BRAINTRAINS

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Scenario 3: Medium-case

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BRAIN-TRAINS

Transversal assessment of new intermodal strategies

WP4: Sustainability impact of intermodality

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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).

In order to analyse the environmental impacts related to intermodal rail freight transport in Belgium, in a first stage we have analysed the environmental impacts of rail freight transport (distinguishing between electric and diesel traction), inland waterways transport and road freight transport independently. Moreover, 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., 2017a). Afterwards, the results in rail freight transport and road freight transport have been updated in the deliverable D.4.3 of the BRAIN-TRAINS project (Merchan et al., 2017b). This is because the information collected on railway infrastructure had been fully modelled and the values of energy consumption in road transport had been revised as a results of enhanced load factors. Finally, the results in impact assessment of road freight transport have been updated again in the present deliverable as a result of the improvement in the method of calculating road infrastructure demand. See APPENDIX I for the updated impact assessment results.

In a second stage we have carried out a study of the environmental impacts related to intermodal rail freight transport. For this, we have studied three consolidated intermodal rail-road routes in Belgium in the deliverable D.4.3 of the BRAIN-TRAINS project (Merchan et al., 2017b). 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 objective of this analysis was to compare the environmental impacts of these intermodal routes depending on the freight transport mode chosen (rail or road transport) for the major part of the intermodal route.

The purpose of this deliverable is to analyse how the increase of rail freight transport in the modal split as a result of the possible development of the intermodal rail freight transport affects the environmental impacts 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 (Troch et al., 2015) as 133%, 64% or 10% for a best-case scenario, medium-case scenario and worst-case scenario, respectively.

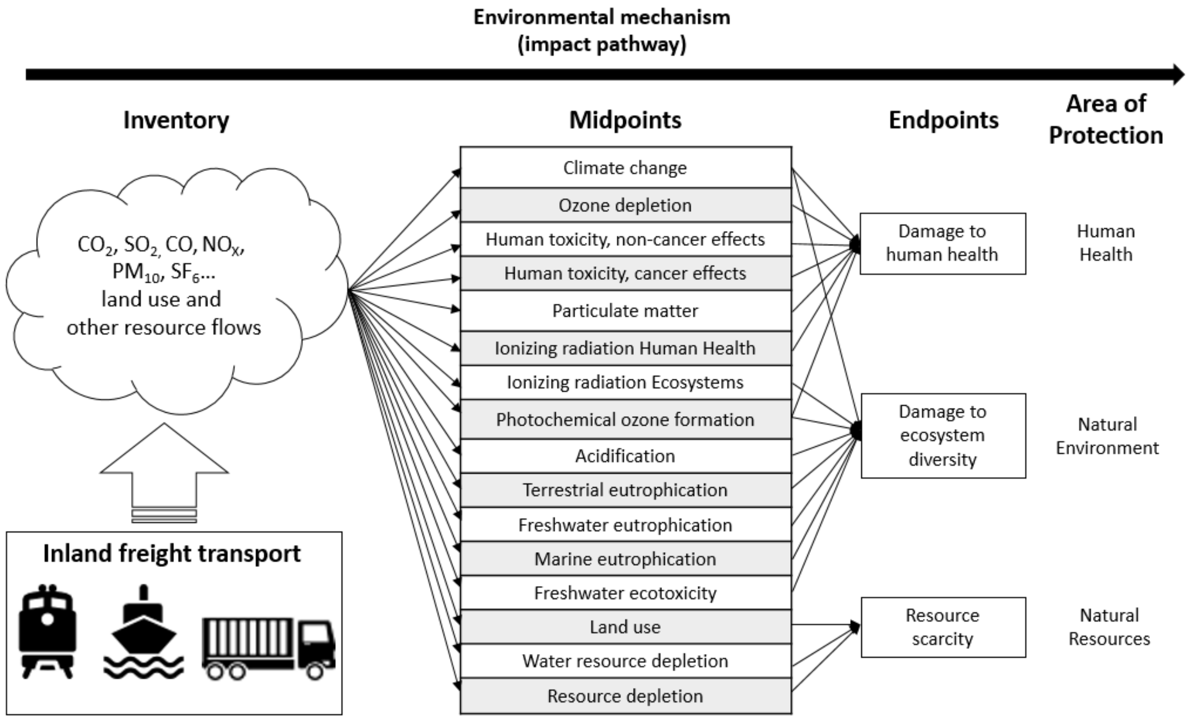
2. LIFE CYCLE ASSESSMENT (LCA) METHODOLOGY

The Life Cycle Assessment (LCA) methodology has been chosen to analyse the environmental impacts of the intermodal rail freight transport in Belgium, which includes the LCA of rail freight transport (distinguishing between electric and diesel traction), inland waterways transport and road freight 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 approach allows us to analyse the overall life cycle of the energy carrier. Thereby, we consider the environmental impacts related to the use of energy (e.g. diesel or electricity) starting from the raw materials extraction (e.g. oil or uranium), continuing with energy generation (e.g. diesel refining or electricity production) and ending with the energy distribution to the traction unit (locomotive, barge or lorry). Besides the assessment of the environmental impacts related to the energy consumption during the transport operation, our LCA study includes the emissions and energy and raw material consumptions from the construction and maintenance of transport infrastructure and the manufacturing and maintenance of transport vehicles.

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, particulate matter emissions, photochemical ozone depletion or human toxicity 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).

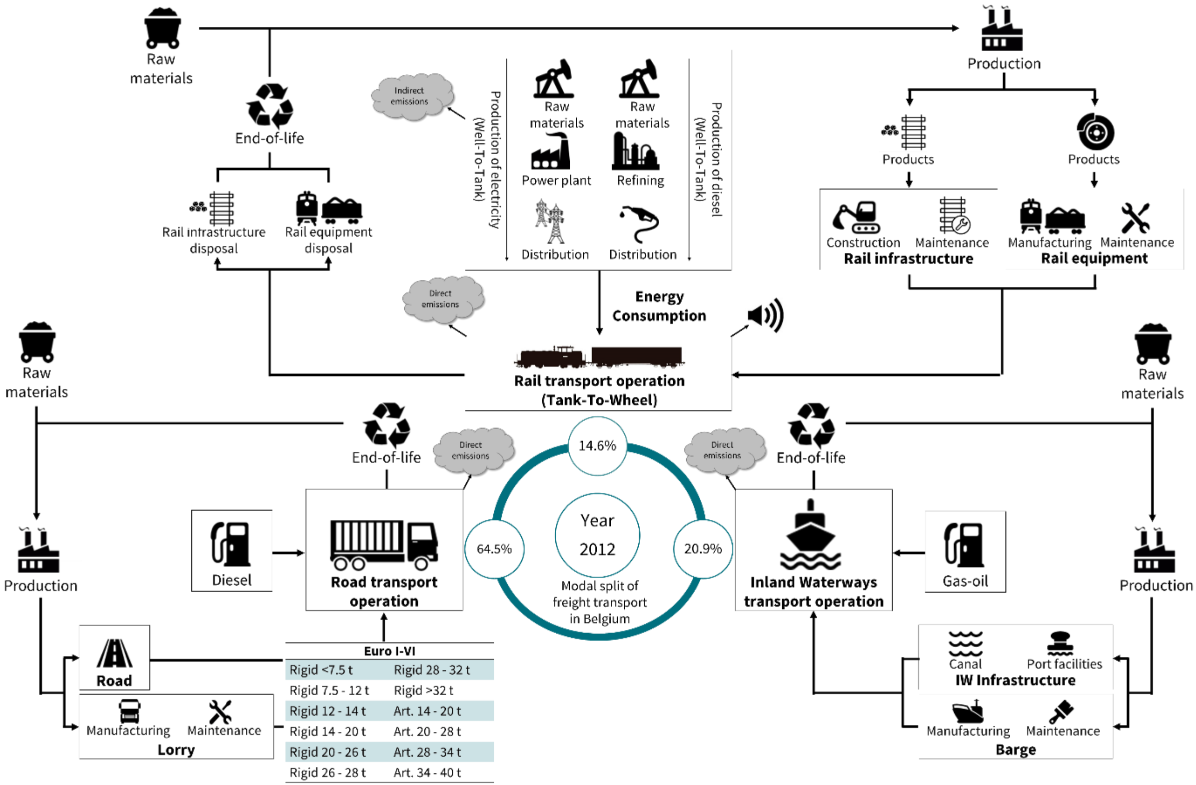
FIGURE 1. DIAGRAM OF THE LIFE CYCLE IMPACT ASSESSMENT METHODOLOGY APPLIED ON INLAND FREIGHT TRANSPORT



SOURCE: 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.

FIGURE 2. INLAND FREIGHT TRANSPORT SYSTEM BOUNDARIES CONSIDERED IN OUR STUDY



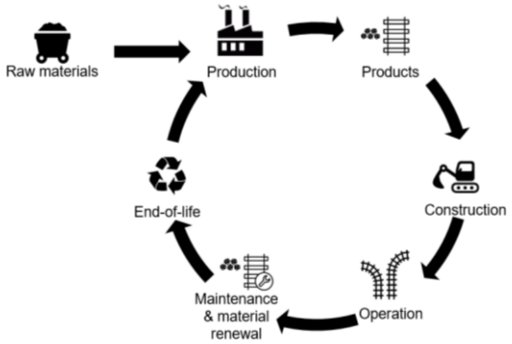
SOURCE: OWN ELABORATION BASED ON SPIELMANN ET AL., 2007

A detailed study of the rail freight transport has been conducted, collecting data directly from Infrabel (the Belgian railway infrastructure manager) and B-Logistics (rebranded to Lineas, April 2017), 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 has been divided in three sub-systems: rail transport operation, rail infrastructure and rail equipment (locomotives and wagons).

For the rail transport operation sub-system, 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 have been determined. In the case of indirect emissions from electric trains, 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. Three types of direct emissions produced during the rail transport operation have 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.

As shown in Figure 3, the subsystem rail infrastructure includes the processes that are connected with the construction, maintenance and disposal 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.

FIGURE 3. LIFE CYCLE ASSESSMENT OF THE RAILWAY INFRASTRUCTURE



The life cycle phases of manufacturing, maintenance and disposal of rail equipment (locomotives and wagons) are taken into account in our study as well.

In the case of both inland waterways transport and road transport in Belgium, the Ecoinvent V3.1 database has been used as a model (Weidema et al., 2013). Analogously to the rail transport system, for the LCA of inland waterways transport, all life cycle phases of inland waterways transport operation, inland waterways infrastructures (including canals and the Port of Antwerp), and manufacturing and maintenance of the barge are included. 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. For the LCA of road transport, all life cycle phases of road transport operation, road infrastructure, and manufacturing and maintenance of the lorry are included. 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.

3. ENERGY CONSUMPTION OF THE INLAND FREIGHT TRANSPORT MODES

The methodology to calculate the energy consumption during the transport operation of the rail freight transport and inland waterways transport in Belgium has been explained in the deliverable D.4.2 of the BRAIN-TRAINS project (Merchan et al., 2017a). For road transport, the methodology to calculate the energy consumption of road transport in Belgium has been explained in the deliverable D.4.3 of the BRAIN-TRAINS project (Merchan et al., 2017b). Table 1 shows the values of energy consumption of rail freight transport, inland waterways transport and road freight transport calculated in our study for several years in Belgium. Furthermore, since the lorry category “articulated lorry 34-40 t” represents approximately 75% of the road freight transport performance (i.e. tonne-kilometres) every year in Belgium, it has been used to compare the different inland freight transport modes because it is representative. For road transport, three scenarios with different load factors of 50%, 60% and 85% have been studied. The choice of these load factors is because the load factor of an average cargo in road transport including empty trips is 50% (EcoTransIT, 2008). Moreover, the load factors of intermodal road transport are 85% for the main haulage and 60% for the post-haulage (Janic, 2008).

TABLE 1. ENERGY CONSUMPTION (KJ/TKM) OF THE INLAND FREIGHT TRANSPORT MODES IN BELGIUM

Energy consumption (kJ/tkm)		2005	2006	2007	2008	2009	2010	2011	2012
Electric trains		-	541	527	549	547	438	454	427
Diesel trains		-	725	685	746	804	760	608	650
Inland waterways transport		-	319	312	304	299	293	290	288
Road transport	Load factor 50%	1000	996	993	987	989	988	-	-
	Load factor 60%	833	830	827	823	824	823	-	-
	Load factor 85%	588	586	584	581	582	581	-	-
Articulated lorry of 34-40 t	Load factor 50%	858	855	853	852	850	849	-	-
	Load factor 60%	715	713	711	710	709	708	-	-
	Load factor 85%	504	503	502	501	500	500	-	-

Table 2 presents the values fixed as reference values for the energy consumption parameter in the deliverable D.1.3 of the BRAIN-TRAINS project (Troch et al., 2015). Subsequently, it has been included in the study the inland waterways transport as well. These values have been extracted from EcoTransIT (2008), which represent a European average and include the energy consumption of both transport operation and fuels and electricity production (EcoTransIT, 2008).

TABLE 2. REFERENCE VALUES FOR THE ENERGY CONSUMPTION PARAMETER OF THE BRAIN-TRAINS PROJECT

Energy consumption (kJ/tkm)	2005
Electric trains	456
Diesel trains	530
Inland waterways transport (downstream)	438
Inland waterways transport (upstream)	727
Articulated lorry of 34 - 40 t (EURO III)	1082

SOURCE: ECOTRANSIT (2008)

If we compare the energy consumptions obtained in our study with the reference values extracted from EcoTransIT (2008), our results show lower energy consumptions for inland waterways transport, road transport and an articulated lorry of 34-40 t. Regarding rail freight transport, electric trains present in our study lower energy consumption after the year 2010 and diesel trains show in our study higher energy consumption than the values of EcoTransIT (2008). 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).

4. SCENARIO DEVELOPMENT

In 2011, the European Commission's White Paper on transport set 10 strategic goals with the objective of increasing the rail market share in Europe. The third strategic goal states that "30% of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and more than 50% by 2050, facilitated by efficient and green freight corridors" (European Commission, 2011).

As shown in table 3, road transport was responsible for 64.5% of the total inland freight expressed in tkm in Belgium in 2012 (i.e. 32105 million tkm), representing the dominant mode of the three major inland transport modes. Inland waterways accounts for 20.9% (10420 million tkm) and rail transport for 14.6% (7279 million tkm) (Eurostat statistics, 2017).

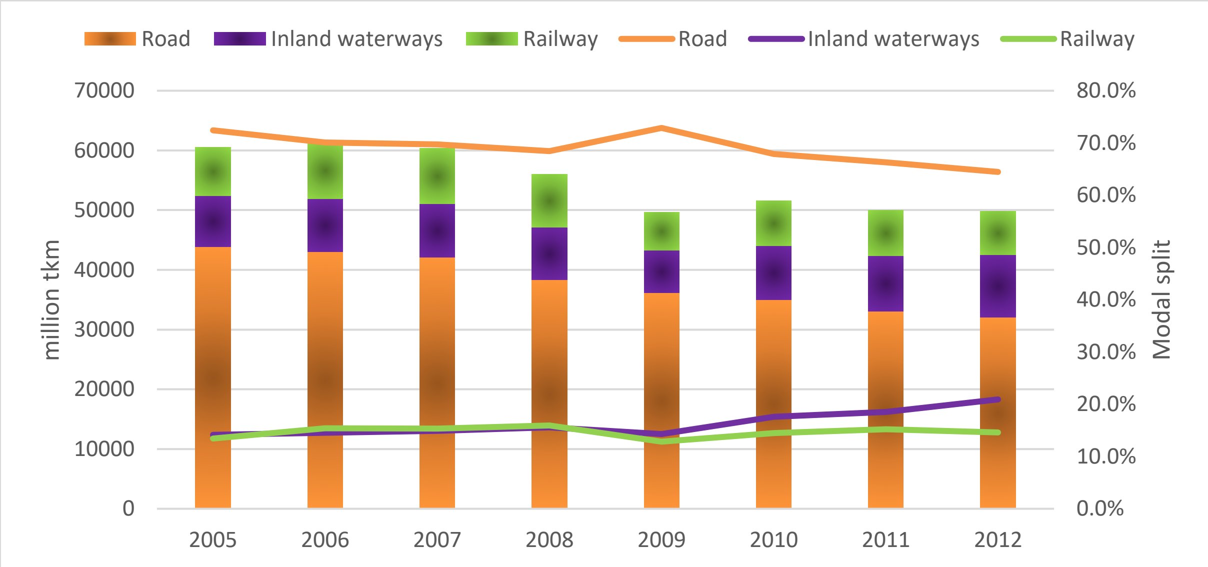
TABLE 3. MODAL SPLIT AND INLAND FREIGHT TRANSPORT IN BELGIUM

		2005	2006	2007	2008	2009	2010	2011	2012
Modal split (%)	Railway	13.4	15.4	15.3	15.9	12.8	14.5	15.2	14.6
	Inland waterways	14.1	14.5	14.9	15.6	14.3	17.6	18.5	20.9
	Road	72.4	70.1	69.7	68.5	72.9	67.9	66.3	64.5
Freight transport (million tkm)	Railway	8 141*	9 461*	9 258	8 927	6 374	7 476	7 593	7 279*
	Inland waterways	8 566	8 908	9 006	8 746	7 087	9 070	9 251	10 420
	Road	43 847	43 017	42 085	38 356	36 174	35 002	33 107	32 105
	TOTAL	60 554	61 386	60 386	56 029	49 635	51 548	49 951	49 804

*SOURCE: EUROSTAT STATISTICS, 2017; *VALUES CALCULATED USING THE MODAL SPLIT*

Figure 4 presents the results in modal split and inland freight transport in Belgium of the period from 2005 to 2012 showed in table 3. According to Eurostat statistics, from 2005 to 2012 there has been a decrease of 10750 million tkm of total inland freight transport in Belgium. However, this decline has affected differently the inland freight transport modes. Thereby, while road transport has decreased in 11742 million tkm and 7.9% of modal split, inland waterways transport has increased in 1874 million tkm and 6.8% of modal split. Otherwise, rail freight transport has experienced a decline in absolute terms of 862 million tkm but a growth in relative terms of 1.2% of modal split. It should be noted how rail freight transport experiences strong competition from inland waterways transport to attract the goods moved by road transport in Belgium.

FIGURE 4. INLAND FREIGHT TRANSPORT (MILLION TKM) AND MODAL SPLIT (%) IN BELGIUM



SOURCE: EUROSTAT STATISTICS, 2017

Three plausible scenarios directly linked to the third strategic goal of the European Commission's White Paper on transport (2011) have been built for further analysis. As a result, a best, a worst and a medium case scenarios have been developed as follows (Troch et al., 2015):

- The best case scenario takes into account a targeted 30% shift from road transport over 300 km towards rail or inland waterways transport by 2030.
- The worst case scenario is based on the assumption of a status quo by 2030. This includes a rise in rail demand in absolute terms, but no additional shift from road transport towards rail or inland waterways transport for distances over 300 km.
- The medium case scenario is an in-between scenario, where the goal for the 30% shift is carried out but not required to be completely reached by 2030. This scenario is augmenting the expected rise in rail demand with a fractional shift from road transport over 300 km towards rail or inland waterways transport.

In the deliverable D.1.3 of the BRAIN-TRAINS project (Troch et al., 2015) the values extracted from EcoTransIT (2008) had been fixed as reference values to develop the scenarios for both parameters: transport emissions (g/tkm) and energy consumption (kJ/tkm). Table 4 presents the reference values extracted from EcoTransIT (2008) and the values proposed for the best-case scenario, medium-case scenario and worst-case scenario.

TABLE 4. PARAMETERS RELATED TO ENVIRONMENT AND VALUES PROPOSED FOR SCENARIO CREATION. *NMHC: NON-METHANE HYDRO CARBONS

Parameters			Reference value	Best-case scenario		Medium-case scenario		Worst-case scenario	
Transport emissions (g/tkm)	CO_2	Road	72	58	-20%	58	-20%	43	-40%
		Electric trains	18	11	-40%	14	-20%	16	-10%
		Diesel trains	35	21	-40%	28	-20%	32	-10%
	NO_x	Road	0.553	0.445	-20%	0.445	-20%	0.330	-40%
		Electric trains	0.032	0.019	-40%	0.026	-20%	0.029	-10%
		Diesel trains	0.549	0.330	-40%	0.440	-20%	0.495	-10%
	SO_2	Road	0.090	0.072	-20%	0.072	-20%	0.054	-40%
		Electric trains	0.064	0.039	-40%	0.051	-20%	0.058	-10%
		Diesel trains	0.044	0.027	-40%	0.035	-20%	0.040	-10%
	NMHC*	Road	0.054	0.043	-20%	0.043	-20%	0.033	-40%
		Electric trains	0.004	0.002	-50%	0.003	-25%	0.004	0%
		Diesel trains	0.062	0.037	-40%	0.050	-20%	0.056	-10%
	Dust	Road	0.016	0.013	-20%	0.013	-20%	0.010	-40%
		Electric trains	0.005	0.003	-40%	0.004	-20%	0.004	-20%
		Diesel trains	0.017	0.010	-40%	0.014	-20%	0.015	-10%
Energy consumption (kJ/tkm)		Road	1082	975	-10%	920	-15%	755	-30%
		Electric trains	456	365	-20%	388	-15%	410	-10%
		Diesel trains	530	425	-20%	450	-15%	475	-10%

SOURCE: TROCH ET AL., 2015

For the best-case scenario, an increase of rail demand by 133% has been estimated considering as reference year 2012. This implies a growth from the 7279 million tkm of rail freight transport to approximately 17000 million tkm of goods transported by rail in the year 2030. A total inland freight transport of 85000 million tkm in the year 2030 has been estimated in the deliverable D.1.3 of the BRAIN-TRAINS project (Troch et al., 2015) and this, together with the 17000 million tkm of rail freight transport considered, results in a modal split share of 20% for rail freight transport in the year 2030. Therefore, the estimated growth of rail freight transport ranges from 14.6% in the year 2012 to 20% in 2030. This growth in rail freight transport could be achieved as a result of increased standardization and interoperability between countries, development of railway infrastructure to increase transport capacity and an expansion of the railway market considering the opportunities in the Eastern European countries. As a result of the improvement of the technology, it has been considered a reduction of 40% of transport emissions for rail freight transport and 20% for road transport. Moreover, a decrease of 20% of energy consumption for rail freight transport and 10% for road transport has been estimated (Troch et al., 2015).

A study by the European Parliament proposes that as a realistic medium-term objective, rail freight transport should have a modal split share of 20% measured in tonne-kilometres, which is in line with our best-case scenario. Furthermore, it states that the 30% shift of road freight over 300 km to rail or waterborne transport by 2030 would imply a transfer of approximately the 3.5% of the total transport of the European Union (European Parliament, 2015).

For the medium-case scenario, an increase of rail demand by 64% has been estimated considering as reference year 2012. This implies a growth from the 7279 million tkm of rail freight transport to approximately 12000 million tkm of goods transported by rail in the year 2030. A total inland freight transport of 71500 million tkm in the year 2030 has been estimated in the deliverable D.1.3 of the BRAIN-TRAINS project (Troch et al., 2015) and this, together with the 12000 million tkm of rail freight transport considered, results in a modal split share of 16.8% for rail freight transport in the year 2030. Therefore, the estimated growth of rail freight transport ranges from 14.6% in the year 2012 to 16.8% in 2030. For this scenario, it has been considered a reduction of 20% of transport emissions and 15% of energy consumption for both rail freight transport and road transport (Troch et al., 2015).

For the worst-case scenario, an increase of rail demand by 10% has been estimated considering as reference year 2012. This implies a growth from the 7279 million tkm of rail freight transport to approximately 8000 million tkm of goods transported by rail in the year 2030. A total inland freight transport of 57000 million tkm in the year 2030 has been estimated in the deliverable D.1.3 of the BRAIN-TRAINS project (Troch et al., 2015) and this, together with the 8000 million tkm of rail freight transport considered, results in a modal split share of 14% for rail freight transport in the year 2030. Therefore, rail freight transport will experience a growth in absolute terms but a slight decline in relative terms in the year 2030. For this scenario, it has been considered a reduction of 10% of transport emissions for rail freight transport and 40% for road transport. Moreover, a decrease of 10% of energy consumption for rail freight transport and 30% for road transport has been estimated (Troch et al., 2015).

In order to analyse how the shift from road transport to rail freight transport affects the environmental impacts of inland freight transport, the modal split share of inland waterways transport has remained at the value of the year 2012 (i.e. 20.9%). Once the values of rail freight transport and inland waterways transport have been calculated, the road freight transport and its modal split for the three scenarios has been determined. Table 5 shows the modal split and inland freight transport estimated for the three scenario in the year 2030.

TABLE 5. MODAL SPLIT AND INLAND FREIGHT TRANSPORT IN BELGIUM FOR THE THREE SCENARIOS

		Year 2012	Scenarios in the year 2030		
			Best-case	Medium-case	Worst-case
Modal split (%)	Railway	14.6	20	16.8	14
	Inland waterways	20.9	20.9	20.9	20.9
	Road	64.5	59.1	62.3	65
Freight transport (million tkm)	Railway	7 279	17 000	12 000	8 000
	Inland waterways	10 420	17 784	14 959	11 926
	Road	32 105	50 216	44 541	37 074
	TOTAL	49 804	85 000	71 500	57 000

Islam et al. (2013) estimated a shift from road to rail of 4.86% for a “white paper high scenario" (equivalent to our best-case scenario) and 1.13 % for a "white paper low scenario" (equivalent to our medium-case scenario). In our study, there has been a shift from road to rail of 5.4% for the best-case scenario and 2.2% for medium-case scenario. Furthermore, it should be noted a shift from rail to road of 0.6% in the worst-case scenario.

5. LIFE CYCLE IMPACT ASSESSMENT OF THE THREE SCENARIOS

A LCA study comprises four stages. First, the goal and scope definition, which in this deliverable is to analyse the environmental impacts of the three scenarios developed for the year 2030. 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 (Weidema et al., 2013). 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 in our study have been 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 purpose of this section is to analyse how the change of the modal split share of rail freight transport (due to the shift from road transport to rail freight transport) affects the environmental impacts of inland freight transport in Belgium. Therefore, we have analysed the environmental impacts of the modal splits of the year 2012 (used as reference year) and the three scenarios of the year 2030 considering the values showed in table 5.

5.1. Life Cycle Impact Assessment (LCIA) of the transport processes used in the scenarios

The environmental impacts of the inland freight transport in the year 2012 have been determined using the following three processes: rail freight transport considering the Belgian traction mix of the year 2012 (86% of electric trains and 14% of diesel trains), inland waterways transport of the year 2012 and average road transport with a load factor of 50% of the year 2010 (last year with available data).

In order to estimate the environmental impacts of the three scenarios in the year 2030, we have considered that the process inland waterways transport remains the same than 2012. For rail freight transport, since the use of diesel trains is decreasing over the years in Belgium (see table 6), we have considered that the rail freight transport will be performed mostly by electric traction in Belgium in the year 2030.

TABLE 6. ELECTRIC AND DIESEL RAIL FREIGHT TRACTION SHARE IN FLANDERS (BELGIUM)

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%

SOURCES: FLEMISH ENVIRONMENT AGENCY (VMM, 2008, 2009, 2010, 2012, 2013)

The electricity supply mix used for electric trains plays an important role in determining the environmental impact. Thereby, depending on the energy split of the country (i.e. the share of nuclear or natural gas power for example), the environmental impacts of the electric rail freight transport varies. Therefore, to determine the environmental impacts related to the electricity production in the year 2030, we have estimated the energy split of Belgium for this year. Table 7 presents the energy split considered for the year 2030 in Belgium. These values have been extracted from a study of Léonard and Belboom (2016) on electricity supply mix in Belgium. For the year 2030, it has been considered a scenario in which all the all targets for CO_2 emission reduction have been achieved and nuclear power is no longer used. Electricity imports from other countries are not considered, thus only the domestic production mix of Belgium has been used.

TABLE 7. DOMESTIC PRODUCTION MIX CONSIDERED FOR THE ELECTRICITY PRODUCTION IN BELGIUM IN THE YEAR 2030

Energy source	2030
Nuclear	0%
Coal	0%
Oil	0%
Natural gas	11.65%
Natural gas, Co-generation	24.07%
Wind, offshore	22.13%
Wind, onshore	12.97%
Biogas	5.75%
Biomass	7.47%
Hydro	0.70%
Waste	2.69%
Photovoltaic	10.56%
Geothermal	2.01%

SOURCE: LEONARD AND BELBOOM, 2016

For road transport in the year 2030, it has been assumed that the share of the population of lorries classified by gross vehicle weight remains stable but the load factor has improved from an average of 50% of load factor in the year 2010 to an average of 60% in the year 2030. Moreover, it has been considered that the emission engine technology Euro VI (which has been introduced in the year 2014) will be the main engine technology in the Belgian heavy duty vehicle market.

Table 8 presents the results obtained in the LCIA of one tonne-kilometre of freight transported by the different transport processes used in the modal split of the scenarios (i.e. reference year 2012 and the best, medium and worst case scenarios for the year 2030). These transport processes are as follows: rail freight transport considering the Belgian traction mix of 2012 (86% of electric trains and 14% of diesel trains), inland waterways transport of the year 2012, average road transport with a load factor of 50% of the year 2010, rail freight transport of the year 2030 (considering only electric traction and the domestic production mix of Belgium in the year 2030) and average road transport with a load factor of 60% and Euro VI emission engine technology for the year 2030.

TABLE 8. LCIA RESULTS OF 1 TKM OF FREIGHT TRANSPORTED BY THE TRANSPORT PROCESSES USED IN THE SCENARIOS

Impact category	Unit	Rail transport in 2012 (Belgian traction mix)	Inland waterways transport in 2012	Average road transport in 2010 (LF 50%)	Electric train 2030	Average road transport in 2030 (LF 60% - Euro VI)
Climate change	kg CO_2 eq	6.42E-02	7.47E-02	1.13E-01	5.36E-02	9.51E-02
Ozone depletion	kg CFC-11 eq	1.19E-08	7.81E-09	2.06E-08	6.13E-09	1.73E-08
Human toxicity, non-cancer effects	CTUh	2.31E-08	1.04E-08	3.14E-08	2.01E-08	2.72E-08
Human toxicity, cancer effects	CTUh	8.10E-09	3.64E-09	4.21E-09	7.82E-09	3.54E-09
Particulate matter	kg $PM_{2.5}$ eq	3.55E-05	4.74E-05	7.94E-05	2.78E-05	5.28E-05
Ionizing radiation HH	kBq U235 eq	5.85E-02	1.26E-02	9.74E-03	4.54E-03	8.17E-03
Ionizing radiation E (interim)	CTUe	9.79E-08	3.60E-08	5.40E-08	1.11E-08	4.53E-08
Photochemical ozone formation	kg NMVOC eq	3.03E-04	5.29E-04	9.37E-04	1.60E-04	2.73E-04
Acidification	molc H+ eq	3.64E-04	6.23E-04	8.40E-04	2.35E-04	3.39E-04
Terrestrial eutrophication	molc N eq	1.04E-03	1.98E-03	3.39E-03	5.70E-04	7.37E-04
Freshwater eutrophication	kg P eq	1.96E-05	1.94E-05	1.01E-05	1.44E-05	8.52E-06
Freshwater ecotoxicity	CTUe	6,20E-01	3.14E-01	1.06E+00	7.16E-01	9.17E-01
Land use	kg C deficit	1,39E-01	1.65E-01	4.61E-01	1.51E-01	3.90E-01
Mineral, fossil & ren. resource depletion	kg Sb eq	2.34E-06	6.62E-07	1.19E-05	2.41E-06	9.96E-06

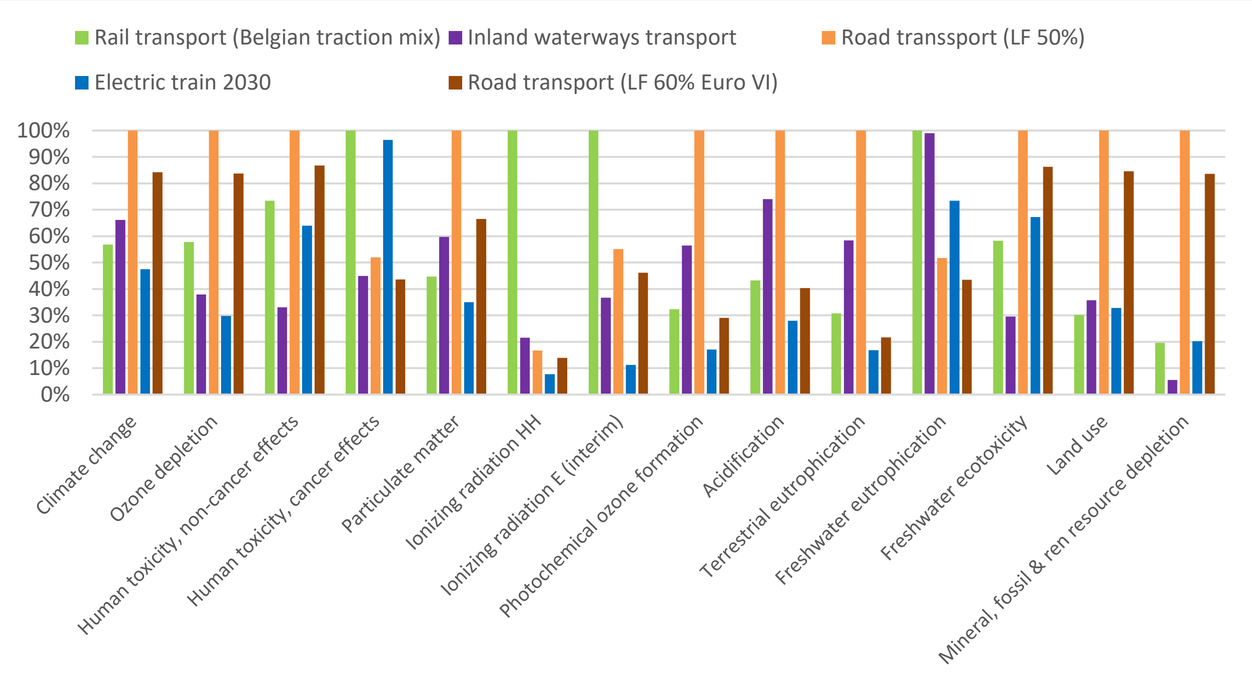
Figure 5 shows a comparison of the results (from table 8) obtained in the LCIA of one tonne-kilometre of freight transported by the inland freight transport modes used in the modal split of the different scenarios. Since each environmental impact indicator is expressed in different units, and to facilitate 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 the mode of transport with less impact and the highest value represents the maximum impact.

The average road transport with a load factor of 50% of the year 2010 presents the maximum impact in ten environmental impact indicators. As shown in table 1, the higher the load factor in road transport, the lower the energy consumption. The average road transport used in the three scenarios of the year 2030 has a load factor of 60% and this, together with the Euro VI emission engine technology, results in a lower environmental impact in all the indicators of the road transport process of the year 2030. The Euro VI emission engine technology influences on the indicators particulate matter, photochemical ozone formation, acidification and terrestrial eutrophication due to the lower exhaust emissions in comparison with the other engine technologies on $PM_{2.5}$, NMVOC and NO_x, respectively.

It should be noted that the articulated lorry of 34-40 t has a smaller difference in the environmental impacts regarding other transport modes than the average road transport process (see Figure 7 in APPENDIX I). This is because the fuel consumption per tkm decreases with the size of the lorry due to increased payload with the gross vehicle weight (GVW) category. Thereby, the average road transport process takes into account from the lorry GVW “rigid < 7.5 t” to “articulated lorry of 34-40 t” with a fuel consumption of 108 g/tkm and 20 g/tkm with a load factor of 50%, respectively.

The process rail freight transport considering the Belgian traction mix of 2012 (86% of electric trains and 14% of diesel trains) presents the maximum impact in the two indicators related with the radiation due to the use of nuclear power in the electricity production in Belgium. Since it has been considered that the nuclear power will be not used in the domestic production mix of electricity in the year 2030 (see table 7), the environmental impact on this indicators of the transport process electric train in the year 2030 are the lowest. Moreover, rail freight transport shows the maximum impact in the indicator “Human toxicity, cancer effects”, but with similar values than the electric train in the year 2030 due to the similar steel demand in the railway infrastructure.

FIGURE 5. LCIA OF 1 TKM OF FREIGHT TRANSPORTED BY THE TRANSPORT PROCESSES USED IN THE SCENARIOS



5.2. Life Cycle Impact Assessment (LCIA) of the scenarios

The LCIA of the different scenarios has been performed using the values of modal split presented in table 5 and the transport processes showed in table 8. Thereby, we have analysed how the change of the modal split share of rail freight affects the environmental impacts of inland freight transport in Belgium. Table 9 presents the results obtained in the LCIA of one tonne-kilometre of freight transported considering the modal split of the reference year 2012 and the best, medium and worst case scenarios for the year 2030.

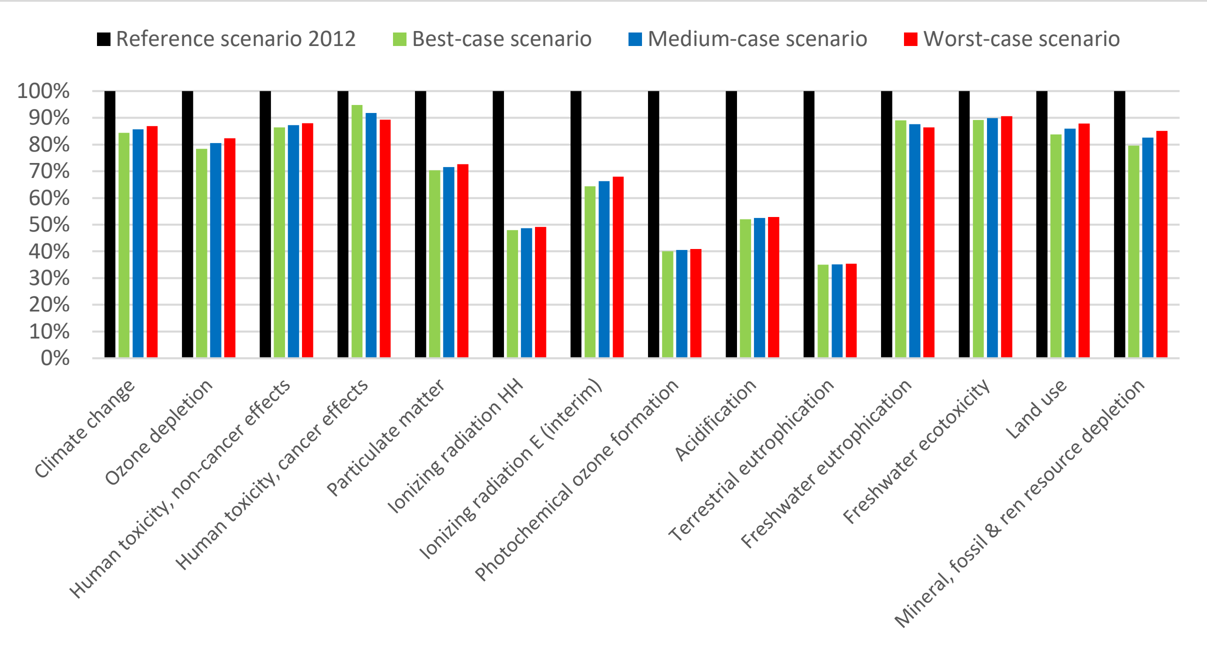
The results obtained from the LCIA of the different scenarios showing the contribution of every transport mode to the total environmental impact are in APPENDIX II. It should be noted that road transport is the main contributor in all the scenarios to the total impact on all the environmental impact indicators. The only exception to this is in indicator ionizing radiation in the reference scenario of the year 2012, where rail freight transport represents 49% of the total impact due to the use of electricity produced partially with nuclear power by the electric trains.

TABLE 9. LCIA RESULTS OF 1 TKM OF FREIGHT TRANSPORTED CONSIDERING THE MODAL SPLIT OF THE SCENARIOS

Impact category	Unit	Reference year 2012	Best-case scenario 2030	Medium-case scenario 2030	Worst-case scenario 2030
Climate change	kg CO_2 eq	9.78E-02	8.25E-02	8.38E-02	8.50E-02
Ozone depletion	kg CFC-11 eq	1.67E-08	1.31E-08	1.34E-08	1.37E-08
Human toxicity, non-cancer effects	CTUh	2.58E-08	2.23E-08	2.25E-08	2.27E-08
Human toxicity, cancer effects	CTUh	4.66E-09	4.41E-09	4.28E-09	4.16E-09
Particulate matter	kg $PM_{2.5}$ eq	6.63E-05	4.67E-05	4.75E-05	4.81E-05
Ionizing radiation HH	kBq U235 eq	1.75E-02	8.38E-03	8.49E-03	8.59E-03
Ionizing radiation E (interim)	CTUe	5.66E-08	3.65E-08	3.76E-08	3.85E-08
Photochemical ozone formation	kg NMVOC eq	7.59E-04	3.04E-04	3.07E-04	3.10E-04
Acidification	molc H+ eq	7.25E-04	3.78E-04	3.81E-04	3.84E-04
Terrestrial eutrophication	molc N eq	2.76E-03	9.64E-04	9.70E-04	9.74E-04
Freshwater eutrophication	kg P eq	1.35E-05	1.20E-05	1.18E-05	1.16E-05
Freshwater ecotoxicity	CTUe	8.42E-01	7.51E-01	7.57E-01	7.63E-01
Land use	kg C deficit	3.52E-01	2.95E-01	3.03E-01	3.09E-01
Mineral, fossil & ren. resource depletion	kg Sb eq	8.16E-06	6.50E-06	6.74E-06	6.95E-06

Figure 6 shows a comparison of the results (from table 9) obtained in the LCIA of one tonne-kilometre of freight transported considering the modal split of the different scenarios.

FIGURE 6. LCIA OF 1 TKM OF FREIGHT TRANSPORTED CONSIDERING THE MODAL SPLIT OF THE DIFFERENT SCENARIOS



The reference scenario of the year 2012 shows the maximum impact in all the environmental impact indicators due to the great influence of the average road transport process with a load factor of 50%. As explained above, this process has the highest energy consumption and exhaust emissions of the transport processes considered in the study. Thereby, even the worst-case scenario, which has a higher road transport share in the modal split (65% compared to the 64.5% of road transport in the reference scenario), has a lower impact in all the scenarios than the reference scenario due to the use of the average road transport process with a load factor of 60% and the Euro VI emission engine technology. It should be noted the influence of the Euro VI emission engine technology used in the road transport process of 2030 on the indicators particulate matter, photochemical ozone formation, acidification and terrestrial eutrophication. Moreover, the non-use of nuclear power in the domestic production mix of electricity in the year 2030 (used by electric trains) influences on the indicators related with the radiation.

Focusing on the three scenarios developed for the year 2030, the higher the share of road transport (and therefore lower the rail freight transport modal split share), the greater the environmental impact. The exception is for both indicators "Human toxicity, cancer effects" and freshwater ecotoxicity, where the rail freight transport causes a greater environmental impact. It should be noted that the differences between scenarios are not really significant.

6. CONCLUSIONS

The load factor and emission engine technology are shown as determining factors in the environmental impacts of road transport. Therefore these factors have a strong influence in the environmental impact of the total inland freight transport due to the prominent position of road transport in Belgium (64.5% of the inland freight transport modal split in the year 2012).

The electricity supply mix plays a fundamental role in the environmental impacts of rail freight transport when using electric traction. Therefore, as the use of electric trains increases in the future and have a higher share of the total inland freight transport, the energy split for the electricity generation will be more important in the environmental impacts of goods transport.

In view of the results obtained in the study of the three scenarios in the year 2030, the increase of rail freight transport in the modal split as a result of the possible development of the intermodal rail freight transport represents an opportunity to attain a more environmentally and health friendly, and energy-efficient transport system.

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.

European Parliament, "Freight on road: why EU shippers prefer truck to trains", Directorate-General for internal policies, Policy department B: Structural and cohesion policies, 2015.

Eurostat Statistics, extracted on 17/08/2017. URL: http://ec.europa.eu/eurostat

Islam, D. M. Z., Jackson, R., Zunder, T. H., Laparidou, K. and Burgess, A., "Triple rail freight demand by 2050 in EU27- realistic, optimistic or farfetched imagination?", World Congress on Railway Research, 2013.

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

Léonard, A., Belboom, S., "Évaluation des impacts environnementaux de la production d'électricité en Belgique par Analyse du Cycle de Vie : Vues du passé, présent et scénarios prospectifs", Rapport final convention ECEB, 2016.

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

Merchan, A., Belboom, S. and Léonard, A., "Deliverable D 4.3 Scenario 2: Worst case. BRAINTRAINS: Transversal assessment of new intermodal strategies, WP4: Sustainability impact", 2017b.

Sala, S., Pant, R., Hauschild, M. and 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.Spielmann, M., Bauer, C., Dones, R., Tuchschmid, M. "Transport Services. Ecoinvent report No. 14", Swiss Centre for Life Cycle Inventories, Dübendorf, 2007.

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

Van de Voorde, E., Vanelslander, T., "Development of rail freight in Europe: What regulation can and cannot do. Belgium case study", Centre on Regulation in Europe, Belgium, 2014.

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 1990-2007. 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.

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

APPENDIX I – LIFE CYCLE IMPACT ASSESSMENT (LCIA) OF INLAND FREIGHT TRANSPORT IN BELGIUM

Table 10 presents the results obtained in the LCIA of one tonne-kilometre of freight transported in Belgium in the year 2010 by rail freight transport considering the Belgian traction mix of 2010 (83% of electric trains and 17% of diesel trains), diesel trains (including shunting activity), electric trains, inland waterways transport and road transport using an articulated lorry of 34-40 t with the load factors of 50%, 60% and 85% (in the last two load factors, a Euro VI emission engine technology has also been used). It should be noted that the impact assessment results of the road transport processes are different from those presented in the deliverable D4.3 of the BRAIN-TRAINS project (Merchan et al., 2017b). As mentioned above, this is because the road infrastructure demand has been updated.

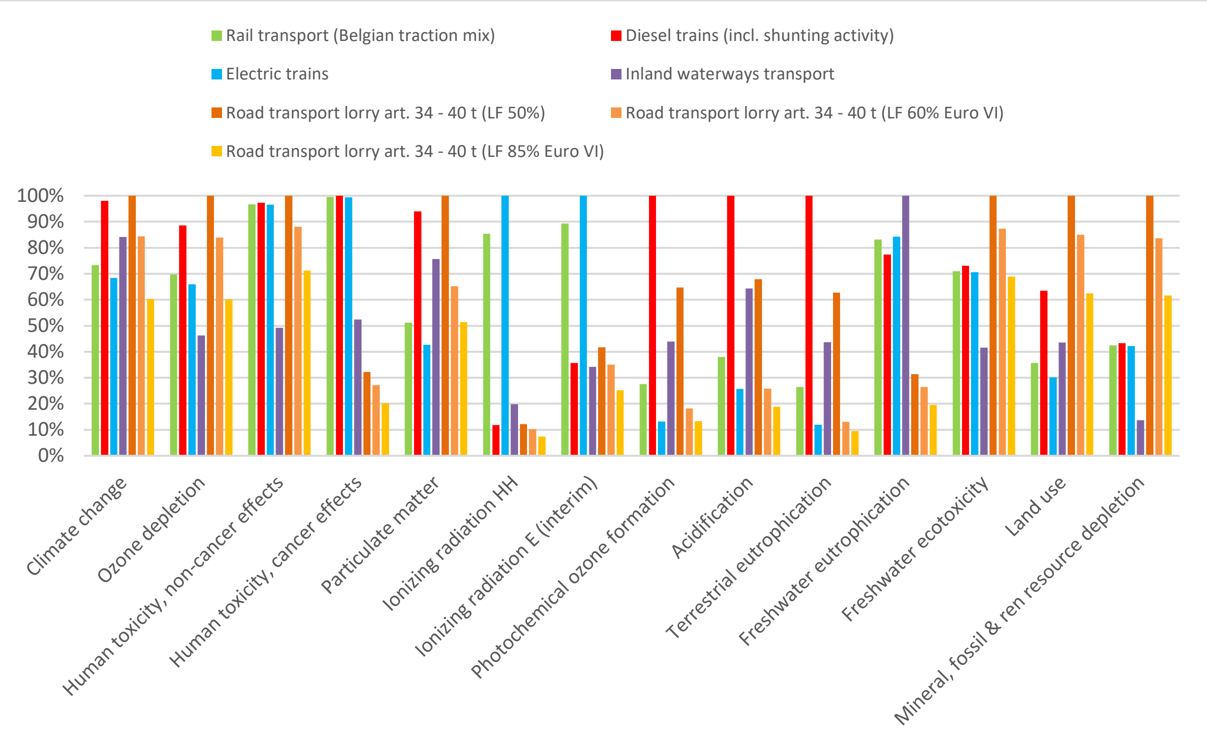
TABLE 10. LCIA RESULTS OF 1 TKM OF FREIGHT TRANSPORTED IN BELGIUM IN THE YEAR 2010

Impact category	Unit	Rail freight transport			Inland waterways transport	Road transport lorry art. 34-40 t		
		Belgian traction mix	Diesel trains	Electric trains		LF 50%	LF 60% (Euro VI)	LF 85% (Euro VI)
Climate change	kg CO_2 eq	6.83E-02	9.14E-02	6.38E-02	7.85E-02	9.32E-02	7.86E-02	5.62E-02
Ozone depletion	kg CFC-11 eq	1.22E-08	1.55E-08	1.15E-08	8.09E-09	1.75E-08	1.47E-08	1.05E-08
Human toxicity, non-cancer effects	CTUh	2.18E-08	2.19E-08	2.17E-08	1.11E-08	2.25E-08	1.98E-08	1.60E-08
Human toxicity, cancer effects	CTUh	7.54E-09	7.58E-09	7.53E-09	3.98E-09	2.44E-09	2.06E-09	1.53E-09
Particulate matter	kg $PM_{2.5}$ eq	3.42E-05	6.28E-05	2.85E-05	5.06E-05	6.69E-05	4.36E-05	3.44E-05
Ionizing radiation HH	kBq U235 eq	5.65E-02	7.80E-03	6.61E-02	1.31E-02	8.02E-03	6.75E-03	4.87E-03
Ionizing radiation E (interim)	CTUe	9.75E-08	3.89E-08	1.09E-07	3.74E-08	4.55E-08	3.82E-08	2.75E-08
Photochemical ozone formation	kg NMVOC eq	3.44E-04	1.25E-03	1.65E-04	5.48E-04	8.08E-04	2.27E-04	1.67E-04
Acidification	molc H+ eq	3.93E-04	1.03E-03	2.66E-04	6.64E-04	7.02E-04	2.68E-04	1.95E-04
Terrestrial eutrophication	molc N eq	1.24E-03	4.68E-03	5.58E-04	2.05E-03	2.94E-03	6.10E-04	4.46E-04
Freshwater eutrophication	kg P eq	1.70E-05	1.58E-05	1.72E-05	2.04E-05	6.40E-06	5.42E-06	4.00E-06
Freshwater ecotoxicity	CTUe	5.71E-01	5.88E-01	5.68E-01	3.35E-01	8.04E-01	7.02E-01	5.54E-01
Land use	kg C deficit	1.44E-01	2.57E-01	1.22E-01	1.76E-01	4.05E-01	3.44E-01	2.53E-01
Mineral, fossil & ren. resource depletion	kg Sb eq	2.25E-06	2.30E-06	2.24E-06	7.26E-07	5.31E-06	4.44E-06	3.27E-06

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. 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.

Figure 7 shows a comparison of the results (from table 10) obtained in the LCIA of different modes of inland freight transport in Belgium in 2010. Diesel trains present the maximum impact in the indicators photochemical ozone formation, acidification 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.

FIGURE 7. LCIA OF INLAND FREIGHT TRANSPORT IN BELGIUM IN THE YEAR 2010



For the indicator climate change, the articulated lorry of 34-40 t with a load factor of 50% presents the maximum impact due to the exhaust emissions during the transport activity. However, diesel trains show a very similar value in this indicator. It should be noted that an articulated lorry of 34-40 t with a load factor of 60% presents nearly the same environmental impact on climate change than inland waterways transport. Although, with a load factor of 85% have the lowest score for this indicator. 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.

APPENDIX II – LIFE CYCLE IMPACT ASSESSMENT (LCIA) OF THE SCENARIOS

a) Reference scenario in the year 2012

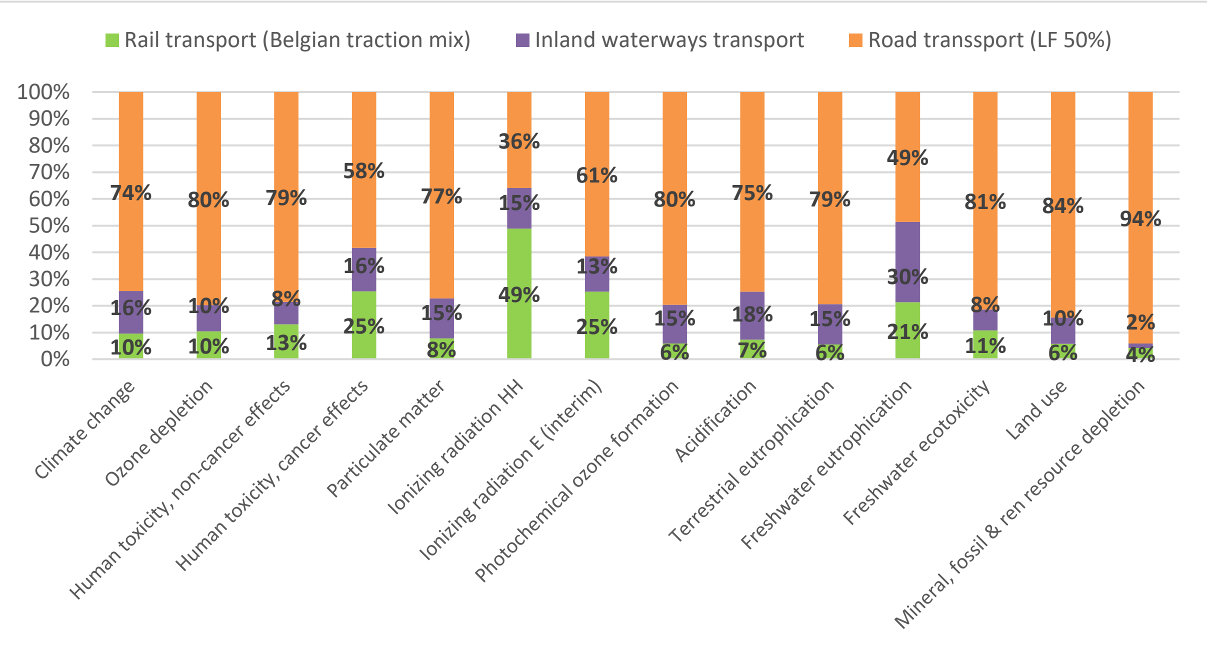
Table 11 presents the results obtained in the LCIA of one tonne-kilometre of freight transported considering the modal split of inland freight transport of the year 2012.

TABLE 11. LCIA RESULTS OF 1 TKM OF FREIGHT TRANSPORTED CONSIDERING THE MODAL SPLIT OF INLAND FREIGHT TRANSPORT OF THE YEAR 2012

Impact category	Unit	TOTAL	Contribution of		
			Rail transport in 2012 (Belgian traction mix)	Inland waterways transport in 2012	Average road transport in 2010 (LF 50%)
Climate change	kg CO_2 eq	9.78E-02	9.37E-03	1.56E-02	7.28E-02
Ozone depletion	kg CFC-11 eq	1.67E-08	1.74E-09	1.63E-09	1.33E-08
Human toxicity, non-cancer effects	CTUh	2.58E-08	3.37E-09	2.17E-09	2.02E-08
Human toxicity, cancer effects	CTUh	4.66E-09	1.18E-09	7.60E-10	2.72E-09
Particulate matter	kg $PM_{2.5}$ eq	6.63E-05	5.18E-06	9.91E-06	5.12E-05
Ionizing radiation HH	kBq U235 eq	1.75E-02	8.55E-03	2.64E-03	6.28E-03
Ionizing radiation E (interim)	CTUe	5.66E-08	1.43E-08	7.52E-09	3.48E-08
Photochemical ozone formation	kg NMVOC eq	7.59E-04	4.42E-05	1.11E-04	6.04E-04
Acidification	molc H+ eq	7.25E-04	5.31E-05	1.30E-04	5.42E-04
Terrestrial eutrophication	molc N eq	2.76E-03	1.52E-04	4.15E-04	2.19E-03
Freshwater eutrophication	kg P eq	1.35E-05	2.86E-06	4.06E-06	6.54E-06
Freshwater ecotoxicity	CTUe	8.42E-01	9.05E-02	6.56E-02	6.86E-01
Land use	kg C deficit	3.52E-01	2.03E-02	3.44E-02	2.97E-01
Mineral, fossil & ren. resource depletion	kg Sb eq	8.16E-06	3.41E-07	1.38E-07	7.69E-06

Figure 8 shows a comparison of the results (from table 11) obtained in the LCIA of one tonne-kilometre of freight transported considering the modal split of the year 2012.

FIGURE 8. LCIA OF 1 TKM OF FREIGHT TRANSPORTED CONSIDERING THE MODAL SPLIT OF THE YEAR 2012



b) Best-case scenario for the year 2030

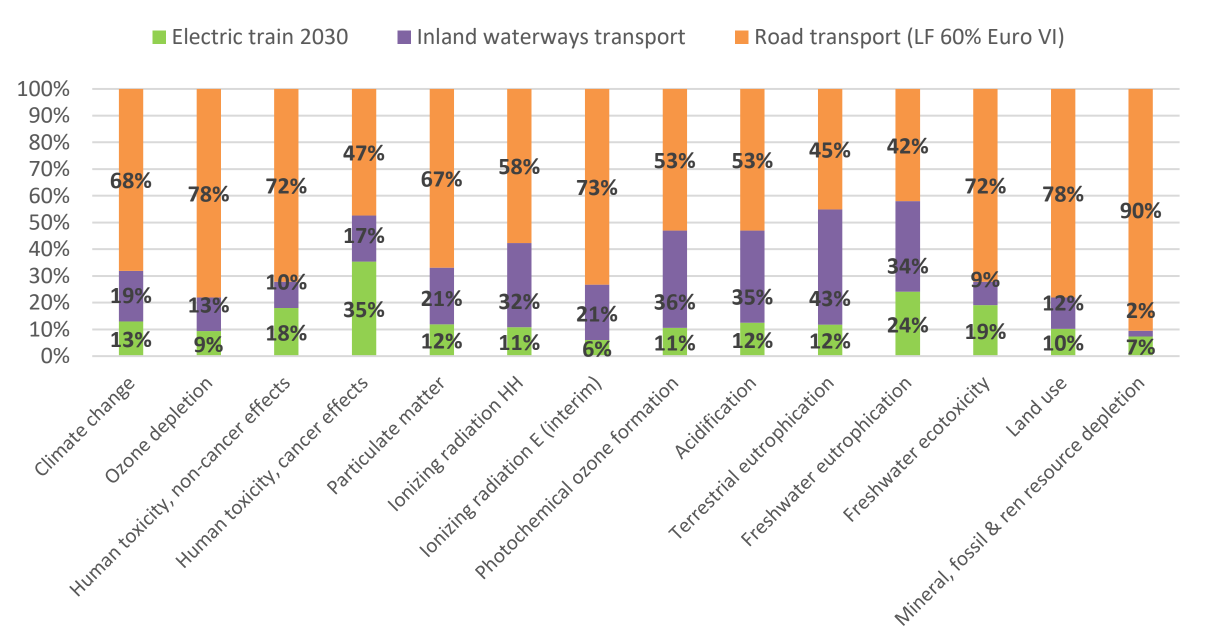
Table 12 presents the results obtained in the LCIA of one tonne-kilometre of freight transported considering the modal split of the best-case scenario for the year 2030.

TABLE 12. LCIA RESULTS OF 1 TKM OF FREIGHT TRANSPORTED CONSIDERING THE MODAL SPLIT OF THE BEST-CASE SCENARIO FOR THE YEAR 2030

Impact category	Unit	TOTAL	Contribution of		
			Electric train 2030	Inland waterways transport in 2012	Average road transport in 2030 (LF 60% - Euro VI)
Climate change	kg CO_2 eq	8.25E-02	1.07E-02	1.56E-02	5.62E-02
Ozone depletion	kg CFC-11 eq	1.31E-08	1.23E-09	1.63E-09	1.02E-08
Human toxicity, non-cancer effects	CTUh	2.23E-08	4.02E-09	2.17E-09	1.61E-08
Human toxicity, cancer effects	CTUh	4.41E-09	1.56E-09	7.61E-10	2.09E-09
Particulate matter	kg $PM_{2.5}$ eq	4.67E-05	5.55E-06	9.92E-06	3.12E-05
Ionizing radiation HH	kBq U235 eq	8.38E-03	9.08E-04	2.64E-03	4.83E-03
Ionizing radiation E (interim)	CTUe	3.65E-08	2.21E-09	7.53E-09	2.67E-08
Photochemical ozone formation	kg NMVOC eq	3.04E-04	3.21E-05	1.11E-04	1.61E-04
Acidification	molc H+ eq	3.78E-04	4.70E-05	1.30E-04	2.00E-04
Terrestrial eutrophication	molc N eq	9.64E-04	1.14E-04	4.15E-04	4.35E-04
Freshwater eutrophication	kg P eq	1.20E-05	2.88E-06	4.06E-06	5.04E-06
Freshwater ecotoxicity	CTUe	7.51E-01	1.43E-01	6.57E-02	5.42E-01
Land use	kg C deficit	2.95E-01	3.02E-02	3.45E-02	2.30E-01
Mineral, fossil & ren. resource depletion	kg Sb eq	6.50E-06	4.81E-07	1.38E-07	5.88E-06

Figure 9 shows a comparison of the results (from table 12) obtained in the LCIA of one tonne-kilometre of freight transported considering the modal split of the best-case scenario.

FIGURE 9. LCIA OF 1 TKM OF FREIGHT TRANSPORTED CONSIDERING THE MODAL SPLIT OF THE BEST-CASE SCENARIO



c) Medium-case scenario for the year 2030

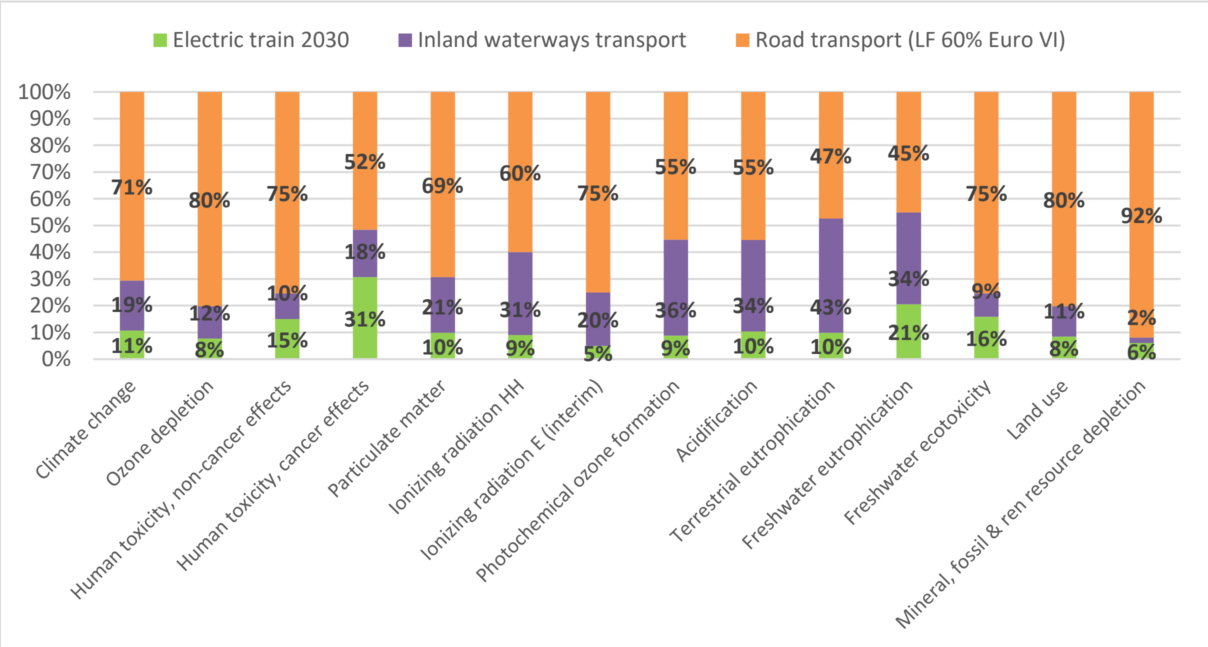
Table 13 presents the results obtained in the LCIA of one tonne-kilometre of freight transported considering the modal split of the medium-case scenario for the year 2030.

TABLE 13. LCIA RESULTS OF 1 TKM OF FREIGHT TRANSPORTED CONSIDERING THE MODAL SPLIT OF THE MEDIUM-CASE SCENARIO FOR THE YEAR 2030

Impact category	Unit	TOTAL	Contribution of		
			Electric train 2030	Inland waterways transport in 2012	Average road transport in 2030 (LF 60% - Euro VI)
Climate change	kg CO_2 eq	8.38E-02	8.99E-03	1.56E-02	5.92E-02
Ozone depletion	kg CFC-11 eq	1.34E-08	1.03E-09	1.63E-09	1.07E-08
Human toxicity, non-cancer effects	CTUh	2.25E-08	3.37E-09	2.17E-09	1.70E-08
Human toxicity, cancer effects	CTUh	4.28E-09	1.31E-09	7.61E-10	2.20E-09
Particulate matter	kg $PM_{2.5}$ eq	4.75E-05	4.66E-06	9.92E-06	3.29E-05
Ionizing radiation HH	kBq U235 eq	8.49E-03	7.62E-04	2.64E-03	5.09E-03
Ionizing radiation E (interim)	CTUe	3.76E-08	1.85E-09	7.53E-09	2.82E-08
Photochemical ozone formation	kg NMVOC eq	3.07E-04	2.69E-05	1.11E-04	1.70E-04
Acidification	molc H+ eq	3.81E-04	3.94E-05	1.30E-04	2.11E-04
Terrestrial eutrophication	molc N eq	9.70E-04	9.57E-05	4.15E-04	4.59E-04
Freshwater eutrophication	kg P eq	1.18E-05	2.42E-06	4.06E-06	5.31E-06
Freshwater ecotoxicity	CTUe	7.57E-01	1.20E-01	6.57E-02	5.71E-01
Land use	kg C deficit	3.03E-01	2.54E-02	3.45E-02	2.43E-01
Mineral, fossil & ren. resource depletion	kg Sb eq	6.74E-06	4.04E-07	1.38E-07	6.20E-06

Figure 10 shows a comparison of the results (from table 13) obtained in the LCIA of one tonne-kilometre of freight transported considering the modal split of the medium-case scenario.

FIGURE 10. LCIA OF 1 TKM OF FREIGHT TRANSPORTED CONSIDERING THE MODAL SPLIT OF THE MEDIUM-CASE SCENARIO



d) Worst-case scenario for the year 2030

Table 14 presents the results obtained in the LCIA of one tonne-kilometre of freight transported considering the modal split of the worst-case scenario for the year 2030.

TABLE 14. LCIA RESULTS OF 1 TKM OF FREIGHT TRANSPORTED CONSIDERING THE MODAL SPLIT OF THE WORST-CASE SCENARIO FOR THE YEAR 2030

Impact category	Unit	TOTAL	Contribution of		
			Electric train 2030	Inland waterways transport in 2012	Average road transport in 2030 (LF 60% - Euro VI)
Climate change	kg CO_2 eq	8.50E-02	7.53E-03	1.56E-02	6.18E-02
Ozone depletion	kg CFC-11 eq	1.37E-08	8.60E-10	1.63E-09	1.12E-08
Human toxicity, non-cancer effects	CTUh	2.27E-08	2.82E-09	2.17E-09	1.77E-08
Human toxicity, cancer effects	CTUh	4.16E-09	1.10E-09	7.61E-10	2.30E-09
Particulate matter	kg $PM_{2.5}$ eq	4.81E-05	3.90E-06	9.92E-06	3.43E-05
Ionizing radiation HH	kBq U235 eq	8.59E-03	6.37E-04	2.64E-03	5.31E-03
Ionizing radiation E (interim)	CTUe	3.85E-08	1.55E-09	7.53E-09	2.94E-08
Photochemical ozone formation	kg NMVOC eq	3.10E-04	2.25E-05	1.11E-04	1.77E-04
Acidification	molc H+ eq	3.84E-04	3.30E-05	1.30E-04	2.20E-04
Terrestrial eutrophication	molc N eq	9.74E-04	8.01E-05	4.15E-04	4.79E-04
Freshwater eutrophication	kg P eq	1.16E-05	2.02E-06	4.06E-06	5.54E-06
Freshwater ecotoxicity	CTUe	7.63E-01	1.00E-01	6.57E-02	5.96E-01
Land use	kg C deficit	3.09E-01	2.12E-02	3.45E-02	2.54E-01
Mineral, fossil & ren. resource depletion	kg Sb eq	6.95E-06	3.38E-07	1.38E-07	6.48E-06

Figure 11 shows a comparison of the results (from table 14) obtained in the LCIA of one tonne-kilometre of freight transported considering the modal split of the worst-case scenario.

FIGURE 11. LCIA OF 1 TKM OF FREIGHT TRANSPORTED CONSIDERING THE MODAL SPLIT OF THE WORST-CASE SCENARIO