Annex 1 to the final report of the LIMOBEL project (Long run impacts of policy packages on mobility in Belgium), study financed by the Belgian FPS Science Policy. (Contract SD/TM/01B)

LIMOBEL Annex 1

E-motion

Part I Road transport
Part II Rail transport
Part III Inland navigation
Part IV Maritime transport
Part V Indirect emissions

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Annex 1: E-motion

Road transport

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List of abbreviations

cc	Cylinder capacity
CO	Carbon monoxide
CO_2	Carbon dioxide
CNG	Compressed Natural Gas
CS	Charge sustaining
DIV	Directie inschrijvingen voertuigen/Direction pour l'immatriculation des véhicules
DME	Dimethyl ether
E-motion	Energy- and emission MOdel for Transport with geographical distributION
FAPETRO	Fonds voor de analyse van petroleumproducten
FPS	Federal Policy Services
FT	Fischer-Tropsch
H2	Hydrogen gas
HDVa	Heavy Duty Vehicles articulated
HDVr	Heavy Duty Vehicles rigid
HFC-134a	tetrafluoroethane
HM	Heavy metals
ICE	Internal Combustion Engine
LPG	Liquefied Petroleum Gas
MAC	Mobile air-conditioning
NEG	New economic geography
NO_x	Nitrogen oxides
Pb	Lead
PHEV	Plug-in Hybrid Electric Vehicle
PLANET	A model of the Belgian Federal PLANning Bureau that models the relationship between the Economy and Transport
PM2.5	Particulate matter with an aerodynamic diameter ≤ 2.5µm
pva	Belgian reference number of a vehicle
FPS	Federal Public Services
SO_2	Sulphur dioxide
t	Tonne
tonne-km	tonne-kilometre
Vkm	Vehicle kilometre
VOC	Volatile organic compounds

1. Introduction

E-motion is the acronym for '*Energy- and emission MOdel for Transport with geographical distributION*'. This environmental impact assessment model calculates and geographically distributes energy consumption and emissions from road transport, rail traffic, inland navigation, maritime transport and off-road transport for Flanders, Wallonia and the Brussels region. Not only inventory studies, but also scenarios can be calculated with E-motion. Future technologies are presented in all modules.

This part gives an overall description of the function and input/output parameters of the road module.

Figure 1 gives an overview of the E-motion road module structure.

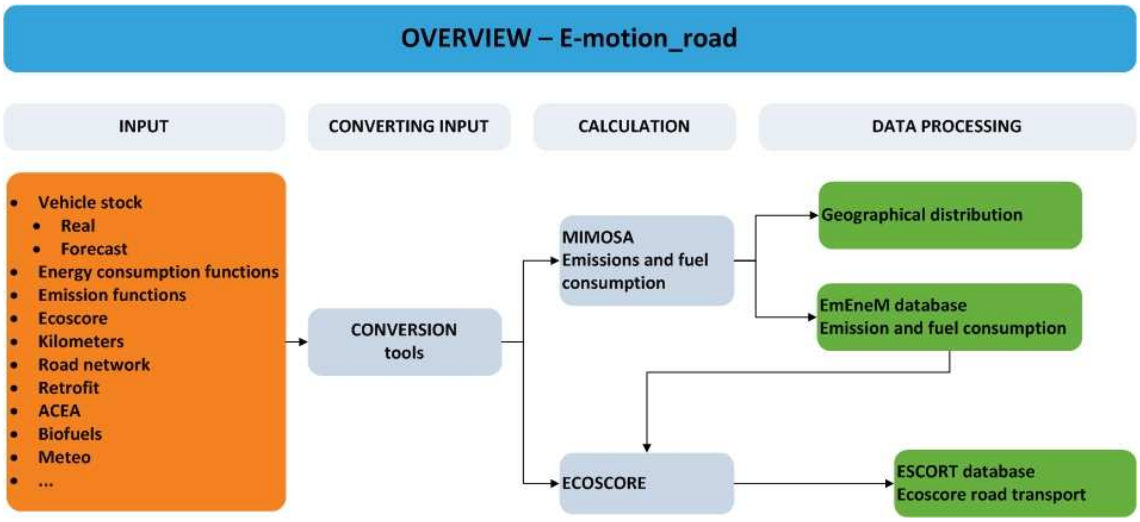

Figure 1: overview of the E-motion road module structure

First, we describe how the heart of the module – MIMOSA – works. Second, we list the most important input parameters with their sources to be able to run MIMOSA. Finally, we will summarize all possible outcomes of the module.

Besides the emissions of passenger cars, E-motion can also model the evolution of the vehicle fleet's ecoscore. Ecoscore is a well-to-wheel indicator expressing the overall environmental impact of a vehicle, taking into account its contribution to global warming, air pollution and noise. The ESCORT database makes it possible to have an idea of the average (unweighted[1]) ecoscore of the fleet. This part of the road module was not used within LIMOBEL, but the influence of different policy measures on the evolution of the Belgian fleet's ecoscore for passenger cars was done within the CLEVER project (Michiels et al., 2011).

[1] not weighted by the number of kilometres driven by each car

How is E-Motion used in LIMOBEL?

The main aim of E-motion in LIMOBEL was to provide the latest know-how on fuel efficiency, emission factors and damage per tonne of emissions. This information is integrated in the PLANET model as an input to calculate the evolution of emissions and environmental damages related to transport. The results on fuel efficiency are also used as an input in the vehicle stock module of PLANET. For more information on damage per tonne of emissions we refer to Annex 2 of the LIMOBEL report.

To come up with fuel consumption and emission figures for PLANET (and NODUS) we defined two policy scenarios and ran both scenarios with E-motion. These scenarios were based on Reference and European scenario of De Vlieger et al. (2009). Adaptations brought into these scenarios are described in this Annex.

To come up with appropriate energy and emission figures calculated fuel consumption and emissions were divided by the kilometres driven. Several aggregation levels are possible (per vehicle type, fuel technology, road type, ...). For passenger cars PLANET was fed with the most disaggregated fuel consumption and emission figures, i.e. per euro class.

2. MIMOSA, the heart of the E-motion road module

Like most European road transport emission models, MIMOSA belongs to the '*average speed macroscopic emission models*', expressing emission and fuel consumption rates for each trip as functions of average speed. This macroscopic approach has the advantage of being simple and easy to apply in emission estimations for larger areas. Furthermore, it allows quantifying the effect of scenarios on technological enhancements or changes in the vehicle fleet, and it can estimate the large scale impact of transportation demand measures by taking into account the changes in vehicle activity data. The first version of MIMOSA was developed by (Mensink et al., 2000) for the city of Antwerp. Later the model was further extended and improved by (Lewyckyi et al., 2004) to calculate emissions and emission reduction scenarios for larger study areas e.g. (Schrooten et al., 2006). Within LIMOBEL and the MIMOSA4 study (Vankerkom et al., 2009), VITO refined, extended and revalidated MIMOSA.

Within the module eight *vehicle categories* can be distinguished with further sub-categories depending on the technology, the age of the vehicle and its cylinder capacity or tonnage. All possible combinations are presented in Table 1. Generally, the classes correspond to those applied in *COPERT 4* (EMEP/CORINAIR, 2007). We extended the technology classes with *alternative motor fuel and vehicles technologies* (petrol PHEV, diesel hybrid CS, diesel hybrid PHEV, electric, H_2 ICE and fuel cell H_2).

Hybrid means that the vehicles are able to drive a certain distance purely on electricity and have the possibility to load their batteries on the net (plug-in) in the future. The micro- or mild hybrid is not incorporated in the hybrid classes, but sorts under the diesel and petrol technologies. Petrol technology also incorporates flexi-fuel vehicles, that could drive on both petrol and ethanol blends.
Within the ('full') hybrid vehicles two types of technologies are considered:

- charge sustaining: the battery loses net no charge: all energy is supplied by the combustion engine. Typical example of such a system is the Toyota Prius.
- charge depleting: here there is a net discharge of the battery, it needs to be charged at the electricity grid (e.g. at night). This type is also known as 'plug-in hybrid' (PHEV).

All modules in E-motion not only aim at calculating *total emission* evaluations, but also calculate *geographically distributed* emissions. This is a necessary step to quantify the impact of traffic flows on air quality. Concerning the emission calculation in MIMOSA, the model uses a 'static' macroscopic approach, i.e. generic speeds per road segment (Vankerkom et al., 2009) are combined with emission factors to calculate the emissions per road segment and per hour. By combining the hourly traffic volumes computed per road segment with fleet statistics and the corresponding emission factors, the MIMOSA calculates geographically distributed traffic emissions within a chosen time frame, varying from one hour to one year.

The emissions include *hot, cold and evaporative* emissions. Cold start emissions can be calculated based on information on the trip length and the ambient temperature. Short trips, carried out with cold engines, will result in higher emissions. Evaporative emissions are only obtained for the running losses, i.e. vapour losses generated in petrol tanks during vehicle operation which are significant at high temperatures. Ambient temperature data are therefore used to calculate these evaporative emissions.

Vehicle Type	Technology	Age	Size
Passenger cars	Diesel Petrol LPG CNG Petrol hybrid CS Petrol PHEV Diesel hybrid CS Diesel PHEV Electric Fuel cell H_2 H_2 ICE	0-15	< 1.4 cc 1.4 < cc < 2.0 > 2.0 cc
Light duty vehicles	Diesel Petrol LPG CNG Petrol hybrid CS Petrol PHEV Diesel hybrid CS Diesel PHEV Electric Fuel cell H_2 H_2 ICE	0-20	< 3.5 t
Rigid trucks	Diesel Diesel hybrid CS Diesel PHEV	0-25	3,5t-7,5t 7,5t-12t 12t-14t 14t-20t 20t-26t 26t-28t 28t-32t 32t-40t
Articulated trucks	Diesel Diesel hybrid CS Diesel PHEV	0-25	14t-20t 20t-28t 28t-34t 34t-40t 40t-50t 50t-60t
Buses	Diesel LPG CNG Diesel hybrid CS Diesel PHEV Electric Fuel cell H_2	0-25	< 15t 15t-18t >18t
Coaches	Diesel LPG CNG Diesel hybrid CS Diesel PHEV Electric Fuel cell H_2	0-25	< 18t > 18t
Mopeds	Petrol	0-25	< 50 cc 2-stroke
Motorcycles	Petrol	0-25	< 50 cc 2-stroke 50cc-250cc 4 stroke 250cc-750cc 4 stroke > 750cc 4-stroke

Table 1: different vehicles in the E-motion road module

3. Input

Like any other model, MIMOSA needs input data to compute the environmental impact. Besides activity data (vehicle stock, kilometres, network), energy consumption and emission functions, fuel characteristics, technological and policy measures are essential to calculate emissions and fuel consumption for a historical year or a well defined scenario.

3.1. Activity data

MIMOSA needs to know which vehicle drives how many kilometres and where these kilometres are driven. Therefore, we need figures on the vehicle stock, corresponding mileages and the distribution of these kilometres on a network. All data within E-motion is region specific.

Statistical activity data

The handling of rough data on road vehicles of different data sources is further computerized within Vlool (fleet inventory) module. The results are used as direct input in MIMOSA. The outcome of Vlool is a region specific vehicle stock from 1993 up to the last available historical year with corresponding mileages into the eight COPERT categories (Table 1). For 1990, 1991 and 1992 no regional information is available. So, we derived the regional stock on the basis of the 1993 stock and the survival rates of the different vehicle categories.

Vlool transforms vehicle data from DIV, De Lijn, MIVB, TEC and Febiac into vehicle stock (eight COPERT categories). First step is the transformation of the DIV vehicle types (Table 2) into COPERT vehicle types. Fuel type is available in the database, but the technology of the vehicles is not. At this moment, transformation of fuel type into technology type is only a problem for the petrol versus hybrid petrol passenger cars. As the number of hybrid petrol car models is still limited (8 in 2008), we extracted these vehicles on the basis of their pva number. The age of all vehicles is directly taken from the DIV database.

For passenger cars, additional information is taken into account, namely the absence/presence of a particulate filter for euro 4 diesel passenger cars. Besides the age of a vehicle, also the euro norm is an important parameter that influences the fuel consumption and polluting behaviour of vehicles. Initially, we wanted to base the classification of new vehicles in euro-classes on statistical data (DIV) from 2000 on. Unfortunately, the detailed information on euro-classes turned out to be useless. Data are not available for all new vehicles, and even if available, unrealistic figures could appear. So, we decided to apply our previous methodology based on the implementation date of European emission directives for new vehicles. Hereby, we expect that new technologies are introduced some months before directives come into force.

Code	Description	Code	Description
AA	SEDAN	L3	MOTORFIETS
AB	HATCHBACK	L4	MOTORFIETS MET SIDECAR
AC	STATIONWAGEN	L5	DRIEWIELER MET MOTOR
AD	COUPE	L6	VIERWIELER MET MOTOR
AE	CABRIOLET	ML	LANDBOUWMOTOR
AF	VOERTUIG MEERDERE DOELEINDEN	MM	MAAIMACHINE
AR	AANHANGWAGEN	MT	BEDRIJFSMATERIEEL
AZ	ZIEKENWAGEN	M2	MOTORFIETS
BC	BUS OF CAR	OA	TRAGE OPLEGGER
BF	BRANDWEERWAGEN	OM	MINIBUS
BP	LICHTE PANTSER	OR	WERKTUIGAANHANGWAGEN
BR	BOOTAANHANGWAGEN	OS	OPLEGGER
CL	LIJKAUTO	PR	ZWEEFVLIEGTUIGAANHANGWAGEN
CO	KAMPEEROPLEGGER	RL	TRAGE AANHANGWAGEN
CR	KAMPEERAANHANGWAGEN	SA	KAMPEERWAGEN
CT	LICHTE VRACHTWAGEN	SB	GEPANTSERD VOERTUIG
CV	VRACHTWAGEN	SC	ZIEKENWAGEN
DT	TAKELWAGEN	SD	LIJKWAGEN
FA	VOERTUIG MEERDERE DOELEINDEN	SW	AUTO DUBBEL GEBRUIK
KG	KRAANAUTO	TB	TROLLEYBUS
LA	LANDBOUWMATERIEEL	TL	LANDBOUWTRACTOR
LC	TRAGE VRACHTWAGEN	TP	ALL TYPES
LS	TRAGE DUBBEL GEBRUIK	TR	TREKKER
LT	TRAGE LICHTE VRACHTWAGEN	TT	TRAAG VOERTUIG (NA OMVORMING)
LV	TRAGE PERSONENAUTO	VC	KAMPEERAUTO
		VP	PERSONENAUTO

Table 2: DIV vehicle type categories

Extra data on maximum drag from the FPS Economy was necessary to set up a methodology to divide *trucks* into different classes depending on the gross weight of the vehicles. The national vehicle statistics (DIV) give no complete insight in the composition of trucks in weight classes. E-motion defines the rigid and articulated vehicle stock (COPERT 4) as respectively the rigid trucks and trucks for combination truck-trailer from the DIV statistics. For rigid trucks all information on maximum mass is available in these statistics. But this is not the case for the combination truck-trailer, for which only the mass of the truck is reported in the national vehicle statistics (DIV). VITO has received data on maximum drag from the FPS Economy and their permission to apply the data. This has enabled us to distribute the articulated vehicle stock over the appropriate weight classes of COPERT 4.

Further, traffic data from FPS Transport and Mobility, De Lijn, MIVB, and TEC is linked with the vehicle stock to compute the *mileages per vehicle* (type, class, technology and age). Starting point are the total kilometres per road type from FPS Transport and

Mobility (website FOD Mobiliteit en Vervoer, 2011c). Yearly figures are available for passenger cars, light duty vehicles, motorcycles and vehicles altogether. Five yearly counting are available for trucks, buses and coaches. As the driving pattern of busses is quite different from those of coaches, we keep the fleet and driven kilometres of these two vehicle types completely separate. This is possible by taking into account detailed vehicle stock and traffic data from the three public transport companies De Lijn, MIVB and TEC. Figure 2 summarizes the different sources and their interaction to come up with total kilometres driven per vehicle and road type for the historical years.

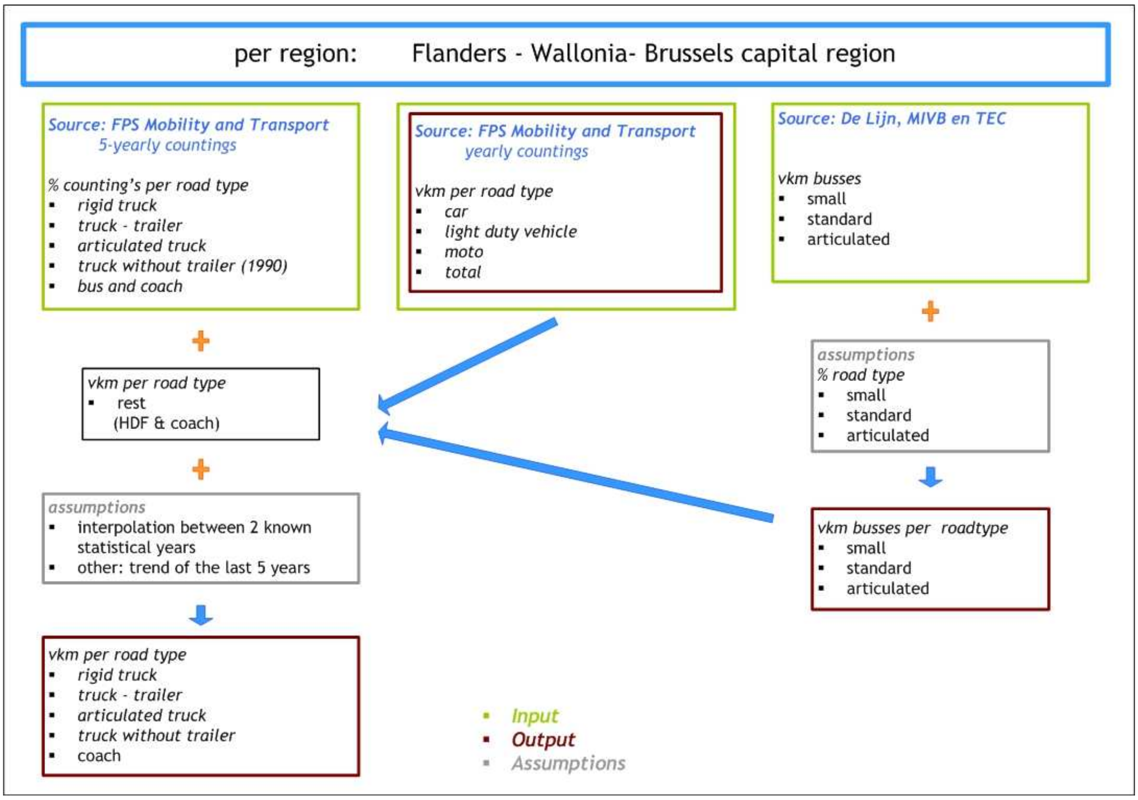

Figure 2: Diagram of the different sources to calculate the historical kilometres per region and vehicle type

The next step is the distribution of the kilometres per vehicle type over the corresponding vehicle stock. For this we use the yearly publications of FPS Transport and Mobility on the annually driven kilometres (website FOD Mobiliteit en Vervoer, 2011a). We use the ratio of the published mileages per vehicle type, fuel type and age to come up with the total mileage per vehicle type for a specific historical year. For passenger cars, we further differentiate the mileages over the different vehicle sizes. A fixed distributive code is used for all years, based on a measuring program of FPD Transport and Mobility in 2004 (website FOD Mobiliteit en Vervoer, 2011b).

The last step of the Vlool module is the conversion of the calculated historical vehicle stock data with corresponding mileages into the right format to run MIMOSA.

Network counting (e.g. FuCAM, Flemish Traffic Centre) are a necessary input to be able to geographically distribute the emissions.

Future activity data

A scenario estimates a future transport situation. The future fleet module (VlooT) automatically forecasts the vehicle stock with corresponding mileages for future years in a specific scenario. The general methodology and most important influencing parameters to forecast these figures will be amplified here.

Starting point is the *vehicle stock* (Table 1) of the *last historical year* with corresponding mileages, the survival rates[2] of existing vehicles and the effects of measures on the mileages. This information makes it possible to predict the total number of kilometres driven by the remaining fleet in the next year (last historical year + 1). Combined with the total exogenously given vehicle kilometres, this computation results in the kilometres driven by new vehicles. The calculations are made per vehicle type.

The *future vehicle technology* presents the distribution of the vehicle technologies over the new vehicles that enter the vehicle fleet. By analyzing the historic trends of the technology distribution of new vehicles and the specific policy measures applied in each scenario, this parameter can be estimated for future scenario years by expert judgement, elasticity values or other available sources. To come up with emission factors for PLANET, we used the technology distribution for new vehicles from the reference scenario within MIRA (De Vlieger et al., 2009). Predictions on mileages per technology type and size – based on trends and policy measures in the specific scenario - make it possible to compute the new vehicle stock.

Model results for the year 'historical year + 1' are complete, iteration until the last scenario year can start.

To *forecast future kilometres* one has to take into account issues like socio-economic prognoses, demographic forecasts, all kinds of policy measures and planned transport infrastructure. At this moment, E-motion does not yet forecasts the total kilometres driven per road type. Within LIMOBEL, the PLANET model generates itself future activities for road transport. However, to generate detailed emission factors to be used as an input in PLANET, VITO assumes evolution of activities as applied for the baseline scenario within other Belspo studies (BIOSES and CLEVER) and uses this to calculate emission factors. Starting point for the prediction of the future total kilometres are the statistics from FPS Mobility and Transport (website FOD Mobiliteit en Vervoer, 2011c), for all three regions. The Flemish Traffic Centre has made predictions on total kilometres driven on the three different road types for Flanders up till 2030 (De Vlieger

[2] The survival rate presents the percentage of existing vehicles (per vehicle type, fuel technology and age category) that will 'survive' to the next year and will therefore belong to an older age category the following year. This parameter can differ according to the scenario. Applying a measure such as a scrapping scheme will for example have a large impact on the survival rates of older vehicles since people will tend to change their old vehicle much sooner for a cleaner/newer one.

et al., 2009). For all regions, this relative increase in future kilometres per road type was taken into account to make up a baseline for the total kilometres driven.

The last step of the VlooT module is the conversion of the calculated vehicle stock data with corresponding mileages into the right format to run MIMOSA for the specific scenario.

Predictions on network intensities (e.g. FuCAM, Flemish Traffic Centre) are a necessary input to be able to geographically distribute the emissions.

3.2. Energy consumption and emission functions

To calculate the environmental impact of road transport, for every type of vehicle (see Table 1), speed related energy consumption and emission functions are necessary.

Energy consumption and CO_2 functions

The latest version of MIMOSA (MIMOSA 4) relies on the COPERT 4 energy consumption functions for the conventional fuels (diesel, petrol and LPG) (EMEP/CORINAIR, 2007). However, COPERT 4 does not define small diesel passenger cars (< 1400 cc). So, we introduced a class of *small diesel passenger cars*. The related CO_2 emission figures were derived from the Belgian CO_2 monitoring programme.

For *improved conventional and alternative motor fuel and vehicle technologies* VITO integrated its own expertise (measurements and literature) and international network. In general, the energy consumption and CO_2 emission functions of new technologies are based on COPERT functions of conventional fuels (e.g. petrol hybrid CS and CNG passenger car derived from petrol; diesel hybrid CS from diesel). However, we adapted the COPERT functions with a correction factor to take into account the new fuel/technology. In addition, a second correction factor is introduced for hybrid technologies (Vankerkom et al., 2009).Within LIMOBEL we further refined the fuel consumption and emission functions of alternative motor fuel and vehicle technologies for hybrid vehicles and CNG and LPG buses.
For *CNG buses* COPERT 4 only prescribed energy consumption and emission functions for urban driving. In previous scenario studies VITO applied these functions for the whole speed range (urban, rural, highway). Within LIMOBEL we made adjustments on the basis of measurements performed by VITO for IEA. For euro II or older CNG buses the fuel consumption functions have to be multiplied by 1.4. For more recent CNG buses this correction factor is only 1.2. We assumed the same correction factor for *LPG buses*. CO_2 emissions for older CNG (and LPG) buses are about 10 % higher than for diesel buses. For more recent CNG and LPG technologies CO_2 emissions are comparable with its diesel variant.

In MIMOSA 4 (version March 2010) the energy consumption of *charge sustaining hybrid vehicles* is based on the adjusted COPERT 4 function. However, we further fine tuned the function on the basis of VITO's expertise. For example, for average speeds above 100 km/h we assumed the yield amounts to 5 % for fuel consumption of CS hybrid vehicles compared to the conventional variant. The COPERT 4 function results in yields of about 40 % for highway traffic. Based on VITO's on-the-field measurements, we believe this is far too optimistic.

Furthermore, we extended the vehicle types with *Plug-in hybrid vehicles (PHEV)*. For Belgium we assume that 40 % of the kilometres are driven by the combustion engine and 60 % from the electric grid. This was decided on the basis of the following information. For PHEV vehicles an American study states that the ratio between kilometres driven by the combustion engine and electric engine amounts to 50/50 (Gonder et al., 2007). An Italian study reports a ratio of 30/70 (website Harry, F., 2011). In Belgium the average distance driven by passenger cars is lower than in the USA. In addition, we wanted to exclude an overestimation of the distance driven by the electric engine. For the kilometres driven by the combustion engines we apply the fuel consumption functions from CS hybrid vehicles. For the kilometres driven by the electric engine, energy consumption figures for electric engines are applied.

CO_2 emissions are calculated starting from the energy consumption figures. We assume *bio fuels* to be CO_2 neutral on the vehicle level. For the CO_2 emissions during the production and transport of bio fuels we refer to Part V (Indirect emissions).

For the energy consumption functions of *passenger cars*, VITO adapts the COPERT 4 energy consumption functions, as these do not take into account the recent CO_2 legislation for new cars. VITO makes adjustments based on its yearly *CO_2 monitoring program on new cars*. Per euro class the COPERT function is differentiated for different building years based on the outcomes of our yearly CO_2 monitoring program.

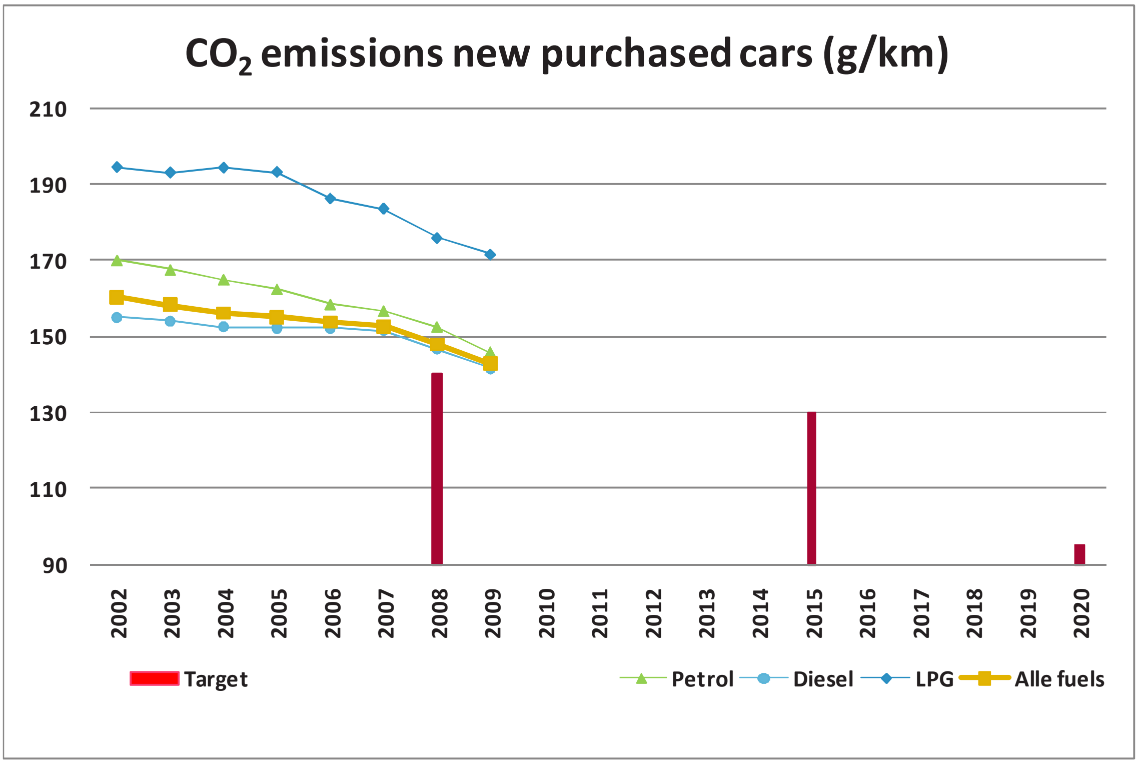

Figure 3: CO_2 monitoring new passenger cars (Belgium)

The euro 4 energy consumption functions in COPERT 4 are higher than those of euro 3. We see the same trend in the CO_2 emission monitoring; however, this trend is less pronounced than in the COPERT 4 figures. Therefore, we use the euro 3 energy consumption function of COPERT 4 as a basis for euro 4 cars and implement the CO_2 evolution that we see in the CO_2 monitoring program from euro 3 on.

For the projections the emission module has the possibility to work with CO_2 targets. We have uncoupled the amount of efficiency improvement by shift to other vehicles types (small, hybrid, …) and the efficiency improvement within the same category (motor management, mild hybrid).

Within LIMOBEL we set up two scenario's concerning the *CO_2 targets of new passenger* vehicles. In the *Baseline scenario E-motion Road* assumes the implementation of the European legislation on CO_2 emissions of new passenger cars (EC/443/2009). So, we assume that the 130 gCO_2/km by shift in technology (e.g. small car, full hybrid) and technological improvement at vehicle level (e.g. aerodynamic, mild hybrid, improved motor management) is met by 2015. The extra 10 gCO_2/km by accompanying measures is not taken into account in the E-motion calculation for PLANET, as no bio fuels were taken into account. The targets values as such are not directly applied in the emission calculation. We take into account that emissions in real traffic are higher than during the European type approval test cycle applied for emission legislation of passenger cars. In the Baseline scenario the proposed

95 gCO_2/km by 2020 is not taken into account, as the Commission will review the implementation in January 2013.

In the *Policy scenario E-motion Road* takes into account the 95 gCO_2/km by 2020. In addition, a further decrease of CO_2 emission of new passenger cars is expected: 80 gCO_2/km by 2025 and 70 gCO_2/km by 2030.

Exhaust emission functions

Fuel related exhaust emissions (CO_2, SO_2, Pb and HM) emissions are assessed on the basis of the fuel consumption and fuel characteristics. CO_2 emissions were already discussed in section "Energy consumption and CO_2 functions". For SO_2 and Pb the sulphur and lead content of the different fuels in Belgium are presented in section 3.3 (Fuel characteristics). Based on COPERT, we expected that 75 % of lead in petrol fuels is emitted to the air. For the emission factors for heavy metals we refer to COPERT 4 (2007).

For *non-fuel related exhaust emissions*, emission functions from COPERT 4 (EMEP/CORINAIR, 2007) are integrated in MIMOSA for the conventional fuels (diesel, petrol and LPG). COPERT 4 reports only few functions for alternative motor fuel and vehicle technologies: charge sustaining petrol hybrid passenger cars, CNG buses and biodiesel. For the other alternatives VITO integrates its own expertise (measurements and literature) and international network (see approach .Energy consumption and CO_2 emissions).

For *biodiesel* we set up exhaust emissions functions for NO_x, PM, VOC and CO based on the effect of a 10 % biodiesel blend compared to conventional diesel (Table 3) (EMEP/CORINAIR, 2007). The effects for other biodiesel blends are deduced by linear interpolation. The bio fuel fraction is considered to be CO_2 neutral at vehicle level.

	Effect
NO_x	3 %
PM	-10 %
VOC	-10 %
CO	-5 %

Table 3: Effect of 10 % biodiesel blend on exhaust emissions

Due to lake of data, for *bio-ethanol* we apply the exhaust emission functions of petrol. Except for CO_2, as bio-ethanol is considered to be CO_2 neutral at vehicle level

However, within LIMOBEL E-motion runs were performed without bio fuels. In fact PLANET needed accurate emission factors without mixing fuel technologies and bio fuel blends. Anyway our assumptions on bio fuels were separately integrated in PLANET.

In general, the emission functions for alternative motor fuel and vehicle technologies in E-motion Road is based on Vankerkom et al. (2009).In LIMOBEL we made some adjustments for hybrid passenger cars as emissions functions for hybrid cars has been adjusted in COPERT 4. The adjusted functions resulted in very low NO_x emissions for hybrid vehicles in highway traffic. So, we derived new NO_x emission functions based on the old and new COPERT 4 function for hybrid petrol.

Finally, electric battery vehicles do not have any exhaust emissions. Highlight, electric vehicles emit non-exhaust emissions (see next paragraph) and indirect emissions through production and transport of electricity (see, Part V).

Non-exhaust emission functions

Non-exhaust emissions from road transport are divided in abrasion of tyres, abrasion of brakes and abrasion of road surface and resuspension. For the applied emission functions we refer to EMEP/CORINAIR (2003) and Sleeuwaert et al. (2006).

3.3. Fuel characteristics

Sulphur content

Table 4 presents the evolution of the sulphur contents in petrol and diesel fuels for road transport in Belgium (FOD Economie,KMO,Middenstand en Energie - Fapetro, 2008). From 1997 on these figures are based on measurements of the sulphur content in fuels for road transport by the division FAPETRO of the FPS Economy and the share of normal and low-sulphur diesel on the Belgian fuel market. On the 1st of January 2009 the European directive 2003/17/EC came into force, so since then only low-sulphur fuels are sold.

For LPG, CNG and biodiesel we assume the sulphur content to be 5 µg/g for all years. For hydrogen, electricity and ethanol direct emissions are set to zero.

Year	Petrol	Diesel
1990	300	1700
1991	300	1300
1992	300	1300
1993	300	1300
1994	300	1300
1995	300	1300
1996	300	600
1997	234	480
1998	154	440
1999	136	406
2000	79	294
2001	58	269
2002	43	47
2003	37,7	43,9
2004	32,3	40,8
2005	14,9	31,3
2006	8,8	24,1
2007	6,9	8,7
2008	6,9	8,5
> 2009	6,9	8,3

Table 4: Sulphur content in diesel and petrol fuel for road transport in Belgium (in µg S/g fuel) used in MIMOSA4

Lead

To quantify the yearly average lead content of petrol for the period 1990-1998, we started from the maximum allowed lead content for the different types of petrol fuels and the sales figures of petrol fuels for road transport Belgium. Since 1999 we apply measured values (FOD Economie,KMO,Middenstand en Energie - Fapetro, 2008). Table 5 shows the evolution of the lead content of petrol fuels for road transport in Belgium.

So, in E-motion no specific lead content is related to a euro-class, as Euro 0 petrol-fuelled vehicles did not always refuel with leaded petrol. Petrol-fuelled vehicles from the late eighties only had to refuel at times leaded petrol. As a result of this approach, calculated emission factors (g/km) are not standard (euro class) related, but weighted averages. The advantage of this approach is that the calculated lead emissions correspond better to the emissions as expected from the sales figures.

Year	Lead content		Share in sales figures		Average lead content	
	Leaded petrol	Unleaded petrol	Leaded petrol	Unleaded petrol		
	g/l	g/l	%	%	g/l	kg/kg
1990	0,15	0,013	73	27	0,11301	0,00015
1991	0,15	0,013	62	38	0,09794	0,00013
1992	0,15	0,013	53	47	0,08561	0,00011
1993	0,15	0,013	43	57	0,07191	0,00010
1994	0,15	0,013	35	65	0,06095	0,000081
1995	0,15	0,013	31	69	0,05547	0,000073
1996	0,15	0,013	26	74	0,04862	0,000064
1997	0,15	0,013	21	79	0,04177	0,000055
1998	0,15	0,013	17	83	0,03629	0,000048
1999	0,15	0,007	4	96	0,01272	0,000017
≥ 2000	-	0,001	0	100	0,001	0,000001

Table 5: Lead content of petrol fuels in Belgium

Fuel specifications

Table 6 presents the fuel specifications as applied in the E-motion model. For the lower combustion heat and the density of fuel we rely on the figures from the FPS Economy. Related CO_2 emissions are taken from IPCC. By doing so, we follow the approach as defined in the Flemish Energy Balance (Aernouts & Jespers, 2009).

	Lower heat of combustion (FPS Economy)	Density (FPS Economy)	CO_2 (IPCC)
	GJ/kg	kg/l	kg/GJ
Diesel	0.042697	0.870	73.326
Petrol	0.043953	0.755	68.607
LPG	0.045949	0.550	62.436
CNG	0.052367	0.0007	55.820
H2 ICE	0.120100	0.0000899	0
Fuel Cell H2	0.120100	0.0000899	0
Biodiesel	0.037700	0.880	75.595
Ethanol	0.026800	0.794	70.912
Methanol	0.019900	0.793	69.000
FT Diesel	0.044000	0.780	70.200
DME	0.028400	0.670	66.581

Table 6: Overview of fuel specifications applied in E-motion

3.4. Speed

Within E-motion road we have the choice to work with hourly speed figures or generic speeds. Within the LIMOBEL project VITO applied adjusted generic speeds as presented in Table 7 (Vankerkom et al., 2009).

Vehicle category	Road type	Smooth traffic [km/h]	Congested traffic [km/h]
Passenger cars	City	29	15
	Rural	56	25
	Highway	110	25
Light trucks	City	29	15
	Rural	56	25
	Highway	110	25
Heavy trucks	City		
	3,5 - 12 tonne	29	15
	> 12 tonne	29	15
	Rural	56	25
	Highway		
	3,5 - 12 tonne	110	25
	> 12 tonne	87	25
Busses & coaches	City		
	bus	15	11
	coach	29	15
	Rural	56	25
	Highway	87	25
Motorcycles	City	29	15
	Rural		
	< 50 cc	43	25
	> 50 cc	56	25
	Highway	110	25

Table 7: Generic speeds per vehicle category and road type

3.5. New euro norms

For cars and light duty trucks we take into account a progress in emission regulation up to euro 6 legislation as decided in Regulation 715/2007 (“political” legislation) and Regulation 692/2008 (“implementing” legislation).

Recently, also for heavy duty vehicles Euro VI emission standards were introduced by Regulation EC/595/2009. The new emission limits become effective from 2013 (new type approvals) and 2014 (all registrations). So, for both baseline and policy scenarios Euro VI heavy duty vehicles are penetrated in the vehicle fleet. Compared to euro V vehicles emission factor of euro VI heavy duty vehicles are expected to lower NO_x emission factor (g/km) by 80 % and PM by 50 %. Furthermore, we assume fuel efficiency of euro VI improved by 5 % compared to euro V vehicles, being a continuation of the efficiency improvement from euro IV to V given by COPERT 4.

3.6. Mobile air conditioning (MAC)

Furthermore, we performed a literature review on the effect of mobile air-conditioning (MAC) systems on fuel consumption and fuel related emissions of passenger cars (Clodic et al., 2005; Rijkeboer et al., 2002; Smokers et al., 2006; Vermeulen et al., 2005). On the basis of this review VITO has set up a methodology to quantify the effect of mobile air-conditioning systems and to integrate the effect in the emission module. We take into account: the number of vehicles equipped with a MAC system, the surplus weight of a MAC, fuel type, the outside temperature and the MAC type. We estimate the effect of MAC systems on fuel consumption, CO_2, SO_2.and lead. For the non-fuel related pollutants, there are only limited data available, so for these pollutants we do not consider any extra emissions due to MAC systems.

In addition, we have also developed a sub-module to estimate the emissions of cooling liquid from MAC systems. Regular and irregular leakages, recharges and end of life emissions are taken into account. For this we have built on the emission inventory expertise of Altdorfer et al. (2007). For the projections we take into consideration the European directive 2006/40/EC on the usage of cooling liquid. The general expectation is that the current cooling liquid HFC-134a will be replaced by CO_2, the so-called R744 MAC systems (Clodic et al., 2005; Smokers et al., 2006).

3.7. Side skirts on trailers

Aerodynamic improvements of truck trailers by mounting e.g. side skirts or aerodynamic side wings on 50 % of the trailer truck results in fuel savings of 15 % (website TU Delft, 2009a; website TU Delft, 2009b).
The baseline scenario of E-motion road does not take into account the introduction of aerodynamic improvements of truck trailers.
In addition, VITO ran a policy scenario in which we assume an average fuel saving of 6 % per equipped vehicle. In this policy scenario we expect a phased introduction of side skirts from 2015 with 20 % implementation and a 100 % implementation by 2020.

3.8. Environmentally-friendly tyres

The European Commission wants to enforce the use of environmentally-friendly tyres for new vehicles from 2012 onwards. TNO assessed fuel savings of 3 % compared to the current tyres (European Commission, 2005; European Union, 2008; Onoda & Gueret, 2007).

Furthermore, the European Commission intends to enforce from 2012 on the tyre pressure monitoring systems (TPMS). Fuel savings would amount to 2.5 % (IEA/AIE, 2007).

Within the baseline scenario no environmentally-friendly tyres are introduced.

In contrast, in the policy scenario of E-motion road we enforced environmentally-friendly tyres for new vehicles in 2012. We assume the existing fleet will be equipped with these tyres between 2012 and 2016.

3.9. Driving behaviour

Contrary to the baseline scenario, the policy scenario of E-motion road considers measures towards the improvement of driving behaviour. Fuel saving for light duty vehicles due to adapted driving behaviour mounts to 3 %. For heavy duty vehicles we assume only 1.5 % fuel saving as a lot of heavy vehicle are already equipped with intelligent semi-automatic gearbox which integrated eco-driving strategy.

4. Output

E-motion road has three output levels: 1) geographic distributed emissions, 2) detailed emission and energy consumption figures and 3) ecoscore values of the car fleet.

By means of counting on the network, MIMOSA automatically distributes the emissions geographically on road segment level or in grid cells of 1 km². Figure 4 gives an example of the NO_X emissions in 2030 in the MIRA reference scenario (De Vlieger et al., 2009).

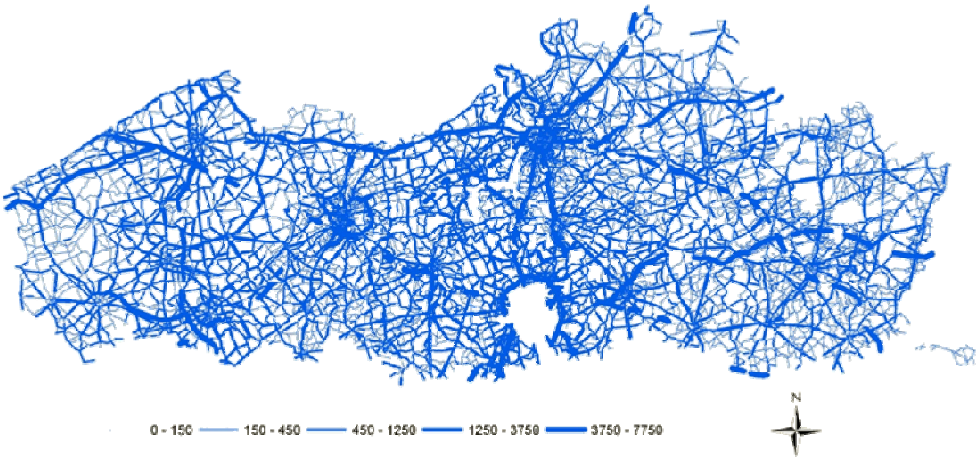

Figure 4: Example of geographically distributed NO_X emissions in Flanders.

VITO also made a tool computing emission results for a specific part within a region e.g. city, province, own definition of a grid, ... without having to define vehicle stock and mileages for this specific region.

User-friendly databases like EmEneM (emissions and fuel consumptions) and ESCORT (Ecoscores) were developed in order to easily consult the results of the scenario calculation. These databases contain the most detailed information on emissions and energy consumption on the one side, and ecoscore values on the other hand. A MySQL browser enables aggregating the figures on the required level.

5. Validation of E-Motion Road

To validate the results generated by E-Motion Road, the energy consumption is compared with the results of VITO's former model SUSATRANS, estimating the energy consumption and emissions for road transport (De Vlieger et al., 2005). As 2003 is the last available historic year within SUSATRANS, the comparison is based on the data and outcome for 2003.

Analyses show three main causes for differences between the results of SUSATRANS and E-Motion Road/MIMOSA4:

1. Adaptations to the generic speeds used in the models;
2. Adaptations of the emission functions (COPERT III in SUSATRANS vs. COPERT 4 in MIMOSA4);
3. Differences in the number of kilometres, which serve as input to the model.

These aspects will be discussed further.

Generic speeds

To investigate the effect of the adaptations to the generic speeds, the MIMOSA4 is re-run using the generic speeds of SUSTRANS. This model run is called "MIMOSA4 – speeds SUSATRANS". Table 8 displays the outcome of this model run and compares it with the results of SUSATRANS and MIMOSA4, in terms of the energy consumption.

Vehicle type	Fuel type	SUSATRANS	MIMOSA4	MIMOSA4 (speeds SUSATRANS)		MIMOSA4 - SUSATRANS	MIMOSA4 (speeds SUSATRANS) - SUSATRANS
PJ		**(1)**	**(2)**	**(3)**		**(4)=(2)-(1)**	**(5)=(3)-(1)**
MOTO	Petrol	1.575	1.417	1.507		-0.158	-0.068
CAR	AMF*	3.282	3.132	3.226		-0.150	-0.056
	Diesel	127.898	111.006	121.222		-16.892	-6.676
	Petrol	79.858	57.054	63.652		-22.804	-16.205
LD Freight	AMF*	0.529	0.324	0.333		-0.205	-0.196
	Diesel	14.084	25.619	27.111		11.534	13.027
	Petrol	0.601	1.600	1.809		1.000	1.209
HD Persons	AMF*	0.000	0.004	0.005		0.004	0.005
	Diesel	6.675	8.122	9.583		1.447	2.908
HD Freight	Diesel	113.061	79.945	87.330		-33.116	-25.731
Total		**347.563**	**288.223**	**315.779**		**-59.340**	**-31.784**

*AMF stands for alternative motor fuels.

Table 8: Analyses on the effect of adapting the generic speeds (2003)

The table shows that more than 46% of the difference (27.586 PJ of the "missing" 59.340 PJ) between SUSATRANS and MIMOSA4 can be attributed to the adjustment of the generic speeds. The table also demonstrates that the remaining difference in PJ between MIMOSA4 including the generic speeds of SUSATRANS and SUSATRANS are mainly situated at the heavy duty transport (i.e. HD Freight + HD Persons). To gain insight in this difference, the number of kilometres driven is examined first.

Number of kilometres

The number of kilometres travelled on the network are analysed separately for light duty (LD) and heavy duty (HD) transport.

For light duty the absolute number of kilometres is more or less equal for the two models. Yet, a change in the distribution of these kilometres over the fuel types and vehicle types is observed. In particular, the number of kilometres for cars declines, based on the data of FOD Mobility. Furthermore, the difference in the distribution over the fuel types for cars is the result of improvements in the registration of the annual mileages of cars, which were previously estimated based on data of only a limited number of years at the Belgian level. As from 2002 these data are available in more detail on a regional level. For example, for petrol cars this amounts to a decrease of 18% (i.e. 26 billion kilometres in TEMAT2004 vs. 22 billion kilometres in this project), as summarized in Table 9.

	TEMAT2004		PODO2010	
MOTO	**1.26%**	**1,049,127,631**	**1.35%**	**1,128,144,638**
Petrol	1.26%	1,049,127,631	1.35%	1,128,144,638
CAR	**93.70%**	**78,322,287,472**	**88.31%**	**73,805,229,405**
Diesel	60.68%	50,716,547,631	59.98%	50,128,146,095
LPG	1.35%	1,131,897,796	1.46%	1,219,167,790
Petrol	31.67%	26,473,842,045	26.87%	22,457,915,520
LDV	**5.04%**	**4,214,215,298**	**10.34%**	**8,644,770,088**
Diesel	4.83%	4,036,913,363	9.64%	8,053,954,436
LPG	0.06%	47,142,575	0.16%	137,493,726
Petrol	0.16%	130,159,360	0.54%	453,321,926
Total	**100.00%**	**83,585,630,401**	**100.00%**	**83,578,144,131**

Table 9: Distribution of the number of kilometres over the vehicle and fuel types (2003)

The increase in the number of kilometres for LDV is also caused by the new data of FOD Mobility, as now more detailed data for delivery trucks are gathered.

For heavy duty (freight+persons), the number of kilometres used in the current project is 3.76% lower compared to TEMAT2004. Especially, a major decrease of the energy consumption of heavy duty diesel freight transport (HDVr and HDVa) is observed. Therefore, the subsequent analyses only concentrate on this category. The difference in the absolute number of kilometres equals 5%, next to a change in the distribution of this number over the road types, as is shown in Table 10.

	TEMAT2004		PODO2010	
Highway	58.08%	5,159,439,733	60.53%	5,094,436,142
Rural	36.33%	3,227,312,659	32.99%	2,776,401,070
Urban	5.58%	495,861,487	6.49%	546,072,567
Total	**100.00%**	**8,882,613,879**	**100.00%**	**8,416,909,779**

Table 10: Number of kilometres for heavy duty freight diesel transport per road type (2003)

Yet, the difference in energy consumption for heavy duty freight diesel transport amounts to 22.76% (MIMOSA4 with SUSATRANS speeds compared to SUSATRANS). Therefore, the effect of the adaptations of the emission functions is additionally examined.

Emission functions

The conversion from COPERT III to COPERT 4 is manifested in the emission factors. Table 11 reflects the calculation of the energy consumption factors for both models (SUSATRANS and MIMOSA4 applying SUSATRANS speeds) for 2003.

	SUSATRANS/TEMAT2004		
	PJ	**km**	**MJ/km**
2003	**(1)**	**(2)**	**(3)=(1)/(2)**
LV	218.86	83,540,546,794	2.73
HV	96.92	9,505,066,087	12.60
	MIMOSA4 (speeds SUSATRANS)		
	PJ	**km**	**MJ/km**
2003	**(4)**	**(5)**	**(6)=(4)/(5)**
LV	200.15	83,582,072,369	2.62
HV	88.07	9,147,153,857	10.60
	Difference SUSATRANS-MIMOSA 4(%)		
	PJ	**km**	**MJ/km**
2003			
LV	-4%	0%	-4%
HV	-24%	-4%	-19%

Table 11: Emission factors for SUSATRANS and MIMOSA4 (applying SUSTRANS speeds) (2003)

This table indicates that the average energy consumption factor for light duty decreased by 4%, due to the transition to the new emission functions in COPERT 4 and the shift in the distribution of the number of kilometres in this category as discussed above.

For heavy duty, the energy consumption factor decreases by 19% in MIMOSA4 compared to SUSATRANS. A share of this difference is explained by the decline in the total number of kilometres for this vehicle category (4% for heavy duty, and even 5%

for heavy duty freight transport). Additionally, this effect can be attributed to the adjustment of the COPERT functions, by analysing the effect on the CO_2 emission factors for heavy duty freight transport. In particular, technology classes EURO II and EURO III are taken into consideration as these technology classes occur most frequently. The effect on CO_2 emission factors amounts to -16.5% for EURO II and -18% for EURO III.

6. Disaggregated fleet emission factors

Within LIMOBEL, the E-motion road module was used to provide updated fuel efficiency and emission factors for PLANET to compute the energy consumption and emissions of the different scenarios.

Detailed emission factors of CO_2, NO_x, $PM_{2.5}$ (exhaust), VOC and $PM_{2.5}$ (non-exhaust) are presented in Table 12, Table 13, Table 14, Table 15 and Table 16 respectively. Exhaust emissions are shown according to vehicle category and fuel technology, whereas non-exhaust emissions are only split up according to vehicle category. Exhaust emission factors for two E-motion scenarios, baseline and policy, are included.

Take into account that *no bio fuels* are integrated in the fleet emission factors in none of the scenarios. For the assumption on the introduction rate of new motor fuel and vehicle, we refer to De Vlieger et al. (2009).

Vehicle category	Fuel technology	Historic	Baseline			Policy		
		2007	2010	2020	2030	2010	2020	2030
MOTO	Petrol	86	83	79	76	83	76	74
CAR	CNG	133	119	100	100	121	81	78
	Diesel	156	153	132	128	152	115	101
	Diesel Hybrid CS			105	104		84	81
	Diesel Hybrid PHEV			42	42		33	33
	Electric	0			0		0	0
	Fuel Cell H2				0			0
	H2 ICE				0			0
	LPG	166	164	148	143	164	133	116
	Petrol	179	174	156	151	174	139	124
	Petrol Hybrid CS	138	127	105	104	126	85	82
	Petrol Hybrid PHEV			42	42		34	33
LDV	CNG	191	193	174	172	193	162	161
	Diesel	225	226	206	197	226	193	185
	Diesel Hybrid CS			164	162		152	151
	Diesel Hybrid PHEV			65	65		61	60
	Electric	0	0		0	0	0	0
	Fuel Cell H2				0			0
	LPG	152	151	138	130	151	129	122
	Petrol	261	265	244	235	265	230	221
HDF	Diesel	689	711	663	661	711	629	627
	Diesel Hybrid CS				475			464
	Diesel Hybrid PHEV				190			185
BUS	CNG		498	495	498		485	494
	Diesel	822	669	601	586	669	598	579
	Diesel Hybrid CS		499	499	489	500	496	486
	Diesel Hybrid PHEV			198	201		197	198
	Electric				0		0	0
	Fuel Cell H2			0	0		0	0
COACH	CNG	778	771			771		
	Diesel	790	710	679	672	709	671	664
	LPG	0						

Table 12: CO_2 exhaust emission factors for road transport (g/km)

Vehicle category	Fuel technology	Historic	Baseline			Policy		
		2007	2010	2020	2030	2010	2020	2030
MOTO	Petrol	0.186	0.222	0.237	0.252	0.222	0.235	0.251
CAR	CNG	0.060	0.039	0.040	0.040	0.039	0.040	0.041
	Diesel	0.680	0.631	0.334	0.189	0.631	0.341	0.191
	Diesel Hybrid CS			0.167	0.150		0.159	0.149
	Diesel Hybrid PHEV			0.062	0.060		0.061	0.060
	Electric	0.000			0.000		0.000	0.000
	Fuel Cell H2				0.000			0.000
	H2 ICE				0.101			0.101
	LPG	0.715	0.296	0.047	0.043	0.288	0.047	0.043
	Petrol	0.511	0.212	0.042	0.040	0.207	0.043	0.040
	Petrol Hybrid CS	0.033	0.030	0.029	0.029	0.030	0.029	0.029
	Petrol Hybrid PHEV			0.012	0.012		0.012	0.012
LDV	CNG	0.218	0.069	0.047	0.046	0.070	0.046	0.046
	Diesel	1.070	0.979	0.519	0.304	0.980	0.532	0.312
	Diesel Hybrid CS			0.252	0.222		0.241	0.220
	Diesel Hybrid PHEV			0.093	0.088		0.091	0.088
	Electric	0.000	0.000		0.000	0.000	0.000	0.000
	Fuel Cell H2				0.000			0.000
	LPG	0.194	0.141	0.030	0.018	0.136	0.030	0.018
	Petrol	1.137	0.638	0.047	0.036	0.622	0.047	0.036
HDF	Diesel	6.737	5.236	0.990	0.549	5.237	0.994	0.552
	Diesel Hybrid CS				0.226			0.226
	Diesel Hybrid PHEV				0.091			0.092
BUS	CNG		2.500	0.672	0.500		0.517	0.500
	Diesel	8.495	4.514	1.245	0.426	4.505	1.304	0.435
	Diesel Hybrid CS		1.484	0.401	0.306	1.488	0.391	0.310
	Diesel Hybrid PHEV			0.131	0.125		0.130	0.126
	Electric				0.000		0.000	0.000
	Fuel Cell H2			0.000	0.000		0.000	0.000
COACH	CNG	16.498	16.500			16.501		
	Diesel	7.941	5.618	1.654	0.575	5.616	1.677	0.577
	LPG	0.000						

Table 13: NO_x exhaust emission factors for road transport (g/km)

Vehicle category	Fuel technology	Historic	Baseline			Policy		
		2007	2010	2020	2030	2010	2020	2030
MOTO	Petrol	0.070	0.056	0.033	0.022	0.056	0.034	0.022
CAR	CNG	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Diesel	0.037	0.027	0.009	0.006	0.027	0.009	0.006
	Diesel Hybrid CS			0.005	0.005		0.005	0.005
	Diesel Hybrid PHEV			0.002	0.002		0.002	0.002
	Electric	0.000			0.000		0.000	0.000
	Fuel Cell H2				0.000			0.000
	H2 ICE				0.000			0.000
	LPG	0.009	0.004	0.001	0.001	0.004	0.001	0.001
	Petrol	0.005	0.001	0.001	0.001	0.001	0.001	0.001
	Petrol Hybrid CS	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Petrol Hybrid PHEV			0.000	0.000		0.000	0.000
LDV	CNG	0.002	0.001	0.001	0.001	0.001	0.001	0.001
	Diesel	0.081	0.064	0.013	0.003	0.064	0.014	0.003
	Diesel Hybrid CS			0.002	0.002		0.002	0.002
	Diesel Hybrid PHEV			0.001	0.001		0.001	0.001
	Electric	0.000	0.000		0.000	0.000	0.000	0.000
	Fuel Cell H2				0.000			0.000
	LPG	0.013	0.008	0.002	0.002	0.008	0.002	0.002
	Petrol	0.010	0.006	0.001	0.001	0.006	0.001	0.001
HDF	Diesel	0.139	0.080	0.016	0.012	0.080	0.017	0.013
	Diesel Hybrid CS				0.005			0.005
	Diesel Hybrid PHEV				0.002			0.002
BUS	CNG		0.005	0.003	0.002		0.003	0.003
	Diesel	0.210	0.080	0.018	0.011	0.079	0.019	0.011
	Diesel Hybrid CS		0.017	0.009	0.009	0.017	0.009	0.009
	Diesel Hybrid PHEV			0.004	0.004		0.004	0.004
	Electric				0.000		0.000	0.000
	Fuel Cell H2			0.000	0.000		0.000	0.000
COACH	CNG	0.020	0.020			0.020		
	Diesel	0.204	0.109	0.026	0.015	0.109	0.026	0.015
	LPG	0.000						

Table 14: $PM_{2.5}$ exhaust emission factors for road transport (g/km)

Vehicle category	Fuel technology	Historic	Baseline			Policy		
		2007	2010	2020	2030	2010	2020	2030
MOTO	Petrol	6.360	4.813	2.371	1.148	4.819	2.408	1.155
CAR	CNG	0.008	0.009	0.009	0.009	0.009	0.009	0.008
	Diesel	0.018	0.011	0.006	0.005	0.011	0.006	0.005
	Diesel Hybrid CS			0.004	0.004		0.004	0.004
	Diesel Hybrid PHEV			0.002	0.002		0.002	0.002
	Electric	0.000			0.000		0.000	0.000
	Fuel Cell H2				0.000			0.000
	H2 ICE				0.009			0.008
	LPG	0.271	0.119	0.009	0.006	0.115	0.009	0.006
	Petrol	0.468	0.114	0.039	0.038	0.112	0.040	0.040
	Petrol Hybrid CS	0.019	0.019	0.019	0.020	0.019	0.019	0.020
	Petrol Hybrid PHEV			0.010	0.010		0.010	0.010
LDV	CNG	0.027	0.007	0.006	0.006	0.007	0.006	0.006
	Diesel	0.077	0.058	0.032	0.028	0.058	0.032	0.028
	Diesel Hybrid CS			0.023	0.023		0.023	0.023
	Diesel Hybrid PHEV			0.009	0.009		0.009	0.009
	Electric	0.000	0.000		0.000	0.000	0.000	0.000
	Fuel Cell H2				0.000			0.000
	LPG	0.288	0.194	0.015	0.009	0.187	0.015	0.009
	Petrol	0.868	0.609	0.021	0.019	0.592	0.021	0.019
HDF	Diesel	0.274	0.144	0.020	0.015	0.144	0.020	0.015
	Diesel Hybrid CS				0.005			0.005
	Diesel Hybrid PHEV				0.002			0.002
BUS	CNG		1.000	1.000	1.000		1.000	1.000
	Diesel	0.498	0.171	0.023	0.013	0.171	0.024	0.013
	Diesel Hybrid CS		0.010	0.010	0.011	0.010	0.011	0.011
	Diesel Hybrid PHEV			0.004	0.004		0.004	0.004
	Electric				0.000		0.000	0.000
	Fuel Cell H2			0.000	0.000		0.000	0.000
COACH	CNG	6.999	7.000			7.000		
	Diesel	0.478	0.239	0.038	0.020	0.239	0.039	0.020
	LPG	0.000						

Table 15: VOC exhaust emission factors for road transport (g/km)

Vehicle category	Pollutant	HISTORIC	Prognoses		
		2007	2010	2020	2030
MOTO	PM2.5	5.9	5.7	5.6	5.6
CAR	PM2.5	11.1	11.2	11.2	11.3
LDV	PM2.5	15.8	15.8	16.0	16.0
HDF	PM2.5	46.6	47.1	46.6	46.7
BUS	PM2.5	31.5	25.6	25.2	25.3
COACH	PM2.5	29.2	26.8	26.3	26.4

Table 16: $PM_{2.5}$ non-exhaust emission factors for road transport (mg/km)

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Annex 1: E-motion – Part II

Rail transport

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List of abbreviations

CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
DMU	Diesel multiple unit
ECF	Energy consumption factor
EF	Emission factor
EMMOSS	Emission model for rail and shipping traffic in Flanders (Emissiemodel voor spoorverkeer en scheepvaart in Vlaanderen), carried out for the Flemish Environmental Agency (VMM) by Transport & Mobility Leuven (TML)
E-Motion	Energy and emission MOdel for Transport with geographical distributION
EMU	Electric multiple unit
Ex-TREMIS	Exploring non-road Transport Emissions in Europe: Development of a Reference System on Emission Factors for Rail, Maritime and Air Transport
gtkm	gross tonne kilometre
HC	Hydrocarbon
HST	High speed train
IC	Intercity train
IPCC	Intergovernmental Panel on Climate Change
IR	Interregional train
J	Joule
Km	Kilometre
kW	Kilowatt
kWh	Kilowatt-hour
ktonne	Kilotonne
L	Local train
MIRA-S	Environmental report Flanders – Scenarios (Milieurapport Vlaanderen - Scenario's)
MU	Multiple unit
N2O	Nitrous oxide
NMBS	Belgian Railway Company (Nationale Maatschappij der Belgische Spoorwegen)
NO_x	Nitrogen oxides
P	Peak hour train
PLANET	Long-run prospects of transport activities, environmental impact and welfare, model, developed by FPB
PM	Particulate matter
PM_{10}	Particulate matter with an aerodynamic diameter of less than 10 micrometre
$PM_{2.5}$	Particulate matter with an aerodynamic diameter of less than 2.5 micrometre
SO_2	Sulphur dioxide
train km	Train kilometre
TSP	Total suspended particles
VMM	Flemish Environmental Agency (Vlaamse Milieumaatschappij)
VOC	Volatile Organic Compounds

1. Introduction

Aiming at calculating the energy consumption and emission factors for rail transport starting from 2005, the methodology summarized in Figure 1 is applied.

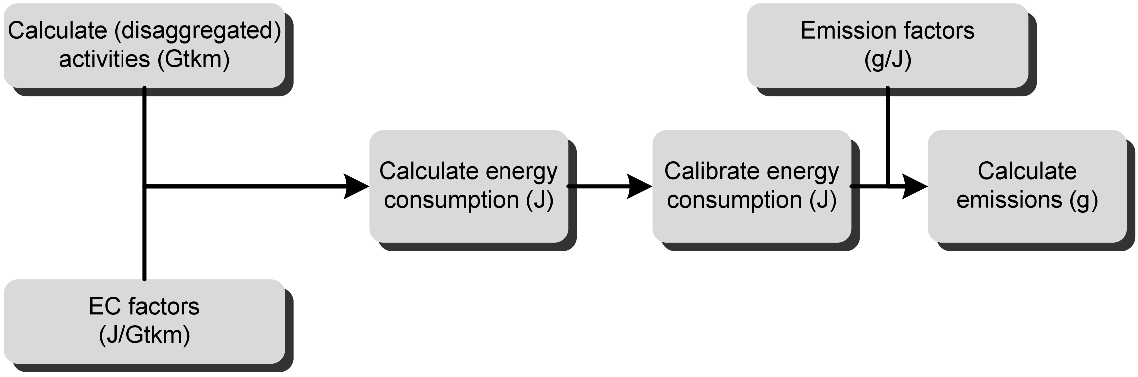

Figure 1: Methodology for calculating energy consumptions and emissions for rail transportation

In general, the model estimates the emissions for rail transportation by multiplying specific energy consumption factors (expressed in Joule) by emission factors (expressed in gramme/Joule). The specific energy consumption factors are calculated based on specific energy consumption factors of train types/services in Belgium (Joule/gross tonne kilometres) and detailed data on the number of gross tonne kilometres. For historic years, these computations are calibrated founded on statistical energy consumption data. The subsequent calculation steps are elaborated on in the following sections.

The energy consumption and emission calculations for historic years before 2005 are based on the methodology forwarded in Ex-TREMIS (Chiffi et al., 2008) and is not described here.

A major improvement of the E-Motion Rail module developed within LIMOBEL and Ex-TREMIS includes the fact that the model accounts for the technological evolution of diesel engines of trains, next to an update of the input data.

2. Disaggregated activity data

E-Motion Rail uses a bottom-up approach starting from detailed activity data obtained from the Belgian national railway company (NMBS/SNCB), supplemented with activity data for other operators. This paragraph describes the information available from NMBS/SNCB and the assumptions made for future prognoses of these activities as well as for activities, both historic and future, of non-NMBS/SNCB operators.

2.1. Train kilometres for NMBS/SNCB

Based on detailed activity data concerning the train kilometres (train km), the number of gross tonne kilometres is derived. For the historic years, these train kilometres are recorded in the statistical year reports of NMBS/SNCB on a much disaggregated level. In particular, the train type (goods/passengers), energy source (diesel/electricity) and service type (goods/IC/IR/HST/P/L) are included, and thus do not have to be calculated in the model.

The train kilometres for the future (starting from 2009) are predicted based on the number of train kilometres of the last available historic data (2008) and the yearly growth rates, according to following formula:

$$trainkm_{y+1} = trainkm_{y} \times (1 + growth\, rate_{y,y+1})$$

The growth rates originate from the report entitled “Toekomstverkenning MIRA-S 2009 – Wetenschappelijk rapport Sector Transport: referentie- en Europascenario” (de Vlieger et al., 2009). The growth rates in this report comprehend estimations for Flanders. In the current research, the same growth rates are assumed for Belgium. Table 1 contains these growth rates, recalculated to yearly growth rates.

The economic equilibrium model PLANET also generates future activities, but as E-Motion Rail has to provide weighted fleet emission factors for PLANET, the preceding assumptions have to be used.

Train type	Energy source	Service type	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Goods	Diesel		1.23%	1.23%	3.68%	3.68%	3.68%	3.68%	3.68%	0.60%	0.60%	0.60%	0.60%
	Electricity		1.09%	1.09%	3.77%	3.77%	3.77%	3.77%	3.77%	0.67%	0.67%	0.67%	0.67%
Passengers	Electricity	IC	6.67%	6.67%	8.21%	8.21%	8.21%	8.21%	8.21%	1.02%	1.02%	1.02%	1.02%
		IR	6.66%	6.66%	8.21%	8.21%	8.21%	8.21%	8.21%	1.02%	1.02%	1.02%	1.02%
		HST	5.44%	5.44%	7.37%	7.37%	7.37%	7.37%	7.37%	0.18%	0.18%	0.18%	0.18%
		L	6.68%	6.68%	8.20%	8.20%	8.20%	8.20%	8.20%	1.03%	1.03%	1.03%	1.03%
		P	6.66%	6.66%	8.19%	8.19%	8.19%	8.19%	8.19%	1.05%	1.05%	1.05%	1.05%
	Diesel	IR	6.44%	6.44%	7.44%	7.44%	7.44%	7.44%	7.44%	0.29%	0.29%	0.29%	0.29%
		L	6.36%	6.36%	7.27%	7.27%	7.27%	7.27%	7.27%	0.24%	0.24%	0.24%	0.24%

Train type	Energy source	Service type	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Goods	Diesel		0.60%	1.22%	1.22%	1.22%	1.22%	1.22%	1.25%	1.25%	1.25%	1.25%	1.25%
	Electricity		0.67%	1.30%	1.30%	1.30%	1.30%	1.30%	1.34%	1.34%	1.34%	1.34%	1.34%
Passengers	Electricity	IC	1.02%	1.34%	1.34%	1.34%	1.34%	1.34%	1.26%	1.26%	1.26%	1.26%	1.26%
		IR	1.02%	1.35%	1.35%	1.35%	1.35%	1.35%	1.25%	1.25%	1.25%	1.25%	1.25%
		HST	0.18%	0.53%	0.53%	0.53%	0.53%	0.53%	0.51%	0.51%	0.51%	0.51%	0.51%
		L	1.03%	1.34%	1.34%	1.34%	1.34%	1.34%	1.25%	1.25%	1.25%	1.25%	1.25%
		P	1.05%	1.33%	1.33%	1.33%	1.33%	1.33%	1.25%	1.25%	1.25%	1.25%	1.25%
	Diesel	IR	0.29%	0.43%	0.43%	0.43%	0.43%	0.43%	0.56%	0.56%	0.56%	0.56%	0.56%
		L	0.24%	0.58%	0.58%	0.58%	0.58%	0.58%	0.45%	0.45%	0.45%	0.45%	0.45%

Table 1: Yearly growth rates of train kilometres

2.2. Gross tonne kilometres NMBS/SNCB

Next, the number of gross tonne kilometres (gtkm) is calculated based on the number of train kilometres.

$$gtkm = train\ km\ \times gross\ train\ weight$$

The gross train weights of NMBS/SNCB trains are estimated by Mr. Bontinck (NMBS holding, 2009) and are recorded in Table 2.

Train type	Energy source	Service type	Gross weight (tonne)
Goods	Diesel		1 500
	Electricity		1 500
Passengers	Electricity	IC	460
		IR	300
		HST	480
		L	220
		P	320
	Diesel	IR	180
		L	180

Table 2: Gross weight of NMBS/SNCB trains

Source: communication with Mr. Bontinck (NMBS holding, 2009).

Subsequently, the calculated gross tonne kilometres are further divided according to the type of the traction vehicle (i.e. locomotive or multiple unit), founded on a distribution supplied by Mr. Bontinck (NMBS holding, 2009).

Train type	Energy source	Service type	% locomotives
Goods	Diesel		100%
	Electricity		100%
Passengers	Electricity	IC	35%
		IR	25%
		HST	0%
		L	0%
		P	50%
	Diesel	IR	0%
		L	0%

Table 3: Distribution according to type of traction vehicle

Source: communication with Mr. Bontinck (NMBS holding, 2009).

The outcome of these computations is the number of gross tonne kilometres travelled per train type, energy source, service type and type of traction vehicle.

2.3. Gross tonne kilometres non-NMBS/SNCB

In the following step, activity data for non-NMBS/SNCB operators are added. As from 2003, non-NMBS/SNCB freight trains also travel on the Belgian train network. Obviously, these train kilometres are not reported on in the yearly statistical reports of NMBS/SNCB. The share of these non-NMBS/SNCB trains in the number of gross tonne kilometres is derived from the activities of freight transport of NMBS/SNCB trains and data supplied by the network administrator Infrabel (Infrabel, 2009). On request, these numbers are treated confidentially. Infrabel's data provide an insight into the share of non-NMBS/SNCB freight traffic with respect to NMBS/SNCB freight trains in the period between 2003 and 2014, indicating a strong increase in this share. Starting from these data, a supplement of 21% to account for non-NMBS/SNCB freight transport is assumed after 2015. This supplement contrasts sharply with the 2% stipulated in the comparable model EMMOSS, developed for the Flemish Environmental Agency (VMM) by Transport & Mobility Leuven (Vanherle et al, 2007).

Furthermore, Infrabel provided information on the share of electric versus diesel freight trains, and on the deployed locomotives. These data is also processed in E-Motion Rail.

3. Energy consumption factors

The specific energy consumption factors used in the current research are provided by Mr. Bontinck (NMBS Holding, 2009) and summarized in Table 4. The model assumes that the losses on the Belgian network for electric trains (i.e. 8% of the energy consumption) are included in these energy consumption factors.

Train type	Energy source	Service type	ECF (kJ/gtkm)
Goods	Electricity		66
	Diesel		175
Passengers	Electricity	IC	130
		IR	160
		HST	155
		L	160
		P	160
	Diesel	IR	506
		L	506

Table 4: Specific energy consumption factors

Source: communication with Mr. Bontinck (NMBS holding, 2009).

For future prognoses, an improvement of the energy efficiency is accounted for. As such, a gradual improvement of 6% between 2005 and 2020 is assumed, conform the Rail energy project (UIC, 2006). This efficiency improvement is spread linearly between 2010 and 2020 and remains constant after that.

4. Energy consumption

4.1. Energy consumption of mainline activities

The energy consumption required for mainline activities is estimated based on the calculated activity data and the energy consumption factors (ECF).

$$Energy\ consumption = gross\ tkm * ECF$$

4.2. Energy consumption of shunting activities

Shunting activities are not included in the activity data. However, these activities do consume energy and generate emissions. Consequently, an energy supplement caused by shunting activity is added. This supplement is estimated by Mr. Bontinck (NMBS holding, 2009) and fixed to 11% for historic years (i.e. up to 2009) and 8.25% for the prognoses (i.e. after 2008).

4.3. Calibration of the energy consumption

The energy consumption of rail traffic caused by NMBS/SNCB is also recorded in the statistical year reports for the historic years. Therefore, this source of information is exerted to calibrate the energy consumption for historic years. For this purpose, the energy consumption is aggregated to the same level as reported by NMBS/SNCB. The calibration factors are then calculated as follows:

$$calibration\ factor = \frac{reported\ energy\ consumption}{calculated\ energy\ consumption}$$

For the prognoses for future years, the calibration factors are assumed to be equal to the average of the corresponding calibration factors of the most recent 4 historic years. The disaggregated energy consumptions are then re-estimated based on these calibration factors.

5. Technological distribution of diesel trains

To estimate the emissions of technology dependent pollutants (PM, HC, CO and NO_x) more accurately, E-Motion Rail considers the technology classes of diesel trains. To this end, the energy consumption is further split according to five technology classes, corresponding to the starting dates of the type approvals and the European guideline (2004/26/EC). For diesel multiple units (DMU), following technology classes are used: <1990, 1990-2002, 2003-2005, 2006-2014, >2015. For locomotives, the model includes these classes: <1990, 1990-2002, 2003-2008, 2009-2014, >2015. An illustration of the distribution of mainline NMBS/SNCB locomotives according to the technology classes is included in Figure 1.

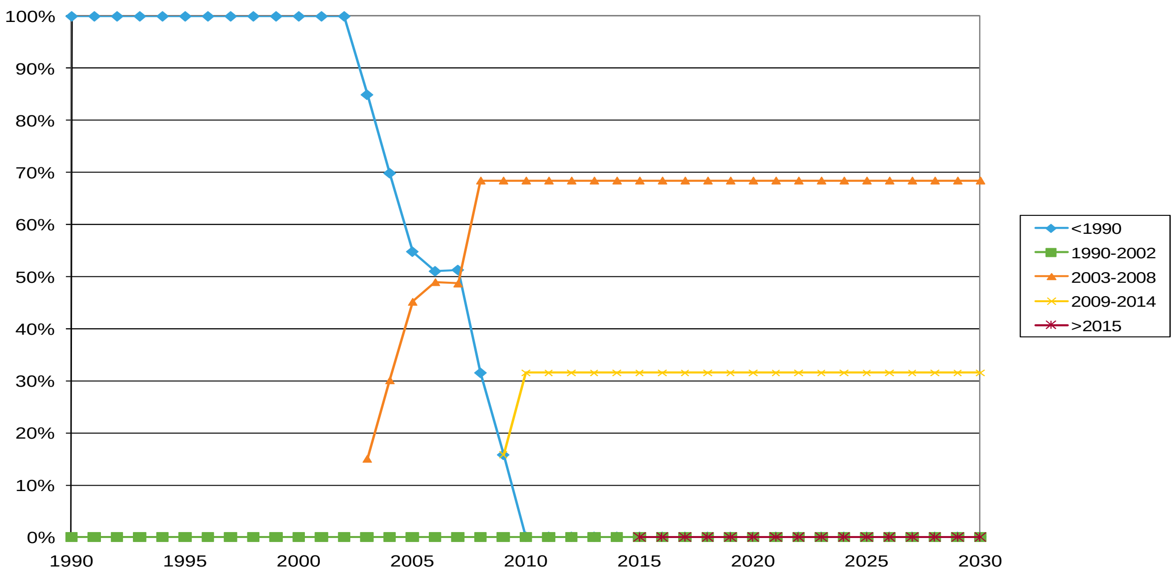

Figure 2: Technology distribution for mainline locomotives of NMBS/SNCB

Source: NMBS Holding (2009).

An estimation of these technology distributions is composed in the project Ex-TREMIS (Chiffi et al., 2008) and complemented on the one hand by Mr. Bontinck for the NMBS/SNCB traffic (NMBS Holding, 2009) and by Mrs. Vandessel for non-NMBS/SNCB traffic (Infrabel, 2009).

The preceding calculation steps result in the energy consumption, subdivided according to train type (goods/passengers), operator (NMBS/SNCB or non-NMBS/SNCB), energy source (diesel/electricity), service type (goods/IC/IR/HST/L/P), type of traction vehicle (locomotive/multiple unit), technology class and shunting (yes/no).

6. Emissions

A distinction is made between exhaust and non-exhaust emissions. For the former, the pollutants are divided into fuel related and technology related. The part entitled “Emissions during the production and transport of energy carriers” of this annex elaborates on the emissions caused by the production and transport of fuel (diesel) and electricity.

6.1. Exhaust emissions

In the next step, exhaust emissions are determined. A distinction is made between fuel related emissions (SO_2, CO_2, CH_4 and N_2O) and technology related emissions (PM, HC, CO and NO_x). Fuel related emissions are calculated by multiplying the corresponding emission factors by the energy consumption.

$$emission = EF * energy\ consumption$$

Both NMBS/SNCB as non-NMBS/SNCB diesel trains are assumed to use the same diesel as the one used for road transportation (De Vlieger et al. 2009). For CO_2, CH_4 and N_2O, IPCC emissions factors are used (IPCC, 1997; IPCC, 2006).

Pollutant	Emission factor(kg/TJ)
CO_2	73 326
N_2O	1.0
CH_4	0.8

Table 5: Fuel related emission factors

Source: IPCC emission factors for CO_2 (IPCC, 1997), N_2O and CH_4 (IPCC, 2006).

SO_2 emissions depend on the sulphur content of the fuel. As the composition of the fuel fluctuates, the corresponding SO_2 emission factor is also year dependent. In Belgium, NMBS/SNCB uses for both mainline and shunting diesel engines the same fuel as road transport. As a result, the SO_2 emission factors can be derived from the sulphur content of this diesel. As from 2003 maximum 0.005% mass percent sulphur is allowed. In reality 0.0047 mass percent is measured (FAPETRO, 2003). Table 6 shows the mass percentages and corresponding SO_2 emission factors used in the current model.

Period	Mass %	SO2 emission factor (kg/TJ)
<1989	0.3	140
1989	0.2	93.7
1990-2002	0.17	79.6
2003-2008	0.00471	2.20
As from 2009	0.00102	0.47

Table 6: SO_2 emission factors

Sources: Chiffi et al. (2008) and EU-directive 2003/17/EC: sulphur content of diesel of 0,001% as from 01/01/2009.

For technology related emissions the model accounts for the engine efficiency.

$$emission = EF \times efficiency \times energy\ consumption$$

The efficiency factor is fuel dependent and equals 0.35 for diesel engines, as is the case in the Ex-TREMIS project (Chiffi et al., 2008).

The technology related emission factors for NO_x, PM, CO and HC originate from the European type approvals, directive 2004/26/EC, which is an amendment of 97/68/EC. The limits recorded in Table 7 are used in the model, as founded on literature review and assuming that the net power of diesel locomotives and multiple units deployed in Belgium exceeds 560 kW but is lower than 2000 kW. It is assumed here that the future emission factors are also established by these directives.

Sources: Halder and Löchter (2005); directive 2004/26/EC – stage IIIA introduced as from 2006 for multiple units and as from 2009 for locomotives; directive 2004/26/EC – stage IIIB introduced as from 2015; UIC Locomotive emission standards (UIC, 2006).

More information concerning these emission factors can be found in Chiffi et al. (2008).

Type of traction vehicle	Technology class	Power dependent emission factors (g/kWh)			
		NOx	PM	CO	HC
Multiple unit	<1990	13.71	0.531	4.7	2.1
	1990-2002	7.01	0.141	2.1	1.0
	2003-2005	7.01	0.141	2.1	0.84
	2006-2014	3.52	0.141	2.1	0.52
	>2014	2.03	0.0253	2.1	0.193
Mainline locomotive	<1990	15.41	0.341	4.7	2.1
	1990-2002	10.71	0.161	2.1	1.0
	2003-2008	9.94	0.161	2.1	0.84
	2009-2014	6.02	0.161	2.1	0.52
	>2014	3.53	0.0253	2.1	0.52
Shunting locomotive	<1990	12.61	0.551	4.7	2.1
	1990-2002	11.91	0.271	2.1	1.0
	2003-2008	9.94	0.161	2.1	0.84
	2009-2014	6.02	0.161	2.1	0.52
	>2014	3.53	0.0253	2.1	0.52

Table 7: Technology related emission factors

6.2. Non-exhaust emissions

Subsequently, non-exhaust emissions ($PM_{2.5}$, PM_{10}, TSP) are derived from the number of train kilometres travelled, because these non-exhaust emissions are principally caused by abrasion of brakes, wheels, rails, and overhead wires of electric trains (Sleeuwaert et al., 2006), and are expressed in g/km. Table 8 displays the decomposition and the level of non-exhaust emissions originating from trains.

g/km	TSP	PM10	PM2.5
Abrasion of brakes	7.420	2.180	2.180
Abrasion of wheels	1.530	0.766	0.000
Abrasion of rails	6.730	3.370	1.680
Abrasion of overhead wires (only for electric trains)	0.187	0.187	0.187
Total diesel trains	**15.680**	**6.316**	**3.860**
Total electric trains	**15.867**	**6.503**	**4.047**

Table 8: PM emission factors for non-exhaust emissions of trains

Source: Sleeuwaert et al. (2006).

The share in non-exhaust emissions of shunting activities is added here, based on a supplement with respect to non-exhaust emissions of mainline activities for freight transport.

7. Geographical distribution

To distribute the emissions of rail transport in Belgium geographically, activity data (gross tonne transported) per railway section, train type, energy source and operator (NMBS/SNCB vs. non-NMBS/SNCB) are provided for the reference year 2008 by Infrabel (2010). Multiplying these tonnages with the length of the corresponding railway section, the number of gross tonne kilometres travelled, can be calculated. Founded on these calculations, fractions are derived to assign energy consumptions and emissions to these railway sections.

8. Results

8.1. Fleet emission factors

Table 9, Table 10 and Table 11 show the weighted fleet exhaust emission factors, non-exhaust emission factors and energy consumption factors respectively. Shunting activities are included separately in these tables as the model assumes that shunting of electric trains is also performed by means of diesel locomotives, and thus generate both exhaust and non-exhaust emissions, and cannot be attributed to the gross tonne kilometres travelled by freight diesel trains for mainline activities.

Train type	Pollutant	Unit	Historic	Baseline		
			2007	2010	2020	2030
Goods – mainline	CO2	g/gtkm	13.2	13.9	12.8	12.8
	NOx	g/gtkm	0.226	0.180	0.178	0.178
	PM2.5	g/gtkm	0.005	0.004	0.004	0.004
	VOS	g/gtkm	0.026	0.016	0.016	0.016
Goods – shunting	CO2	g/gtkm	0.737	0.552	0.469	0.468
	NOx	g/gtkm	0.011	0.007	0.006	0.006
	PM2.5	g/gtkm	0.000	0.000	0.000	0.000
	VOS	g/gtkm	0.001	0.001	0.000	0.000
Passengers	CO2	g/gtkm	35.5	35.0	32.9	32.9
	NOx	g/gtkm	0.330	0.325	0.115	0.115
	PM2.5	g/gtkm	0.007	0.006	0.002	0.002
	VOS	g/gtkm	0.047	0.046	0.012	0.012

Table 9: Exhaust emission factors for diesel trains

Train type	Energy source	Pollutant	Unit	Historic	Baseline		
				2007	2010	2020	2030
Goods - mainline	Diesel	PM2.5	g/km	3.86	3.86	3.86	3.86
	Electricity	PM2.5	g/km	4.05	4.05	4.05	4.05
Goods – shunting	Diesel	PM2.5	g/km	0.43	0.30	0.27	0.27
Passengers	Diesel	PM2.5	g/km	3.86	3.86	3.86	3.86
	Electricity	PM2.5	g/km	4.05	4.05	4.05	4.05

Table 10: Non-exhaust emission factors for all trains

Train type	Energy source	Unit	Historic	Baseline		
			2007	2010	2020	2030
Goods – mainline	Diesel	kJ/gtkm	180	190	175	175
	Electricity	kJ/gtkm	75	71	66	66
Goods – shunting	Diesel	kJ/gtkm	10	8	6	6
Passengers	Diesel	kJ/gtkm	484	477	449	449
	Electricity	kJ/gtkm	130	133	125	125

Table 11: Energy consumption factors for all trains

Moreover, for non-exhaust emissions a distinction is made between diesel and electric trains, because electric trains generate additional emissions with respect to diesel trains due to abrasion of overhead wires (cf. supra). Non-exhaust emissions are time independent.

Both exhaust emission as energy consumption factors mainly decline for the prognoses, due to the assumed technological improvements.

The exhaust emission factors computed in this project, assume that no bio fuels are used. The effect on these direct emission factors of addition of 10% bio diesel is recorded in Table 12. The effect for other blend percentages can be estimated by linearly extrapolating for this percentage.

Pollutant	Effect
CO2	0%
NOx	+3%
PM	-10%
VOS	-10%
CO	-5%

Table 12: Effect on emissions by 10% addition of bio fuel (bio diesel)

Source: EMEP/CORINAIR (2007).

8.2. Geographic distribution

Figure 3 and Figure 4 illustrate the geographical distribution of CO_2 and NO_x emissions for the prognoses of 2010 in the baseline scenario, as generated by mainline activities of both freight and passenger diesel trains.

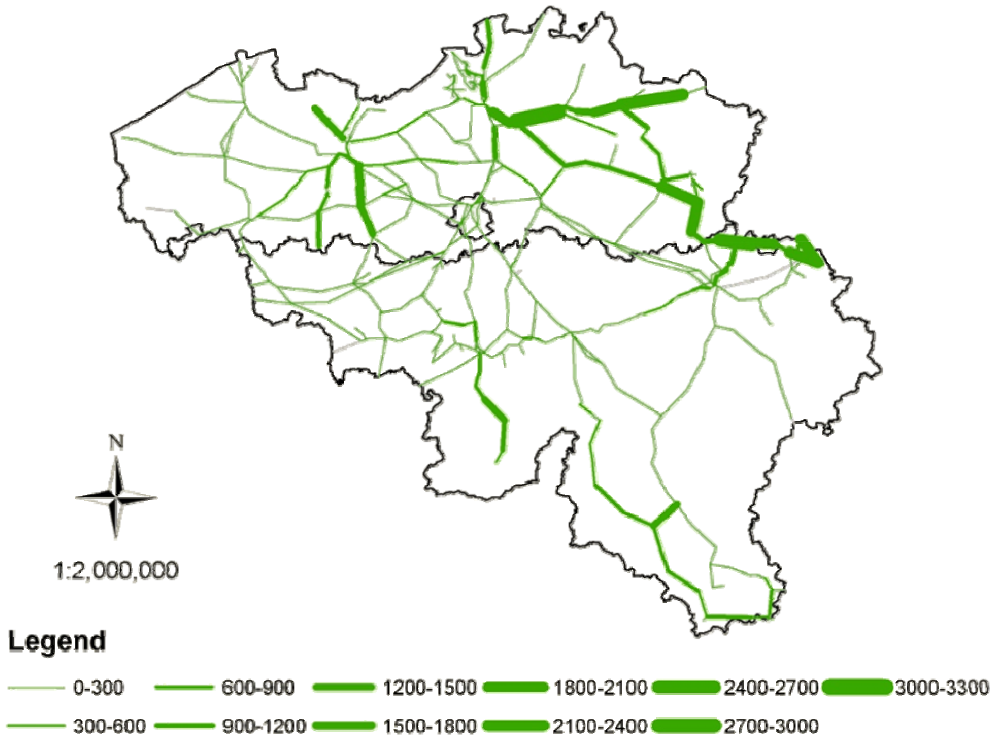

Figure 3: CO_2 emissions of diesel rail transportation (in tonne) for the baseline scenario, prognoses for 2010

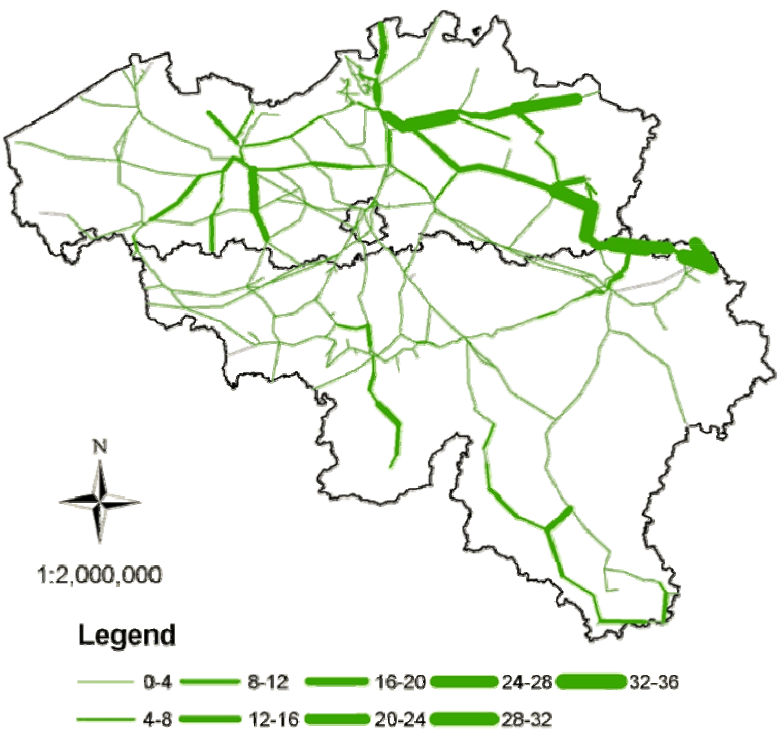

Figure 4: NO_x emissions of diesel rail transportation (in tonne) for the baseline scenario, prognoses for 2010

9. Validation of E-Motion Rail

In this section, E-Motion Rail is compared to EMMOSS, a model to calculate the emissions for maritime transport, inland navigation and rail for Belgium, developed under the authority of the Flemish Environmental Agency (VMM) by Transport & Mobility Leuven (TML) (Vanherle et al., 2007). Resemblances and dissimilarities are discussed, next to the effect on emissions for railway transportation in Flanders.

9.1. Resemblances in methodology and assumptions

Both EMMOSS and the current E-Motion module calculate energy consumptions and exhaust emissions for rail transport based on a bottom-up approach. Both models found their calculations on activity data of railway traffic, as expressed in gross tonne kilometres. The annual growth rates for the number of gross tonne kilometres in Flanders used in EMMOSS (De Vlieger et al., 2009), are also applied to the prognoses within E-Motion Rail for the number of gross tonne kilometres in Belgium. Furthermore, the activity data in both models are split according to the train type, service type, energy source and type of traction vehicle.

Both models assume a surcharge for non-NMBS/SNCB operators and for shunting.

The resulting activity data are combined with specific energy consumption factors to obtain the energy consumption in both models. These energy consumptions are calibrated on statistical data in both models

Additionally, a classification to include the technological improvements of the traction vehicle's engine is provided in EMMOSS as well as in E-Motion Rail. The technology related emissions (NO_x, PM, CO en HC) are strongly dependent on this technology classification.

9.2. Dissimilarities in methodology and assumptions

Obviously, the two models into consideration display some differences as well. Table 13 presents these differences, which are also discussed further in the following paragraphs.

Aspect	EMMOSS	E-Motion	Effect
Historic reference year	Last statistical year = 2007	Last statistical year = 2008	Effect on activity level, energy consumptions and emissions through annual growth rates
Non-NMBS/SNCB operators	Fixed supplement of 2%; all non-NMBS/SNCB operators are "old" diesel locomotives	Supplement based on data from Infrabel; non-NBS/ SNCB are partly electrified and partly renewed	Large impact on activity level, energy consumption and emissions: 2003-2010 lower supplement in E-Motion Rail; 2011-2030 higher supplement in E-Motion Rail
Shunting	8.8% for all historic years; 6.6% for prognoses	11% for all historic years; 8.25% for prognoses	Effect on energy consumption and emissions
Calibration energy consumption	Calibration based on one reference year (2005)	Calibration for all available historic years (2005-2008)	Effect on calibration factor for energy consumptions, and resulting energy consumption and emissions
Technology classes	Based on type approvals and only distinction made between "old" and "new" (i.e. HLD77 for locomotives and MW41 for multiple units)	Based on emission legislation and age of the traction vehicles	Effect on technology related emissions (CO, NOx, PM2.5, VOS)
Technology related emission factors	Based on data from type approvals	Based on combination of emission legislation and real situation (AEAT, 2005)	Effect on technology related emissions, due to higher emission factors in EMMOSS

Table 13: Differences between EMMOSS and E-Motion Rail

Firstly, the historic reference year of both models differs: EMMOSS uses 2007, while E-Motion Rail uses 2008 as last available historic reference year to calculate prognoses for the future. Consequently, the predicted activity data in both models vary, causing the derived energy consumptions and emissions to diverge, considering ceteris paribus conditions.

Furthermore, both models apply a surcharge for non-NMBS/SNCB operators. Yet, EMMOSS presumes a fixed percentage, whereas this surcharge in E-Motion Rail increases gradually, based on insights supplied by Infrabel (cf. supra). Between 2003 and 2010, the supplement for non-NMBS/SNCB in E-Motion Rail is lower than in EMMOSS (i.e. 2%); as from 2011, this supplement exceeds the presumed percentage of EMMOSS (i.e. up to 21%). This difference between the two models largely impacts the activity level, energy consumptions and emissions. Additionally, both models assume a different distribution of the activities of non-NMBS/SNCB over the energy sources and the technology classes of the traction vehicles. E-Motion Rail posits a small fraction of electrification for non-NMBS/SNCB operators, while EMMOSS supposes that non-NMBS/SNCB operators only deploy diesel locomotives. Moreover, E-Motion Rail assigns a small fraction of these non-NMBS/SNCB diesel trains to "newer" technology classes (i.e. the engine's build year between 1990-2002). Conversely, EMMOSS attaches all non-NMBS/SNCB locomotives to their class “old” (i.e. engine’s build year <1990).

Likewise, the surcharge for shunting activities with respect to mainline activities is not similar for both models, having an effect on the derived energy consumptions and emissions.

EMMOSS calibrates the computed energy consumptions for all years based on reported energy consumptions for only one historic year, in particular 2005. In E-Motion Rail, this calibration is performed for all historic years. For future years, E-Motion Rail applies an average calibration factor.

Concerning the technology distribution of the engine of the traction vehicle, EMMOSS distinguishes two technology classes (old or new, i.e. HLD77 for locomotives introduced as from 2000 and MW41 for diesel multiple units introduced between 2002 and 2005). E-Motion Rail provides more technology classes, based on the starting dates of the type approvals and on the European guideline 2004/26/EC. The distribution of the calculated energy consumptions over these technology classes strongly diverges for the two models.

In addition to this, the corresponding specific emission factors for the technology related emissions (NO_x, PM, CO en HC) differ. For all technology classes, the factors applied in EMMOSS exceed the corresponding emission factors in E-Motion Rail. These two aspects influence the technology related emissions to a large extent, as will be described in the following paragraph.

9.3. Effect on emissions

The effect of the differences between EMMOSS en E-Motion Rail on CO_2 en NO_x emissions by rail transport in Flanders are presented in Figure 5 and Figure 6 respectively. To this end, E-Motion Rail was re-run several times, varying the input data and/or assumptions discussed supra according to the input data and/or assumptions of EMMOSS. The legends in these figures reflect these different runs of E-Motion, as explained here:

- EMMOSS signifies that the results originate from the EMMOSS model developed by TML; E-Motion signifies that the results originate from E-Motion Rail developed in the course of this project.
- Reference year refers to the last historic year on which the future prognoses are based. 2007 is the last historic year in EMMOSS, whereas 2008 is the last historic year in E-Motion Rail.
- Non-NMBS refers to the assumption concerning the surcharge for non-NMBS/SNCB operators. In EMMOSS the assumptions defined in MIRA-S are applied (i.e. 2% for all years as from 2005). In E-Motion Rail yearly varying numbers obtained from Infrabel actualizing the surcharges assumed in MIRA-S, are applied.

- Shunting refers to the assumption concerning the surcharge for shunting activities. In EMMOSS, the assumptions defined in MIRA-S are applied (i.e. 8.8% for all historic years and 6.6% for all prognoses). In E-Motion Rail, these numbers were updated in the course of the current project (i.e. 11% for all historic years and 8.25% for all prognoses).

- Technology refers to the combination of the assumptions with respect to the (number of) technology classes (and the distribution according to these classes) and the technology related emission factors. In EMMOSS the assumptions defined in MIRA-S are applied. In E-Motion Rail, these assumptions were updated in the course of the current project:

    - Concerning the technology classes, EMMOSS only provides a subdivision according to “old” and “new” traction vehicles (HLD77 for locomotives and MW41 for multiple units). In E-Motion Rail, a more advanced subdivision is used, based on the emission legislation. Furthermore, for non-NMBS/SNCB operators, EMMOSS assumes only “old” diesel engines, whereas E-Motion Rail assumes that a small part deploys electric locomotives, and a small portion of the remaining diesel locomotives uses new engines (i.e. technology class 1990-2002).

    - Concerning the technology related emission factors, EMMOSS applies emission factors from type approvals, while E-Motion Rail applies emission factors from European legislation, and considers the actual situation.

Both figure show that E-Motion Rail and EMMOSS (dark blue line) generate practically the same results, in case E-Motion Rail implements the assumptions of MIRA-S and uses 2007 as historic base year (red line).

When E-Motion Rail relaxes the assumption concerning the surcharges for non-NMBS/SNCB operators and for shunting to those described in this project (yellow line), the emissions show an increasing rise (especially between 2010 and 2015 due to the increasing surcharge for non-NMBS/SNCB operators in E-Motion Rail with respect to the fixed percentage in MIRA-S).

The difference in technology classes and their corresponding technology related emissions (light blue line compared to yellow line) obviously do not affect the emissions expressed in CO_2 equivalents in Figure 5, while a clear impact is shown on NO_x emissions in Figure 6.

Finally, the use of the historic reference year 2008 (green line) instead of 2007 (light blue line) causes the emissions to decline, as the real historic data in 2008 are lower than the predicted data for 2008 in EMMOSS, due to the start of the economic crisis in 2008.

Summarized, the course of the green and the dark blue line illustrates the difference between the current version of E-Motion Rail and EMMOSS (applying MIRA-S assumptions) respectively.

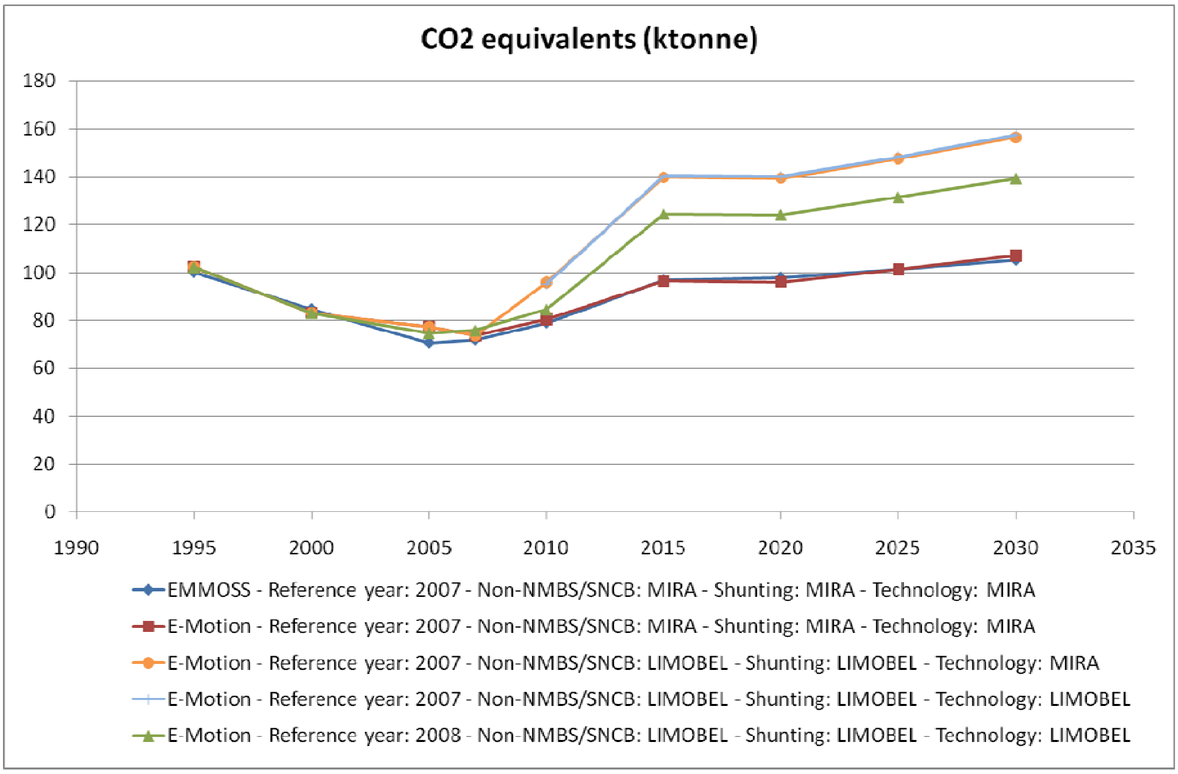

Figure 5: Comparison of EMMOSS to E-Motion Rail - CO_2 equivalents (in ktonne)

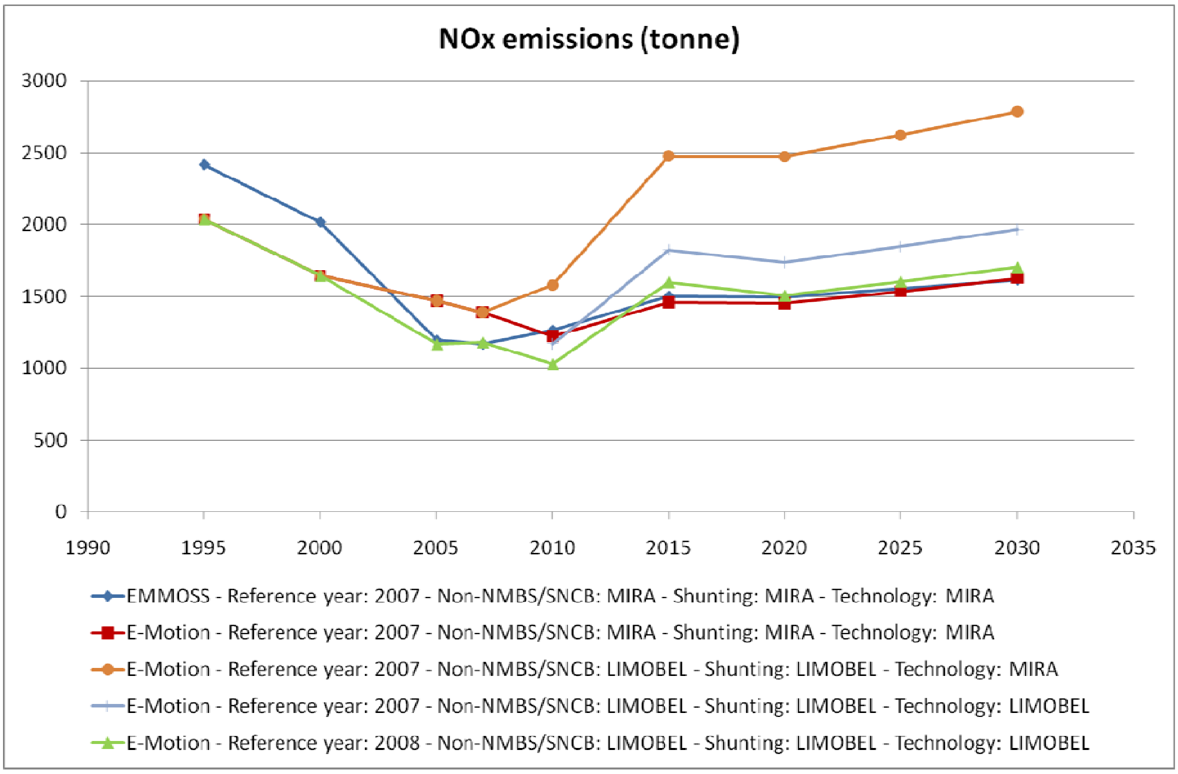

Figure 6: Comparison of EMMOSS to E-Motion Rail - NO_x emissions (in tonne)

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Annex 1: E-motion – Part III

Inland navigation

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Table of Contents

List of abbreviations

#	Number
BO	Classification of pushed barges
CEMT	Classification of waterways in Europe according to their dimensions, as determined by Conférence Européenne des Ministres de Transport
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
EMMOSS	Emission model for rail and shipping traffic in Flanders (Emissiemodel voor spoorverkeer en scheepvaart in Vlaanderen), carried out for the Flemish Environmental Agency (VMM) by Transport & Mobility Leuven (TML)
E-motion	Energy- and emission MOdel for Transport with geographical distributION
EMS	Emission registration and monitoring for navigation (Emissieregistratie en – Monitoring Scheepvaart)
g	Gramme
g/tkm	Gramme per tonne kilometre
ITB	Instituut voor het Transport Langs de Binnenwateren NV
Kg	Kilogramme
Km	Kilometre
km/h	Kilometre per hour
kW	Kilowatt
kWh	Kilowatt-hour
m	Metre
m/s	Metre per second
MIRA-S	Environmental report Flanders – Scenarios (Milieurapport Vlaanderen – Scenario's)
N_2O	Nitrous oxide
NH_3	Ammonia (laughing gas)
NMVOC	Non-methane VOC
NO_x	Nitrogen oxides
PBV	Promotie Binnenvaart Vlaanderen
$PM_{2.5}$	Particulate matter with an aerodynamic diameter of less than 2.5 micrometre
PROLIBIC	Upcoming BELSPO project– Cluster of the transport related projects PROMOCO, LIMOBEL, BIOSES and CLEVER
SO_2	Sulphur dioxide
t	Tonne
tkm	Tonne kilometres
VOC	Volatile Organic Compounds
WenZ	Waterwegen en Zeekanaal NV, waterway administration

@to be completed

1. Introduction

The aim of E-Motion for inland navigation, or abbreviated E-Motion Inav, consists of estimating the energy and fuel consumptions and emissions of inland navigation in Belgium. The general methodology of this module is presented in Figure 1.

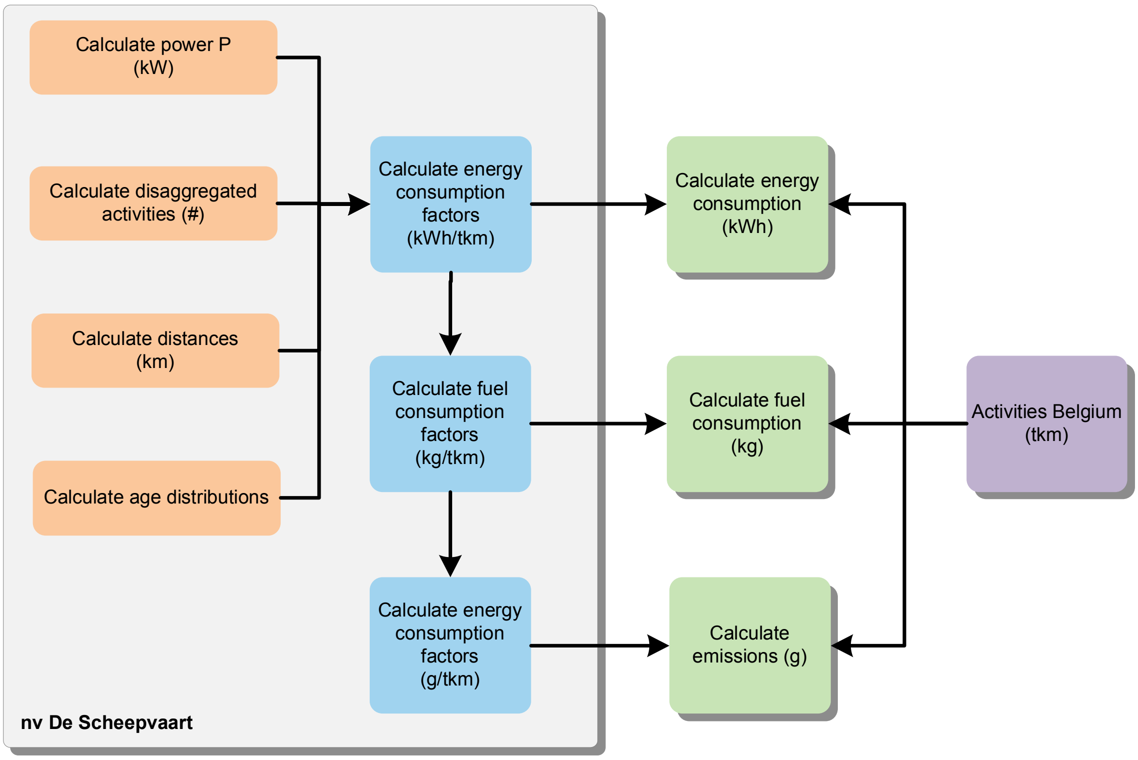

Figure 1: General methodology to calculate energy and fuel consumptions and emissions for inland navigation

Based on specific energy consumption, fuel consumption and emission factors – which are calculated within the model - and the number of tonne kilometres travelled on the Belgian waterway network, energy consumptions, fuel consumptions and emissions can be derived. To this end, data was requested at the different waterway administrations. Because only the data concerning activities on the waterways under the administration provided by nv De Scheepvaart are sufficiently detailed, the model first calculates specific emission and energy consumption factors per CEMT-class for these waterways, which is depicted by the grey box in Figure 1. It is thus assumed here that the traffic on these waterways is representative with respect to composition of the fleet for waterways of the same size in Belgium, as based on the CEMT class (expert judgment made by Mrs. Hilde Bollen, (PBV, 2009)). As such, the mix of the ships which travel on the Albert canal, is supposed to characterize the composition of the fleet on all “large” waterways in Belgium (i.e. CEMT VI or more). For small waterways (i.e. CEMT II and

Va), the Kempische Canals (i.e. all navigable waterways of nv De Scheepvaart to the north of the Albert canal) can be assumed to be representative, as they are navigated frequently. The navigable waterways in Belgium and those under the administration of nv De Scheepvaart are depicted in Figure 2.

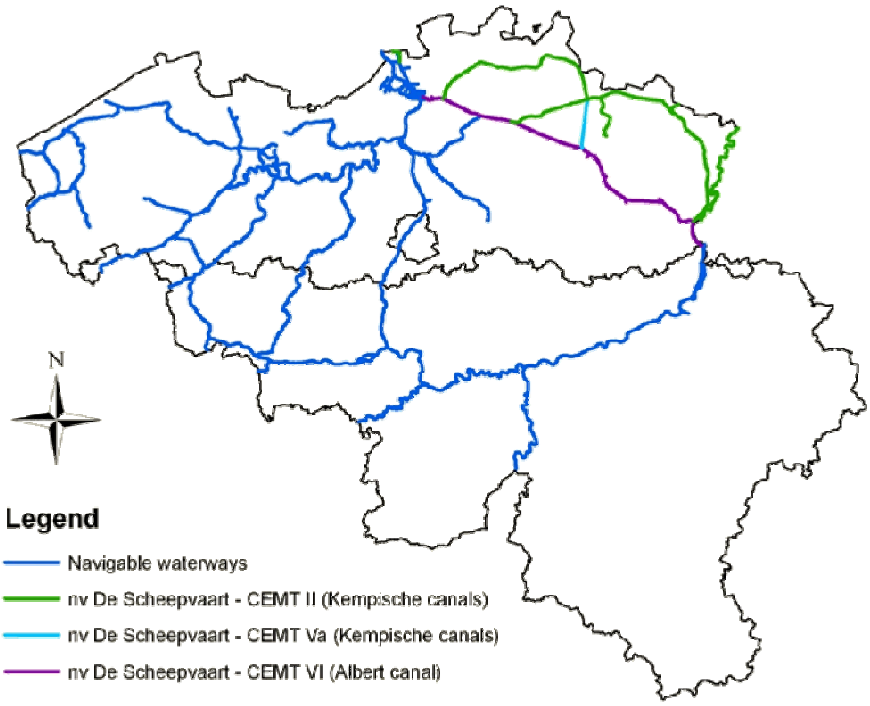

Figure 2: Navigable waterways in Belgium

Consequently, the outcome of the calculation steps for the waterways under the administration of nv De Scheepvaart is applied to all waterways in Belgium. The calculation of the specific energy and fuel consumption and emission factors is inspired by EMS protocols (Ministerie van Verkeer en Waterstaat, 2003a, 2003b), and is conform the methodology applied in EMMOSS (Vanherle et al., 2007). Each calculation step is elaborated on infra.

2. Pre-calculation steps

The calculation of energy and fuel consumptions of an inland navigation ship is fed by the power required to navigate this ship on a specific waterway section on the one hand, and the ship's activity and distance travelled on this waterway section on the other hand. The following paragraphs describe these preparatory calculation steps.

2.1. Power

The power to navigate a vessel is to a great extent subject to its dimensions and navigation speed, as explained in Bolt (2003). However, it is not feasible to estimate the power for each ship individually. Therefore, the calculations take into account the average dimensions for a number of characterizing ship classes. These ship classes include small ship, Spits, Kempenaar, new Kempenaar, Canal du Nord, Dortmund-Eems canal ship, Rhine-Herne canal ship, large container ship, large Rhine ship for motor vessels and small pushed convoy (BO1-3), small pushed convoy (BO4), double pushed convoy, single pushed convoy and pushed convoy for CEMT IV for pushed vessels according to the classes defined by PBV (2011).

The features for these ship classes - including CEMT class, ship length, ship width and average tonnage - can be found on the website of PBV (2011). The ship properties, covering average draught – charged and discharged - and age type (see 2.4), are adopted from EMMOSS (Vanherle, 2007). For ship types not occurring in EMMOSS, average draught and age type are estimated based on the most resembling ship class as defined by the remaining features. The resulting dimensions used in E-Motion Inav are summarized in Table 1 for motor vessels and in Table 2 for pushed vessels.

To be able to calculate the power required to navigate a vessel on a certain waterway segment, the resistance is estimated first. Three components make up the total resistance. To start with, the frictional resistance R_f is estimated (Bolt, 2003).

$$R_f = 52 \times (\log VL + 4)^{-2} \times \left(L \times B + 2 \times L \times T_{avg}\right) \times V^2$$

Having

V	=	navigation speed (m/s)
L	=	vessel length (m)
B	=	vessel width (m)
T_{avg}	=	average vessel draught (m)

Ship class	Age type	Width (m)	Length (m)	Draught charged (m)	Draught dis-charged (m)
Small ship	L	5.00	28.00	2.2	0.5
Spits	L	5.05	38.70	2.2	0.5
Kempenaar	L	6.60	60.00	2.5	0.6
New Kempenaar	L	7.20	55.00	2.5	0.6
Canal du Nord	L	5.75	60.00	3.2	0.6
Dortmund-Eems canal ship	M	8.20	73.50	2.5	0.7
Rhine-Herne canal ship	S	9.80	82.50	2.5	0.8
Large Rhine ship	S	11.40	95.00	2.7	0.8
Large container ship	S	17.00	135.00	3.0	0.4

Table 1: Ship dimensions for motor vessels

Ship class	Age type	Width (m)	Length (m)	Draught charged (m)	Draught dis-charged (m)
Small pushed convoy (BO1-3)	L	7.50	78.00	2.6	0.4
Small pushed convoy (BO4)	M	8.20	85.00	2.7	0.4
Single pushed convoy	S	11.40	190.00	3.5	0.4
Double pushed convoy	S	22.80	190.00	3.5	0.4
Pushed convoy for CEMT IV	M	9.50	100.00	3	0.4

Table 2: Ship dimensions for pushed vessels

Secondly, the residual resistance R_p is calculated (Bolt, 2003).

$$R_p = C_p \times \frac{1}{2} \times \rho \times V^2 \times B \times T_{max}$$

Having

C_p	=	coefficient for residual resistance, here assumed to be equal to 0.15
ρ	=	water density, equal to 1000 kg/m³
V	=	vessel speed (m/s)
B	=	vessel width (m)
T_{max}	=	maximum vessel draught (m)

The third component, the residual resistance R_z, is not estimated, analogous to the example calculations on page 7 of Bolt (2003), as this component is negligibly small. The total resistance R_t then equals the sum of the two first resistance terms.

$$R_t = R_f + R_p$$

Subsequently, the required engine power, including losses on the axes and transmission, can be derived as follows (Bolt, 2003):

$$P_b = 2 \times u_{rel} \times R_t$$

Having

u_{rel} = navigation speed corrected for the effect on limited water, which is here assumed to equal the average speed V.

The navigation speeds applied in these formulas are adopted from EMMOSS (Vanherle et al., 2007). Table 3 and Table 4 record these navigation speeds for motor vessels and pushed vessels respectively.

Ship class	Loaded			Unloaded		
	CEMT VI	CEMT V	CEMT II	CEMT VI	CEMT V	CEMT II
Small ship	12	12	11	15	15	15
Spits	12	12	11	15	15	15
Kempenaar	13	13	10	15	15	15
New Kempenaar	15	13	10	15	15	8
Canal du Nord	15	13	10	15	15	8
Dortmund-Eems canal ship	15	13	9	15	15	8
Rhine-Herne canal ship	16	14	9	17	16	8
Large Rhine ship	16	13	9	17	16	8
Large container ship	16	13	9	17	16	8

Table 3: Average speed for motor vessels (in km/h)

Ship class	Loaded			Unloaded		
	CEMT VI	CEMT V	CEMT II	CEMT VI	CEMT V	CEMT II
Small pushed convoy (BO1-3)	13	13	10	15	15	15
Small pushed convoy (BO4)	15	13	10	15	15	8
Single pushed convoy	16	13	9	17	16	8
Double pushed convoy	16	13	9	17	16	8
Pushed convoy CEMT IV	16	14	9	17	16	8

Table 4: Average speed for pushed vessels (in km/h)

2.2. Disaggregated activities

In order to calculate average fleet energy consumption and fuel consumption factors per CEMT class for the selected representative waterways, detailed activity data recording the number of ship passages, transported tonnages and number of tonne kilometres travelled are required. To this end, data concerning navigation on the waterways of nv De Scheepvaart are requested. Even though the acquired information is very extensive, the different data sets are not sufficiently disaggregated. Therefore, these data sets are combined as described in the remainder of this paragraph to obtain the information on the desired level of detail, i.e. per year, per waterway section and direction (upstream or downstream), per ship type (motor or pushed vessel), tonne class (<300t, 301-650t, 651-800t, 801-1350t, 1351-2000t, >2000t) and load factor (charged or discharged).

One of the datasets provided by nv De Scheepvaart includes the yearly number of ship passages and transported tonnages, disaggregated per year, waterway section, direction and load factor (for discharged vessels only number of ship passages are given). This dataset serves as basis for the subsequent calculations. For historic years the data are used as such. However, the model also integrates future prognoses. As this stage concentrates on forming an idea of the composition of the fleet and their activities on the representative waterways (i.e. relative numbers), the absolute number of ship passages and transported tonnages are not required for future years. Therefore, for future prognoses the number of ship passages and transported tonnages of the last available historic year are used as basis. The model provides the possibility to correct for future load efficiency improvements, causing the share of discharged vessels to decline with respect to the historic reference year, as follows:

$$n_{y,l=0} = n_{y_r,l=0} \times (1 - e_{y,y_r})$$

Having

n	=	number of ship passages
y	=	prognosis year
y_r	=	historic reference year
e_{y,y_r}	=	efficiency improvement in year y with respect to the reference year y_r
l	=	load factor (0 = discharged)

Yet, the current model calculations assume no load efficiency improvement.

A second dataset contains an indication of the distribution of the vessels according to ship type (motor or pushed vessel), disaggregated according to waterway and year. Assuming that this distribution applies to all waterway sections of the same waterway, to all directions and to all load factors, the number of ship passages and the transported tonnages are distributed over the ship types according to this information.

Thirdly, nv De Scheepvaart supplied information on the yearly number of ship passages and transported tonnages, disaggregated per waterway, direction and tonne class. Based on this data, a distribution of the number of ship passages and transported tonnages over the defined tonne classes is derived for each waterway and direction. These distributions per year, waterway and direction is applied to the number of ship passages and transported tonnages estimated in the previous step, keeping them the same for the different waterway sections (of the waterway into consideration), ship types and load factors. For the future prognoses, the average distribution of the last historic year is applied.

The outcome of these calculation steps consists of the number of ship passages and transported tonnages, broken down according to the waterway section, direction, load factor, ship type and tonne class.

2.3. Distances

To be able to calculate the total energy consumption required by a vessel to navigate a certain route (i.e. waterway section), the number of kilometres travelled has to be known. Consequently, the current paragraph focuses on determining the average distance travelled by each combination of ship class and load factor on each waterway section and in each direction. To this end, nv De Scheepvaart provided information on the distances between each two adjoining observation points (i.e. origin-destination distances). After having pre-processed these data, the model derives a distance for each waterway section, direction, load factor, ship class, ship type, tonne class and year.

Yet, not all vessels travelling on a certain section do cover the whole distance of this waterway section. They may charge or discharge in between, make a U-turn, and navigate back in the opposite direction. Because of this, the model calibrates the distance of each section based on the reported number of tonne kilometres per waterway. To this end, the number of tonne kilometres on the detailed level (waterway section, direction, load factor, ship class, ship type, tonne class and year) is theoretically estimated first by multiplying the number of transported tonnages by the calculated distance.

Given that the reported number of yearly travelled tonne kilometres is only available for loaded vessels and at the level of the waterway, the number of tonne kilometres calculated here is aggregated to this level. A calibration factor is then worked out for each waterway and year:

$$cf_{y,w} = \frac{reported\ tkm_{y,w,l=1}}{\sum calculated\ tkm_{y,s_w,i,l=1,h,c,o}}$$

Having

$cf_{y,w}$	=	calibration factor for year y and waterway w
$tkm_{y,w,l=1}$	=	number of tonne kilometres travel in year y on waterway w
$tkm_{y,s_w,i,l=1,h,c,o}$	=	number of tonne kilometres travelled in year y on waterway section s_w (belonging to waterway w) and in direction i by loaded ships (load factor $l = 1$) of ship type h, ship class c and tonne class o

The resulting calibration factors are used to correct to the theoretic distances travelled on each waterway section, assuming that the correction factors can be extrapolated to all waterway sections of a certain waterway, disregarding the navigation direction, load factor, ship class, ship type and tonne class, but accounting for fluctuation between years (e.g. due to the appearance or disappearance of an attractive landing stage on a specific waterway section).

Based on these calibrated distances, the number of tonne kilometres is added to the activity data, by multiplying the transported tonnages and the calibrated distances.

2.4. Age distribution

As the fuel use and the emissions of NO_x, $PM_{2.5}$, CO and VOC are technology related, the activity data need to be further refined. Therefore, technology classes are determined, depending on the build year of the ship's propulsion engine, as is the case in EMMOSS (Vanherle et al., 2007). To this end, three main age types are defined (S, M and L) and assigned to the ship classes, as shown in Table 1 for motor vessels and in

Table 2 for pushed vessels. For age type S the maximum age of the vessels is 20 years, for age type M 25 years and for age type L 30 years. Following build year categories are included in the model: 1900 - 1974 (only for age type L), 1975 - 1979 (only for age type L), 1980 - 1984, 1985 - 1989, 1990 - 1994, 1995 - 2001, 2002 - 2006, 2007 - 2011, 2012 - 2015, 2016 - 2020, 2021 - 2030.

A Weibull distribution (Vanherle et al., 2007) is estimated based on the average age of the vessel's engine. The Weibull parameters for the different age types S, L and M are displayed in Table 5.

Age type	S	M	L
κ	2	2	2
λ	2	2.5	3
Median age	8.3	10.4	12.5

Table 5 : Parameters Weibull age distribution

Source: Vanherle et al. (2007).

The age distribution for the build year category $(a_2 - a_1)$ is formulated as follows:

$$P_{(a_2-a_1)} = \left(1 - e^{-\left(\frac{\frac{y-a_1}{5}}{\lambda}\right)^{\kappa}}\right) - \left(1 - e^{-\left(\frac{\frac{y-a_2}{5}}{\lambda}\right)^{\kappa}}\right)$$

Having

a_1	=	lower limit in the age class
a_2	=	upper limit in the age class
y	=	year for which the calculations are set up
λ , κ	=	weibull parameters for a certain age type (S, M or L)

At this point it is not possible to link the age distribution to the number of ship passages, transported tonnages and tonne kilometres travelled, because the activity data do not include the ship class (e.g. small ship, Spits, Kempenaar, ...). The activity data only contain the ship type and tonne class, and a one-to-one relationship between this combination of ship type and tonne class on the one hand and ship class on the other hand cannot be deduced from statistics. Consequently a mapping between ship type/ tonne class and ship class is formulated in this research, based on the average tonnage for each ship class.

For motor vessels, statistical information of ITB (2008) is applied to split the number of ship passages and the transported tonnage over the ship classes. The resulting mapping of ship type/tonne class to ship class is shown in Table 6.

Tonne class	Ship class	Distribution number of ship passages	Distribution transported tonnages
<300 t	Small ship	1.0	1.0
301 - 650 t	Spits	0.7	0.6
	Kempenaar	0.3	0.4
651 - 800 t	New Kempenaar	1.0	1.0
801 - 1350 t	Canal du Nord	0.5	0.5
	Dortmund-Eems canal ship	0.5	0.5
1351 - 2000 t	Rhine-Herne canal ship	1.0	1.0
>2000 t	Large container ship	0.3(*)	0.3(*)
	Large Rhine ship	0.7(*)	0.7(*)

Table 6: Mapping for motor vessels from tonne class to ship class

(*) Assumptions based on expert judgement by Mrs. Hilde Bollen (PBV, 2010).

CEMT	Tonne class	Ship class	Distribution number	Distribution number
II	**<300 t**	Small pushed convoy (BO1-3)	1	1
	301 - 650 t	Small pushed convoy (BO1-3)	1	1
	651 - 800 t	Small pushed convoy (BO4)	1	1
	801 - 1350 t	Small pushed convoy (BO4)	1	1
	1351 - 2000 t	Small pushed convoy (BO4)	1	1
	>2000 t	Small pushed convoy (BO4)	1	1
IV	**<300 t**	Pushed convoy for CEMT IV	1	1
	301 - 650 t	Pushed convoy for CEMT IV	1	1
	651 - 800 t	Pushed convoy for CEMT IV	1	1
	801 - 1350 t	Pushed convoy for CEMT IV	1	1
	1351 - 2000 t	Pushed convoy for CEMT IV	1	1
	>2000 t	Pushed convoy for CEMT IV	1	1
VI	**<300 t**	Single pushed convoy	1	1
	301 - 650 t	Single pushed convoy	1	1
	651 - 800 t	Single pushed convoy	1	1
	801 - 1350 t	Single pushed convoy	1	1
	1351 - 2000 t	Single pushed convoy	1	1
	>2000 t	Single pushed convoy	0.5	0.5
		Double pushed convoy	0.5	0.5

Table 7: Mapping for pushed vessels from CEMT class of waterway and tonne class of vessel to ship class

For pushed vessels, the mapping from tonne class to ship class is influenced by the CEMT class of the waterway. In this case a one-to-one mapping exists, except for CEMT VI waterways and tonne class >2000t. The number of ship passages and the transported tonnages are distributed equally over single and double pushed convoys, as shown in Table 7.

Having implemented these mappings between ship type/tonne class and ship class, the age distribution is applied to the activity data.

3. Specific energy and fuel consumption and emission factors

3.1. Specific energy consumption factors

The outcome of the preceding computations consists of the yearly number of ship passages, the transported tonnages and tonne kilometres and distances travelled, disaggregated according to waterway section, direction, ship class (ship type and tonne class), build year class and load factor, next to the required navigation power for each section, direction, ship class and load factor. Combining these results, the corresponding energy consumption is derived (Hulskotte et al., 2003).

$$E_{s_w,i,l,c,b} = n_{s_w,i,l,c,b} \times P_{s_w,i,l,c} \times \frac{d_{s_w,i,l,c}}{V_{s_w,i,l,c}}$$

Having

$E_{s_w,i,l,c,b}$	=	energy consumption (in kWh) for vessels travelled on waterway section s_w in direction i with load factor l, ship class c and build year class b
$n_{s_w,i,l,c,b}$	=	number of vessels travelled on waterway section s_w in direction i with load factor l, ship class c and build year class b
$P_{s_w,i,l,c}$	=	power (in kW) required to navigate on waterway section s_w in direction i with a vessel with load factor l and ship class c
$d_{s_w,i,l,c,b}$	=	distance travelled (in km) on waterway section s_w in direction i by a vessel with load factor l and ship class c
$V_{s_w,i,l,c,b}$	=	average vessel speed (in km/h) on waterway section s_w in direction i for a vessel with load factor l and ship class c

Next, specific energy consumption factors for loaded vessels per CEMT class and per year can be easily deduced by dividing the total annual energy consumption per CEMT class by the total annual tonne kilometres per CEMT class. Subsequently, an energy supplement for discharged vessels for each CEMT class is calculated.

$$ECS_{y,cemt,l=0} = \frac{\sum E_{y,cemt,l=0}}{\sum E_{y,cemt,l=1}}$$

Having

$ECS_{y,cemt,l=0}$	=	energy consumption supplement for unloaded vessels ($l = 0$) in year y for a waterway with CEMT class $cemt$
$E_{y,cemt,l}$	=	energy consumption for loaded/unloaded vessels ($l = 1$ for loaded vessels, and $l = 0$ for unloaded vessels) in year y for a waterway with CEMT class $cemt$

Furthermore, an energy supplement for auxiliary engines is added in the model as well. Auxiliary engines are used to provide electricity and heating on board, and to a limited extent also for manoeuvring. Because of the introduction of onshore electricity supply, the amount of electricity generated by auxiliary engines will decrease. Consequently, the model includes this decrease according to the formula below and the assumption in Table 8, as adopted from MIRA-S (De Vlieger et al., 2009).

$$ECS_{y,aux} = supplement_{y,aux} \times (1 - p_{on\ shore\ supply,y} \times p_{on\ shore\ time,y})$$

Having

$ECS_{y,aux}$	=	energy consumption supplement for auxiliary engines in year y
$supplement_{y,aux}$	=	supplement for auxiliary engines in year y
$p_{onshore\ supply}$	=	share of onshore electricity supply in year y
$p_{onshore\ time}$	=	share of time spent onshore in year y

Period	Supplement for auxiliary engines	Share of onshore electricity supply	Share of onshore time
<2009	0.1	0.0	0.5
2010-2014	0.1	0.2	0.5
>2015	0.1	0.5	0.5

Table 8: Assumption concerning the energy supplement of auxiliary engines

Source: De Vlieger et al. (2009).

The outcome of these computations consists of specific energy consumption factors in kWh/tkm, per year and CEMT class, next to the corresponding energy supplements for discharged vessels and for auxiliary engines.

A note on these calculations: the energy consumptions derived here cover the energy required to navigate the vessels on the waterways, disregarding the engine efficiency, and thus do not reflect the amount of energy/fuel actually needed by the engines to perform these activities. The next paragraph concentrates on the fuel consumption required to generate this energy consumption.

3.2. Specific fuel consumption factors

In the current step, the fuel consumption is calculated based on the energy consumptions and taking into account the engine's technology, reflected in the propulsion engine's build year class. Additionally, the model considers for the effect of future efficiency improvements on the fuel consumption. An example of upcoming efficiency improvements is caused by the introduction of on board cruise control to guide bargees to follow the most economical navigation planning, the so-called tempomaat. The cruise control is assumed to cause a decrease in fuel consumption of 10% (De Vlieger et al., 2009). The implementation levels of the cruise control are summarized in Table 9 for motor vessels and in Table 10 for pushed vessels (De Vlieger et al., 2009).

Ship class	2007-2009	2010-2014	2015-2030
Small ship	5%	75%	75%
Spits	5%	75%	75%
Kempenaar	5%	75%	75%
New Kempenaar	25%	90%	95%
Canal du Nord	25%	90%	95%
Dortmund-Eems canal ship	25%	90%	95%
Rhine-Herne canal ship	50%	95%	95%
Large Rhine ship	50%	95%	95%
Large container ship	50%	95%	95%

Table 9: Implementation level of cruise control for motor vessels

Source: De Vlieger et al. (2009).

Ship class	2007-2009	2010-2014	2015-2030
Small pushed convoy (BO1-3)	5%	75%	75%
Small pushed convoy (BO4)	5%	75%	75%
Single pushed convoy	50%	95%	95%
Double pushed convoy	50%	95%	95%
Pushed convoy CEMT IV	25%	90%	95%

Table 10: Implementation level of cruise control for pushed vessels

Source: De Vlieger et al. (2009).

Taking these considerations into account, the total fuel consumption is calculated as follows:

$$FC_{sw,i,l,c,b} = E_{sw,i,l,c,b} \times FCF_b \times (1 - p_{tempomaat} \times ef_{tempomaat})$$

Having

$FC_{s_w,i,l,c,b}$	=	fuel consumption (in kg fuel) for vessels travelled on waterway section s_w in direction i with load factor l, ship class c and build year class b
$E_{s_w,i,l,c,b}$	=	energy consumption (in kWh) for vessels travelled on waterway section s_w in direction i with load factor l, ship class c and build year class b
FCF_b	=	fuel consumption factor (in kg/kWh) for build year class b
$p_{tempomaat}$	=	implementation level tempomaat
$ef_{tempomaat}$	=	effect of the efficiency improvement due to cruise control

The fuel consumption factors differ according to the propulsion engine's build year class on the one hand, and according to the fuel used (diesel vs. bio-diesel). In the current research, the introduction of bio-diesel in inland navigation is not taken into account in this part. An overview of the fuel consumption factors per build year class is provided in Table 11.

Build year class	Diesel
<1975	235
1975-1979	230
1980-1984	225
1985-1989	220
1990-1994	210
1995-2001	205
2002-2006	200
2007-2011	200
2012-2015	200
2016-2020	200
2021-2030	200

Table 11: Fuel consumption factors for inland navigation (in g/kWh)

Source: Hulskotte et al. (2003).

Next, specific fuel consumption factors in g/tkm per year and CEMT class, as well as fuel consumption supplements for discharged vessels and consumption supplements for auxiliary engines, can be derived in the same way as described for the energy consumption factors and energy supplements for discharged vessels and auxiliary engines and is not further elaborated here.

3.3. Specific emission factors

Technology related emissions

Based on the computed energy consumptions, technology related emissions, which depend on the build year of the vessel engine, are calculated. Table 12 displays the technology related emission factors used in the current research.

Build year class	NO_x	$PM_{2.5}$	CO	VOC	NMVOC	CH_4
<1975	10	0.6	4.5	1.2	1.152	0.048
1975-1979	13	0.6	3.7	0.8	0.768	0.032
1980-1984	15	0.6	3.1	0.7	0.672	0.028
1985-1989	16	0.5	2.6	0.6	0.576	0.024
1990-1994	14	0.4	2.2	0.5	0.48	0.020
1995-2001	11	0.3	1.8	0.4	0.384	0.016
2002-2006	8	0.3	1.5	0.3	0.288	0.012
2007-2011	6	0.2	1.3	0.2	0.192	0.008
2012-2015	6	0.2	1.3	0.2	0.192	0.008
2016-2020	6	0.2	1.3	0.2	0.192	0.008
2021-2030	6	0.2	1.3	0.2	0.192	0.008

Table 12: Technology related emission factors (g/kWh)

Sources: Hulskotte et al. (2003) and Vanherle et al. (2007).

Following formula is applied to estimate technology related emissions:

$$M_{s_w,i,l,c,b,p} = E_{s_w,i,l,c,b} \times EF_{b,p}$$

Having

$M_{s_w,i,l,c,b},p$ = emission (in g) of pollutant p for vessels travelled on waterway section s_w in direction i with load factor l, ship class c and build year class b

$E_{s_w,i,l,c,b}$ = energy consumption (in kWh) for vessels travelled on waterway section s_w in direction i with load factor l, ship class c and build year class b

$EF_{b,p}$ = emission factor for pollutant p for build year class b

Fuel related emissions

Fuel related emissions are derived by applying the fuel related emission factors reported in Table 13 and Table 14, to the total fuel use per waterway section, direction, load factor, ship class and build year class, as calculated in paragraph 3.2.

$$M_{s_w,i,l,c,b,p} = FC_{s_w,i,l,c,b} \times EF_p$$

Having

$M_{s_w,i,l,c,b},p$ = emission (in g) of pollutant p for vessels travelled on waterway section s_w in direction i with load factor l, ship class c and build year class b

$FC_{s_w,i,l,c,b}$ = fuel consumption (in kg fuel) for vessels travelled on waterway section s_w in direction i with load factor l, ship class c and build year class b

EF_p = emission factor (in g/tkm) for pollutant p

Table 13 shows the emission factors for CO_2, N_2O and NH_3, whereas Table 14 records the emission factors for SO_2, which are time dependent due to the varying sulphur content in the fuel used.

CO_2	N_2O	NH_3
3100	0.025367	0.007

Table 13: Fuel related emission factors (g/kg fuel)

Period	SO_2	Mass% sulphur
<2007	3.4	0.17%
2008-2015	2.0	0.10%
2016-2020	2.0	0.10%
2021-2030	2.0	0.10%

Table 14: Time dependent SO_2 emission factors (g/kg fuel)

Source: IPCC (1997), IPCC (2006) and EMEP/Corinair (2007).

Emission factors

Specific emission factors in g/tkm per year and CEMT class can now be computed in the same way as described in section 3.1 for the specific energy consumption factors. Likewise, emission supplements for discharged vessels and auxiliary engines are determined.

In order to obtain energy consumption, fuel consumption and emission factors for the LIMOBEL project, weighted over the entire Belgian waterway network and the inland navigation fleet, the total energy consumption, fuel consumption and emissions are determined first. To this end, the energy consumption, fuel consumption and emission factors resulting from the previous calculation steps are applied to all waterways in

Belgium, based on the number of tonne kilometres navigated on each waterway, as explained in the following paragraph.

4. Fleet energy consumption, fuel use and emission factors

First, historic data concerning the activities on the Belgian waterways are gathered and prognoses concerning future activities on these waterways are formulated. The historic data consist of the number of tonne kilometres travelled on the waterway network, as obtained from the different waterway administrations (WenZ, nv De Scheepvaart and L'Office de Promotion des Voies Navigables).

Unfortunately, no data concerning the tonne kilometres travelled by inland navigation vessels for each of the Belgian harbours are available. To get an idea on this number, the total number of tonne kilometres for all harbours in Belgium can be derived from data originating from the Studiedienst van de Vlaamse Regering. The total number of tonne kilometres for all regions including the harbours is recorded, next to the number of tonne kilometres for each region excluding the harbours. The difference between these two data sets is the total number of tonne kilometres for all Belgian harbours. This number is dispersed over the different harbours according to their share in the total charged and discharged tonnes in the Belgian harbours.

For the prognoses of the tonne kilometres, the last available statistical data are combined with annual growth rates for Flanders, recorded in Table 15 (De Vlieger et al., 2009), assuming the same growth rates for Belgium.

Period	Growth rate
2007-2010	1.61%
2011-2015	1.29%
2016-2020	1.19%
2021-2025	1.26%
2026-2030	1.13%

Table 15: Yearly growth rates for tonne kilometres

Source: MIRA-S (De Vlieger et al., 2009).

Next the total Belgian energy consumption, fuel consumption and emissions are computed by applying respectively the energy consumption, fuel consumption and emission factors and supplements per year and per CEMT class to the corresponding acquired annual tonne kilometres per waterway. Below, the formulas for calculating the total energy consumption are elaborated. First, the energy consumption of the propulsion engines of loaded vessels is calculated for each waterway.

$$E_{y,l=1,w} = ECF_{y,l=1,cemt} \times tkm_{y,w}$$

Having

$E_{y,l=1}$ = total energy consumption of the propulsion engines of loaded vessels ($l = 1$) on waterway w in year y

$ECF_{y,l=1,cemt}$ = energy consumption factor for loaded vessels ($l = 1$) in year y on a waterway with CEMT class $cemt$

$tkm_{y,w}$ = tonne kilometres travelled by loaded vessels ($l = 1$) in year y on waterway w

Subsequently, the energy consumption of the propulsion engines of unloaded vessels is determined for each waterway.

$$E_{y,l=0,w} = ECS_{y,l=0,cemt} \times E_{y,l=1,w}$$

Having

$E_{y,l=0}$ = total energy consumption of the propulsion engines of unloaded vessels ($l = 0$) on waterway w in year y

$ECS_{y,l=0,cemt}$ = energy consumption supplement for unloaded vessels ($l = 0$) in year y on a waterway with CEMT class $cemt$

$E_{y,l=1}$ = total energy consumption of the propulsion engines of loaded vessels ($l = 1$) on waterway w in year y, as calculated in the previous step

Then the energy consumption of auxiliary engines for both loaded and unloaded vessels are derived for each waterway.

$$E_{y,aux,w} = ECS_{y,aux} \times (E_{y,l=1,w} + E_{y,l=0,w})$$

Having

$E_{y,aux,w}$ = total energy consumption of the auxiliary engines of both loaded and unloaded vessels on waterway w in year y

$ECS_{y,aux}$ = energy consumption supplement for auxiliary engines in year y

$E_{y,l=1}$ = total energy consumption of the propulsion engines of loaded vessels ($l = 1$) on waterway w in year y, as calculated in previously

$E_{y,l=0}$ = total energy consumption of the propulsion engines of unloaded vessels ($l = 0$) on waterway w in year y, as calculated in the previous step

The total annual energy consumption on a waterway now equals the sum of these three components:

$$E_{y,t,w} = E_{y,l=1,w} + E_{y,l=0,w} + E_{y,aux,w}$$

Having

$E_{y,t,w}$	=	total energy consumption of all engines and all vessels in year y on waterway w
$E_{y,l=1}$	=	total energy consumption of the propulsion engines of loaded vessels ($l = 1$) on waterway w in year y, as calculated in previously
$E_{y,l=0}$	=	total energy consumption of the propulsion engines of unloaded vessels ($l = 0$) on waterway w in year y, as calculated in the previous step
$E_{y,aux,w}$	=	total energy consumption of the auxiliary engines of both loaded and unloaded vessels on waterway w in year y

Summing the total annual energy consumptions over all waterways in Belgium and dividing this result by the total number of tonne kilometres travelled on waterways in Belgium, results in yearly weighted fleet energy consumption factors. The method can be applied to calculate the yearly weighted fleet fuel consumption and emission factors likewise.

5. Geographical distribution

The emissions caused by inland navigation can be distributed geographically, founded on the annual emissions per waterway. These emissions are spread evenly over the whole length of waterways, as no detailed data on the activities per waterway section are available.

6. Results

The development of this module to calculate the weighted fleet energy consumption, fuel consumption and emission factors for inland navigation has reached its final phase, and only requires validation within the follow-up project PROLIBIC (BELSPO project called Cluster of the transport related projects PROMOCO, LIMOBEL, BIOSES and CLEVER). The results of this module are expected in spring 2011.

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Annex 1: E-motion – Part IV

Maritime transport

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List of abbreviations

AIS	Automatic Identification System
As	Arsenic
Cd	Cadmium
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
Cr	Chromium
Cu	Copper
DWT	Deadweight
ECF	Energy consumption factor
EF	Emission factor
EMMOSS	Emissiemodel voor spoorverkeer en scheepvaart in Vlaanderen
E-motion	Energy- and emission MOdel for Transport with geographical distributION
Ex-TREMIS	Exploring non road Transport Emissions in Europe: Development of a Reference System on Emissions Factors for Rail, Maritime and Air Transport
Hg	Mercury
HM	Heavy Metals
IPCC	Intergovernmental Panel on Climate Change
kW	Kilowatt
kWh	Kilowatt-hour
LNG	Liquefied Natural gas
MCR	Maximum Continuous Rate
MET	Main engine type
MOPSEA	Monitoring Programme on air polution from SEA-going vessels
N_2O	Nitrous oxide (laughing gas)
NH_3	Ammonia
Ni	Nickel
NMVOC	Non Methane Volatile Organic Compounds
NO_X	Nitrogen oxides
PAH	Polycyclic Aromatic Hydrocarbon
Pb	Lead
PJ	Petajoule
PM	Particulate Matter
PM_1	Particulate matter with an aerodynamic diameter of less than 1 µm
PM_{10}	Particulate matter with an aerodynamic diameter of less than 10 µm
$PM_{2.5}$	Particulate matter with an aerodynamic diameter of less than 2.5 µm
RoRo	Roll-on/Roll-off
Se	Selenium
SO_2	Sulphur dioxide
UNCTAD	United Nations Conference on Trade and Development
VLIZ	Flanders Marine Institute (Vlaams Instituut voor de Zee)
VOC	Volatile Organic Compounds
Zn	Zinc

1. Introduction

E-motion is the acronym for 'Energy- and emission MOdel for Transport with geographical distributION'. This environmental impact assessment model calculates and geographically distributes energy consumption and emissions from road transport, rail traffic, inland navigation, maritime transport and off-road transport for Flanders, the Walloon provinces and the Brussels region. Not only inventory studies, but also scenario's can be calculated with E-motion. Future technologies are presented in all models.

This annex gives an overall description of the function and input/output parameters of the Maritime model (E-Motion Mari).

Figure 1 gives an overview of the input and output parameters of the E-motion maritime model.

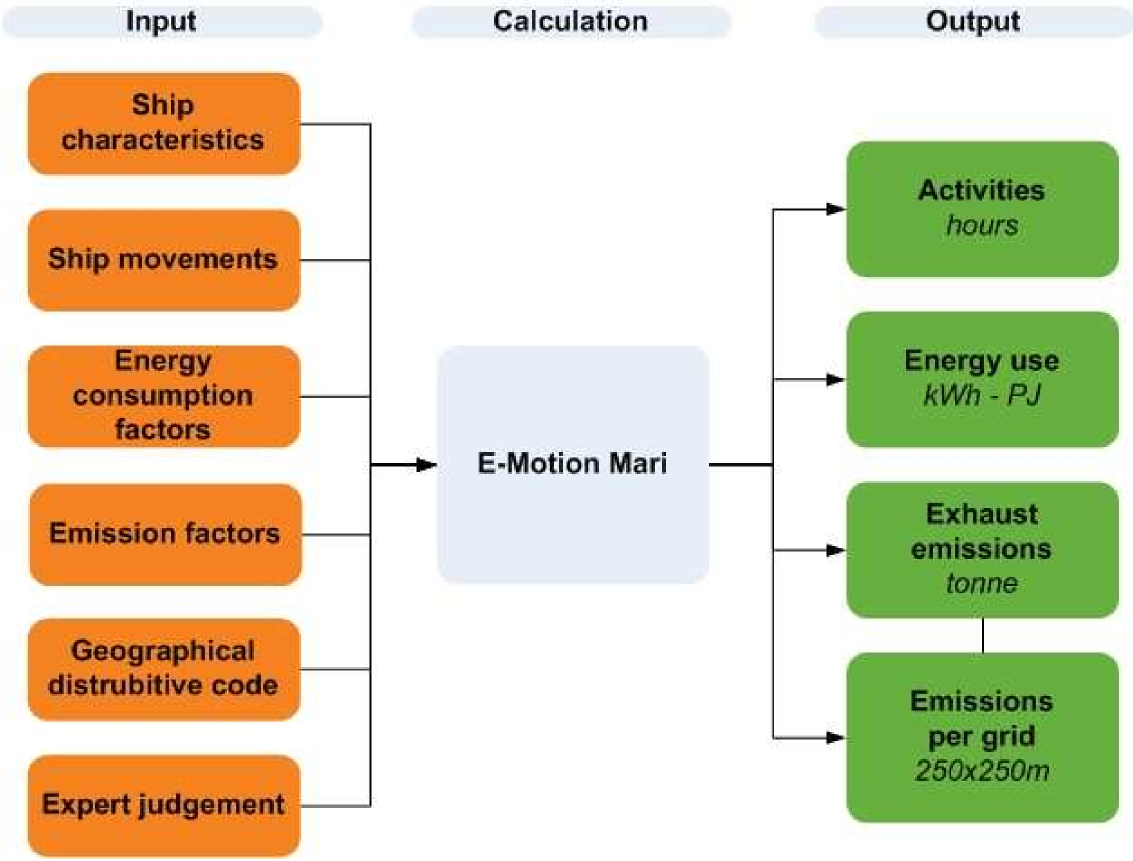

Figure 1: Input and output parameters of the E-motion Mari

The calculation of emissions and energy consumption for maritime transport within E-Motion is implanted on the methodology of MOPSEA (Gommers et al., 2007) and Ex-TREMIS (Chiffi et al., 2008).

The model is built upon three modules: the *fleet module* which defines the vessel categories and their segmentation, the transport *activity module* which calculates the vessel movements and hours of navigation for the different stages, the *emission module* which provides energy consumption and emission factors for the final calculation to come up with total energy consumption and emission figures as output.

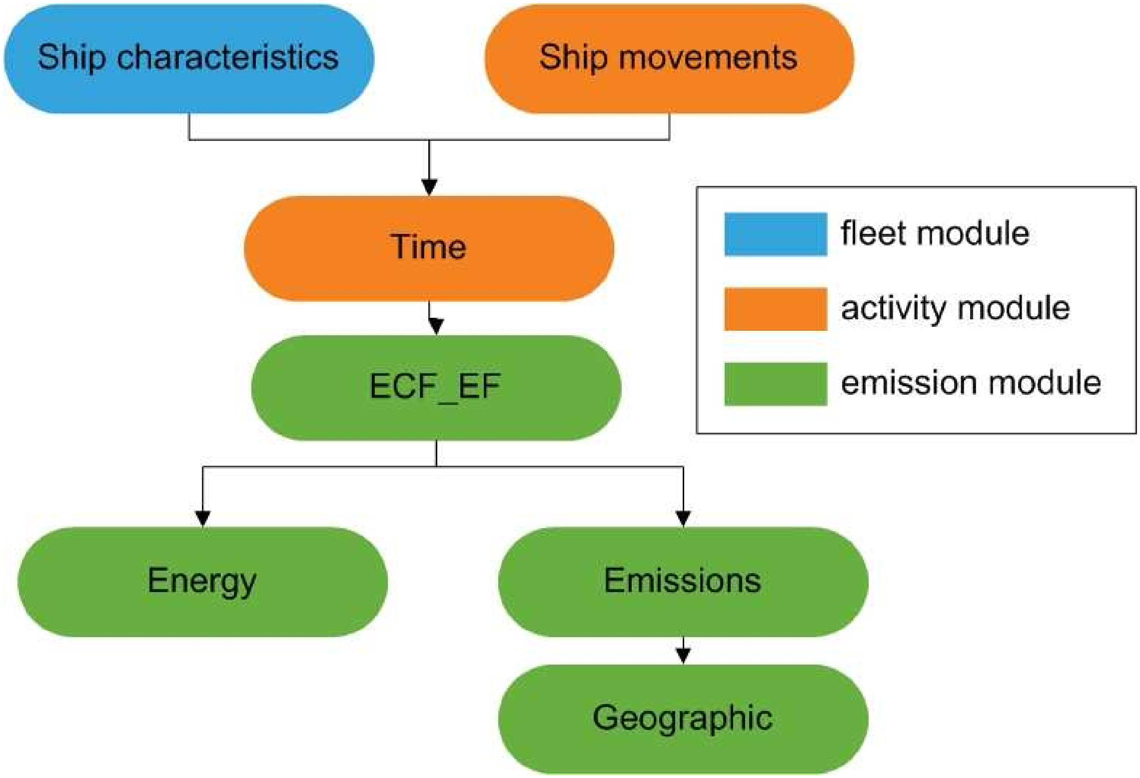

Figure 2: Relationship between the three modules in the maritime model

First, we will describe how we define the vessel fleet and the vessel movements for historical and future years. Second, we will list the sources used to provide the maritime model with technology dependent energy consumption and emission factors. Third, we will resume all possible outcomes of the model. Final, we will demonstrate the geographical tool for the Belgian Continental Shelf and the Dutch part of the river Scheldt.

2. Fleet module

The vessel fleet is subdivided according to 10 vessel types, 5 length classes, 3 main engine types, 4 fuel types and 12 technology classes. Average engine powers per ship type and ship length are included in the fleet module, as well as average dead-weights (DWT).

2.1. Vessel types

Sea-going vessels are divided into 10 different vessel types:
- chemical tanker;
- container vessel;
- dry bulk carrier;
- gas tanker;
- general cargo vessel;
- LNG tanker;
- crude oil tanker;
- passenger ship;
- reefer;
- RoRo vessel.

The same classification is used as in the MOPSEA project. The corresponding vessel types between IHS Fairplay (former Lloyd's Register Fairplay) database and E-motion is presented in Table 1.

2.2. Length classes

The duration of the navigation phases in harbours mainly depends on the length of the vessels; therefore we made a classification according to their length instead of their gross tonnage. 5 different length classes are included in the maritime model:
- < 100 m;
- 100 – 150 m;
- 150 – 200 m;
- 200 – 250 m;
- > 250 m.

Lloyd's Register Fairplay		E-motion
MAIN TYPE	**SUB TYPE**	
BULK CARRIERS	Aggregates Carrier	Dry bulk carrier
	Bulk Carrier	Dry bulk carrier
	Bulk/Oil Carrier	Dry bulk carrier
	Cement Carrier	Dry bulk carrier
	Limestone Carrier	Dry bulk carrier
	Ore Carrier	Dry bulk carrier
	Ore/Oil Carrier	Dry bulk carrier
	Refined Sugar Carrier	Dry bulk carrier
	Self-Discharging Bulk Carrier	Dry bulk carrier
	Wood Chips Carrier	Dry bulk carrier
DRY CARGO/PASSENGER	Barge Carrier	General Cargo
	Container Ro-Ro Cargo Ship	Containers
	Container Ship	Containers
	Deck Cargo Ship	General Cargo
	General Cargo Ship	General Cargo
	Heavy Load Carrier	General Cargo
	Livestock Carrier	General Cargo
	Nuclear Fuel Carrier	General Cargo
	Palletised Cargo Ship	General Cargo
	Passenger (Cruise) Ship	Passenger ship
	Passenger Ship	Passenger ship
	Passenger/General Cargo Ship	Passenger ship
	Passenger/Ro-Ro Cargo Ship	Passenger ship
	Refrigerated Cargo Ship	Reefers
	Ro-Ro Cargo Ship	RoRo
	Stone Carrier	General Cargo
	Vehicles Carrier	RoRo
TANKERS	Bitumen Tanker	Chemical tanker
	Chemical Tanker	Chemical tanker
	Chemical/Oil Products Tanker	Chemical tanker
	Crude Oil Tanker	Oil bulk (crude)
	Edible Oil Tanker	Chemical tanker
	Fruit Juice Tanker	Chemical tanker
	LNG Tanker	LNG tanker
	LPG Tanker	Gas tanker
	Molasses Tanker	Chemical tanker
	Oil Products Tanker	Oil bulk (crude)
	Vegetable Oil Tanker	Chemical tanker
	Wine Tanker	Chemical tanker

Table 1: Corresponding vessel types

2.3. Main engine type

The main engine type of a marine vessel in the model is a 2-stroke or 4-stroke engine, except for LNG tankers. The model includes steam turbines as main engine for LNG tankers. These engines are not really energy efficient in comparison with 2-stroke and

4-stroke engines. But LNG tankers dispose of free gas boil off of methane that can be used as fuel for a steam turbine.

The share of different main engine types per ship type and length class are taken from MOPSEA (Gommers et al., 2007).

2.4. Fuel type

The maritime model includes 4 different fuel types:

- heavy fuel oil;
- diesel oil;
- gas oil;
- gas boil off.

Until the beginning of the eighties, the majority of the main engines used diesel oil as fuel type for manoeuvring activities. Improvements in technology (manoeuvrability) enabled building at the end of the eighties main engines using heavy fuel oil. The fuel type used by 2-stroke and 4-stroke engines in harbours and on the river Scheldt is therefore dependent on the technology class of the vessel. Vessels built before 1985 use diesel oil in the E-motion maritime model, whereas vessels built after 1985 use heavy fuel oil. The fuel type used in the Belgian Continental Shelf is heavy fuel oil. LNG tankers use gas boil off as fuel for their steam turbines.

Until the beginning of the eighties, the majority of the auxiliaries in marine vessels used diesel oil as fuel type. Improvements in technology made it possible for auxiliaries built at the end of the eighties to use heavy fuel oil. The fuel type used by auxiliaries in the maritime model depends on the technology class of the vessel. Vessels built before 1998 use diesel oil, vessel built after 1985 use heavy fuel oil. The MARPOL Annex IV directive imposes the use of 0.1m% sulphur from January 1ste 2010 for sea-going vessels at berth with a minimum duration of 2 hours. Therefore, the model takes diesel oil as fuel type for auxiliaries at berth from 2010 on.

2.5. Technology class

The vessel’s build year is an important parameter in the methodology for calculating emissions and energy consumption figures. The age of the engines is for most vessels the same as the age of the vessel. 12 different technology classes are defined in the E-motion maritime model:

- < 1975;
- 1975 - 1979;
- 1980 - 1984;
- 1985 – 1989;
- 1990 – 1994;
- 1995 – 1999;
- 2000 – 2004;
- 2005 – 2009;
- 2010 – 2014;
- 2015 – 2019;
- 2020 – 2024;
- > 2025.

The source used to divide the historical fleet into different technology classes are the tables on *"Age distribution of the world merchant fleet by types of vessel"* published by the UNCTAD secretariat in its *Review of maritime Transport* (website UNCTAD, 2010). We keep the relative distribution of ages from the last historical year constant for future years.

2.6. Power of the engines

The power of the engines – per ship type and length class - is taken from the EMMOSS model (Vanherle et al., 2007). Figures are presented in Table 2.

kW	<100m	100-150m	150-200m	200-250m	>250m
Main engines					
Chemical tanker	2047	3788	7546	11897	15084
Containers	2686	5802	13500	21251	35195
Dry bulk carrier	2403	4307	7342	10243	15431
Gas tanker	3842	6895	13866	24476	43759
General Cargo	1497	3340	8047	12966	33847
LNG tanker					30000
Oil bulk (crude)	1825	3514	7437	12105	14994
Passenger ship	1518	7954	14481	21431	31353
Reefers	3898	9063	13891	36424	86627
RoRo	3809	6188	19562	22267	28332
Auxiliaries					
Chemical tanker	409	758	1509	2379	3017
Containers	537	1160	2700	4250	7039
Dry bulk carrier	481	861	1468	2049	3086
Gas tanker	768	1379	2773	4895	8752
General Cargo	299	668	1609	2593	7749
LNG tanker					6000
Oil bulk (crude)	365	703	1487	2421	2999
Passenger ship	683	3579	6516	9644	14109
Reefers	780	1813	2778	7285	17325
RoRo	762	1238	3912	4453	5666

Table 2: Average power (main engine and auxiliaries) per ship type and length class (Vanherle et al., 2007)

The power needed from the auxiliaries during navigation for air conditioning, ventilation, preheating of heavy fuel, ... is dependent of ship type and length class and ranges between 250 and 500 kW (Gommers et al., 2007).

2.7. DWT of the vessels

The DWT of the vessels is calculated from the power of the main engines (Endersen & Sørgård, 1999). The figures used in the E-motion maritime model are presented in Table 3.

DWT	<100m	100-150m	150-200m	200-250m	>250m
Chemical tanker	3443	10334	35380	79768	121870
Containers	3197	7829	20902	35425	63691
Dry bulk carrier	3645	11711	34030	66235	150322
Gas tanker	5884	13904	38847	89594	210548
General Cargo	2338	7018	23408	44994	167493
LNG tanker					65223
Oil bulk (crude)	2805	9038	34472	82275	120575
Passenger ship	98	1116	2685	4768	8328
Reefers	4239	10502	16623	46867	118974
RoRo	2553	4795	21379	25295	34586

Table 3: Average DWT per ship type and length class in the maritime model

3. Activity module

The fleet module is linked to the amount of vessel movement combined with durations of different navigation phases. Different figures are used per ship type and length class.

3.1. Vessel movements

Harbours

The number of vessel movements per vessel type, length class and type of movement (harbour specific) is provided by the harbours themselves for several statistical years. The different type of movements required to complete all vessel movements are extracted from the detailed dataset of the harbours received for the MOPSEA project (Gommers et al., 2007).

For the harbour of Antwerp, we received data from 2000 on, for the harbour of Ghent from 2001 on, for the harbour of Ostend from 1998 on and for the harbour of Zeebrugge from 2003 on.

Extrapolation to 1990 is founded on statistics concerning freight and passenger traffic. Extrapolation up to 2030 is based on prognoses for freight and passenger traffic (Vanherle et al., 2007). The series of freight and passenger traffic is transformed into growth figures. We take into account the DWT of the vessels to be able to predict the amount of vessels required for transporting the freight and passenger traffic.

We will explain the extrapolation for future years, starting from the last historical year. The methodology for the extrapolation up to 1990 is similar. Yet, the starting point here is the first historical year with detailed vessel movement data (different for the 4 harbours).

The total DWT for the last historical year is calculated by combining - per ship type and length class - the amount of vessels and the DWT of the vessel. The amount of DWT for the next year is further calculated on the basis of the year specific growth figure and the total amount of DWT for the last historical year.

$$DWT_{y+1,s,l} = r_{y,y+1} \times DWT_{y,s,l}$$

With y = year
s = ship type
l = length class
r = growth rate

A correction on the total amount of DWT for the next year is performed if we want to take into account load improvements. The distribution of the total DWT (next year) over the different length classes is done by a distributive code. This code is based on the distribution of the length classes – per ship type – in the preceding year, and the predicted change in vessel sizes (assumption). In a last step, we transform the amount of DWT per ship type and length class back into amount of ships. These calculations are repeated until the fleet of 2030 is predicted.

Belgian Continental Shelf and Dutch part of the river Scheldt

Analysing AIS data - obtained for the year 2009 from Flanders Marine Institute (VLIZ) - enabled extraction of different shipping routes. The data obtained on the on hand static data (shipID, ship type and ship length) and on the other hand dynamic position data (shipID, longitude, latitude, time).
Future work includes linking the activities in the Belgian harbours with the defined shipping routes in the Belgian Continental Shelf and on the Dutch part of the river Scheldt. This linking can be done for all historical as well as for all future years.

3.2. Hours per navigation phase

Harbours

Detailed activity data – expressed in hours - per vessel type, length class and movement (region specific) are extracted from the MOPSEA model (Gommers et al., 2007), as well as the technological aspects of the different navigation phases (load factor) per specific movement. As mentioned in section 4, the load factor has an important influence on the energy consumption and emission factors.

Belgian Continental Shelf and Dutch part of the River Scheldt

The AIS data for the year 2009 are also analysed to enable attributing navigation hours to the different shipping routes. Average anchoring times (buoy A1) are extracted as well from the database. The load factor used for the different navigation phases in the Belgian Continental Shelf are taken from the MOPSEA model (Gommers et al., 2007). Those for the navigation phases on the Dutch part of the river Scheldt are assumed to equal those used for the Belgian part of the river Scheldt in the harbour of Antwerp.

4. Sources for energy consumption and emission factors

The energy sources used for all vessel operations (navigation and (un)loading) are presented in Table 4. Energy consumption factors for the different fuels are expressed in “g/kWh”. They take into account the engine type, the technology class of the engine, the load factor and/or the used fuel.

Engine	Energy sources
Main engine	Heavy fuel oil, diesel oil, gas boil off
Auxiliary	Heavy fuel oil, diesel oil, gas boil off
Onshore	Electricity

Table 4: Energy sources maritime vessels

Emission factors for different pollutants (Table 5) are recorded in the E-motion maritime model. As for the energy consumption factors, the emission factors depend on the engine type, the technology class, the load factor of the engine and/or the used fuel.

Pollutant group	Pollutants
Technology related	CO, NO_X, VOC, CH_4, NMVOC
Fuel related	CO_2, SO_2, N_2O, NH_3
Particulate matter (PM)	PM_{10}, $PM_{2.5}$, PM_1
Heavy metals (HM)	As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn
Polycyclic Aromatic Hydrocarbon (PAH)	naftaleen, antraceen, fenantreen, fluoranteen, pyreen, benz(a)antraceen, chryseen, benz(b)fluoranteen, benz(k)fluoranteen, benz(a)pyreen, indeno(1,2,3-cd)-pyreen, benz(ghi)peryleen, acenafteen, acenaftyleen, fluoreen, di-benzo(ah)anthracene

Table 5: Different pollutant in the E-motion maritime model

Table 6 and Table 7 give an overview of the used sources to include detailed energy consumption and emission factors of respectively main engines and auxiliaries in the maritime model of E-motion.

Main engines		
2-stroke, 4-stroke		
ECF		Inventory and forecasting of maritime emissions in the Belgian sea territory, an activity-based emission model. (Schrooten et al., 2008)
Technology_EF	NO_x, CO, VOC	Emissieregistratie en –Monitoring Scheepvaart. (MVW, 2003)
	CH_4, NMVOC	Methoden voor de berekening van de emissies door mobiele bronnen in Nederland. (Klein et al., 2007)
Fuel_EF	CO_2	Greenhouse gas inventory reference manual. (IPCC, 1997)
	SO_2	MARPOL Annex VI convention, 2005/33/EC Directive
	N_2O, NH_3	Methoden voor de berekening van de emissies door mobiele bronnen in Nederland. (Klein et al., 2007)
PM_EF		Assessment of emissions of PM and NO_x of sea-going vessels by field measurements. (Duyzer et al., 2006)
HM_EF		EMEP/CORINAIR Emission Inventory Guidebook. (EMEP/CORINAIR, 2007)
PAH_EF		Methoden voor de berekening van de emissies door mobiele bronnen in Nederland. (Klein et al., 2007)
Steam turbine (gas boil off)		
ECF		Inventory and forecasting of maritime emissions in the Belgian sea territory, an activity-based emission model. (Schrooten et al., 2008)
Technology_EF	NO_x, CO, VOC	Uittreksel van de interne TNO-handleiding voor het vaststellen van verbrandingsemissies. (Scheffer & Jonker, 1997)
	CH_4, NMVOC	Evaluatie van de inschatting van NMVOS-emissies door verbrandingsprocessen in Vlaanderen. (Lodewijks et al., 2005)
Fuel_EF	CO_2	Greenhouse gas inventory reference manual. (IPCC, 1997)
	SO_2	MARPOL Annex VI convention, 2005/33/EC Directive
	N_2O, NH_3	Assumption:= 0 (only a very small number of vessels)
PM_EF		Inventory and forecasting of maritime emissions in the Belgian sea territory, an activity-based emission model. (Schrooten et al., 2008)
HM_EF		Assumption:= 0 (only a very small number of vessels)
PAH_EF		Assumption:= 0 (only a very small number of vessels)

Table 6: Sources used for the energy consumption and emission factors of main engines

Auxiliaries		
ECF		Emissiefactoren voor de binnenscheepvaart. (Oonk et al., 2003)
Technology_EF	NO_x, CO, VOC	Emissieregistratie en –Monitoring Scheepvaart. (MVW, 2003)
	CH_4, NMVOC	Methoden voor de berekening van de emissies door mobiele bronnen in Nederland. (Klein et al., 2007)
Fuel_EF	CO_2	Greenhouse gas inventory reference manual. (IPCC, 1997)
	SO_2	MARPOL Annex VI convention, 2005/33/EC Directive
	N_2O, NH_3	Methoden voor de berekening van de emissies door mobiele bronnen in Nederland. (Klein et al., 2007)
PM_EF		Emissieregistratie en –Monitoring Scheepvaart. (MVW, 2003)
HM_EF		EMEP/CORINAIR Emission Inventory Guidebook. (EMEP/CORINAIR, 2007)
PAH_EF		Methoden voor de berekening van de emissies door mobiele bronnen in Nederland. (Klein et al., 2007)

Table 7: Sources used for the energy consumption and emission factors of auxiliaries

5. Output

5.1. Energy use

The calculation of the energy uses is divided into 4 parts:

- energy use main engines;
- energy use auxiliaries for hotelling (Endersen & Sørgård, 1999);
- energy use auxiliaries for (un)loading;
- onshore energy use.

Energy use main engines

We take into account the main engine power, the engine load (MCR), engine type and technology class to calculate the energy use of the main engines. The equation for the calculation of the energy use of main engines is given below:

$$E_{ME} = \sum P_{ME_{v,m}} \times n_{v,m} \times h_{v,m,l} \times MCR_{v,m,l} \times p_{e,v,m} \times p_{t,v}$$

With E = energy consumption (kWh)
ME = main engine
P = power (kW)
v = vessel type
n= amount
m = length class
l = navigation phase
h = hours (h)
MCR = engine load
p = share
e = engine type
t = technology class

Energy use auxiliaries for hotelling

We take into account the power needed from the auxiliaries for air conditioning, ventilation, preheating of heavy fuel oil, ... and the technology class of the engine. The equation for the calculation of the energy use of auxiliaries for hotelling is given below:

$$E_{AH} = \sum P_{AH_v} \times n_v \times h_v \times p_{t,v}$$

With E = energy consumption (kWh)
A = auxiliaries
H = hotelling
P = power (kW)
v = vessel type
n = amount
h = hours (h)
t = technology class
p = share

Energy use auxiliaries for (un)loading

Activity data needed for the calculation of the energy used from auxiliaries for loading and unloading activities are the hours at berth. Further input variables are the power of the auxiliaries, the load factor and the technology class of the engines. The equation for the calculation of the energy use of auxiliaries for loading and unloading activities is given below:

$$E_{AL} = \sum P_{A_{v,m}} \times p_{P_{AL_{v,m}}} \times (1 - p_{onshore_{v,m}}) \times n_{v,m} \times h_{v,m} \times p_{t,n}$$

With E = energy consumption (kWh)
A = auxiliaries
L = (un)loading
P = power (kW)
v = vessel type
m = length class
p = share
n = amount
h = hours (h)
t = technology class

Onshore energy use

Onshore energy use for loading and unloading activities is equal to the part of energy needed for loading and unloading activities and not generated by the auxiliaries of the vessels. The equation for the calculation of the onshore energy use for loading and unloading activities is given below:

$$E_{O=} \sum P_{A_{v,m}} \times p_{P_{AL_{v,m}}} \times p_{onshore_{v,m}} \times n_{v,m} \times h_{v,m} \times p_{t,n}$$

With E = energy consumption (kWh)
A = auxiliaries
O = onshore
L = (un)loading
v = vessel type
m = length class
p = share
n = amount
h = hours (h)
t = technology class

5.2. Fuel use

The calculation of the fuel uses is divided into 2 parts:

- fuel use main engines;
- fuel use auxiliaries.

Fuel uses of the vessel’s engines are calculated by combining the energy use and the corresponding energy consumption factor.

Fuel use main engines

The energy consumption factors for the main engines are specific for each combination of engine type, engine load condition and technology class.

$$FC_{ME} = \sum E_{ME_{k,t,g}} \times FCF_{k,t,g}/1000000$$

With FC = fuel consumption (tonne)
ME = main engine
E = energy consumption (kWh)
k = engine type
t = technology class
g = load factor
FCF = fuel consumption factor (g/kWh)

Fuel use auxiliaries

The energy consumption factors for auxiliaries are technology class and fuel type specific.

$$FC_{A} = \sum E_{A_{t,f}} \times FCF_{t,f}/1000000$$

With FC = fuel consumption (tonne)
A = auxiliaries
E = energy consumption (kWh)
t = technology class
f = fuel type
FCF = fuel consumption factor (g/kWh)

5.3. Emissions

The calculation of the emissions is divided into 2 parts:

- emissions main engines;
- emissions auxiliaries.

Exhaust emissions of the vessel's engines can be calculated by combining the energy use and the corresponding emission factor.

Emissions main engines

$$EM_{ME} = \sum E_{ME} \times EF/1000000$$

With EM= emission (tonne)
ME = main engine
E = energy consumption (kWh)
EF = emission factor (g/kWh)

Emission factors for NO_X, CO, VOC, CH_4 and NMVOC are defined per engine type, engine load and technology class. The MARPOL Annex VI legislation impacts the NO_X

emission factor for engines from 2000 on. The SO_2 emission factor depends on the sulphur content of the fuels (Table 8).

m% sulphur	< 2006	2007 - 2009	> 2010
Diesel oil	0.2	0.2	0.1
Heavy fuel oil	2.7	1.5	1.5
Gas boil off	0	0	0

Table 8: Sulphur content in marine fuels (baseline scenario)

PM emission factors (PM_{10}, $PM_{2.5}$ and PM_1) are dependent of the sulphur content in the fuel and the type of engine. CO_2, N_2O, NH_3, heavy metal and polycyclic aromatic hydrocarbon emission factors are all fuel type dependent. The IPCC CO_2 emission factors used here for marine fuels are presented in Table 9.

Fuel type	CO_2 (kg/ton fuel)
Diesel oil	3100
Heavy fuel oil	3110
Gas boil off	2930

Table 9: IPCC (IPCC, 1997) CO_2 emission factors for marine fuels

Emissions auxiliaries

$$EM_A = \sum E_A \times EF/1000000$$

With EM= emission (tonne)
A = auxiliaries
E = energy consumption (kWh)
EF = emission factor (g/kWh)

The emission factors for auxiliaries used in E-motion are fuel type specific for all pollutants. The NO_X, CO, VOC, CH_4, NMVOC and PM emission factors depend on the technology class.

6. Geographical distribution

6.1. Harbours

For the 4 harbours, a geographical distributive code for different polygons (Table 10, Figure 3, Figure 4 and Figure 5) is defined based on the detailed MOPSEA data (Gommers et al., 2007) for the year 2004. The emissions are further distributed on a 250x250m grid.

Harbour	Amount of polygons
Antwerp	17
Zeebrugge	3
Ghent	16
Ostend	1

Table 10: Amount of polygons per harbour

The level of detail per polygon for the geographical distributive code is:

- vessel type;
- length class;
- navigation phase.

The geographical distributive code for the harbour of Antwerp is different for the period 1990-2005 and the period 2006-2030 because of the use of the Deurganckdock in the last period. From 2006 on, we split the emissions of the container vessels in the harbour of Antwerp and attribute 20% to the Deurganckdock (TM Leuven, 2010).

Figure 3: The geographical definition of the 17 polygons in the harbour of Antwerp

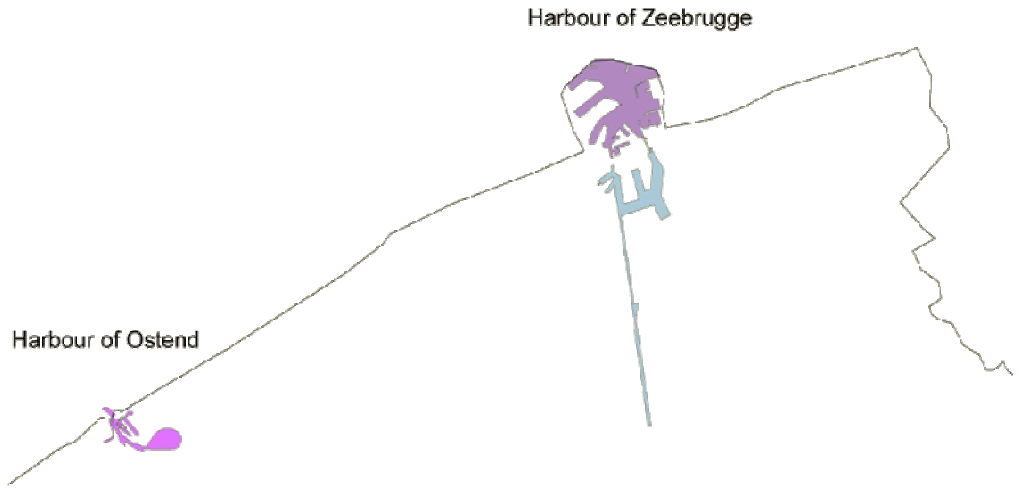

Figure 4: The geographical definition of the 3 polygons in the harbour of Zeebrugge and 1 polygon on the harbour of Ostend

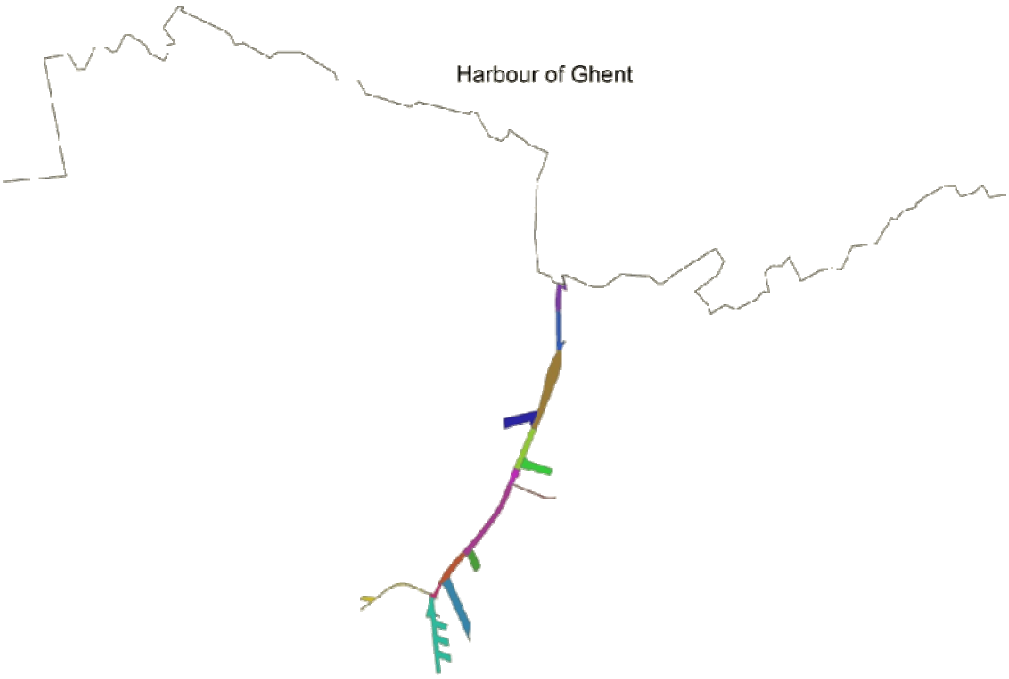

Figure 5: The geographical definition of the 16 polygons in the harbour of Ghent

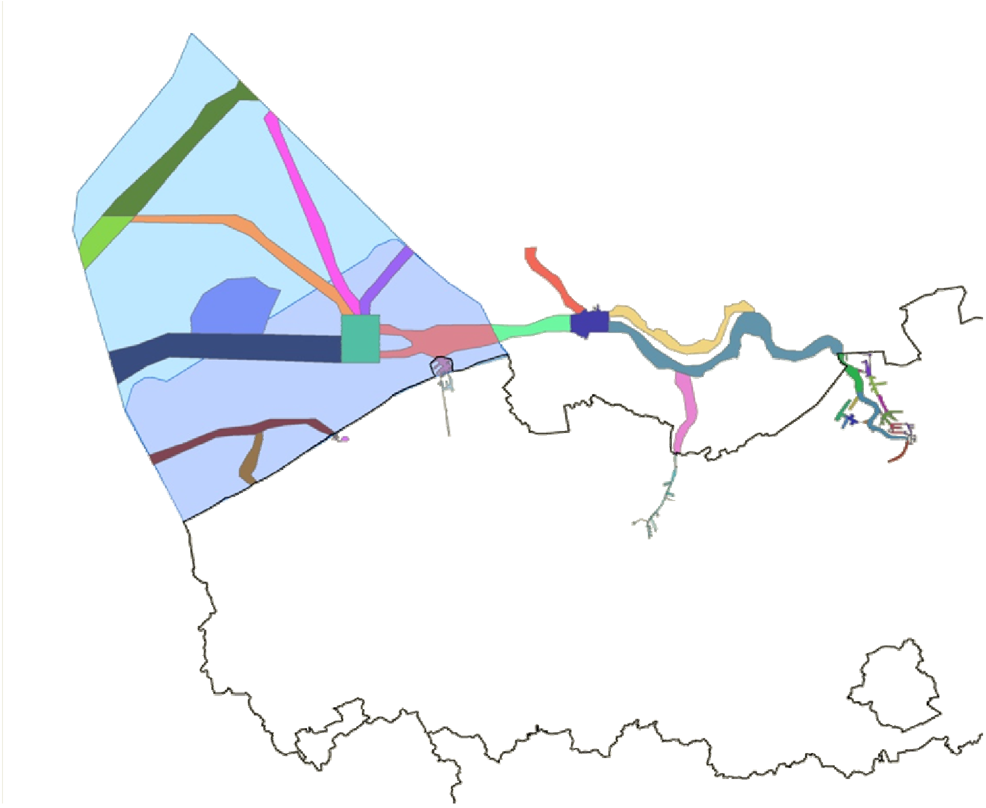

Figure 6: The geographical definition of the different polygons in the Belgian Continental Shelf and the Dutch part of the river Scheldt

6.1. Belgian Continental Shelf and Dutch part of the river Scheldt

Shipping routes are defined for the Belgian Continental Shelf and the Dutch part of the river Scheldt founded on AIS data for the year 2009 (Figure 6).

The geographical distributive code is also extracted from the AIS dataset for the year 2009 within the Belspo project SHIPFLUX (website Belspo, 2011). As for the harbours, this code is specific for vessel type, length class and navigation phase and further distributed on a 250x250m grid.

7. Results

The methodological development of the E-motion maritime model has reached its final phase. Yet, the link between vessel movements in the harbour and those in the Belgian Continental Shelf and in the Dutch part of the river Scheldt needs to be established to be able to compute energy consumption figures and emissions for the entire period 1990-2030. Further, figures on energy demand of auxiliaries for loading and unloading activities needs to be investigated.

A rough validation of the model has already been performed, but a detailed validation is still required.

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Annex 1: E-motion – Part V

Indirect emissions: emissions during the production and transport of energy carriers

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List of abbreviations

BIOSES	Project on sustainable bio fuel use in Belgium
CH_4	Methane
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2-eq	CO_2 equivalents
EU	European Union
FT-diesel	Fischer-trosch (synthetic) diesel
g	Gramme
GHG	Green house gases
HFO	Heavy fuel oil
JEC	Joint Research Centre EC, EUCAR and CONCAWE
LNE	Department Leefmilieu, Natuur en Energie of the Flemish Government
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MJ	Mega Joule
N_2O	Nitrous oxide (laughing gas)
NMVOC	Non-methane volatile organic compounds
NO_x	Nitrogen oxides
PM	Particulate matter
PM_{10}	Particulate matter with an aerodynamic diameter of less than 10 µm
SO_2	Sulphur dioxide
SUSATRANS	Sustainability assessment of technologies and modes in the transport sector in Belgium (De Vlieger, et.al., 2005)

1. Introduction

Emissions released during the production and transport of the different energy carriers are also referred to as indirect emissions. Vito updated these emissions within the BIOSES project (Pelkmans et al., 2011). This part is an extract of the section on "Indirect emissions" of the report on task 4.3 within BIOSES and resumes the assumptions and results. To quantify these indirect emissions, the energy consumption of road vehicles, trains and vessels (MJ per energy carrier) is multiplied by specific emission factors per energy carrier (g/MJ). In this section we amplify on our choices on indirect emission factors. Pollutants involved are CO_2-equivalents (CO_2, CH_4, N_2O), NO_x, PM, NMVOC and SO_2. We also aspire considering a variation of the indirect emission factors over time with a time horizon up to 2030.

2. Calculation

2.1. Conventional fuels

Conventional fuels include diesel, petrol, gasoil, kerosene, heavy fuel oil (HFO) and LPG.

For greenhouse gas (GHG) emissions released during the production and transportation of conventional fuels we assume the "best estimate value" (in CO_2-eq/MJ) - as reported by JEC (2008) - as a starting point for the year 2008.

For conventional fuels we expect an increase of the emission factors for indirect emissions. The epoch of easy accessible and cheap crude oil is finishing. In addition, it becomes more and more difficult for the production to follow the demand. Therefore, more unconventional and hardly reachable sources of oil have to be exploited, such as crude oil of the polar region, ultra-heavy crude, tar sand (Canada) and synthetic fuels from natural gas and coal. We presume the "maximum value" of JEC (2008) to be realistic for 2020 and extrapolate the evolution between 2008 and 2020 to estimate emission factors for 2030.

Indirect emission factors for NO_x, PM_{10} and SO_2 of conventional fuels are based on den Boer et al. (2008). These emission factors decrease over the years due to more stringent National Emission Ceilings (NEC) in 2020. Beyond 2020 we assume the emission factors to remain constant at the level 2020.

For NMVOC neither JEC (2008) nor den Boer et al. (2008) report indirect emission factors, so we decide to lean on our previous study SUSATRANS (De Vlieger et al., 2005). For LPG we depart from SUSATRANS for indirect emissions of NO_x, PM_{10} and SO_2 too.

Table 1 presents an overview of the evolution of the emission factors related to the production and transport of energy carriers. Beside the conventional fuels also alternative energy carriers are shown, as discussed in the next paragraphs.

2.2. Biodiesel

Based on the results of work packet 2 of the BIOSES project we assumed biodiesel used in Belgium is made of rapes, soya beans and waste cooking oil, each having a certain fraction of the market (Boureima et al., 2009; Turcksin et al., 2010).

For biodiesel from rape and soya bean indirect emission factors for GHG are taken from JEC (2008). The "best estimate value" is assumed to be valid for 2010. We expect emissions to still have a potential to decrease due to e.g. more efficient and cleaner tractors and transport and further optimisation of the production process of biodiesel. For biodiesel produced from rapes (EU) we assume the "minimum value" of JEC (2008) to be representative for 2020 and 2030. For biodiesel from soya beans (Brazil, Argentina) the “minimum value” reported in JEC (2008) is assumed to be representative for the total production for the Belgian market by 2030. For the years between 2020 and 2030, the prognoses are linearly intrapolated. A small percentage (10%) of the biodiesel originate from waste cooking oil (Belgium). Here, the indirect emission factors from Boureima et al. (2009) and Turcksin et al. (2010) are applied, as no figures are given by JEC (2008) for biodiesel from waste cooking oil. Table 2 presents the contribution of each raw material in the biodiesel market in Belgium and the related GHG emission factors. Also the weighted emission factors are presented.

Energy carrier	Source	CO_2eq			NO_x			PM			NMVOC			SO_2		
		2010	2020	2030	2010	2020	2030	2010	2020	2030	2010	2020	2030	2010	2020	2030
diesel	crude oil	14.5	16.0	17.5	0.021	0.018	0.018	0.002	0.002	0.002	0.088	0.088	0.088	0.053	0.050	0.050
petrol	crude oil	12.9	14.6	16.4	0.026	0.022	0.022	0.003	0.003	0.003	0.211	0.211	0.211	0.063	0.059	0.059
LPG	crude oil	8.1	8.5	8.9	0.020	0.017	0.017	0.002	0.002	0.002	0.057	0.057	0.057	0.030	0.028	0.028
kerosene	crude oil	14.2	16.1	18.1	0.299	0.256	0.256	0.002	0.002	0.002	0.211	0.211	0.211	0.052	0.049	0.049
diesel oil	crude oil	11.5	12.7	13.9	0.017	0.014	0.014	0.002	0.002	0.002	0.088	0.088	0.088	0.043	0.040	0.040
HFO	crude oil	10.1	11.3	12.6	0.017	0.014	0.014	0.002	0.002	0.002	0.088	0.088	0.088	0.043	0.040	0.040
biodiesel	mix	44.6	35.3	32.8	0.143	0.090	0.036	0.033	0.021	0.008	0.018	0.018	0.018	0.080	0.050	0.020
FT-diesel	farmed wood		6.9	6.9	0.101	0.063	0.025	0.021	0.013	0.005	0.027	0.027	0.027	0.043	0.027	0.011
bio-ethanol	mix	40.8	33.9	27.0	0.178	0.111	0.044	0.192	0.120	0.048	0.023	0.023	0.023	0.087	0.054	0.022
CNG	natural gas	12.6	15.0	17.4	0.011	0.011	0.011	0.001	0.001	0.001	0.028	0.028	0.028	0.017	0.017	0.017
biogas	mix	20.5	18.6	16.7	0.022	0.014	0.005	0.005	0.003	0.001	0.005	0.005	0.005	0.012	0.008	0.003
electricity	mix	85.0	97.0	109.0	0.079	0.060	0.045	0.001	0.001	0.003	0.004	0.004	0.004	0.028	0.021	0.019
hydrogen	mix	112.8	139.0	126.1	0.078	0.084	0.090	0.003	0.005	0.007	0.039	0.111	0.183	0.020	0.022	0.023

Table 1: Evolution of emissions factors related to the production and transport of energy carriers for transport in Belgium (in g/MJ)

Biomass	Fraction	2010	2020	2030
Rape	0.7	41.6	31.9	31.9
Soya bean	0.2	72.8	60.5	48.1
Waste cooking oil	0.1	8.7	8.7	8.7
Weighted		***44.6***	***35.3***	***32.8***

Table 2: Emission factors for greenhouse gases related to the production and transport of biodiesel (in gCO_2eq/MJ)

Also the other emission factors to assess indirect emissions from biodiesel are based on Turcksin et al. (2010). Although for NO_x, PM_{10} and SO_2 we expect emission factors not to be constant during the period 2010-2030. We believe they will decrease with 75% by 2030 compared to 2010, see Table 1.

2.3. Synthetic diesel

We assumed that synthetic diesel is produced based on farmed wood through Biomass-To-Liquids pathway. The conversion exists of wood gasification followed by Fischer-Tropsch synthesis. For the indirect emission factor of GHG emissions the "best estimate value" as reported by JEC (2008) is applied. The other emission factors are based on Boureima et al. (2009) and Turcksin et al. (2010). For NO_x, PM_{10} and SO_2 the emission factors are assumed to decrease with 75% by 2030 compared to 2010, see Table 1.

2.4. Bio-ethanol

Rye/wheat, sugar beets and cane are forwarded as the basic materials for bio-ethanol for transport in Belgium (Boureima et al., 2009; Turcksin et al., 2010).

For bio-ethanol the indirect emission factors for GHG are taken from JEC (2008). For bio-ethanol produced from rye/wheat, two conversion processes are assumed to be effective. One includes a more conservative process, while the other one consists of a more sophisticated process where the energy for the ethanol plant is provided by a straw-fired Combined Heat and Power plant to provide the required heat. The "best estimate value" is assumed to be valid for 2010. Also in this case, the emissions are expected to still have a potential to decrease due to e.g. more efficient and cleaner tractors and transport and further optimisation of the production process of bio-ethanol. We presume the "minimum value" reported by JEC (2008) to be realistic for 2020, and extrapolate the 2010-2020 evolution up to 2030.
For bio-ethanol from sugar beets, the "best estimate value for a conventional process" for 2010 is applied. For 2030 we expect the slops by-product to be used as feedstock for biogas. For the years in-between we extrapolate between both values.

Emission factors for bio-ethanol from sugar cane also decrease, expecting that the surplus bagasse is used externally to generate heat by 2030, displacing fossil diesel. For both “best estimate values” reported by JEC (2008) are taken. Table 3 presents the contribution of each raw material in the bio-ethanol market in Belgium and the related GHG emission factors. Also the weighted emission factors are presented.

Biomass	Fraction	2010	2020	2030	Comment
Rye/wheat	0.35	61.2	53.7	46.2	Conventional process
	0.35	26.6	19.7	12.8	Energy by straw-fired CHP power plant
Sugar beet	0.2	38.1	31.6	25	
Sugar can	0.1	24.2	18.7	13.1	
Weighted		***40.8***	***33.9***	***27.0***	

Table 3: Emission factors for greenhouse gases related to the production and transport of bio-ethanol (in gCO_2eq/MJ)

For NO_x, PM_{10} and SO_2 the same approach is applied as for biodiesel: emission factors decrease with 75% by 2030 compared to 2010, see Table 3.

2.5. Natural gas

For CNG the production pathways as described by Hertveldt et al. (2009) are used. This methodology jis based on the IEA prospects for natural gas provisioning of the European Union (see Table 4).

	Supply (fraction)			gCO_2eq/MJ		
	2010	**2020**	**2030**	**2010**	**2020**	**2030**
CNG Europe	0.61	0.43	0.25	8.9	10.1	11.3
CNG piping	0.15	0.30	0.46	14.8	16.0	17.3
LNG	0.24	0.27	0.29	20.4	21.6	22.8
Weighted				***12.6***	***15.0***	***17.4***

Table 4: Contribution different production pathways for CNG and GHG emission factors related to the production and transport of CNG/LNG

For the GHG emissions related to the production and transport of CNG (LNE) the “best estimate value” from JEC (2008) is assumed to be applicable for the year 2008. The “maximum value” of JEC is put as representative for 2020. Prognoses for 2030 are generated by extrapolating the 2008-2020 evolution. This increase in emission factors is due to the reasons already mentioned in section 2.1 (Conventional fuels). Table 4 shows the indirect GHG emissions of CNG for 2010, 2020 and 2030.

For the other pollutants emission factors reported in SUSATRANS (De Vlieger.et al., 2005) are applied (see Table 1).

2.6. Biogas

In the current project, biogas as a possible energy carrier for transport in Belgium is assumed to be made from Belgian sewage sludge and Belgian manure. Indirect emissions are taken from Boureima et al. (2009). This is also the case for GHG emissions, as JEC figures (2008) seemed far too optimistic (for Belgium). Although a time evolution is introduced based on the best estimate and minimum value reported by JEC (2008), see **Error! Reference source not found.**. For the emission factors of he other pollutants we refer to Table 1.

	Fraction	2010	2020	2030
Sewage sludge	0.75	25.3	22.9	20.6
Liquid manure	0.25	6.2	5.6	5.0
Weighted		***20.5***	***18.6***	***16.7***

Table 5: Emission factors for greenhouse gases related to the production and transport of biogas (in CO_2eq/MJ)

2.7. Electricity

The emissions related to the production and transport of electricity are based on VITO's expertise on the Belgian and Flemish market. For GHG emissions figures for Belgium are generated (Lodewijks, 2010). For the other emissions figures are derived from the EURbis scenario defined in Flemish environmental prospect report 2030 (Lodewijks et al., 2009). The increase in greenhouse gas emission factors is due to the hypothesis that nuclear power plants are fading out gradually between 2015 and 2025.
An overview of the indirect emissions of electricity for use in means of transport is provided in Table 1.

2.8. Hydrogen

The production pathways for hydrogen to be used as energy carrier in transport are defined based on an internal expert judgment at VITO (see Table 6).

For hydrogen the indirect emission factors for GHG are taken from JEC (2008). For hydrogen produced from natural gas, we assume the same origin as mentioned in section 2.5 (natural gas). Related emission factors for hydrogen production and compression are applied. Table 6 shows the weighted emission factors for hydrogen produced from natural gas. Hydrogen produced from biomass is expected to be made for 50% out of farmed wood and 50% wood waste. Here GHG emission factors remain constant as new technologies are involved. The “best estimate value” reported by JEC (2008) is applied. Emission factors for hydrogen produced by means of electrolysis are based on JEC (2008) figures from EU-mix electricity with the assumption half on-site electrolysis and half central electrolysis.

	Supply (fraction)			gCO_2eq/MJ			Comment
	2010	2020	2030	2010	2020	2030	
Natural gas	0.9	0.5	0.1	100.5	97.0	93.4	supply see Table 4
Biomass	0	0.05	0.2	13.8	13.8	13.8	farmed wood
	0	0.05	0.2	12.2	12.2	12.2	wood waste
Electricity	0.1	0.4	0.5	223.1	223.1	223.1	electrolysis
Weighted				***112.8***	***139.0***	***126.1***	

Table 6: Contribution different production pathways for hydrogen and GHG emission factors related to the production and transport of hydrogen

Table 6 presents the contribution of the different pathways for hydrogen production for transport for the Belgian market and the related GHG emission factors together with the weighted factors.

For the other pollutants emission factors reported in SUSATRANS (De Vlieger et al., 2005) are applied (see Table 1).

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