN BELGIUM

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 9, 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 9. EXAMPLE OF INTERMODAL FREIGHT TRANSPORT WITH MAIN HAULAGE



In order to analyse the environmental impacts related to intermodal rail freight transport, we have studied three consolidated intermodal rail-road routes in Belgium. Since the Port of Antwerp is the largest port in Belgium and the second in Europe in both total maritime freight volume and total tonnage and TEU (twenty-foot equivalent unit) of containers, the three intermodal routes of our study have the Port of Antwerp in common. These routes are “Port of Antwerp - Port of Zeebrugge”, “Port of Antwerp – Kortrijk” and “Port of Antwerp - Terminal Container Athus”. The purpose of this analysis is to compare the environmental impact of these intermodal routes depending on the freight transport mode chosen (rail or road transport) for the main haulage (major part of the intermodal route).

For the intermodal freight trains and lorries considered in the intermodal routes of our study the load factors of Janic (2008) have been used. A train load factor of 75% for intermodal freight trains has been considered. For intermodal road transport between intermodal terminals (main haulage) a load factor of 85% has been used, and for the post-haulage by road transport the load factor of 60% has been considered (Janic, 2008).

For the intermodal freight trains of the intermodal routes “Port of Antwerp - Port of Zeebrugge” and “Port of Antwerp - Kortrijk”, we have considered an average of 26 wagons per train with a capacity of 3 TEU per wagon, resulting in an average container unit capacity of 78 TEU per train. For road transport, a capacity of 2 TEU per lorry have been used. Therefore, 39 lorries are needed to transport the same amount of TEU than an average train. The average gross weight considered for the TEU is 14.3 t, including 2.3 t of the container weight and a load per container of 12 t (Janic, 2008).

Intermodal terminals are essential in the intermodal 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) and EcoTransIT (2008) estimate an energy consumption in the transhipment processes of 16560 kJ and 15840 kJ per TEU, respectively. In order to obtain the energy consumption for the transhipment of the 78 TEU considered in the intermodal routes of our study, an energy consumption of 16560 kJ per TEU has been used. Thus, for the transhipment of 78 TEU, an energy consumption of 1291680 kJ is obtained for the intermodal routes "Port of Antwerp - Port of Zeebrugge" and "Port of Antwerp - Kortrijk".

3.1. Intermodal route from the Port of Antwerp to the Port of Zeebrugge

As shown in figure 10, the intermodal connection between seaports "Port of Antwerp - Port of Zeebrugge" includes the processes of transhipment in the Port of Antwerp, the main haulage by train or by road and the transhipment in the Port of Zeebrugge.

FIGURE 10. INTERMODAL ROUTE "PORT OF ANTWERP - PORT OF ZEEBRUGGE"

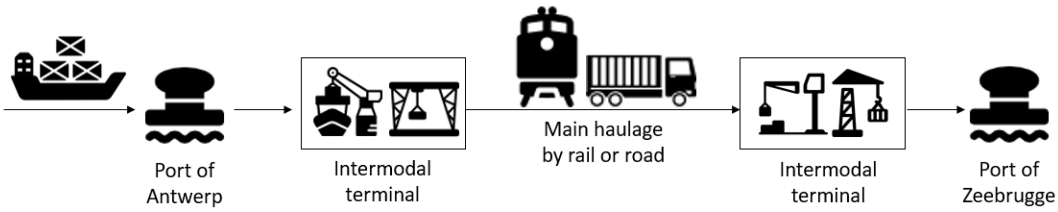


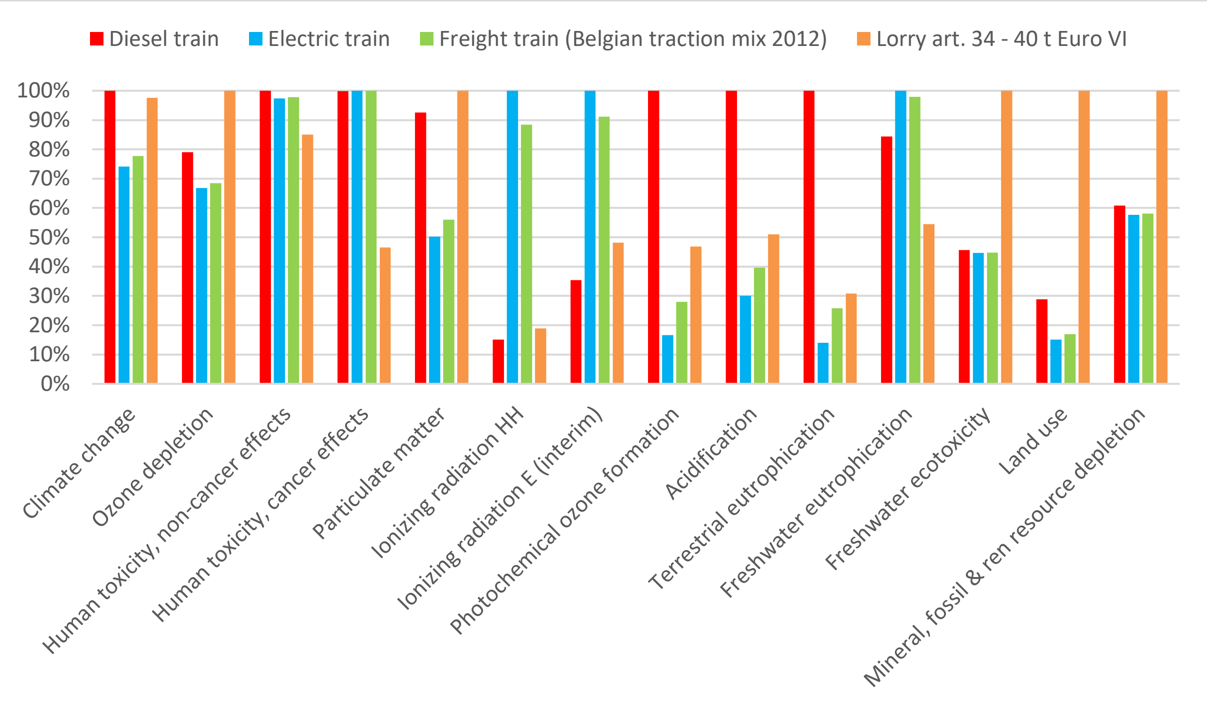
Table 6 shows the main characteristics of the intermodal route "Port of Antwerp - Port of Zeebrugge" using as mode of transport for the main haulage rail transport or road transport. As explained above, the energy consumption estimated for the transhipment of 78 TEU is 1291680 kJ. An average gross weight of 14.3 t/TEU for the 78 TEU transported has been considered and this, together with the load factors of 75% for freight trains and 85% for road transport, results in a tonnage total of 837 t per train and 948 t for the 39 lorries. The distances between the Port of Antwerp and the Port of Zeebrugge by train and by road have been calculated using EcoTransIT World (www.ecotransit.org).

TABLE 6. MAIN CHARACTERISTICS OF THE INTERMODAL ROUTE "PORT OF ANTWERP - PORT OF ZEEBRUGGE"

		Main haulage by train	Main haulage by road
1. Transhipment in the Port of Antwerp (kJ)		1291680	
2. Main haulage	Load factor	75%	85%
	Tonnage (t)	837	948
	Distance (km)	139.5	96.44
	Transport performance (tkm)	116699	91434
3. Transhipment in the Port of Zeebrugge (kJ)		1291680	

In order to determine the different environmental impacts produced depending on the choice of mode of transport for the intermodal route "Port of Antwerp - Port of Zeebrugge", we have performed an analysis considering the main characteristics showed in table 6. As shown in figure 11, four modes of transport have been chosen for the main haulage: a diesel train, an electric train, a freight train with the Belgian traction mix of 2012 and an articulated lorry of 34-40 t Euro VI. A comparison of the results obtained in the LCIA for the intermodal route “Port of Antwerp - Port of Zeebrugge” using different freight transport modes for the main haulage has been performed.

FIGURE 11. LCIA OF THE INTERMODAL ROUTE “PORT OF ANTWERP - PORT OF ZEEBRUGGE”



Diesel trains have the maximum impact in 5 indicators mainly as a result of the exhaust emissions. Electric trains show the maximum impact in 3 indicators, being two of them related with the radiation due to the use of nuclear power in the electricity production in Belgium. Moreover, electric trains show the maximum impact in the indicator “Human toxicity, cancer effects”, but with similar values than the other rail freight transport modes.

The articulated lorry of 34-40 t Euro VI presents the maximum impact in 6 indicators. For the indicator photochemical ozone formation, the articulated lorry of 34-40 t Euro VI have a lower impact than diesel trains due to the lower exhaust emissions on NMVOC of the lorries Euro VI. Similarly, for the indicators acidification and terrestrial eutrophication, the articulated lorry of 34-40 t Euro VI have a lower impact than diesel trains due to the lower exhaust emissions on NO_x of the lorries Euro VI.

3.2. Intermodal route from the Port of Antwerp to Kortrijk

As shown in figure 12, the intermodal route “Port of Antwerp - Kortrijk” includes the processes of transhipment in the Port of Antwerp, the main haulage by train or by road and the transhipment in the intermodal terminal of Kortrijk. Moreover, a post-haulage distance of 50 km by road with a load factor of 60% has been considered (Janic, 2008).

FIGURE 12. INTERMODAL ROUTE “PORT OF ANTWERP - KORTRIJK”

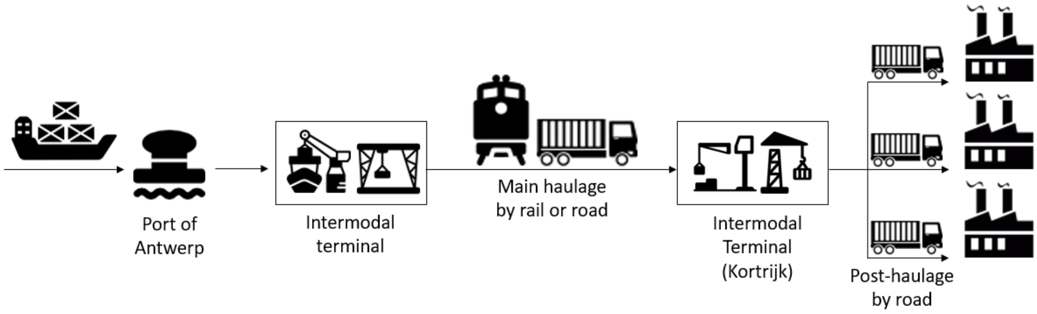


Table 7 shows the main characteristics of the intermodal route “Port of Antwerp - Kortrijk” using as mode of transport for the main haulage rail transport or road transport. As explained above, the energy consumption estimated for the transhipment of 78 TEU is 1291680 kJ. An average gross weight of 14.3 t/TEU for the 78 TEU transported has been considered and this, together with the load factors of 75% for freight trains and 85% for road transport, results in a tonnage total of 837 t per train and 948 t for the 39 lorries. The distances between the Port of Antwerp and Kortrijk by train and by road have been calculated using EcoTransIT World (www.ecotransit.org). For the post-haulage by road, a load factor of 60% has been used, resulting in a tonnage of 669 t.

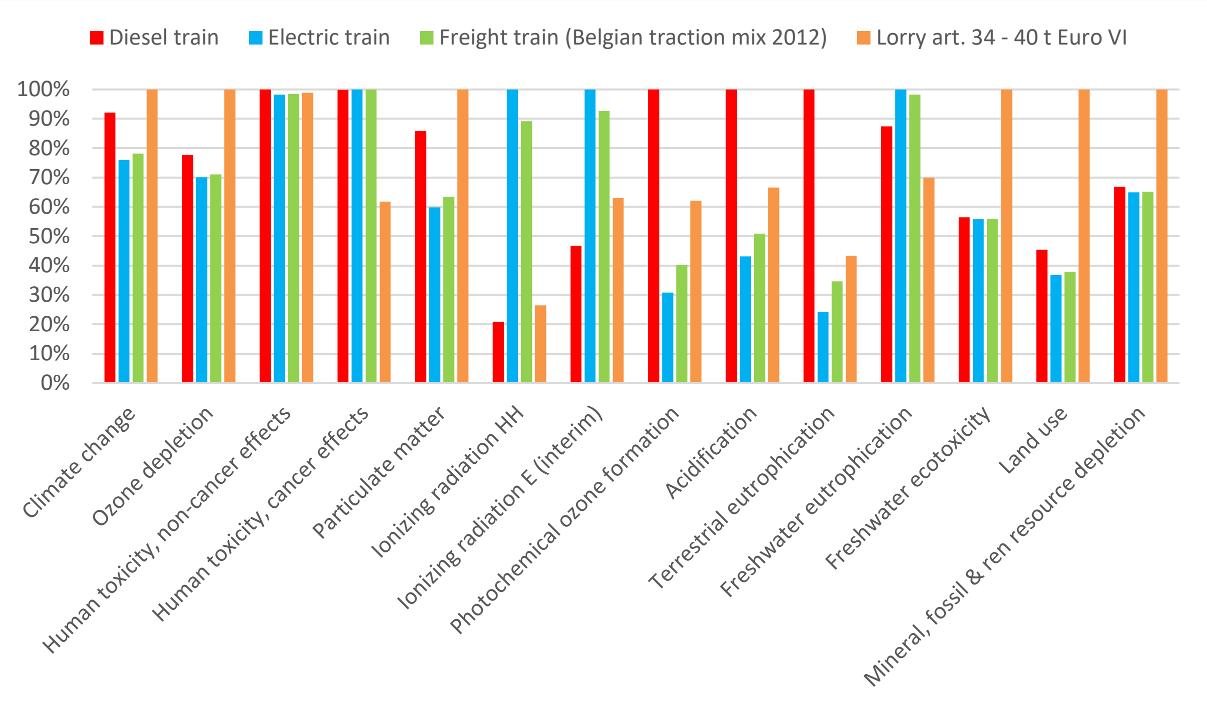
TABLE 7. MAIN CHARACTERISTICS OF THE INTERMODAL ROUTE “PORT OF ANTWERP - KORTRIJK”

		Main haulage by train	Main haulage by road
1. Transhipment in the Port of Antwerp (kJ)		1291680	
2. Main haulage	Load factor	75%	85%
	Tonnage (t)	837	948
	Distance (km)	122.25	97.97
	Transport performance (tkm)	102268	92884
3. Transhipment in the intermodal terminal (kJ)		1291680	
4. Post-haulage	Load factor	60%	
	Tonnage (t)	669	
	Distance (km)	50	
	Transport performance (tkm)	33462	

In order to determine the different environmental impacts produced depending on the choice of mode of transport for the intermodal route “Port of Antwerp - Kortrijk”, we have performed an analysis considering the main characteristics showed in table 7. Thereby, four modes of transport have been chosen for the main haulage: a diesel train, an electric train, a freight train with the Belgian traction mix of 2012 and an articulated lorry of 34-40 t Euro VI. We have considered for the post-haulage by road an articulated lorry of 34-40 t Euro VI.

As shown in figure 13, a comparison of the results obtained in the LCIA for the intermodal route “Port of Antwerp - Kortrijk” using different freight transport modes for the main haulage has been performed.

FIGURE 13. LCIA OF THE INTERMODAL ROUTE "PORT OF ANTWERP - KORTRIJK"



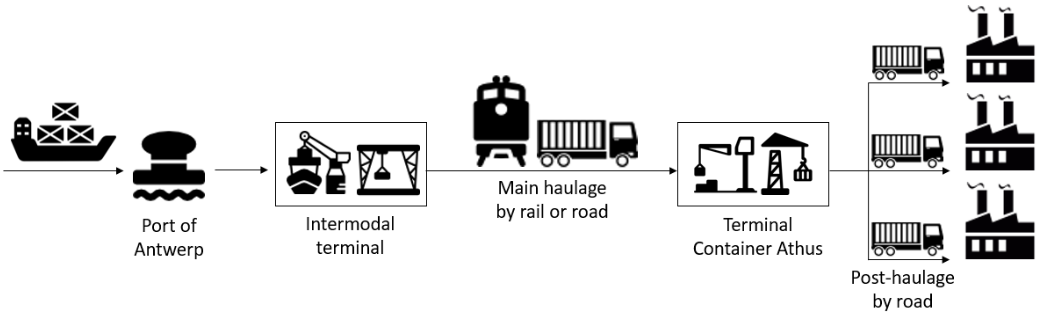
Diesel trains have the maximum impact in 4 indicators mainly as a result of the exhaust emissions. Electric trains show the maximum impact in 3 indicators, being two of them related with the radiation due to the use of nuclear power in the electricity production in Belgium. Moreover, electric trains show the maximum impact in the indicator "Human toxicity, cancer effects", but with similar values than the other rail freight transport modes.

The articulated lorry of 34-40 t Euro VI presents the maximum impact in 6 indicators. For the indicator photochemical ozone formation, the articulated lorry of 34-40 t Euro VI have a lower impact than diesel trains due to the lower exhaust emissions on NMVOC of the lorries Euro VI. Similarly, for the indicators acidification and terrestrial eutrophication, the articulated lorry of 34-40 t Euro VI have a lower impact than diesel trains due to the lower exhaust emissions on NO_x of the lorries Euro VI.

3.3. Intermodal route from the Port of Antwerp to Terminal Container Athus

In collaboration with Terminal Container Athus, we have collected data of the intermodal route "Port of Antwerp - Terminal Container Athus". Furthermore, detailed information on electricity and diesel consumption for the handling of containers in the intermodal terminal of Terminal Container Athus has been collected as well. As shown in figure 14, the intermodal route "Port of Antwerp – Terminal Container Athus" includes the processes of transhipment in the Port of Antwerp, the main haulage by train or by road and the transhipment in Terminal Container Athus. Moreover, a post-haulage distance of 50 km by road with a load factor of 60% has been considered (Janic, 2008).

FIGURE 14.INTERMODAL ROUTE “PORT OF ANTWERP - TERMINAL CONTAINER ATHUS”



An average of 70.3 TEU per train have been calculated for the intermodal freight trains of Terminal Container Athus, which implies the need of 35.15 lorries to transport the same amount of TEU than an average train. The average gross weight considered for the TEU is 14.3 t. For the transhipment of the containers, an average of 5204 kJ of electricity and 45.35 MJ per TEU have been calculated for Terminal Container Athus, resulting in a total of 50559 kJ of energy per TEU. Therefore, for the transhipment of 70.3 TEU, an energy consumption of 365831 kJ of electricity and 3188 MJ of diesel is obtained for the intermodal terminal of Terminal Container Athus.

Table 8 shows the main characteristics of the intermodal route “Port of Antwerp – Terminal Container Athus” using as mode of transport for the main haulage rail transport or road transport. The energy consumption estimated for the transhipment in the Port of Antwerp of 70.3 TEU is 1164030 kJ. An average gross weight of 14.3 t/TEU for the 70.3 TEU transported has been considered and this, together with the load factors of 75% for freight trains and 85% for road transport, results in a tonnage total of 754 t per train and 854 t for the 35.15 lorries. For the post-haulage by road, a load factor of 60% has been used, resulting in a tonnage of 603 t.

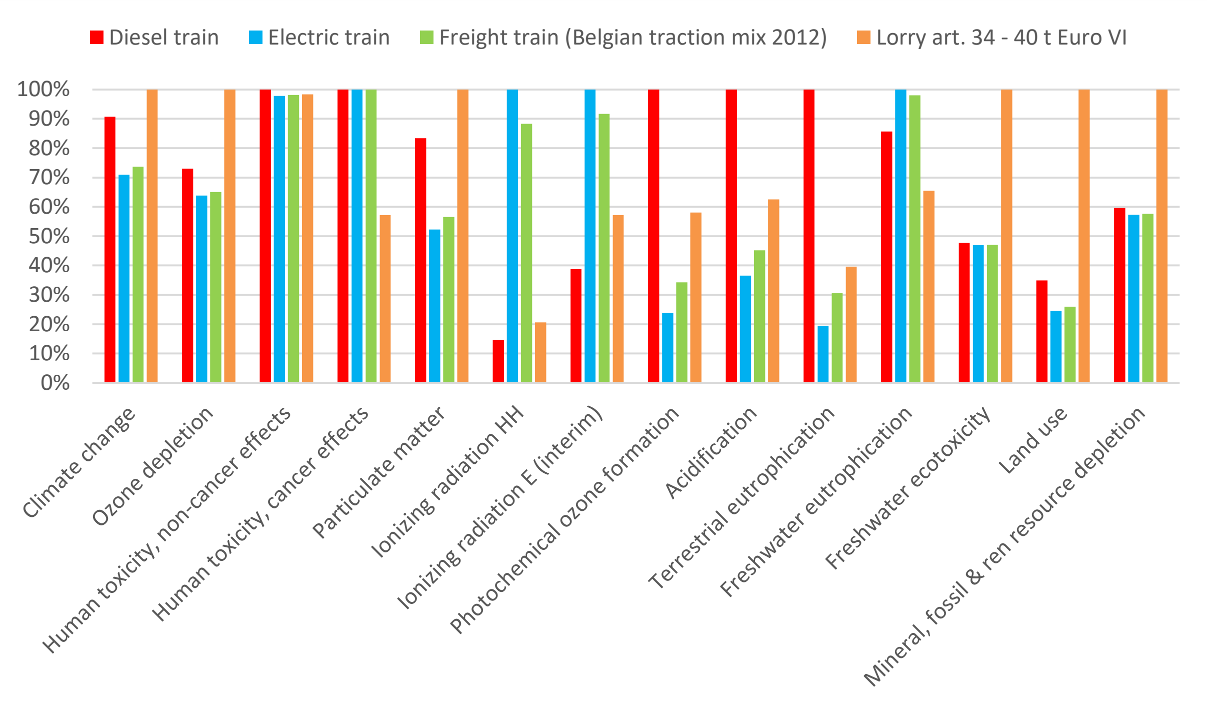
TABLE 8. MAIN CHARACTERISTICS OF THE INTERMODAL ROUTE “PORT OF ANTWERP – TERMINAL CONTAINER ATHUS”

		Main haulage by train	Main haulage by road
1. Transhipment in the Port of Antwerp (kJ)		1164030	
2. Main haulage	Load factor	75%	85%
	Tonnage (t)	754	854
	Distance (km)	307	245
	Transport performance (tkm)	231441	209327
3. Transhipment in Terminal Container Athus	Electricity (kJ)	365831	
	Diesel (MJ)	3188	
4. Post-haulage	Load factor	60%	
	Tonnage (t)	603	
	Distance (km)	50	
	Transport performance (tkm)	30155	

In order to determine the different environmental impact produced depending on the choice of mode of transport for the intermodal route “Port of Antwerp - Terminal Container Athus”, we have performed an analysis considering the main characteristics showed in table 8. Thereby, four modes of transport have been chosen for the main haulage: a diesel train, an electric train, a freight train with the Belgian traction mix of 2012 and an articulated lorry of 34-40 t Euro VI. We have considered for the post-haulage by road an articulated lorry of 34-40 t Euro VI.

As shown in figure 15, a comparison of the results obtained in the LCIA for the intermodal route "Port of Antwerp - Terminal Container Athus" using different freight transport modes for the main haulage has been performed.

FIGURE 15. LCIA OF THE INTERMODAL ROUTE "PORT OF ANTWERP - TERMINAL CONTAINER ATHUS"



Diesel trains have the maximum impact in 4 indicators mainly as a result of the exhaust emissions. Electric trains show the maximum impact in 3 indicators, being two of them related with the radiation due to the use of nuclear power in the electricity production in Belgium. Moreover, electric trains show the maximum impact in the indicator "Human toxicity, cancer effects", but with similar values than the other rail freight transport modes.

The articulated lorry of 34-40 t Euro VI presents the maximum impact in 6 indicators. For the indicator photochemical ozone formation, the articulated lorry of 34-40 t Euro VI have a lower impact than diesel trains due to the lower exhaust emissions on NMVOC of the lorries Euro VI. Similarly, for the indicators acidification and terrestrial eutrophication, the articulated lorry of 34-40 t Euro VI have a lower impact than diesel trains due to the lower exhaust emissions on NO_x of the lorries Euro VI.

4. CONCLUSIONS

The increased demand for rail transport promoted by the European Commission's White Paper on transport (2011) may represent a challenging target to the rail freight sector due to the high amount of goods that this implies. Moreover, the growth in rail freight transport could lead the need for the expansion of the railway network, which encompasses a range of environmental effects that should be studied.

The improvement of rail infrastructure might influence the development of rail freight transport. Therefore, the standardisation in Europe of different elements such as the track gauge, the loading gauge of tunnels and bridges and the electrification systems would enhance the interoperability of rail freight transport in long distances. Furthermore, greater availability of intermodal terminals would improve the lack of direct rail links and the weak access to the rail network. These enhancement in the flexibility of the rail transport would stimulate a modal shift from road transport to rail transport.

Intermodal freight transport represents an opportunity to attain a more environmentally and health friendly, energy-efficient and competitive transport system. It could be achieved 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. The use of road transport would be limited to the shortest possible initial and final parts of the transport chain.

In the upcoming deliverables we will analyse how the possible increase of rail freight transport in the modal split affects the environmental impact of inland freight transport in Belgium. More precisely, the increase of rail demand to be analysed has been estimated in the deliverable D.1.3 of the BRAIN-TRAINS project as 133%, 64% or 10% for a best best-case scenario, medium-case scenario and worst-case scenario, respectively (Troch et al., 2015).

REFERENCES

EcoTransIT, “EcoTransIT: Ecological Transport Information Tool Environmental. Methodology and Data”, ifeu - Institut für Energieund Umweltforschung Heidelberg GmbH, Germany, 2008.

European Commission - Joint Research Centre - Institute for Environment and Sustainability, “International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance”, Publications Office of the European Union: Luxembourg, 2010.

European Commission, “White Paper on transport. Roadmap to a single European transport area – Towards a competitive and resource-efficient transport system”, Directorate-General for Mobility and Transport, 2011.

Eurostat Statistics, extracted on 12/10/2015. URL: http://ec.europa.eu/eurostat

IBGE, « Les données de l'IBGE : Interface santé et environnement. 38. Créosote”, Bruxelles Environnement – Observatoire des données de l’environnement, 2011.

Infrabel, “Fascicule 52. Prescriptions Techniques relatives aux entreprises. Travaux de voie”, 2007

ITF, Eurostat, UNECE, “Illustrated Glossary for Transport Statistics. Common glossary for International Transport Forum at the OECD, Eurostat and United Nations Economic Commission for Europe”, 4th Edition, 2009.

Janic, M., “An assessment of the performance of the European long intermodal freight trains (LIFTS)”, Transportation Research Part A 42, pp 1326-1339, 2008

Messagie, M., van Lier, T., Rangajaru, S., van Meirlo, J., “Energie-intensiteit van personen- en goederenvervoer”, studie uitvoerd in opdracht van de Vlaamse Milieumaatschappij”, MIRA, Vrije Universiteir Brussel, 2014.

Merchan, A., Belboom, S., Léonard, A., “Deliverable D 4.2 Scenario 1: Best case. BRAINTRAINS: Transversal assessment of new intermodal strategies, WP4: Sustainability impact”, 2017.

Ntziachristos, L., Samaras, Z., “1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles”, EMEP/EEA air pollutant emission inventory guidebook 2013 - Technical guidance to prepare national emission inventories, European Environment Agency, 2014. http://www.eea.europa.eu//publications/emep-eea-guidebook-2013

Sala, S., Pant, R., Hauschild, M., Pennington, D., “Research Needs and Challenges from Science to Decision Support. Lesson Learnt from the Development of the International Reference Life Cycle Data System (ILCD) Recommendations for Life Cycle Impact Assessment”, Sustainability, 4, 1412-1425, 2012.

Service Public de Wallonie, “Bilan énergétique de la Wallonie 2012. Bilan de consommation des transports”, 2014.

SNCB, “Rapport de développement durable 2008”, 2009.

SNCB, “Entreprise durable, le groupe SNCB sur la voie du développement durable”, 2013.

SNCB, “Entreprise durable, le groupe SNCB sur la voie du développement durable”, 2015.

Spielmann, M., Bauer, C., Dones, R., Tuchschmid, M. “Transport Services. Ecoinvent report No. 14”, Swiss Centre for Life Cycle Inventories, Dübendorf, 2007.

Tawfik, C., Limbourg, S., “Bi-level optimization in the context of intermodal pricing: state of art”, Transportation Research Procedia, 10, 634-643, 2015.

Troch, F., Vanelslander, T., Sys, C., Stevens, V., Verhoest, K., Mostert, M., Tawfik, C., Limbourg, S., Merchan, A., Belboom, S., Léonard, A., “Deliverable D 1.3 Scenario development. BRAINTRAINS: Transversal assessment of new intermodal strategies”, 2015. http://www.brain-trains.be/

UIC, “SUWOS. Sustainable wooden railway sleepers”, 2013.

Vanelslander, T., Troch, F., Dotsenko, V., Pauwels, T., Sys, C., Tawfik, C., Mostert, M., Limbourg, S., Stevens, V., Verhoest, K., Merchan, A., Belboom, S. and Léonard, A., “Brain-trains: transversal assessment of new intermodal strategies: deliverable D 1.1 – 1.2 SWOT analysis”, University of Antwerp, 2015.

VMM, “Lozingen in de lucht 1990-2006. Vlaamse Milieumaatschappij”, 2007.

VMM, “Lozingen in de lucht 1990-2007. Vlaamse Milieumaatschappij”, 2008.

VMM, “Lozingen in de lucht 1990-2008. Vlaamse Milieumaatschappij”, 2009.

VMM, “Lozingen in de lucht 1990-2009. Vlaamse Milieumaatschappij”, 2010.

VMM, “Lozingen in de lucht 2000-2011. Vlaamse Milieumaatschappij”, 2012.

VMM, “Lozingen in de lucht 2000-2012. Vlaamse Milieumaatschappij”, 2013.

VMM, “Lozingen in de lucht 2000-2013. Vlaamse Milieumaatschappij”, 2014.

Weidema B.P., Bauer, C., Hischier, R., Mutel, C., Nemecek, T., Reinhard, J., Vadenbo, C.O., Wernet, G., “The ecoinvent database: Overview and methodology, Data quality guideline for the ecoinvent database version 3”, 2013. www.ecoinvent.org

APPENDIX I - Direct emissions (Tank-to-Wheel emissions) of inland freight transport

This section shows the direct emissions obtained in the BRAIN-TRAINS project and the reference values from the Ecoinvent v3 database. These pollutants as direct emissions do not yet represent environmental impact categories such as climate change or acidification. These direct emissions during transport operation are part of the inventory analysis and this, together with the energy consumption during transport operation and the emissions, energy and material consumptions from the vehicle and infrastructure stages, constitute the required elements to model the freight transport system. It is necessary to consider all the elements from the inventory analysis to evaluate the contribution of the freight transport to environmental impact categories. Therefore, this section presents pollutant emissions as substances produced during the transport activity and not as environmental impacts.

Table 9 presents the direct emissions of rail freight transport in Belgium using the Belgian traction mix of diesel and electric traction showed in figure 3. Moreover, the reference process of Ecoinvent v3 database “Transport, freight train {BE}| processing | Alloc Rec, U” is used as reference values.

TABLE 9. DIRECT EMISSIONS (G/TKM) OF RAIL FREIGHT TRANSPORT (BELGIAN TRACTION MIX OF DIESEL AND ELECTRIC TRACTION) IN BELGIUM

Rail transport (Belgian traction mix) (g/tkm)	2006	2007	2008	2009	2010	2011	2012	Ecoinvent v3 2014
CO_2	12.62	12.08	11.95	9.99	9.25	7.23	6.55	11.55
SO_2	1.93E-04	6.91E-05	6.08E-05	5.08E-05	4.70E-05	3.68E-05	3.33E-05	2.20E-03
Cd	4.01E-08	3.84E-08	3.80E-08	3.17E-08	2.94E-08	2.30E-08	2.08E-08	3.67E-08
Cu	6.82E-06	6.53E-06	6.46E-06	5.40E-06	5.00E-06	3.91E-06	3.54E-06	6.24E-06
Cr	2.01E-07	1.92E-07	1.90E-07	1.59E-07	1.47E-07	1.15E-07	1.04E-07	1.84E-07
Ni	2.81E-07	2.69E-07	2.66E-07	2.22E-07	2.06E-07	1.61E-07	1.46E-07	2.57E-07
Se	4.01E-08	3.84E-08	3.80E-08	3.17E-08	2.94E-08	2.30E-08	2.08E-08	3.67E-08
Zn	4.01E-06	3.84E-06	3.80E-06	3.17E-06	2.94E-06	2.30E-06	2.08E-06	3.67E-06
Pb	4.41E-10	4.22E-10	4.18E-10	3.49E-10	3.23E-10	2.53E-10	2.29E-10	4.04E-10
Hg	8.02E-11	7.68E-11	7.60E-11	6.35E-11	5.88E-11	4.60E-11	4.16E-11	7.32E-11
CO	6.34E-02	6.07E-02	6.00E-02	5.02E-02	4.65E-02	3.63E-02	3.29E-02	5.80E-02
NO_X	2.21E-01	2.11E-01	2.09E-01	1.75E-01	1.62E-01	1.26E-01	1.14E-01	2.02E-01
$PM_{2.5}$	5.14E-03	4.92E-03	4.86E-03	4.06E-03	3.76E-03	2.94E-03	2.66E-03	4.71E-03
PM_{10}	1.57E-02	1.57E-02	1.57E-02	1.57E-02	1.57E-02	1.57E-02	1.56E-02	1.60E-02
$PM_{10} > PM > PM_{2.5}$	7.10E-03	7.08E-03	7.08E-03	7.01E-03	6.99E-03	6.92E-03	6.90E-03	7.07E-03
Methane	5.22E-04	4.99E-04	4.94E-04	4.13E-04	3.82E-04	2.99E-04	2.71E-04	4.77E-04
Toluene	1.60E-04	1.54E-04	1.52E-04	1.27E-04	1.18E-04	9.20E-05	8.33E-05	1.47E-04
Benzene	4.01E-04	3.84E-04	3.80E-04	3.17E-04	2.94E-04	2.30E-04	2.08E-04	3.67E-04
Xylene	1.60E-04	1.54E-04	1.52E-04	1.27E-04	1.18E-04	9.20E-05	8.33E-05	1.47E-04
NMVOC	2.03E-02	1.95E-02	1.93E-02	1.61E-02	1.49E-02	1.17E-02	1.06E-02	1.86E-02
Ammonia	8.02E-05	7.68E-05	7.60E-05	6.35E-05	5.88E-05	4.60E-05	4.16E-05	7.32E-05
N_2O	4.01E-04	3.84E-04	3.80E-04	3.17E-04	2.94E-04	2.30E-04	2.08E-04	3.67E-04
SF_6 from electricity	5.05E-06	4.89E-06	5.24E-06	5.55E-06	4.46E-06	4.65E-06	4.50E-06	3.18E-06
Emissions to soil of Fe	1.78E-02	1.78E-02	1.78E-02	1.78E-02	1.78E-02	1.78E-02	1.78E-02	1.78E-02

Table 10 presents the direct emissions of diesel trains including shunting activity in Belgium using the diesel consumption showed in table 1.

TABLE 10. DIRECT EMISSIONS (G/TKM) OF DIESEL TRAINS (INCLUDING SHUNTING ACTIVITY) IN BELGIUM

Diesel trains (including shunting activity) (g/tkm)	2006	2007	2008	2009	2010	2011	2012
CO_2	53.33	50.34	54.82	59.10	55.90	44.66	47.79
SO_2	8.14E-04	2.88E-04	2.79E-04	3.01E-04	2.84E-04	2.27E-04	2.43E-04
Cd	1.70E-07	1.60E-07	1.74E-07	1.88E-07	1.78E-07	1.42E-07	1.52E-07
Cu	2.88E-05	2.72E-05	2.96E-05	3.19E-05	3.02E-05	2.41E-05	2.58E-05
Cr	8.48E-07	8.00E-07	8.71E-07	9.39E-07	8.88E-07	7.10E-07	7.60E-07
Ni	1.19E-06	1.12E-06	1.22E-06	1.31E-06	1.24E-06	9.94E-07	1.06E-06
Se	1.70E-07	1.60E-07	1.74E-07	1.88E-07	1.78E-07	1.42E-07	1.52E-07
Zn	1.70E-05	1.60E-05	1.74E-05	1.88E-05	1.78E-05	1.42E-05	1.52E-05
Pb	1.86E-09	1.76E-09	1.92E-09	2.07E-09	1.95E-09	1.56E-09	1.67E-09
Hg	3.39E-10	3.20E-10	3.49E-10	3.76E-10	3.55E-10	2.84E-10	3.04E-10
CO	2.68E-01	2.53E-01	2.75E-01	2.97E-01	2.81E-01	2.24E-01	2.40E-01
NO_X	9.32E-01	8.80E-01	9.58E-01	1.03E+00	9.77E-01	7.81E-01	8.36E-01
$PM_{2.5}$	2.17E-02	2.05E-02	2.23E-02	2.40E-02	2.27E-02	1.82E-02	1.94E-02
PM_{10}	1.65E-02	1.64E-02	1.65E-02	1.66E-02	1.65E-02	1.63E-02	1.64E-02
PM_{10} > PM >$PM_{2.5}$	8.49E-03	8.38E-03	8.54E-03	8.68E-03	8.57E-03	8.19E-03	8.30E-03
Methane	2.20E-03	2.08E-03	2.27E-03	2.44E-03	2.31E-03	1.85E-03	1.97E-03
Toluene	6.78E-04	6.40E-04	6.97E-04	7.51E-04	7.11E-04	5.68E-04	6.08E-04
Benzene	1.70E-03	1.60E-03	1.74E-03	1.88E-03	1.78E-03	1.42E-03	1.52E-03
Xylene	6.78E-04	6.40E-04	6.97E-04	7.51E-04	7.11E-04	5.68E-04	6.08E-04
NMVOC	8.59E-02	8.11E-02	8.84E-02	9.52E-02	9.01E-02	7.20E-02	7.70E-02
Ammonia	3.39E-04	3.20E-04	3.49E-04	3.76E-04	3.55E-04	2.84E-04	3.04E-04
N_2O	1.70E-03	1.60E-03	1.74E-03	1.88E-03	1.78E-03	1.42E-03	1.52E-03
Emissions to soil of Fe	1.78E-02	1.78E-02	1.78E-02	1.78E-02	1.78E-02	1.78E-02	1.78E-02

Table 11 presents the direct emissions of electric trains in Belgium using the electricity consumption showed in table 1. The only direct emissions produced by electric locomotives are the direct emissions from abrasion of brake linings, wheels and rails. Moreover, we have considered as direct emissions the SF_6 emissions to air during conversion of electricity at traction substations.

TABLE 11. DIRECT EMISSIONS (G/TKM) OF ELECTRIC TRAINS IN BELGIUM

Electric trains (g/tkm)	2006	2007	2008	2009	2010	2011	2012
PM_{10}	1.55E-05	1.55E-05	1.55E-05	1.55E-05	1.55E-05	1.553E-05	1.55E-05
SF_6	6.62E-09	6.44E-09	6.71E-09	6.68E-09	5.35E-09	5.545E-09	5.21E-09
PM_{10} > PM >$PM_{2.5}$	6.67E-06	6.67E-06	6.67E-06	6.67E-06	6.67E-06	6.673E-06	6.67E-06
Emissions to soil of Fe	1.78E-05	1.78E-05	1.78E-05	1.78E-05	1.78E-05	1.779E-05	1.78E-05

Table 12 presents the direct emissions of inland waterways transport in Belgium using the fuel consumption showed in table 2.

TABLE 12. DIRECT EMISSIONS (G/TKM) OF INLAND WATERWAYS TRANSPORT IN BELGIUM

Inland waterways transport (g/tkm)	2006	2007	2008	2009	2010	2011	2012	Ecoinvent v3 2014
CO_2	23.63	23.14	22.55	22.12	21.72	21.46	21.34	29.60
SO_2	2.98E-02	2.92E-02	1.42E-02	1.39E-02	1.37E-02	1.35E-04	1.35E-04	5.64E-03
Cd	7.45E-08	7.30E-08	7.11E-08	6.97E-08	6.85E-08	6.77E-08	6.73E-08	9.39E-08
Cu	1.27E-05	1.24E-05	1.21E-05	1.19E-05	1.16E-05	1.15E-05	1.14E-05	1.60E-05
Cr	3.72E-07	3.65E-07	3.55E-07	3.49E-07	3.42E-07	3.38E-07	3.36E-07	4.70E-07
Ni	5.21E-07	5.11E-07	4.98E-07	4.88E-07	4.79E-07	4.74E-07	4.71E-07	6.58E-07
Se	7.45E-08	7.30E-08	7.11E-08	6.97E-08	6.85E-08	6.77E-08	6.73E-08	9.39E-08
Zn	7.45E-06	7.30E-06	7.11E-06	6.97E-06	6.85E-06	6.77E-06	6.73E-06	9.39E-06
Pb	8.19E-10	8.02E-10	7.82E-10	7.67E-10	7.53E-10	7.44E-10	7.40E-10	1.88E-07
Hg	1.49E-10	1.46E-10	1.42E-10	1.39E-10	1.37E-10	1.35E-10	1.35E-10	6.58E-10
CO	2.01E-02	1.97E-02	1.92E-02	1.88E-02	1.85E-02	1.83E-02	1.82E-02	2.54E-02
NO_X	3.72E-01	3.65E-01	3.55E-01	3.49E-01	3.42E-01	3.38E-01	3.36E-01	4.70E-01
$PM_{2.5}$	6.88E-03	6.73E-03	6.56E-03	6.44E-03	6.32E-03	6.25E-03	6.21E-03	8.67E-03
PM_{10}	2.90E-04	2.85E-04	2.77E-04	2.72E-04	2.67E-04	2.64E-04	2.62E-04	3.71E-04
PM_{10} > PM > $PM_{2.5}$	5.74E-04	5.62E-04	5.47E-04	5.37E-04	5.27E-04	5.21E-04	5.18E-04	7.23E-04
Methane	1.79E-04	1.75E-04	1.71E-04	1.67E-04	1.64E-04	1.62E-04	1.61E-04	2.25E-04
Toluene	5.96E-05	5.84E-05	5.69E-05	5.58E-05	5.48E-05	5.41E-05	5.38E-05	7.52E-05
Benzene	1.42E-04	1.39E-04	1.35E-04	1.33E-04	1.30E-04	1.29E-04	1.28E-04	1.78E-04
Xylene	5.96E-05	5.84E-05	5.69E-05	5.58E-05	5.48E-05	5.41E-05	5.38E-05	7.52E-05
NMVOC	7.45E-03	7.30E-03	7.11E-03	6.97E-03	6.85E-03	6.77E-03	6.73E-03	9.39E-03
Ammonia	3.86E-04	3.78E-04	3.69E-04	3.62E-04	3.55E-04	3.51E-04	3.49E-04	4.87E-04
N_2O	5.96E-04	5.84E-04	5.69E-04	5.58E-04	5.48E-04	5.41E-04	5.38E-04	3.11E-03
Benzo(a)pyrene	5.74E-08	5.62E-08	5.47E-08	5.37E-08	5.27E-08	5.21E-08	5.18E-08	7.24E-11
HCl	7.90E-06	7.73E-06	7.53E-06	7.39E-06	7.26E-06	7.17E-06	7.13E-06	9.95E-06

Table 13 shows the direct emissions produced during the road transport operation in Belgium with a load factor of 50%. Moreover, the reference process of Ecoinvent v3 database “Transport, freight, lorry >32 metric ton, Euro 3 {RER}| Alloc Rec, U” has been used as reference values.

TABLE 13. DIRECT EMISSIONS OF AVERAGE ROAD TRANSPORT AND AN ARTICULATED LORRY 34-40 T

Load Factor 50+%	Average road transport (g/tkm)						Articulated lorry 34-40 t (g/tkm)						Ecoinvent v3
	2005	2006	2007	2008	2009	2010	2005	2006	2007	2008	2009	2010	2014
CO_2	74.12	73.83	73.56	73.17	73.29	73.21	63.56	63.38	63.21	63.14	63.03	62.96	55.09
SO_2	1.45E-03	1.12E-03	4.17E-04	3.69E-04	3.70E-04	3.69E-04	1.24E-03	9.59E-04	3.59E-04	3.18E-04	3.18E-04	3.18E-04	2.82E-04
Cd	2.34E-07	2.33E-07	2.32E-07	2.31E-07	2.31E-07	2.31E-07	2.00E-07	2.00E-07	1.99E-07	1.99E-07	1.99E-07	1.98E-07	1.50E-07
Cu	3.97E-05	3.96E-05	3.94E-05	3.92E-05	3.93E-05	3.92E-05	3.41E-05	3.40E-05	3.39E-05	3.38E-05	3.38E-05	3.37E-05	3.66E-07
Cr	1.17E-06	1.16E-06	1.16E-06	1.15E-06	1.16E-06	1.15E-06	1.00E-06	9.99E-07	9.96E-07	9.95E-07	9.94E-07	9.92E-07	5.18E-07
Ni	1.64E-06	1.63E-06	1.62E-06	1.61E-06	1.62E-06	1.62E-06	1.40E-06	1.40E-06	1.39E-06	1.39E-06	1.39E-06	1.39E-06	1.52E-07
Se	2.34E-07	2.33E-07	2.32E-07	2.31E-07	2.31E-07	2.31E-07	2.00E-07	2.00E-07	1.99E-07	1.99E-07	1.99E-07	1.98E-07	1.73E-09
Zn	2.34E-05	2.33E-05	2.32E-05	2.31E-05	2.31E-05	2.31E-05	2.00E-05	2.00E-05	1.99E-05	1.99E-05	1.99E-05	1.98E-05	3.00E-05
Pb	2.57E-09	2.56E-09	2.55E-09	2.54E-09	2.54E-09	2.54E-09	2.20E-09	2.20E-09	2.19E-09	2.19E-09	2.19E-09	2.18E-09	9.00E-07
Hg	4.67E-10	4.66E-10	4.64E-10	4.61E-10	4.62E-10	4.62E-10	4.01E-10	4.00E-10	3.99E-10	3.98E-10	3.97E-10	3.97E-10	9.15E-08
Cr(IV)	2.34E-09	2.33E-09	2.32E-09	2.31E-09	2.31E-09	2.31E-09	2.00E-09	2.00E-09	1.99E-09	1.99E-09	1.99E-09	1.98E-09	1.04E-09
As	2.34E-09	2.33E-09	2.32E-09	2.31E-09	2.31E-09	2.31E-09	2.00E-09	2.00E-09	1.99E-09	1.99E-09	1.99E-09	1.98E-09	1.73E-09
CO	1.72E-01	1.57E-01	1.40E-01	1.25E-01	1.15E-01	1.06E-01	1.49E-01	1.36E-01	1.22E-01	1.10E-01	1.02E-01	9.31E-02	8.24E-02
NMVOC	3.72E-02	3.34E-02	2.95E-02	2.60E-02	2.36E-02	2.14E-02	3.08E-02	2.80E-02	2.51E-02	2.24E-02	2.06E-02	1.87E-02	1.26E-02
NO_X	8.56E-01	8.11E-01	7.64E-01	7.21E-01	6.79E-01	6.40E-01	7.44E-01	7.09E-01	6.70E-01	6.37E-01	6.00E-01	5.62E-01	4.46E-01
N_2O	1.27E-03	1.27E-03	1.28E-03	1.29E-03	1.54E-03	1.77E-03	1.12E-03	1.15E-03	1.17E-03	1.19E-03	1.42E-03	1.67E-03	3.71E-04
NH_3	2.98E-04	2.97E-04	2.96E-04	2.94E-04	3.60E-04	4.17E-04	2.29E-04	2.29E-04	2.29E-04	2.29E-04	2.80E-04	3.34E-04	1.56E-04
$PM_{2.5}$	2.38E-02	2.15E-02	1.91E-02	1.70E-02	1.56E-02	1.42E-02	2.11E-02	1.93E-02	1.74E-02	1.57E-02	1.45E-02	1.32E-02	8.96E-03
indeno(1,2,3-cd)pyrene	1.44E-07	1.43E-07	1.43E-07	1.42E-07	1.43E-07	1.43E-07	1.11E-07	1.11E-07	1.11E-07	1.11E-07	1.11E-07	1.11E-07	-
benzo(k)fluoranthene	6.25E-07	6.24E-07	6.22E-07	6.18E-07	6.21E-07	6.20E-07	4.81E-07	4.81E-07	4.81E-07	4.81E-07	4.81E-07	4.81E-07	-
benzo(b)fluoranthene	5.59E-07	5.58E-07	5.57E-07	5.53E-07	5.56E-07	5.55E-07	4.30E-07	4.30E-07	4.30E-07	4.30E-07	4.30E-07	4.30E-07	-
benzo(a)pyrene	9.24E-08	9.22E-08	9.20E-08	9.14E-08	9.18E-08	9.17E-08	7.11E-08	7.11E-08	7.11E-08	7.11E-08	7.11E-08	7.11E-08	-

APPENDIX II – Life Cycle Impact Assessment of the different rail freight transport modes

Table 14 presents the results obtained in the Life Cycle Impact Assessment (LCIA) of one tonne-kilometre of freight transported by rail in Belgium using the Belgian traction mix of diesel and electric traction and the reference values from Ecoinvent v3 database "Transport, freight train {BE}| processing | Alloc Rec, U".

TABLE 14. LCIA OF RAIL FREIGHT TRANSPORT (BELGIAN TRACTION MIX OF DIESEL AND ELECTRIC TRACTION) IN BELIGIUM

Impact category	Unit	2006	2007	2008	2009	2010	2011	2012	Ecoinvent v3
Climate change	kg CO_2 eq	6.97E-02	6.82E-02	7.17E-02	7.88E-02	6.83E-02	6.09E-02	6.42E-02	5.37E-02
Ozone depletion	kg CFC-11 eq	1.38E-08	1.34E-08	1.39E-08	1.43E-08	1.22E-08	1.24E-08	1.19E-08	9.01E-09
Human toxicity, non-cancer effects	CTUh	2.04E-08	2.02E-08	2.05E-08	2.45E-08	2.18E-08	2.15E-08	2.31E-08	1.16E-08
Human toxicity, cancer effects	CTUh	6.38E-09	6.32E-09	6.32E-09	8.31E-09	7.54E-09	7.35E-09	8.10E-09	5.21E-09
Particulate matter	kg $PM_{2.5}$ eq	3.35E-05	3.29E-05	3.32E-05	3.80E-05	3.42E-05	3.20E-05	3.55E-05	2.86E-05
Ionizing radiation HH	kBq U235 eq	6.93E-02	6.66E-02	6.92E-02	7.07E-02	5.65E-02	6.55E-02	5.85E-02	4.35E-02
Ionizing radiation E (interim)	CTUe	1.16E-07	1.12E-07	1.17E-07	1.21E-07	9.75E-08	1.09E-07	9.79E-08	7.56E-08
Photochemical ozone formation	kg NMVOC eq	4.02E-04	3.89E-04	3.92E-04	3.80E-04	3.44E-04	2.96E-04	3.03E-04	3.34E-04
Acidification	molc H+ eq	4.23E-04	4.13E-04	4.16E-04	4.37E-04	3.93E-04	3.51E-04	3.64E-04	3.51E-04
Terrestrial eutrophication	molc N eq	1.47E-03	1.42E-03	1.43E-03	1.37E-03	1.24E-03	1.06E-03	1.04E-03	1.23E-03
Freshwater eutrophication	kg P eq	1.62E-05	1.57E-05	1.64E-05	1.89E-05	1.70E-05	1.62E-05	1.96E-05	9.99E-06
Marine eutrophication	kg N eq	1.36E-04	1.32E-04	1.33E-04	1.27E-04	1.15E-04	9.86E-05	9.78E-05	1.13E-04
Freshwater ecotoxicity	CTUe	5.21E-01	5.18E-01	5.28E-01	6.35E-01	5.71E-01	5.66E-01	6.20E-01	2.86E-01
Land use	kg C deficit	1.41E-01	1.40E-01	1.43E-01	1.57E-01	1.44E-01	1.33E-01	1.39E-01	1.10E-01
Water resource depletion	m^3 water eq	-4.29E-05	-4.37E-05	-4.26E-05	-6.43E-05	-5.32E-05	-4.16E-05	-4.46E-05	-5.29E-05
Mineral, fossil & ren. resource depletion	kg Sb eq	2.12E-06	2.10E-06	2.14E-06	2.52E-06	2.25E-06	2.25E-06	2.34E-06	1.24E-06

Tables 15 shows the results obtained in the LCIA of one tonne-kilometre of freight transported by diesel trains.

TABLE 15. LCIA OF DIESEL TRAINS (INCLUDING SHUNTING ACTIVITY) IN BELGIUM

Impact category	Unit	2006	2007	2008	2009	2010	2011	2012
Climate change	kg CO_2 eq	8.38E-02	8.03E-02	8.59E-02	9.72E-02	9.14E-02	7.72E-02	8.32E-02
Ozone depletion	kg CFC-11 eq	1.44E-08	1.38E-08	1.48E-08	1.63E-08	1.55E-08	1.29E-08	1.38E-08
Human toxicity, non-cancer effects	CTUh	1.79E-08	1.79E-08	1.82E-08	2.38E-08	2.19E-08	2.12E-08	2.36E-08
Human toxicity, cancer effects	CTUh	6.03E-09	6.02E-09	6.00E-09	8.23E-09	7.58E-09	7.35E-09	8.09E-09
Particulate matter	kg $PM_{2.5}$ eq	5.62E-05	5.41E-05	5.74E-05	6.70E-05	6.28E-05	5.43E-05	5.89E-05
Ionizing radiation HH	kBq U235 eq	7.04E-03	6.82E-03	7.23E-03	8.20E-03	7.80E-03	6.82E-03	7.27E-03
Ionizing radiation E (interim)	CTUe	3.61E-08	3.45E-08	3.71E-08	4.12E-08	3.89E-08	3.26E-08	3.48E-08
Photochemical ozone formation	kg NMVOC eq	1.18E-03	1.12E-03	1.21E-03	1.32E-03	1.25E-03	1.02E-03	1.09E-03
Acidification	molc H+ eq	9.59E-04	9.14E-04	9.83E-04	1.10E-03	1.03E-03	8.59E-04	9.25E-04
Terrestrial eutrophication	molc N eq	4.43E-03	4.20E-03	4.55E-03	4.96E-03	4.68E-03	3.80E-03	4.07E-03
Freshwater eutrophication	kg P eq	1.28E-05	1.28E-05	1.31E-05	1.69E-05	1.58E-05	1.51E-05	1.69E-05
Marine eutrophication	kg N eq	4.06E-04	3.85E-04	4.17E-04	4.55E-04	4.29E-04	3.49E-04	3.74E-04
Freshwater ecotoxicity	CTUe	4.85E-01	4.86E-01	4.93E-01	6.39E-01	5.88E-01	5.69E-01	6.32E-01
Land use	kg C deficit	2.35E-01	2.28E-01	2.42E-01	2.72E-01	2.57E-01	2.21E-01	2.37E-01
Water resource depletion	m^3 water eq	2.53E-06	1.82E-06	3.42E-06	-5.15E-06	-5.59E-06	-6.95E-06	-9.95E-06
Mineral, fossil & ren. resource depletion	kg Sb eq	1.93E-06	1.93E-06	1.97E-06	2.50E-06	2.30E-06	2.22E-06	2.45E-06

Tables 16 shows the results obtained in the LCIA of one tonne-kilometre of freight transported by electric trains in Belgium.

TABLE 16. LCIA OF ELECTRIC TRAINS IN BELGIUM

Impact category	Unit	2006	2007	2008	2009	2010	2011	2012
Climate change	kg CO_2 eq	6.54E-02	6.44E-02	6.77E-02	7.50E-02	6.38E-02	5.77E-02	6.12E-02
Ozone depletion	kg CFC-11 eq	1.37E-08	1.33E-08	1.36E-08	1.39E-08	1.15E-08	1.23E-08	1.16E-08
Human toxicity, non-cancer effects	CTUh	2.11E-08	2.09E-08	2.11E-08	2.46E-08	2.17E-08	2.15E-08	2.30E-08
Human toxicity, cancer effects	CTUh	6.49E-09	6.42E-09	6.42E-09	8.32E-09	7.53E-09	7.35E-09	8.10E-09
Particulate matter	kg $PM_{2.5}$ eq	2.64E-05	2.62E-05	2.64E-05	3.21E-05	2.85E-05	2.77E-05	3.17E-05
Ionizing radiation HH	kBq U235 eq	8.86E-02	8.55E-02	8.65E-02	8.34E-02	6.61E-02	7.68E-02	6.67E-02
Ionizing radiation E (interim)	CTUe	1.40E-07	1.37E-07	1.39E-07	1.38E-07	1.09E-07	1.24E-07	1.08E-07
Photochemical ozone formation	kg NMVOC eq	1.60E-04	1.59E-04	1.63E-04	1.88E-04	1.65E-04	1.56E-04	1.78E-04
Acidification	molc H+ eq	2.57E-04	2.54E-04	2.58E-04	3.03E-04	2.66E-04	2.53E-04	2.74E-04
Terrestrial eutrophication	molc N eq	5.48E-04	5.43E-04	5.60E-04	6.41E-04	5.58E-04	5.27E-04	5.62E-04
Freshwater eutrophication	kg P eq	1.73E-05	1.66E-05	1.74E-05	1.93E-05	1.72E-05	1.64E-05	2.00E-05
Marine eutrophication	kg N eq	5.21E-05	5.16E-05	5.32E-05	6.07E-05	5.30E-05	5.01E-05	5.40E-05
Freshwater ecotoxicity	CTUe	5.32E-01	5.28E-01	5.37E-01	6.35E-01	5.68E-01	5.65E-01	6.18E-01
Land use	kg C deficit	1.12E-01	1.12E-01	1.15E-01	1.33E-01	1.22E-01	1.16E-01	1.23E-01
Water resource depletion	m^3 water eq	-5.70E-05	-5.81E-05	-5.54E-05	-7.64E-05	-6.27E-05	-4.83E-05	-5.01E-05
Mineral, fossil & ren. resource depletion	kg Sb eq	2.18E-06	2.16E-06	2.19E-06	2.53E-06	2.24E-06	2.26E-06	2.32E-06