LIMBO model

Calculation of the emissions of L-category vehicles in the Netherlands

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Contents

1 Introduction

In this report the LIMBO model is presented. LIMBO is short for "lichte mobiele bronnen" which translates to light mobile sources. The model is used to estimate the fleet development and associated emissions of these light mobile sources or European L-category vehicles (l-cats). Although l-cats are often referred to as "powered two-wheelers", or "mopeds and motorcycles", they consist of a wide range of vehicles with two, three or four wheels. Nonetheless, mopeds and motorcycles do make up the largest share of this group. An overview of different types of l-cats in European regulations with examples of typical vehicles is given in [1]. This table is also added to the Appendix (Appendix A). Since then (2017), the l-cat family has grown with different types of electric vehicles. Especially the (electric) speed-pedelec (L1e-B) is quickly entering the Dutch fleet.

The LIMBO-model and its predecessors have been developed for estimating the total emissions of l-cats in the Netherlands. L-cat emissions are calculated by the Taskforce Traffic and Transport of the Pollutant Release and Transfer Register (PRTR). The predictive part of the model has been developed for the Netherlands Environmental Assessment Agency (PBL). This model is used in the Climate and Energy Outlook (KEV) and Emission Estimates of Air Pollutants (ERL) to study the effect of climate and air quality policies.

The report is structured as follows:

- Chapter 2 gives a brief overview of the history of the model
- Chapter 3 shows the results of a number of studies that have been performed in order to estimate the model's parameters
- Chapter 4 describes the methodology and the used input variables such as emission factors
- Chapter 5 illustrates the main results of the model
- Chapter 6 discusses future improvements to the model

2 Model history

A first version of the fleet-development model for l-cats (then only powered two-wheelers) was developed for the PRTR in 2011 [2]. As new regulatory classes entered the market, there was a need to better understand the fleet composition and the share of vehicles that comply to different European emission standards (euro classes) and their associated emission factors. By then there was no detailed registration data available. The fleet composition was estimated on the basis of vehicle sales and an outflow function. Vehicle kilometres were scaled to the total kilometres registered by the Central Bureau of Statistics (CBS).

In 2015 the model has undergone a large update based on new emission measurements of Euro 2 mopeds [3]. Emission factors for mopeds have been updated based on the measurements and a distinction is made based on engine type (two-stroke or four-stroke) and maximum allowed speed (the 25km/h “snorfiets” and the 45 km/h “bromfiets”). Further, a third vehicle category was added: the diesel-powered mini-car (“brommobiel”).

In 2019, the model has been expanded to calculate the emissions for future years (and named the PREBROMET model) as input for the projections by PBL. Around the same time TNO and CBS started using the license plate registration data from the Netherlands Vehicle Authority (RDW) to calculate the fleet composition of road traffic bottom-up (on the basis of individual vehicles). The availability of RDW-data gave better insight into the composition and development of the fleet. Furthermore, analysis showed that import of second-hand motorcycles makes up a significant share of the inflow into the fleet, increasing the average age and emission factors of motorcycles.

Starting in 2020 the model has been rebuilt in Python (the previous versions was a Microsoft Access database) and renamed the LIMBO-model. In this version the fleet model has been changed to make better use of the bottom-up results and include import vehicles. The traffic performance model has been updated based on license plate scans and analysis of odometer registrations. The emission model mostly remained the same but emission factors are updated regularly.

3 Analyses

Multiple analyses and studies have been carried out to provide the required input data for the model. These analyses are described in the next sections.

3.1 Yearly mileages for mopeds

Emissions from road vehicles, such as mopeds, depend on the use of the vehicle (expressed in kilometres driven) on the one hand, and the emission factor related to this vehicle on the other hand. It is therefore important to know how many kilometres are driven by which vehicle in order to estimate the emissions. For mopeds and other light l-cats (see 4.2.1.1), in contrary to e.g. passenger cars and motorcycles, there is no obligation to register the odometer readings. That means that there is no registry data that can be used for analysing the development of kilometres driven over the lifetime of a vehicle.

In the past, the yearly mileages for mopeds have been estimated with the use of a survey conducted by the Central Bureau of Statistics (CBS) [4]. However, this survey dates back to 2014 and the numbers are still marked as temporary. Furthermore, the table has little detail on the development of kilometres driven, specifically for older vehicles. The main reason for this is that mopeds are only registered in the license plate registry since 2005. Older vehicles have been included in the registry but the date of first admission (and the vehicle age) is unknown. Since 2015 the CBS results have not been updated and CBS publishes no official statistics on the yearly mileage of mopeds.

In 2020 TNO [5] proposed an alternative method to estimate the kilometres driven for mopeds by combining different datasets. The average mileages per year were estimated on the basis of manual odometer readings in moped parking lots. The development of the kilometres driven over the age of the vehicle was estimated by comparing the vehicles registered with the number of vehicles seen on the road (with license plate cameras). This study showed that the mileages for moped might have been overestimated by the CBS study, especially for older mopeds.

As the license plate scans in the TNO study were all conducted in a big city some time ago, before 2018, new license plate scans have been performed on 10 locations, spread over different locations in the Netherlands. The scans were performed in urban as well as rural areas and cities of different sizes. In the following paragraphs the selection of locations, the execution and analysis of the scans and the implementation of the results in the LIMBO model are described.

3.1.1 Selection of locations and measurement plan

The license plate scans were meant to get a better understanding of the kilometres driven for especially older mopeds. Therefore, the locations of license plate scans were chosen in municipalities with a relatively high share of mopeds with an admission date before 2011 (which is the cut-off date for environmental zones for mopeds, e.g. in the Hague[1]).
Figure 3.1 shows a great difference between municipalities.

[1] https://www.denhaag.nl/nl/verkeer-en-vervoer/milieuzone-oude-brom-en-snorfietsen/

In and around municipalities with environmental zones (the Hague, Amsterdam) the share of older (pre 2011) mopeds was below 15% while in municipalities in rural areas outside the Randstad the share could be as high as 80%.

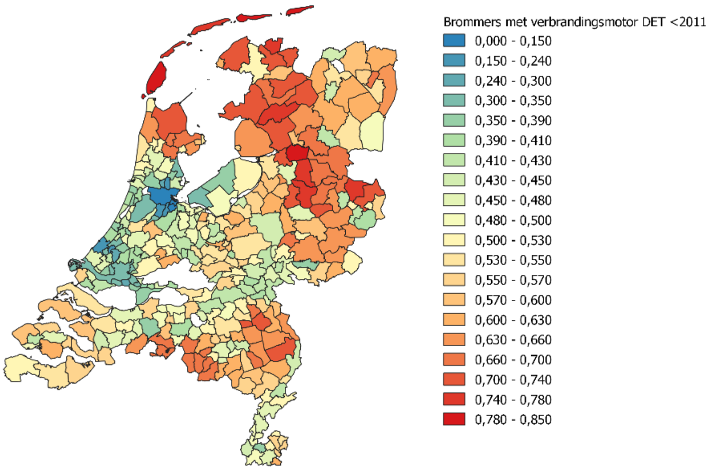


Figure 3.1: Share of registered mopeds with a date of first admission before 2011 (source: RDW, 2022).

Besides the share of older mopeds, the locations were selected on the basis of three criteria to represent a variety of municipalities with different characteristics that might affect the use of mopeds. The locations were found in different provinces to guarantee a geographical spread over the country. The locations were further sought in municipalities from different levels of urbanisation (represented by the number of addresses per square kilometre[2]. Finally, locations were sought in municipalities of different sizes (number of residents). Only in the largest category (over 250 thousand residents), no location was selected. At the time (2022) the category only contained the four largest cities of the Netherlands which all have a limited share of older mopeds. The selected locations are shown in Table 3.1.

Table 3.1: Selected municipalities for license plate scans.

Municipality	share DET <2011*	Urbanisation**	Number of residents (*1000)**
Steenwijkerland	74%	Hardly urbanised	20 to 50
Westerkwartier	71%	Not urbanised	50 to 100
Medemblik	68%	Hardly urbanised	20 to 50
Heerenveen	67%	Moderately urbanised	50 to 100
Molenlanden	62%	Not urbanised	20 to 50
Heerlen	56%	Strongly urbanised	50 to 100
Ede	54%	Strongly urbanised	100 to 150
Westland	48%	Moderately urbanised	100 to 150
Eindhoven	47%	Extremely urbanised	150 to 250
Hilversum	47%	Extremely urbanised	50 to 100

*source: RDW (2022) **source: CBS (2022)

[2] https://www.cbs.nl/en-gb/our-services/methods/definitions/degree-of-urbanisation

The exact locations of the license plate cameras were chosen in consultation with traffic experts from the municipalities. The fleet composition of the scanned vehicles was compared to the composition of registered vehicles in close proximity to the location, which is shown in Figure 3.2.

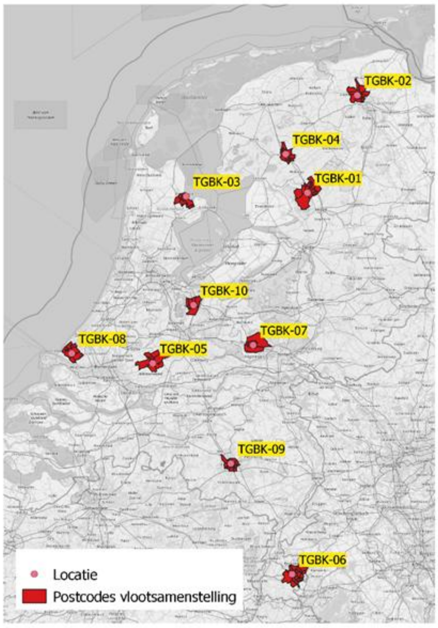


Figure 3.2: Selected locations and postal code areas used for the analysis.

Table 3.2 shows the measurement period and the number of vehicles that passed the cameras per location. The scan periods were chosen after the summer holidays and outside the fall break to capture as much commuting vehicles as possible.

Table 3.2: Measurement period and the number of scanned vehicles per location.

Location	Start	End	Passages
TGBK-01-Blokzijlseweg-Oost	19-9-2022	2-10-2022	383
TGBK-02-Friesestraatweg-Oost	3-10-2022	16-10-2022	811
TGBK-03-Oosterdijk-Noord	29-8-2022	11-9-2022	300
TGBK-04-Stationstunnel-Zuid	3-10-2022	16-10-2022	1004
TGBK-05-N216-Zuid	3-10-2022	16-10-2022	176
TGBK-06-Wijngaardsweg-West	31-10-2022	13-11-2022	441
TGBK-07-Stationstunnel-Noord	14-10-2022	27-10-2022	4664
TGBK-08-Kruisbroekweg-West	3-10-2022	16-10-2022	1865
TGBK-09-Vestdijk-Noord	5-10-2022	18-10-2022	8555
TGBK-10-Stationstunnel-Oost	3-10-2022	16-10-2022	5144
Total	**29-8-2022**	**13-11-2022**	**23343**

3.1.2 Analysis of results

For each location the (fleet) composition of scanned mopeds was compared to the composition of registered mopeds in surrounding postal code areas. In order to do so, the scan data (consisting of passage time and license plate) were merged with the RDW vehicle registration data. After the merge, the mopeds were filtered from the dataset (some scans included a few passenger cars or vans) and the age of the mopeds was calculated using the date of admission. The same was done for the corresponding fleet data, i.e. filtering all mopeds and calculating the age. Mopeds older than 15 years were grouped together as moped registration only began in 2005. Per age group the share of scanned vehicles and the share of registered vehicles was calculated. Assuming each scanned vehicle represents an equal number of kilometres driven, the yearly mileage for a certain age category can be calculated by dividing the share of scanned vehicles by the share of registered vehicles. I.e. if a vehicle has more passages than registrations, this is an indication of driving more kilometres per year. This is shown in Figure 3.3 for a single location. The bars show the share of scanned (orange) and registered (blue) vehicles for each age category. The dots show the share of scanned vehicles divided by the share of registered vehicles. This gives an indication of the relative yearly mileage per age group. Note that, as the number of kilometres that each scan represents is unknown, the picture only shows the relative yearly mileage. Based on this method, the picture clearly shows that the yearly mileage decreases with the age of the vehicle.

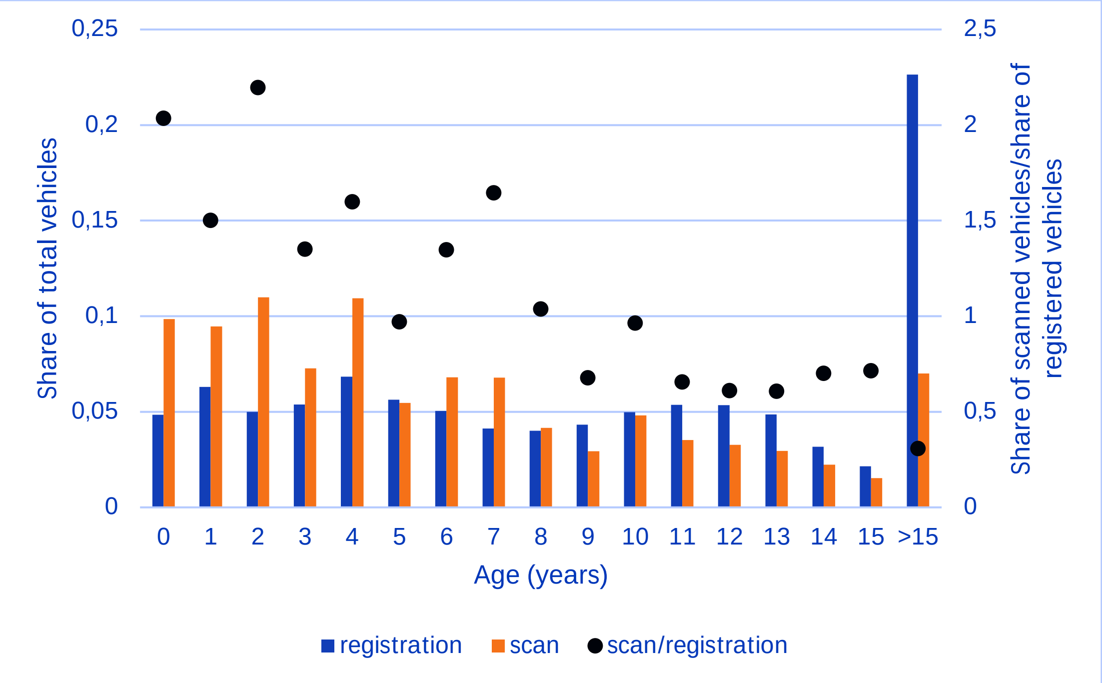


Figure 3.3: Share of scanned vehicles and registered vehicles per age group for location 10. The bars show the share of the fleet per age group. The dots show these two values divided by each other and give an indication of the relative yearly mileage.

The analysis was done for all locations as is summarized in Figure 3.4. As can be expected there is a large spread in relative mileage as some age groups were not or barely seen on the road for some locations. However, there are some clear trends in the complete dataset.

The most kilometres are driven during the first four years after the vehicle's registration, after which the mileage gradually decreases. Vehicles over 15 years of age are seen a lot less on the road than one might expect from their share in the fleet.

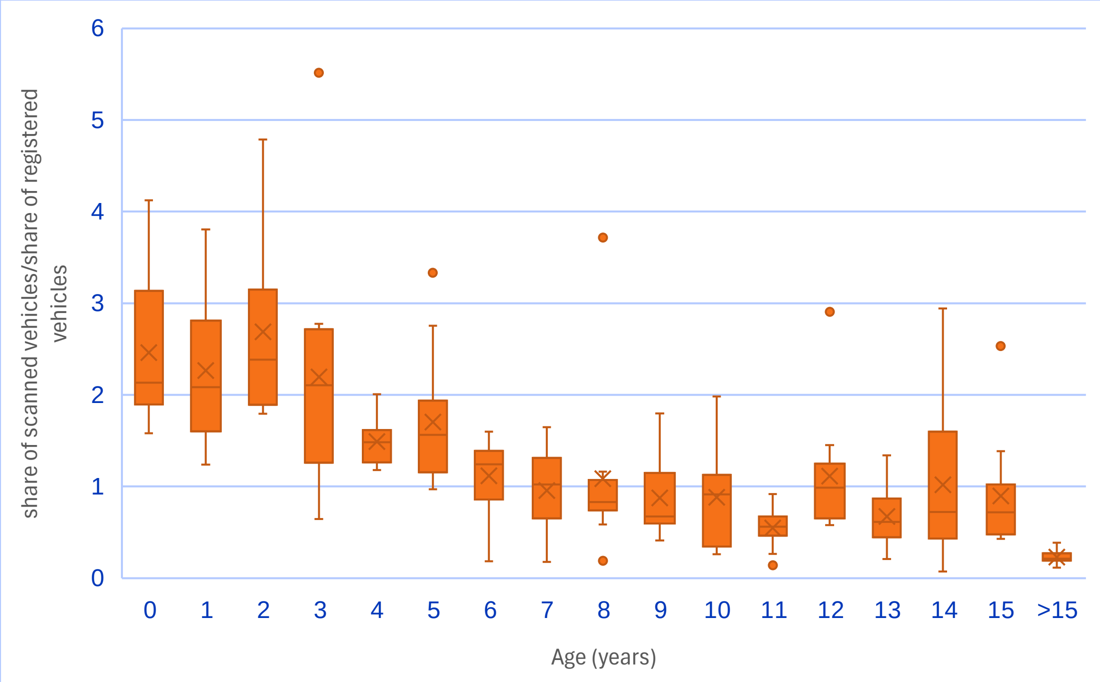


Figure 3.4 The boxplot shows the spread of relative mileage (scanned vehicles/registered vehicles) per age group. The box represents the middle 50% of the data. The whiskers show the minimum and maximum values except the outliers, represented by dots. The median is shown as a horizontal line in the box and the mean is shown as an 'x'.

As in [5] the total kilometres driven in the first five life years of the vehicle (age 0-4) are assumed to add up to 10088 km. This way the relative mileage was converted to absolute mileage. Finally, the absolute mileage was used to fit a new function, using the same function type proposed in the aforementioned study:

Vehicle mileage (life year) = a*exp(b*life year).

The parameters found in the current study (a= 2509, b=-0.104) lead to a slightly lower mileage in the first year and a slower decrease over vehicle's life compared to the previous study (a=3542, b=-0.2). The fleet statistics contain the total number of vehicles per vehicle age (calculated from the year of registration). It is assumed that vehicles are spread evenly across the age groups, i.e. the yearly mileage for vehicles of N years old is calculated as the mean of kilometres driven in life year N and life year N+1.

Figure 3.5 compares the functions in the old model (based on the CBS survey), the previous study (based on license plate scans in large cities) and the current report. Both latter studies have shown that it is expected that the CBS survey highly overestimated the mileages driven by older vehicles, this can be clearly seen in the picture. The previous study seems to have underestimated the mileage from older vehicles as can be expected as license plate scans in larger cities (with fewer old mopeds) were compared to the fleet composition of the country as a whole.

The new study compared a geographically varied set of license plate scans with local fleet compositions in order to make a fair comparison between the vehicles registered and the vehicles on the road. Therefore, the new model uses the parameters as calculated based on this study. It should, however, be noted that the yearly mileage of mopeds is still highly uncertain compared to e.g. passenger cars and motorcycles.

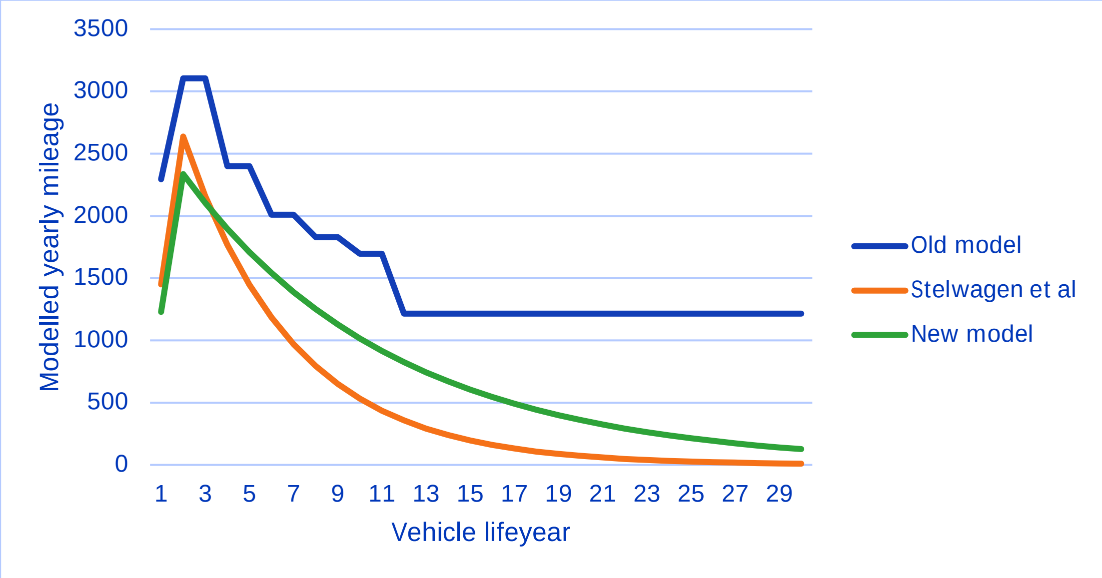


Figure 3.5: Average milage per moped per year based on the survey (blue), the previous study (orange) and the current study (green).

3.2 Yearly mileages for motorcycles

For motorcycles, registration data of odometer readings is used to estimate the kilometres driven per year. For the analysis, all registered odometer readings of motorcycles up until March 2022 have been requested from the RDW. The dataset contains over a million odometer registrations for about half a million motorcycles, this is shown in Table 3.3.

Table 3.3: Composition of dataset.

Motorcycle type	Fuel	Number of odometer registrations	Number of license plates	Registrations per license plate	Active fleet (1-1-2022)*
Motorcycle	Petrol	1164341	475670	2.4	651835
	Electricity	964	625	1.5	1022
Heavy quad	Petrol	4086	2571	1.6	12812
	Electricity	436	394	1.1	1233

*Source: RDW

Although registration of odometer readings has been mandatory for motorcycles since July 1st 2021[3], the dataset contains odometer readings as far back as 1989. Figure 3.6 shows that the number of odometer registrations has increased to just over 100 thousand in 2021. Note that this is after only half a year of mandatory registration, so this number is expected to have been increased further from 2022 onwards.

[3] https://mijn.bovag.nl/actueel/nieuws/verplichte-tellerstandenregistratie-bij-motoren-va

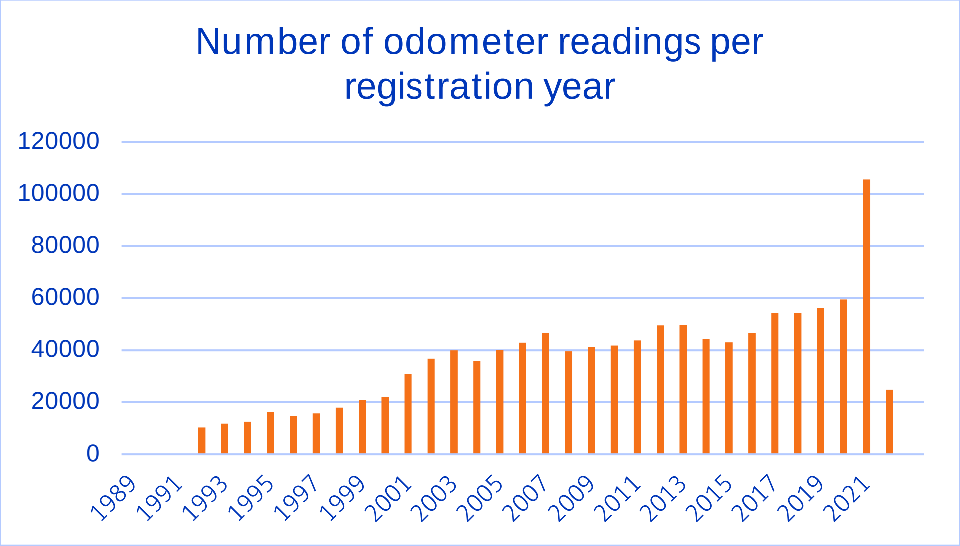


Figure 3.6: Number of odometer readings per registration year of the odometer reading.

Figure 3.7 shows the development of the average odometer reading per motorcycle in the registration data. The average odometer reading has been stable at approximately 28,000 km since 2013 and increased slightly since the mandatory registration. This suggests that the mandatory registration leads to better registration of odometer readings for older vehicles (with higher mileages) but this not been studied further.

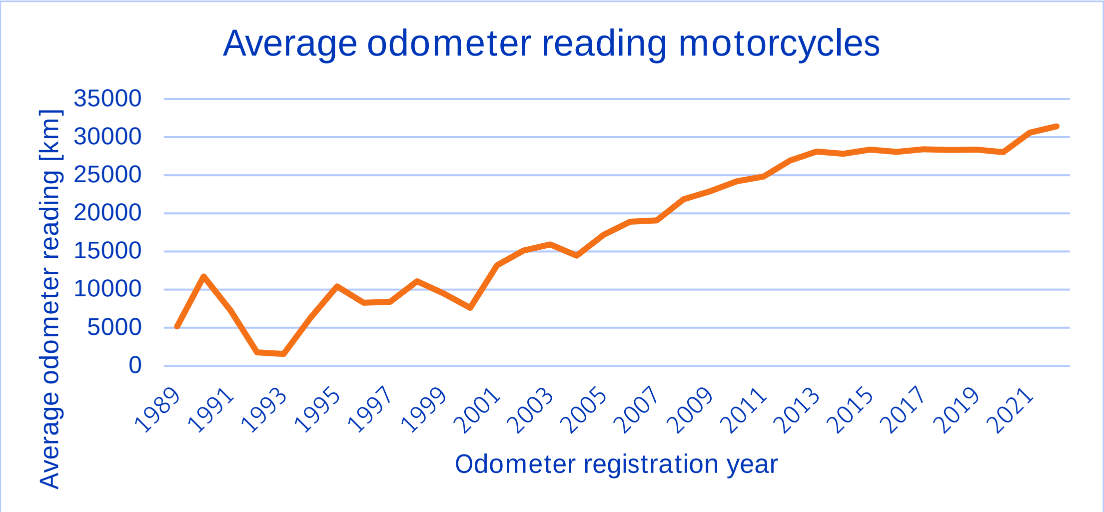


Figure 3.7: Average odometer reading per motorcycle per registration year (of all available motorcycles combined).

3.2.1 Data preparation and analysis

Before the yearly mileages were analysed, data preparation and data cleaning needed to be performed.

Firstly, only registrations from vehicles with registration date (of the reading) after the date of admission of the vehicles were allowed.

In the dataset pairs of consecutive registrations for the same vehicle (license plate) were sought. Those pairs spanning a period of at least 0.5 years and at most 2 years were selected for the analysis.

For every selected pair the yearly mileage and the age of the motorcycle has been determined. The yearly mileage is calculated as follows:

Yearly mileage = (km_end_of period – km_start_of_period) / duration [days] * 365.25

Note that the yearly mileage of motorcycles is not spread evenly over the year as they drive more kilometres in summertime than in wintertime.

The age of the vehicle is determined as the age of the vehicle in the middle of the period, rounded down to a whole year.

The resulting dataset is cleaned by filtering negative mileages. Outliers were filtered according to the interquartile range (IQR) method for each age group separately. All datapoints, that had a yearly mileage larger than the third quartile plus 1.5 times the IQR (third quartile minus first quartile), were removed. This rather stringent filtering was chosen since the average mileage for older motorcycles was determined by only a few motorcycles with very high mileages.

After filtration, the dataset contained 350,142 pairs of consecutive registrations. The data has not been grouped further for vehicle- or fuel type as the majority of data pairs (98.5%) represented petrol motorcycles. When more electric motorcycles are registered, the analysis should be repeated for these vehicles.

Finally a simple exponential function was fitted to the average mileages to be used for the LIMBO-model. Figure 3.8 shows a comparison between the data, the fitted function and the values used in the previous model.

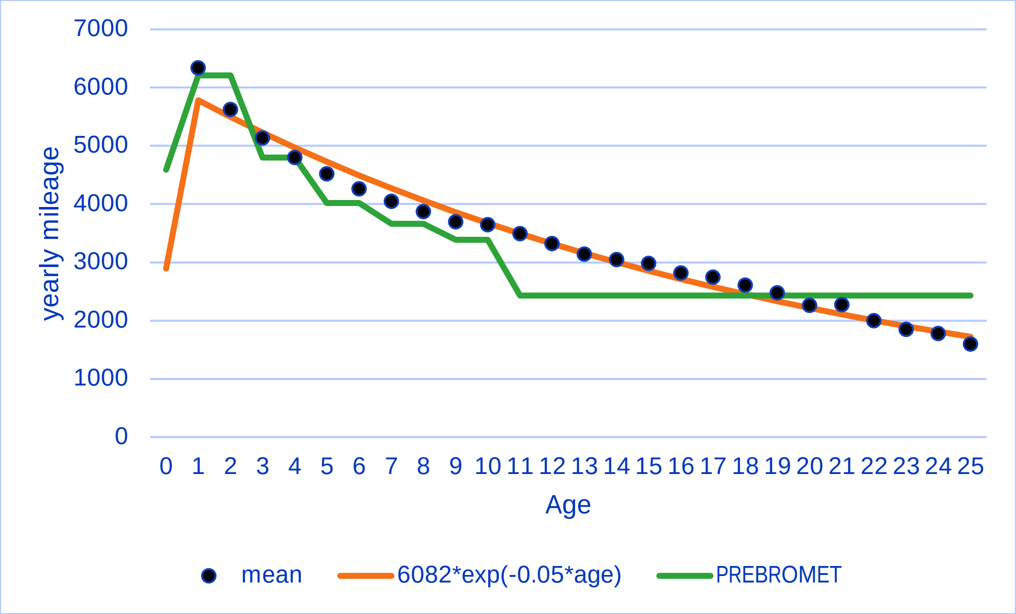


Figure 3.8: Average mileage per vehicle age in the dataset (dots), fitted formula (orange) and previous model (green).

3.3 Fleet development

Fleet development parameters were calculated by analysing license plate registration data by RDW. The methodology for analysing RDW license plate data is explained in more detail in the series of import-export reports from TNO, e.g. [6].

The dataset used for these analyses contained all l-cat vehicles that have been registered at any time between 2013 and 2022, a total of 2,801,254 unique license plates. The dataset contained a combination of vehicle information (e.g. date of registration, fuel type, vehicle type), status information (e.g. no status (active), exported, scrapped) and user information (type of user). This data was used to make snapshots of the fleet every half year (January 1st and July 1st) and grouping the vehicles on a number of properties. The properties used are shown in Table 3.4.

Table 3.4: Properties used for analysis of fleet development parameters

Name	Source
VERSIT+ class	Determined on the basis of vehicle properties as known from the RDW data, see also 4.2.1
Energy carrier	Based on VERSIT+ class
Vehicle type	Based on VERSIT+ class
Year of construction	Based on Date of first Admission (DET)
Registration year	Based on Date of first registration in the Netherlands (DER)
Import or new registration	If DET = DER new registration, else import vehicle
Type of owner (private, company or dealer)	From RDW user data
Status (active, exported, scrapped)	From RDW status data
number of license plates	Result of grouping per date
date	The date of the snapshot

4 Methodology

4.1 Overview

The LIMBO model consists of three layers, the fleet model, the traffic performance model and the emission model. Figure 4.1 gives a general overview of the model.

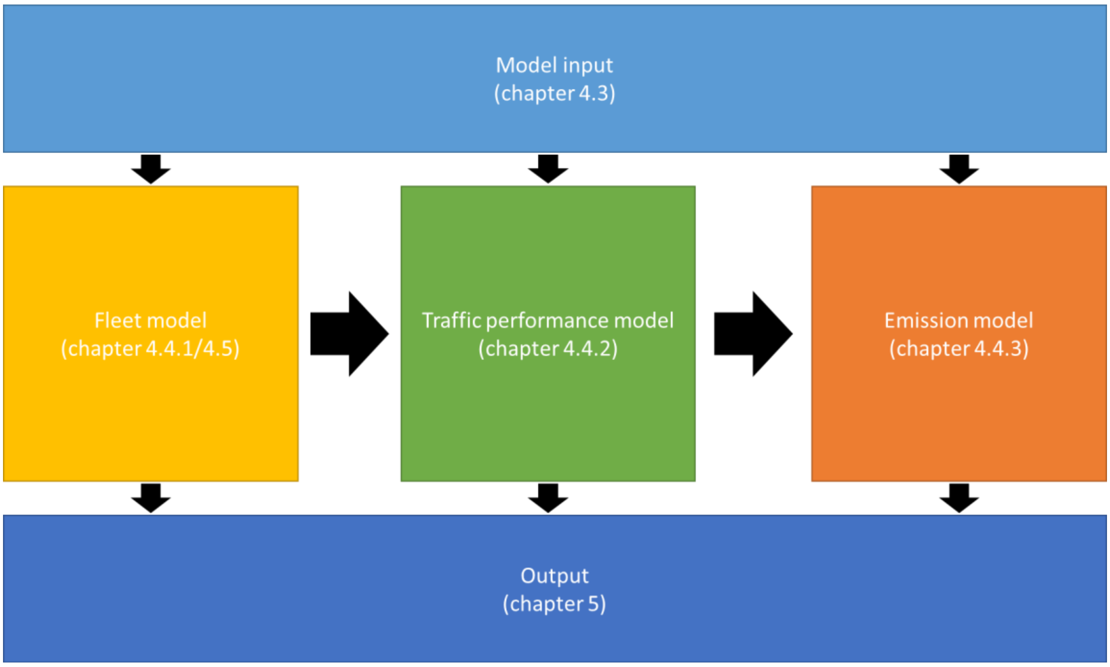


Figure 4.1: Overview of the LIMBO model.

The model input consists of an Excel sheet with model parameters and input data. They are described in Chapter 4.2 and 4.3.

In the fleet model the vehicle fleet is estimated. For historic years this is done based on the sales and registration data of vehicles. For prognoses this is done by estimating the inflow (import and new sales) and outflow (export and scrappage) into the fleet year by year. The historic fleet model is described in Chapter 4.4.1 and the prognosis fleet model is described in Chapter 4.5. A detailed flow chart of both models is given in Appendix B.1 and B.2.

In the traffic performance model the traffic performance (kilometres driven) of the fleet is estimated based on the age of individual vehicles. The traffic performance model is the same for the historic and prognosis model and is described in Chapter 4.4.2. A detailed flow chart is given in Appendix B.3.

In the emission model the total emissions are calculated. For most emission compounds the emissions are calculated by multiplying the traffic performance by the emission factor (typical emissions e.g. in g/km), but emissions can also depend on fuel use or active days per year.

The emission model is the same for historic and prognosis years although not all compounds are calculated for both. The different emission calculations are described in Chapter 4.4.3 and a flow chart of the emission model can be found in Appendix B.4.

The output consists of the results of the model. The output for the fleet model consists of the number of vehicles per year. The output for the traffic performance model consists of the kilometres driven per year. The output of the emission model consists of the emissions per year. Chapter 5 gives an example of the output data for the current version of the calculations.

4.2 Model parameters

4.2.1 VERSIT+ classes

The VERSIT+ class is used to categorize road vehicles based on their emission performance and associated emission factors. It has first been used in the VERSIT+ emission model [7] and is currently used for the bottom-up calculation of the emissions and emission factors of road traffic as documented by Emissieregistratie [8].

The VERSIT+ class is a code of 8 or more characters describing:

1. The vehicle type (3 characters, e.g. LBF = Lichte BromFiets (moped))
2. The fuel type (1 character, e.g. B = benzine (petrol))
3. The euro class (4 characters, e.g. EUR2 = Euro 2)
4. Additional information (each time 3 characters, e.g. 2TK = tweetakt (two-stroke)

Each vehicle gets assigned a VERSIT class based on their characteristics.

4.2.1.1 Vehicle type

The vehicle type is determined on the basis of the European vehicle category of the vehicle[4]. For L1e-B vehicles, further distinction is made based on the maximum allowed speed of the moped as this effects the rules for the use of these vehicles in the Netherlands. In the model no distinction is made between L3e (motorcycle without a side-car) and L4e (motorcycle with a side-car) vehicles as the number of vehicles with a side-car is limited and the same emission limits apply.

Table 4.1 shows the different vehicle types that are distinguished in the model and the link to European vehicle categories.

Based on the maximum speed and maximum cylinder capacity a distinction can be made between **light l-category vehicles** (LBF, LBS, LBP, LT2, LQ6) and **heavy l-category vehicles** (LMF, LT5, LQ7).

[4] https://alternative-fuels-observatory.ec.europa.eu/general-information/vehicle-types

Table 4.1: VERSIT+ vehicles distinguished in the LIMBO model.

European vehicle category	Vehicle type VERSIT+	Vehicle type	Group	Definition
L1e	LBF	Bromfiets	Light l-cats	Moped with a maximum speed not exceeding 45 km/h
	LBS	Snorfiets	Light l-cats	Moped with a maximum speed not exceeding 25 km/h
	LBP	Speed-pedelec	Light l-cats	High-powered e-bike with a maximum support speed not exceeding 45 km/h
L2e	LT2	Lichte tricycle	Light l-cats	Three-wheeled vehicle with a maximum speed not exceeding 45 km/h
L3e	LMF	Motorfiets	Heavy l-cats	Motorcycle
L4e	LMF	Motorfiets	Heavy l-cats	Motorcycle with a sidecar
L5e	LT5	Zware tricycle	Heavy l-cats	Three-wheeled vehicle with a maximum speed exceeding 45 km/h
L6ee	LQ6	Lichte quad	Light l-cats	Four-wheeled vehicle with a maximum speed not exceeding 45km/h
L7e	LQ7	Zware quad	Heavy l-cats	Four-wheeled vehicle with a maximum speed exceeding 45 km/h and unladen mass not exceeding 450 kg (550 kg for vehicles carrying goods)

4.2.1.2 Fuel type

The fuel types found in l-category vehicles are described in Table 4.2. Diesel is only used for minicars (part of the LQ6 vehicles). All other vehicles only use petrol or electricity/hydrogen.

Table 4.2: Fuel types in the LIMBO model

Fueltype VERSIT+	Energiedrager	Energy-carrier
B	Benzine	Petrol
D	Diesel	Diesel
E	Elektriciteit	Electricity
H	Waterstof	Hydrogen

4.2.1.3 Euro class

The euro class describes the emission limits that apply to the vehicle. Emission limits for mopeds and motorcycles have been set by the European commission since 1999 [9]. The current emission limit is Euro 5 and applies to all
l-category vehicles. The euro class is estimated on the basis of the date of first registration of the vehicle.

Table 4.3 shows the euro classes and the date all new vehicles are assumed to apply the limits. Note that the number of Euro 3 light l-cats is negligible due to the absence of an official end date for Euro 2.

Table 4.3: VERSIT+ euro classes, regulations and introduction years.

VERSIT+ euroclass	Regulation light l-cats	Regulation heavy l-cats	Introduction year light l-cats	Introduction year heavy l-cats
EUR0	No regulations apply			
EUR1	97/24/EG	97/24/EG	1999	1999
EUR2	97/24/EG	2002/51/EC	2002	2003
EUR3	97/24/EG	2002/51/EC	-*	2006
EUR4	168/2013/EU and 134/2014/EU		2018	2017
EUR5	168/2013/EU and 134/2014/EU		2021	2021

* Although Euro 3 was introduced in 2014, Euro 2 mopeds were still allowed until the introduction of Euro 4 and Euro 3 mopeds were hardly sold in the Netherlands [10]

4.2.1.4 Engine power

Emission limits for motorcycles depend on the engine power of the vehicle and the engine power is therefore added to the VERSIT+ class. Table 4.4 shows the VERSIT+ addition and the associated engine power.

Table 4.4: Engine power classes for heavy l-cats

European vehicle category	VERSIT+ engine power	Engine power
L3e-A1	LCH	<= 11kW
L3e-A2	MED	11-<=35 kW
L3e-A3	ZWA	>35 kW

4.2.1.5 Two-stroke/four-stroke

For Euro 2 mopeds a distinction is made between two-stroke and four-stroke engines. Newer mopeds are assumed to have a four-stroke engine and older mopeds are assumed to have a two-stroke engine. The engine type is not part of the registration data, so the cut-off is based on the date of first admission of the vehicle. There is no clear cutoff date (four-stroke gradually gained the upper hand) so the introduction year is based on expert judgement. Table 4.5 shows the cutoff dates.

Table 4.5: Two-stroke, four-stroke engines for light l-cats

VERSIT+ stroke addition	Description	Euro class (introduction year)
2TK	Two-stroke	Euro 2 (2008 and before)
4TK	Four-stroke	Euro 2 (2009 and after)

4.2.2 Road types

The kilometres driven are spread over three road types, i.e. urban, rural and motorway. Light l-cats are not allowed on the motorway, and therefore make use of urban and rural roads only. The road type affects the emission factors. The road types are summarized in Table 4.6.

Table 4.6: Road types in the LIMBO model.

Roadtype	Description	L-cats
WT1	Urban roads	All
WT2	Rural roads	All
WT3	Motorways	Only heavy l-cats

4.2.3 Fleet development parameters

4.2.3.1 Survival rate

The survival rate represents the probability that a vehicle of a certain age is still active in the fleet one year later. Older vehicles usually have a higher chance of leaving the fleet through scrappage or export. The survival rate is estimated by analysing vehicle registration data from the RDW. Figure 4.2 shows the cumulative survival rates per age. The survival rates have been calculated for the three main vehicle categories from the old model as the newer categories do not have sufficient data to calculate these rates. The graph shows that half of the newly registered light l-cats leave the fleet within 15 years, while more than half of the heavy l-cats are still in the fleet after 30 years.

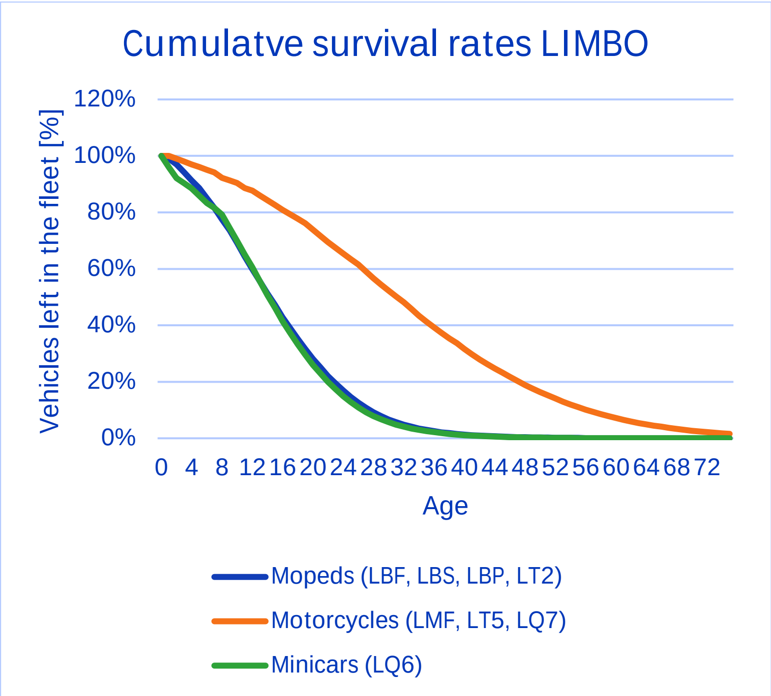


Figure 4.2: Cumulative survival rates used in the LIMBO model.

4.2.3.2 Import age

Part of the vehicles that enter the fleet have already been used outside of the Netherlands and enter the country through import. Analysis of registration data has shown that this is mostly the case for heavy l-cats. This is shown in Figure 4.3. About 95% of the light l-cats is sold in the Netherlands, but nearly half of the heavy l-cats entered the fleet through import. Therefore, import is only calculated for heavy l-cats. Light l-cats are assumed to only enter the fleet through new sales in the Netherlands.

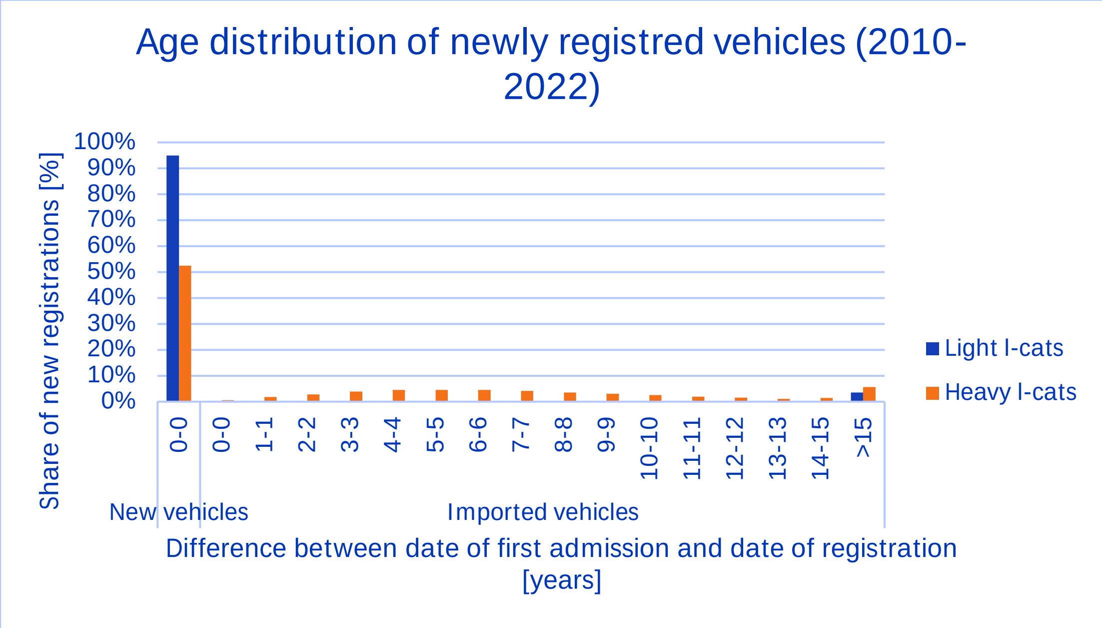


Figure 4.3: Share of imported vehicles and import age for light and heavy I-cats (source: RDW).

The age distribution for imported vehicles is based on the registration data from the RDW. For the historic fleet composition, the age distribution per registration year is taken directly from the RDW registration data. I.e. the age distribution at registration is assumed to be equal to the age distribution of the vehicles that are still in the fleet for a specific registration year.

For the prognosis years the age distribution of imported vehicles is assumed to be equal to the age distribution of imported vehicles in 2022 (the last year for which registration data was available). The distribution that is used in the 2024 input file is shown in Figure 4.4. The fuel type and engine power of imported vehicles are based on the shares found in RDW-registration data for vehicles from the same build year. For future years the shares of 2022 are used.

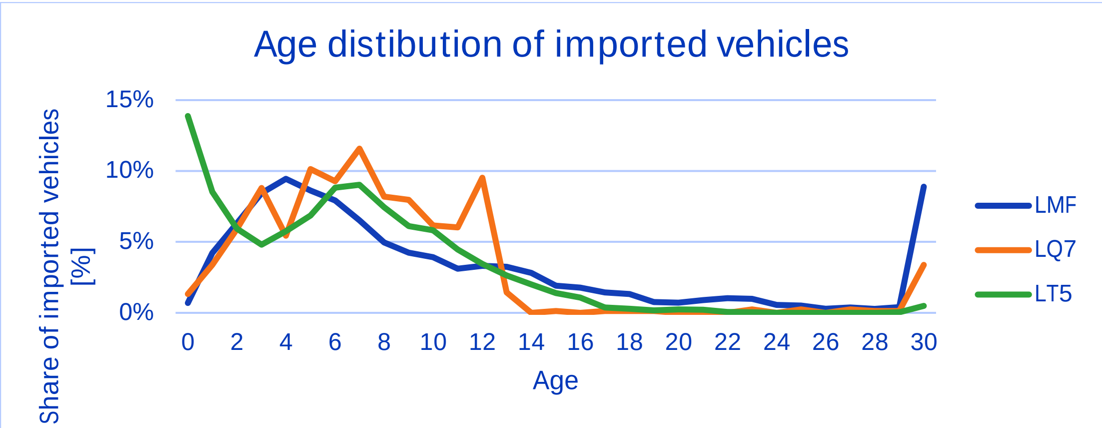


Figure 4.4: Age distribution of imported heavy I-cat vehicles in the LIMBO model.

4.2.4 Vehicle kilometres driven

4.2.4.1 Annual kilometres driven

The analyses that led to the estimation of the kilometres driven per vehicle per year are described in Chapter 3.1 (light l-cats) and 3.2 (heavy l-cats). Figure 4.5 shows the resulting input parameters for light and heavy l-cats, as used in the standard input data. Note that vehicles with an age of 0 years include vehicles that entered the fleet during the year and on average drive only half a year.

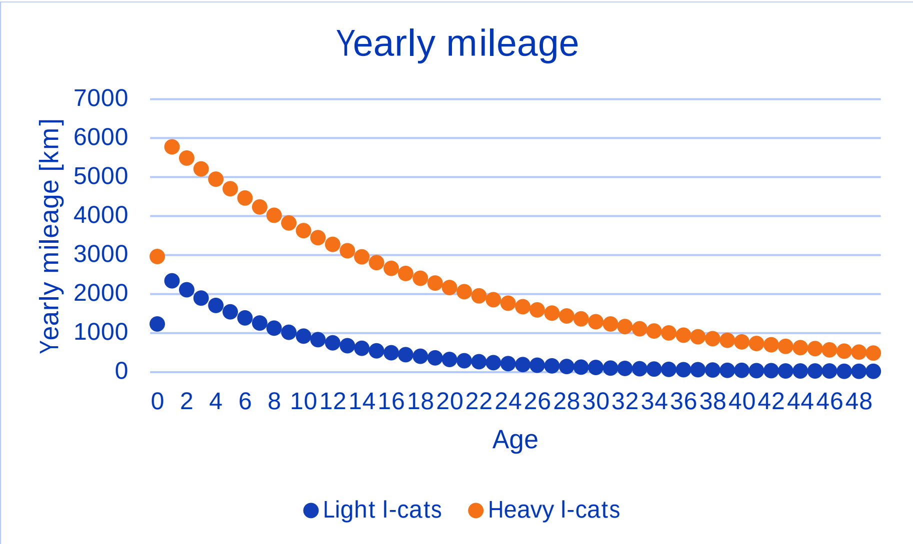


Figure 4.5: Yearly mileage for light and heavy l-cats.

4.2.4.2 Road type distribution

The road type distribution for l-cats is based on expert judgement, discussed in the taskforce traffic and transport of the PRTR, and in line with earlier versions of the model. Table 4.7 shows the distribution.

Table 4.7: Road type distribution (share of total kilometres driven).

VERSIT+ vehicle	Engine power	WT1	WT2	WT3
LBF		70%	30%	-
LBP		70%	30%	-
LBS		70%	30%	-
LMF	LCH	20%	50%	30%
LMF	MED	15%	45%	40%
LMF	ZWA	15%	40%	45%
LMF		15%	45%	40%
LT2		70%	30%	-
LT5		15%	45%	40%
LQ6		50%	50%	-
LQ7		15%	45%	40%

4.2.5 Emission factors

Emission factors reflect the average emissions in g/km for a certain VERSIT+ class and road type. The emission factors that are applied in the LIMBO model are reported yearly in the methodology report (hereafter MR) of the taskforce traffic and transport of the PRTR. The current emission factors (round of 2024) are found in table 3.11 of the accompanying tables [8].

4.2.5.1 Exhaust emission factors per kilometre per VERSIT+ class

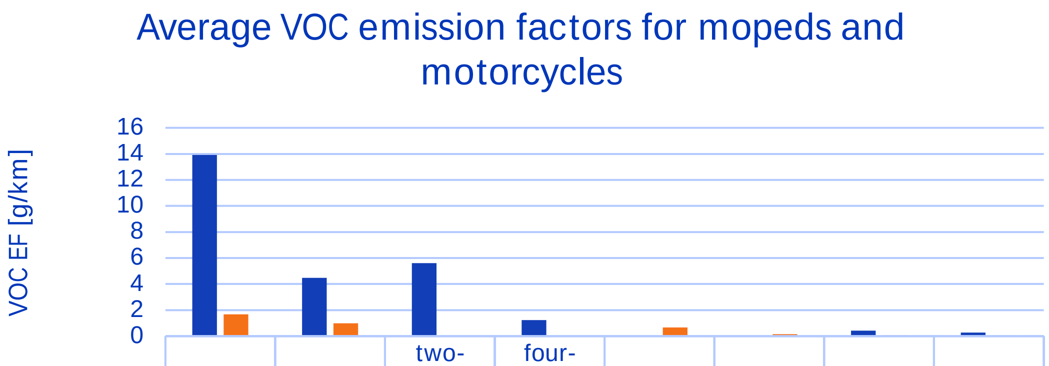
TNO maintains the list of exhaust emission factors based on emission measurements and effect studies of new emission classes. Below is a timeline of the development of emission factors for mopeds and motorcycles. More information on the measurements programs and analyses can be found in the mentioned reports.

- In 2014 all the emission factors in the model were recalculated [3].
- In 2017 a report has been published with measurement results for a wide range of mopeds [10].
- Together with some international partners TNO evaluated the new regulations for Euro 5 mopeds [1].
- In order to estimate the emission factors for Euro 5 vehicles, a number of Euro 4 mopeds and motorcycles have been measured by TNO and other partners in the ERMES group[5].
- The three sources above led to an update of the emission factors in 2019 [11].
- Measurements on Euro 5 mopeds led to an update on the emission factors of these vehicles [12].

Exhaust emission factors are maintained for carbon monoxide (CO), Volatile Organic Compounds (VOC), nitrogen oxides (NOx), ammonia (NH3), particulate matter (PM), elemental carbon (EC) and carbon dioxide (CO2). To illustrate the development of emission factors the VOC and CO emission factors are shown, since l-cats have a large contribution to the total emissions of traffic and transport for these components .

Figure 4.6 shows the average VOC emission factors for mopeds and motorcycles in the current version of the model. The oldest mopeds have the highest emission factors, with values around 14 g/km. With the introduction of Euro 1 and the four-stroke engine, emissions have decreased to the level of motorcycles (around 1-1.5 g/km). The introduction of Euro 3 (for motorcycles), 4 and 5 have decreased the emission factors further to around 282 mg/km for mopeds and 47 mg/km for motorcycles. Still, mopeds emit a lot more than the emission limit, which is 100 mg/km for all Euro 5 l-cats [9].

[5] European Research on Mobile Emission Sources, see https://ermes-group.eu/

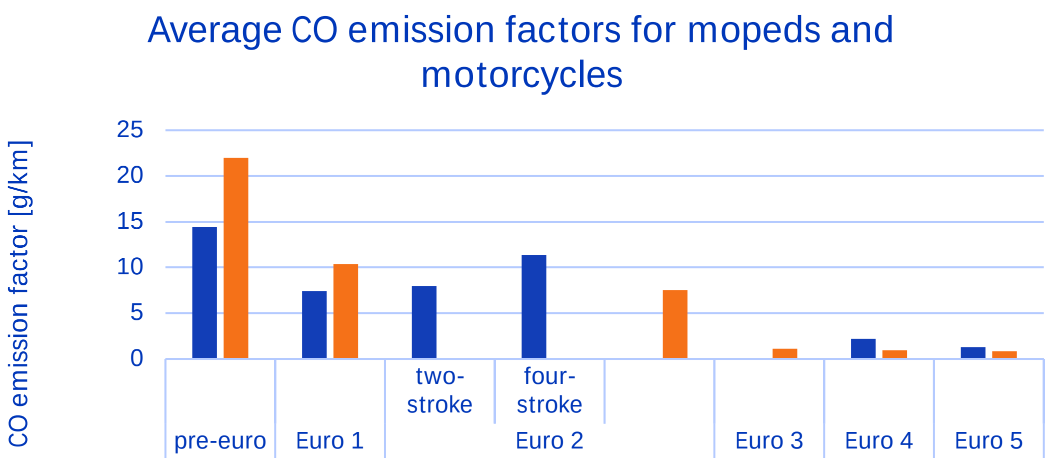


	pre-euro	Euro 1	two-stroke	four-stroke Euro 2		Euro 3	Euro 4	Euro 5
Moped	13,910	4,467	5,619	1,234			0,436	0,282
Motorcycle	1,675	0,990			0,665	0,143	0,090	0,047

Moped Motorcycle

Figure 4.6: Average VOC emission factors (weighted over all road types and engine power classes) for mopeds and motorcycles.

Figure 4.7 shows the average CO emission factors for mopeds and motorcycles. Pre-euro motorcycles emit more than 20 g/km and pre-euro mopeds just under 15 g/km. Introduction of Euro 1 reduced the emission factors by around a half. With the introductions of Euro 3 (for motorcycles) and Euro 4 and 5 emissions have reduced further to 1.3 g/km for mopeds and 0.8 g/km for motorcycles. The Euro 5 emission limit is 1 g/km for all l-cats [9] so mopeds still emit more than the limit.



	pre-euro	Euro 1	two-stroke	four-stroke Euro 2		Euro 3	Euro 4	Euro 5
Moped	14,442	7,431	7,987	11,390			2,185	1,304
Motorcycle	22,002	10,347			7,525	1,114	0,951	0,847

Moped Motorcycle

Figure 4.7: Average CO emission factors (weighted over all road types) for mopeds and motorcycles.

4.2.5.2 Energy use of electric vehicles

The energy use of electric vehicles (in MJ/km) is estimated on the basis of consumer tests of electric l-cats by the Royal Dutch Touring Club (ANWB) and the Cyclists Union [13], [14], [15]. Energy use for electric heavy l-cats is scaled, assuming that the ratio in fuel consumption between light- and heavy l-cats is equal to the ratio in energy consumption. The same holds for the conversion to energy consumption factors per road type. The resulting factors are shown in Table 4.8.

Table 4.8: Energy consumption factors.

VERSIT+ class	WT1 [MJ/km]	WT2 [MJ/km]	WT3 [MJ/km]
LBFEZEEV	0.16	0.16	-
LBPEZEEV	0.06	0.06	-
LBSEZEEV	0.07	0.07	-
LMFEZEEV	0.45	0.29	0.34
LQ6EZEEV	0.28	0.25	-
LQ7EZEEV	0.68	0.52	0.34
LT2EZEEV	0.16	0.16	-
LT5EZEEV	0.66	0.39	0.38

4.2.5.3 Heating value

The heating values (MJ/kg) for petrol and diesel are calculated by CBS and reported yearly in table 2.6 of the MR. The heating value is used for the calculation of fuel consumption.

4.2.5.4 Fuel emission factors

Emission factors for lead, sulphur oxide and heavy metals are based on fuel consumption and are reported yearly in the MR. They are updated in the input file when needed:

- Lead and sulphur: Table 3.7
- Heavy metals: Table 3.6 A

4.2.5.5 Emissions from wear

4.2.5.5.1 Emission factors per km

Total wear emission factors are found in table 3.3A of the MR. Wear emissions consist of particles from brake wear, tyre wear and road wear. Separate emission factors are given for light l-cats (mopeds) and heavy l-cats (motorcycles) but no further distinction is made. Total particulate mass is further assigned to a fraction PM10 (particles < 10 μm), a fraction coarse particles (particles >= 10 μm) and a fraction that remains on the vehicle. All PM10 is assumed to be emitted into the air. Coarse particles are assigned to soil, sewer and water according to table 3.3B of the MR.

4.2.5.5.2 ZOAB correction

Particulate emissions to soil, sewer and water are corrected for the use of ZOAB (Zeer Open AsfaltBeton, porous asphalt) on motorways. The share of porous asphalt on motorways and associated correction factors can be found in MR table 3.8A.

4.2.5.5.3 PAH

Polycyclic Aromatic Hydrocarbons (PAH) emission factors for wear emissions are given in g/kg wear. Emission factors for tyre wear are given in MR table 3.6C. The table gives a reduced factor, to incorporate the reduction of PAH-components in tyres, and a non-reduced factor. Note that for all years the non-reduced factor is used, as the reduction is included in the speciation profile (table 3.6D). PAH emission factors for road wear depend on the road type and associated share of tar containing asphalt granulate. Emission factors can be found in MR table 3.8B

4.2.5.5.4 DEHP and nonylphenol

Emission factors for nonylphenol and Di(2-ethylhexyl)phthalate (DEHP) in tyre wear are taken from the factsheet on tyre wear [16].

4.2.5.6 Speciation of organic gases

Speciation profiles are used to estimate the release of the various organic compounds that are part of the total VOC (Volatile Organic Compounds) emissions. The VOC profiles have been estimated in [2]. The used profiles for VOC-emissions of l-cats are shown in Table 4.9. For light l-cats there is a profile for petrol vehicles and a profile for diesel vehicles. For heavy l-cats (which are all petrol) there is a profile for vehicles with a catalyst and vehicles without a catalyst. For evaporative emissions, two profiles are used to reflect the fuel quality. These profiles have been taken over from the previous model and further research is required to see if these profiles are still up-to-date, especially for newer vehicles.

Table 4.9: VOC speciation profiles.

Vehicle	Geregistreerde_stof_naam (ER database)	Description
All petrol light l-cats	KWst. verbr. bromfiets en 2-takt motorfiets	Hydrocarbons from combustion, moped and 2-stroke motorcycle
Heavy l-cats Euro 1 and older	KWst. verbr. motorfietsen 4-takt, zonder kat	Hydrocarbons from combustion, 4-stroke motorcycle without catalyst
Heavy l-cats Euro 2 and younger	KWst. verbr. motorfietsen 4-takt, met kat	Hydrocarbons from combustion, 4-stroke motorcycle with catalyst
All diesel light l-cats	KWst. verbr. Motoren li. voertuigen 2000 en later, li.diesel	Hydrocarbons from combustion motorcycles, light vehicles 2000 and after, diesel
Petrol evaporation (until 1999)	KWst. benzinedamp, 1999 en eerder	Hydrocarbons from petrol evaporation, 1999 and before
Petrol evaporation (2000 onwards)	KWst. benzinedamp, 2000 en later	Hydrocarbons from petrol evaporation, 1999 and after

4.2.5.7 Speciation of PAH

Just like for the VOC, speciation profiles are used as well to estimate the emissions of PAH (Polycyclic Aromatic Hydrocarbons). For exhaust emissions they are calculated as a fraction of total PM (particulate mass) and VOC. The PAH-profiles for exhaust emissions can be found in the MR (table 3.10). Speciation profiles for PAH from tyre wear can be found in MR table 3.6D. Speciation profiles for PAH from road wear can be found in MR table 3.8C.

Just like for the VOC-profiles, there has been no update from the previous model and further research is required to test if the profiles need to be updated for modern vehicles (with aftertreatment).

4.2.5.8 Petrol evaporation

Fuel evaporation from the fuel tank and supply system (diurnal evaporation) is calculated in grams per day. Different emission factors are used for heavy and light l-cats, dependent on the average size of the fuel tank. Fuel evaporation during running of the engine is calculated on the basis of kilometres driven. Separate emission factors are used for light and heavy l-cats. For heavy l-cats a distinction is made between vehicles with a carburettor and vehicles with direct fuel injection. Emission factors are taken from the methodology report (table 3.2). The amount of heavy l-cats with a carburettor is assumed to have linearly decreased from 100% up until 1997 until 10% from 2018 onwards.

4.2.5.9 Combustion of engine oil

Combustion of engine oil in litres per km is based on the emission factors in the methodology report (table 3.4). The heavy metal emission factors in µg/kg engine oil are found in methodology report table 3.6A.

4.3 Input data

This Chapter describes the input data that is used for the estimation of the fleet size and fleet composition.

4.3.1 Fleet size and fleet composition

Since 2018 (and looking back to 2011) the fleet-composition is calculated bottom-up. The bottom-up fleet composition is a dataset containing the number of registered vehicles per sight year, VERSIT+ class and build year. This dataset is updated yearly by CBS and TNO. TNO determines the VERSIT+ class for all registered vehicles, and CBS determines the number of active vehicles per year based on the license plate registration by the RDW. For earlier years (before 2011), the total fleet size is taken from yearly reports by Dutch industry organisations RAI and BOVAG and statistics from CBS. The fleet composition for these years is estimated by the model (see 4.4.1). The applied sources for the fleet size are summarized in Table 4.10 below.

Table 4.10: Sources for the fleet size.

Vehicles	Years	Source fleet size
Light l-cats (except mini cars)	1990-2000	Assumption
Light l-cats (except mini cars)	2000-2005	Bromfietsinformatie by BOVAG/RAI
Light l-cats (except mini cars)	2005-2010	Kerncijfers Tweewielers by BOVAG/RAI
Minicars	1990-1994	(non-existent)
Minicars	1994-2007	Model estimation
Minicars	2007-2010	CBS
Heavy l-cats	1990-2010	Kerncijfers Tweewielers by BOVAG/RAI
All vehicles	2011 onwards	Bottom-up calculation (CBS)

4.3.2 Historic sales

Historic sales data for the years before the bottom-up calculation are taken over from the PREBROMET model. From 1985 onwards, sales data from the BOVAG/RAI is used (the yearly report "Kerncijfers Tweewielers"). The euro class is based on the sales year.

Further classification of the sales counts per VERSIT+ class is based on the following assumptions:
- Before 2001 only 5% of Euro 2 mopeds had a four-stroke engine
- From 2007 onwards, the sales of mopeds with four-stroke engine was larger than that of two-stroke engines
- Two-stroke sales were only 10% from 2011 onwards
- Shares of electric vehicles are based on fleet statistics by CBS.

Sales data for moped cars is based on CBS data.

4.3.3 Total kilometres driven

The total vehicle mileage for motorcycles (including other heavy l-cats) for historic years is based on reports by CBS. As CBS no longer publishes the total mileage for motorcycles since 2020 the value for 2019 is kept constant. CBS is currently analysing the odometer data from motorcycles. When new values are calculated by CBS they will be introduced in the model. Vehicle mileages for light l-cats are calculated by the model itself, based on the yearly mileages estimated in 4.2.4.1.

4.3.4 Fuel prognosis

The share of electric vehicles for newly sold vehicles in future years is an input to the model. In the default input sheet (also used for the calculations in Chapter 5) a linear extrapolation of sales data from previous years is used.

4.3.5 Prognosis of new sales

The model provides three options for the calculation of newly sold vehicles.

The user needs to select an option and provide the associated input data:

- Equal fleet: The fleet size of all vehicle type remains constant. Outflow of vehicles is matched by an equal inflow, as explained in paragraph 4.5.1, and the user does not need to provide an input.
- New sales: The user specifies the new sales per vehicle type per prognosis year and the fleet size is calculated as explained in paragraph 4.5.2.
- Fleet size: The user specifies the fleet size per vehicle type per prognosis year and the new sales are calculated by the model, as explained in paragraph 4.5.3.

In the default input sheet, the fleet size option is chosen and the fleet size development from recent years is extrapolated linearly.

4.3.6 Prognosis of kilometres driven

The total kilometres driven for future years are defined in the input sheet. The default input sheet provides linear extrapolation of recent trends.

4.4 Calculations

4.4.1 Historic fleet development

4.4.1.1 Year-to-year fleet development historic years

The historic fleet is built up by adding new vehicles (new sales and import vehicles) and removing the outflow (based on the survival rate).

The base year for the calculation is 1960 and the base fleet are the new sales for this year. Then the following algorithm is repeated for subsequent years until the first bottom-up year (2011):

$$Number\ of\ vehicles\ (year+1) = \sum_{age} Number\ of\ vehicles\ (year)_{age} * survival\ rate_{age} + new\ sales\ (year) + \sum_{age} import\ vehicles * share\ import_{age}$$

4.4.1.2 Bottom-up fleet development

For bottom-up years (2011 until the last historic year), the fleet composition is known and can be used directly from the input sheet. However, since light l-cats have only been registered since 2005, the age distribution of older vehicles is unknown (all vehicles have 2005 as year of first registration (YFR)). Therefore, the age distribution of light l-cats from before 2005 is estimated on the basis of the last historic year (as described in 4.4.1.1):

$$Number\ vehicles_{age} = Number\ of\ light\ lcats\ (YFR = 2005) * Share\ of\ light\ lcats\ (2010)_{age}$$

4.4.1.3 Scaling to bottom-up composition and input number of vehicles

The fleet composition based on sales data is corrected on the basis of the bottom-up fleet composition by scaling the fleet size per VERSIT+ class (VC) to the first bottom-up year:

$$Number\ of\ vehicles_{VC}(year) = Number\ of\ vehicles_{VC}(year) * \frac{Number\ of\ vehicles_{VC}(2010)}{Number\ of\ vehicles\ bottom-up_{VC}\ (2010)}$$

Finally, the number of vehicles per vehicle category per year is scaled to the number of vehicles per year from the input file.

4.4.2 Kilometres driven

The kilometres driven are calculated by multiplying the number of vehicles per age class by their associated yearly mileage from the input sheet.

Afterwards, the kilometres driven per vehicle category are scaled to match the total kilometres driven from the input sheet.

Finally, the kilometres driven per road type are calculated by multiplying the total kilometres driven per vehicle type by the associated share per road type.

4.4.3 Emissions and fuel use

4.4.3.1 Emissions dependent on kilometres driven

Most emissions are calculated by multiplying the millions kilometres driven (MKM) per VERSIT+ class (VC) and road type (RT) by the associated emission factor (EF):

$$Emission_{VC,RT}[kg] = EF_{VC,RT}\left[\frac{g}{km}\right] * MKM_{VC,RT} * \frac{1}{1000}$$

4.4.3.2 Fuel use and fuel dependent emissions

Fuel use is calculated by multiplying the million kilometres driven (MKM) per VERSIT+ class (VC) and fuel type (ft) by the associated energy use (E) and heating value (HV). The fuel-dependent emissions are then calculated by multiplying the fuel use by the emission factor (EF) from the input file:

$$Emission_{VC,ft}[kg] = MKM_{VC,ft} * E_{VC}\left[\frac{MJ}{km}\right] * HV_{ft}\left[\frac{kg}{MJ}\right] * EF_{ft}\left[\frac{g}{kg}\right] * \frac{1}{1000}$$

Energy use for conventional (petrol or diesel powered) vehicles is derived from the CO2 emission factors, the carbon content of the fuel type and the heating value.

4.4.3.3 Emissions for petrol evaporation

VOC emissions from petrol evaporation consist of two parts. The first part (diurnal evaporation is calculated by multiplying the number of vehicles with the average number of days per year (365.25) and the emission factor. The second part (evaporation during running of the engine) is calculated by multiplying the kilometres driven by the emission factor. The total evaporative emissions are the sum of the two.

4.4.3.4 Electricity used

Energy used of electric vehicles (in MJ) is calculated by multiplying the kilometres driven by the energy use (in g/MJ).

4.5 Projection of fleet development

4.5.1 Equal fleet

When “equal fleet” (see 4.3.5) is selected in the input sheet, the model uses the new sales to maintain the fleet size per vehicle type. However, negative vehicle sales are not allowed so the fleet is allowed to grow when the number of imported vehicles is larger than the number of outflowing vehicles.

$$New\ sales\ (year + 1) = Min(Fleet\ (year) + outflow - \ import, 0)$$

The outflow is calculated in the same manner as for the historic years.

4.5.2 New sales

When "new sales" is selected, the new sales per vehicle type are taken directly from the input sheet and the fleet development is calculated in the same manner as for the historic years.

4.5.3 Fleet size

When "fleet size" is selected, the model uses the new sales to reach the fleet size from the input sheet. However, negative new sales are not allowed and the fleet can become larger than specified.

$$New\ sales\ (year+1) = Min(Fleet\ (year+1, input) - Fleet\ (year) + outflow - \ import, 0)$$

5 Model output

In this Chapter several results from the model calculations are shown. The historic results (up until 2023) are based on the actual development of the fleet as registered by the RDW and reported in the PRTR 2024. The outlooks (2025 onwards) are based on a model run with an updated version of the model. The results have not yet been used for any official outlook by PBL or others, and are therefore only added for illustrative purposes to show the working of the model. The input (and thus the result) does not necessarily reflect the effect of current policies.

5.1 Fleet development

At the start of the timeseries in 1990, the fleet of light l-cats consists purely of Euro 0 petrol mopeds (Figure 5.1). As no formal registration exists for the early years the fleet size is estimated at a constant 700 thousand vehicles. From 2005 onwards mopeds are registered by the RDW and it is possible the follow the development of the fleet size which has grown to about 1.2 million mopeds in 2020. Vehicles complying with stricter emission regulations gradually flow into the fleet. Diesel minicars ("brommobielen") have been in the fleet since 2004 but make up a limited part of the total fleet. Electric vehicles have taken a considerate share of new sales in recent years. Extrapolation of recent years leads to a steady increase of the fleet size with electric vehicles slowly replacing the ones with combustion engines.

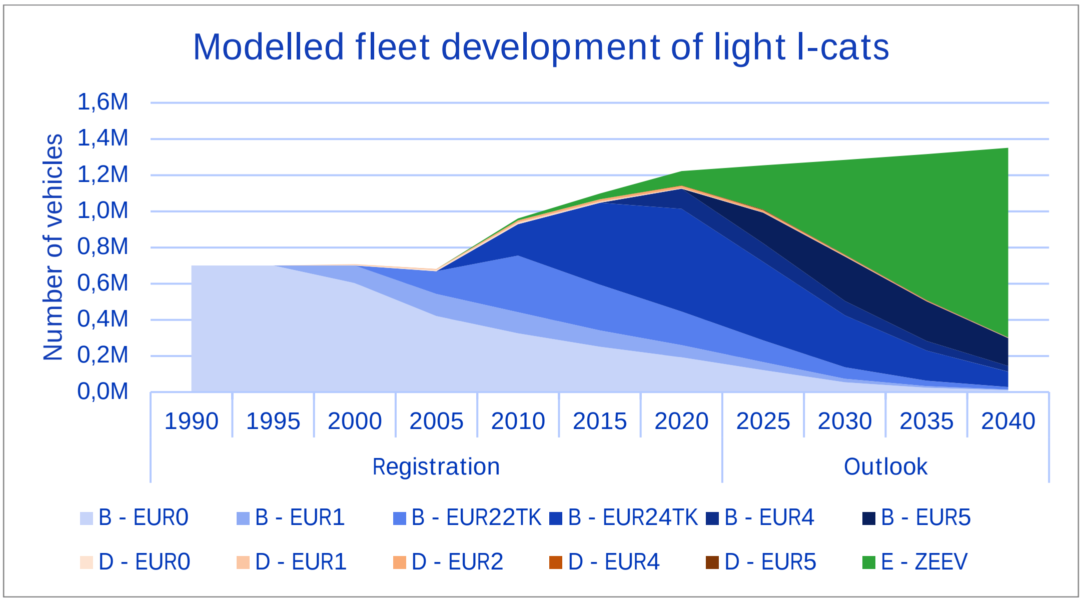


Figure 5.1: Modelled fleet composition of light l-cats per fuel type (B= petrol, D = diesel, E = electric) and euro class (2TK = two stroke, 4TK = four stroke, ZEEV = Zero-emission).

Figure 5.2 shows the modelled fleet composition of motorcycles and other heavy l-cats. Official registration of motorcycles exists since the beginning of the time-series. Since 1990, the total fleet has grown from 160 thousand motorcycles to about 700 thousand in 2020.

Unlike light l-cats electric motorcycles have not been registered on large scale in the Netherlands and petrol vehicles remain dominant in the fleet, also in the outlook. As heavy l-cats have a longer lifespan than light l-cats, the older euro classes remain in the fleet for a longer time.

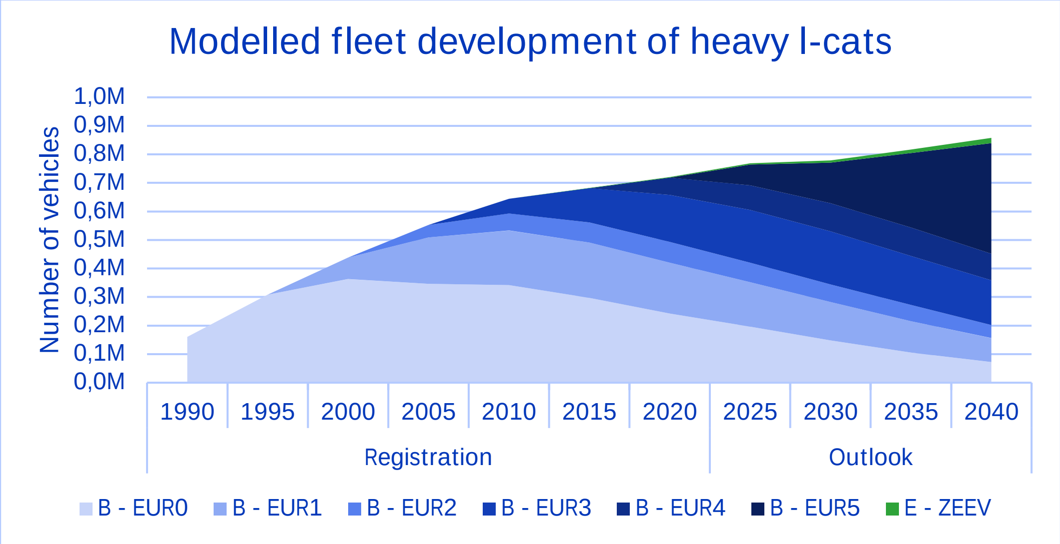


Figure 5.2: Modelled fleet composition of heavy l-cats per fuel type (B= petrol, E = electric) and euro class (ZEEV = Zero-emission).

5.2 Kilometres driven

The kilometres driven for light l-cats are calculated directly from the fleet composition. The result is shown in Figure 5.3. As younger vehicles are expected to drive the majority of the kilometres, the newer euro classes and electric vehicles make up a larger share of the kilometres than the fleet.

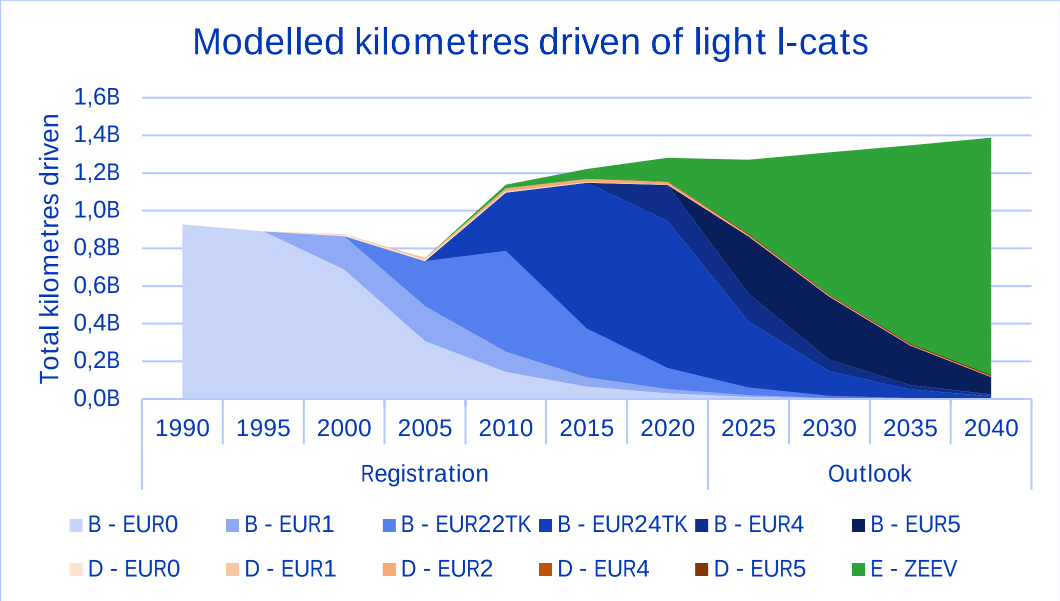


Figure 5.3: Modelled kilometres driven of light l-cats per fuel type (B= petrol, D = diesel, E = electric) and euro class (2TK = two stroke, 4TK = four stroke, ZEEV = Zero-emission).

For heavy l-cats the same can be seen in Figure 5.4 although a small share of Euro 0 vehicles still remain seen on the road, even in 2040.

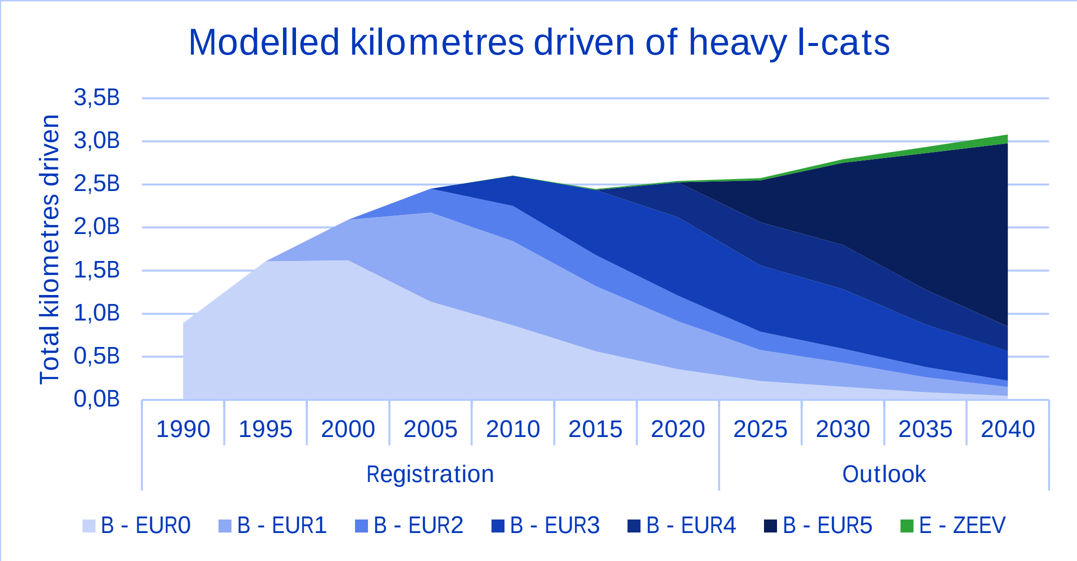


Figure 5.4: Modelled kilometres driven of heavy l-cats per fuel type (B= petrol, E = electric) and euro class (ZEEV = Zero-emission).

5.3 Emissions

The total emissions for CO and NMVOC are shows in this Chapter. These components are chosen since l-cats have a relatively large contribution to these emissions compared to other road vehicles. The total modelled emissions of carbon monoxide for light l-cats are shown in Figure 5.5. The graph shows that CO emissions for mopeds have decreased dramatically since the introduction of Euro 4. Electric vehicles obviously have no exhaust emissions.

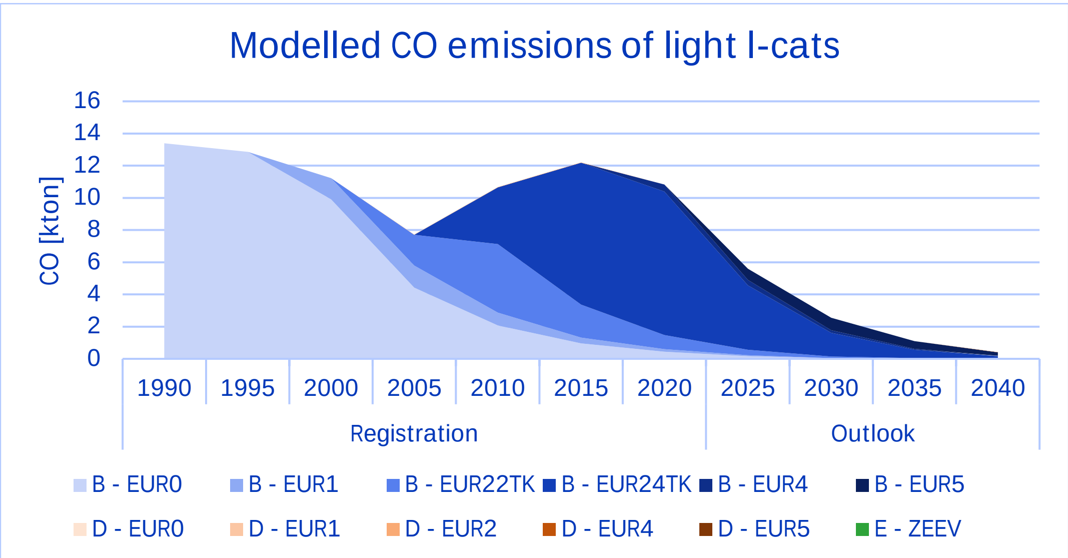


Figure 5.5: Modelled CO emissions of light l-cats per fuel type (B= petrol, D = diesel, E = electric) and euro class (2TK = two stroke, 4TK = four stroke, ZEEV = Zero-emission).

Figure 5.6 shows the modelled CO emissions of heavy l-cats. When comparing the picture to the kilometres driven it becomes clear that subsequent euro classes have decreased the emission factors for motorcycles. The total CO emissions have peaked in 2000 at about 40 kton and are expected to decrease to around 5 kton in 2040.

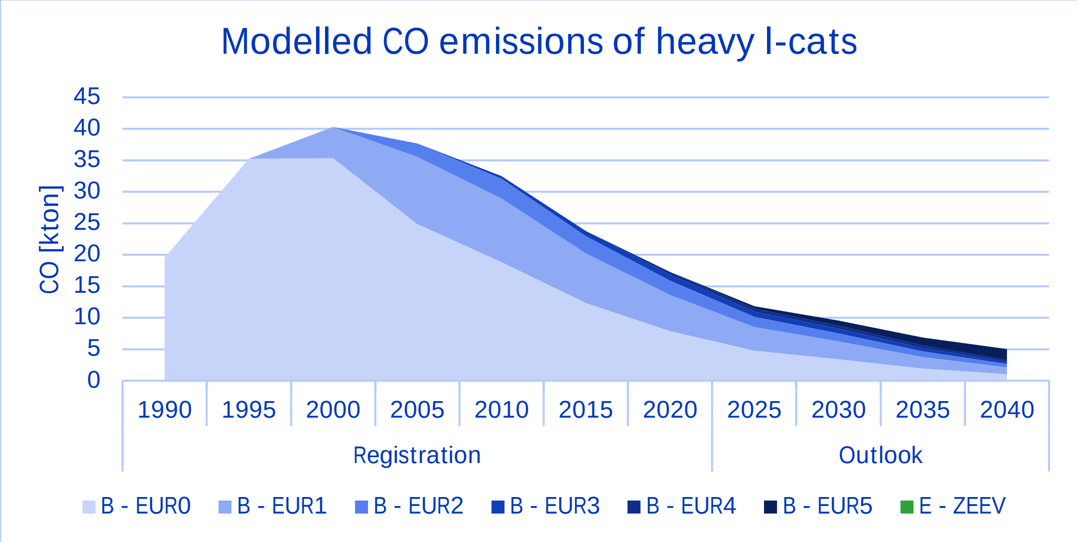


Figure 5.6: Modelled CO emissions of heavy l-cats per fuel type (B= petrol, E = electric) and euro class (ZEEV = Zero-emission).

NMVOC (Non-methane Volatile Organic Compounds) emissions for light l-cats have decreased with the introduction of subsequent euro classes but the biggest decreased was caused by the introduction of the four stroke engine (Figure 5.7). The modelled NMVOC emissions for light l-cats have decreased from 13 kton in 1990 to nearly 0 in 2040.

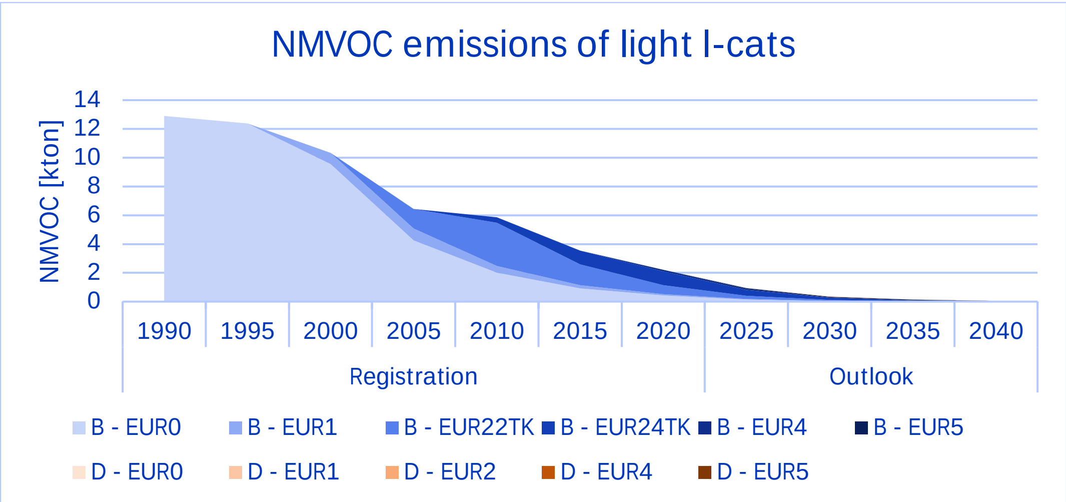


Figure 5.7: Modelled NMVOC emissions of light l-cats per fuel type (B= petrol, D = diesel, E = electric) and euro class (2TK = two stroke, 4TK = four stroke, ZEEV = Zero-emission).

Figure 5.7 shows the modelled development of NMVOC emissions for heavy l-cats. As for light l-cats the emissions have decreased with the introduction of new euro classes. Older motorcycles do not emit as much NMVOC as two stroke mopeds and the total emissions are thus significantly lower, peaking at 3 kton in 2000.

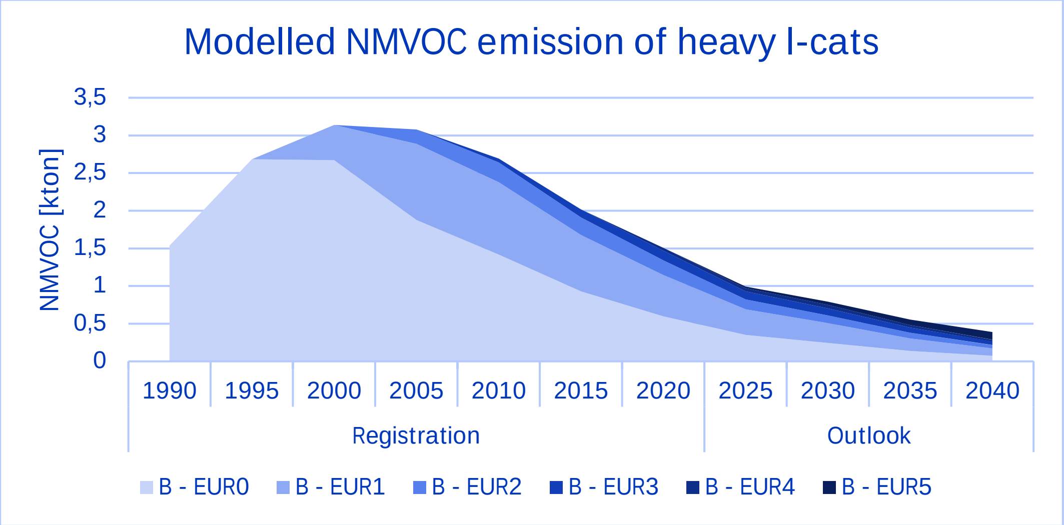


Figure 5.8: Modelled NMVOC emissions of heavy l-cats per fuel type (B= petrol, E = electric) and euro class (ZEEV = Zero-emission).

6 Discussion and recommendations

6.1 Total mileage mopeds is uncertain

The total mileage for mopeds is highly uncertain. The new methodology (based on the license plate scans) seems to be an improvement for the kilometres driven by older mopeds but is based on a limited number of license plate scans and readings of odometer meters. This is nowhere near as accurate as the kilometres driven for passenger cars and to lesser extent motorcycles as these are based on odometer readings on nearly the complete fleet. The license plate scans and odometer checks should be repeated regularly (at least once per 5 years).

6.2 Repeat odometer analysis now there is more data

The analysis of odometer data for motorcycles was conducted just after obligatory registration for all motorcycles. Now that there is more data available, the analysis should be repeated. When there is sufficient data available, motorcycles might be included in the bottom-up calculation for road traffic.

6.3 Updates of emission factors and speciation profiles

Some emission factors and speciation profiles have been copied from earlier versions of the model and need to be updated or at least checked if they are still up to date.

The following seem the most urgent:

- Speciation profiles for VOC and PAH are based on a literature study dating back to 2011, i.e. based on vehicles without proper aftertreatment systems and with much higher emissions.
- Emission factors for Euro 5 motorcycles are still based on preliminary estimations, before introduction. Emission factors should be based on the vehicles currently on the road.
- Particle emissions from wear are not well known, both for conventional and electric vehicles. Currently a single value is used for all vehicles. A first step could be to scale the emission factors to the mass and power of the vehicles.
- Particle emissions for e-bikes, speed-pedelecs and fatbikes are not included at all.

6.4 Keep on tracking trends in electrification

Trends in electrification of I-cats should be monitored closely and included in the model.

6.5 Ageing, malfunctioning, tampering, cold start and driving behaviour

Currently there is only one emission factor for each VERSIT+ class, i.e. the emission factors is assumed to be equal over the lifetime of the vehicle and the duration of a trip. However, especially for newer vehicles, the level of the emission factors depends on proper working of the aftertreatment systems.

For other vehicle types elevated emissions are seen in the following situations:

- Ageing: The working of the emission control systems reduces over the lifetime of a vehicle
- Defects: Defects in the emission control systems or other parts in the engine can have an impact on the emission levels.
- Modification and tampering: The working of the emission control systems reduces due to modifications to the vehicle or wilfully removing or turning of the emission control systems.
- Cold start: Emission control systems do not work properly during heating up of the engine
- Driving behaviour, sportive driving behaviour, especially with hard acceleration can increase the emission levels.

More research and measurement programs are required to see if these effects should be incorporated in the emission factors for I-cats.

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Signature

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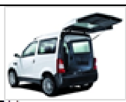
Jan Hoegee Research manager	Emiel van Eijk Author

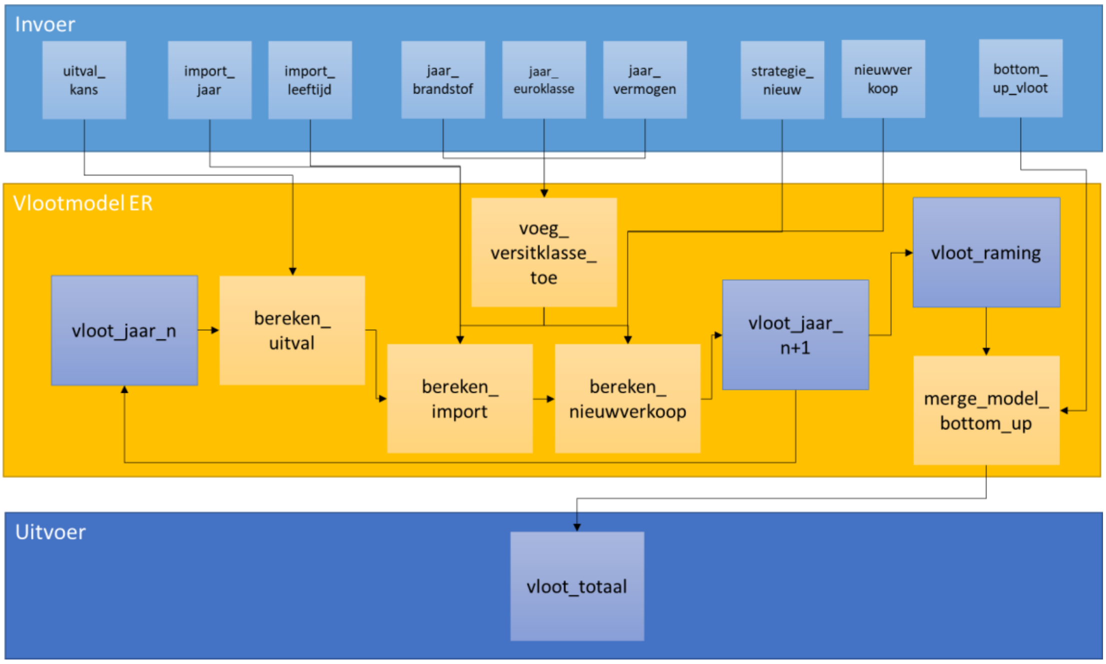
Appendix A
L-cat categorisation

Examples of l-cat vehicles per category (taken from [1]).

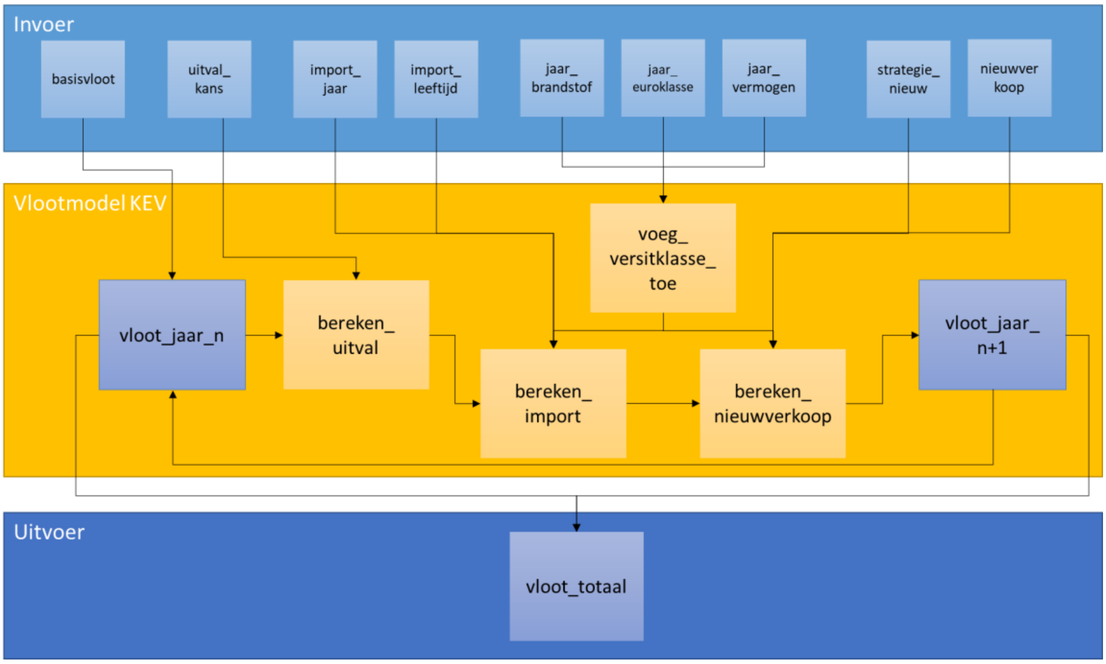
Vehicle categorisation	Typical Photos of Models			Key specifications
L1e- A Powered cycle				≤50 cc (PI), ≤25 km/h, ≤1 kW
L1e -B Two-wheel moped				≤50 cc (PI), ≤45 km/h, ≤4 kW
L2e Three-wheel moped	 L2e-P	 L2e-U		≤50 cc (PI) / ≤500 cc (CI), ≤45 km/h, <4 kW, ≤270 kg
L3e Two-wheel motorcycle	 L3e-A1	 L3e-A2	 L3e-A3	A1: ≤125 cc, ≤11 kW, ≤0.1 kW/kg A2: ≤35 kW, ≤0.2 kW/kg A3: >35 kW, >0.2 kW/kg
L4e Two-wheel motorcycle with side-car				Equivalent to the corresponding L3e
L5e-A Tricycle				3 wheels, ≤1000 kg, max 5 seats
L5e-B Commercial tricycle				3 wheels, ≤1000 kg, max 2 seats, loading volume ≥ 0.6m^3
L6e-A Light on-road quad				≤50 cc (PI) / ≤500 cc (CI), ≤45 km/h, ≤4 kW, ≤425 kg
L6e-B Light quadri-mobile	 L6e-BP	 L6e-BU		≤50 cc (PI) / ≤500 cc (CI), ≤45 km/h, ≤6 kW, ≤425 kg
L7e-A Heavy on-road quad	 L7e-A1	 L7e-A2		≤15kW, ≤450 kg
L7e-B Heavy all terrain quad	 L7e-B1	 L7e-B2		B1: ≤90 km/h, ≤450 kg B2: ≤15kW, ≤450 kg
L7e-C Heavy quadri-mobile	 L7e-CU	 L7e-CP		CU: ≤90 km/h, ≤15kW ≤600 kg CP: ≤90 km/h, ≤15kW ≤450 kg

Appendix B
LIMBO model flowcharts

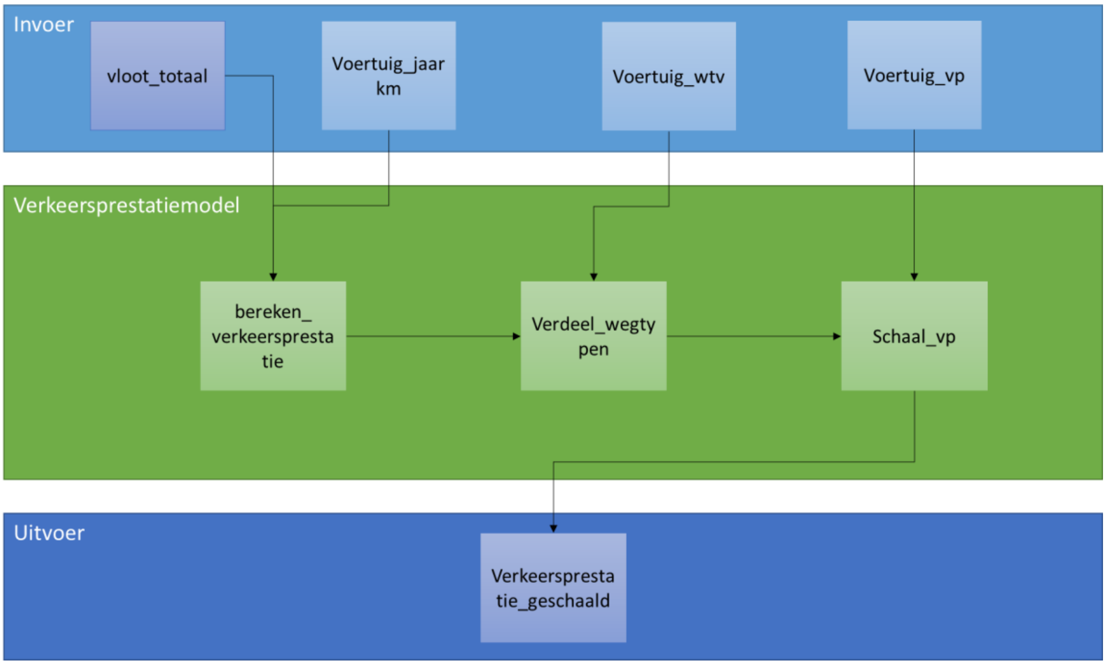
B.1 Fleet model PRTR



B.2 Fleet model KEV

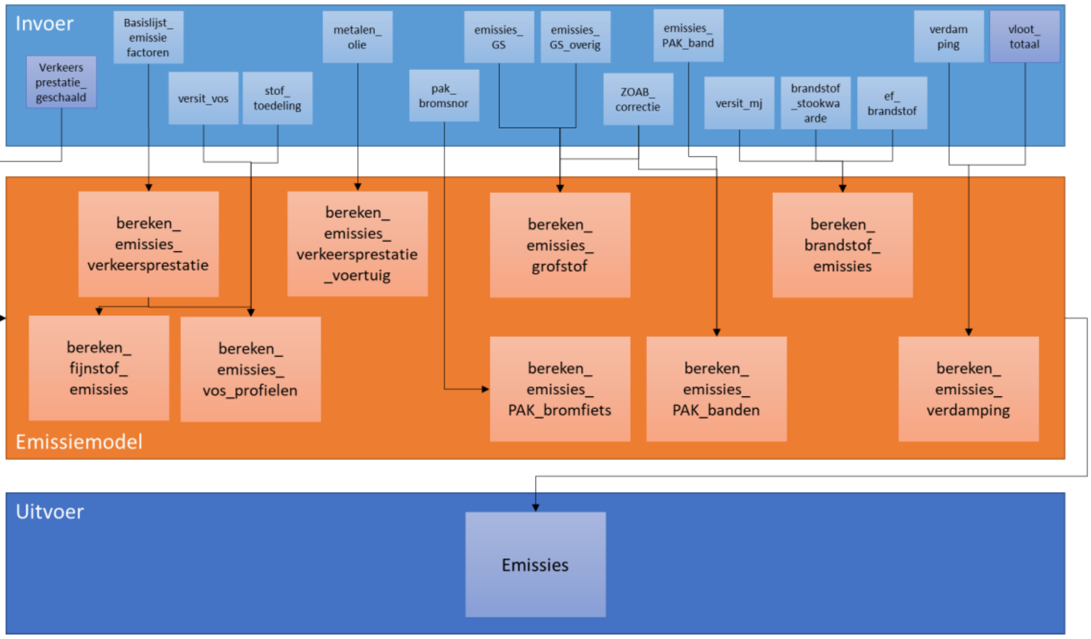


B.3 Traffic performance model



wtv = Wegtypeverdeling (road type distribution)
vp = verkeersprestatie (traffic performance or total kilometres driven)

B.4 Emission model



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