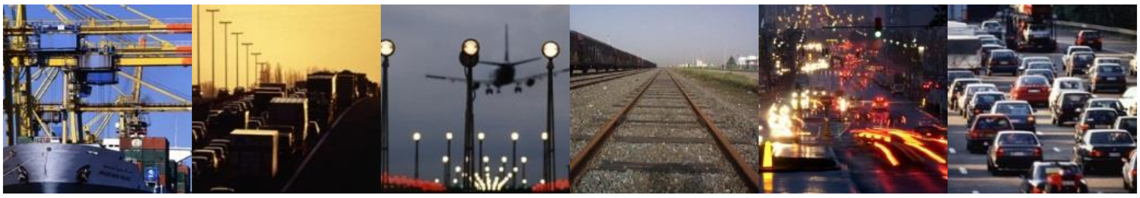
Powered two-wheelers and their impact on mobility, the environment and road safety

A study on the Belgian market

Report by **Transport & Mobility Leuven** (Rosanne Vanpée, Roeland Vandenberghe) in cooperation with **VIAS Institute** (Kishan Vandael Schreurs, Aline Delhaye) and **FPS Mobility and Transport**

20 April 2022



TRANSPORT & MOBILITY LEUVEN

Transport & Mobility Leuven
Diestsesteenweg 57
3010 Leuven
Belgium
www.tmleuven.be

VIAS institute

Federale Overheidsdienst Mobiliteit en Vervoer
Service public fédéral Mobilité et Transports

Contents

Executive summary

Powered two- and three-wheelers (PTWs) currently represent a relatively small part of the vehicle fleet in Belgium, but their share is growing fast. Especially smaller motorized two-wheelers including mopeds, scooters and speed pedelecs demonstrate double digit growth numbers in terms of new registrations. The number of motorcycles in Belgium increases as well, although at a slower pace than mopeds. At the same time, the market for passenger cars is stagnating.

Despite this significant growth in PTW activity, this transport mode has been largely ignored in the literature. Only a handful of studies examine the potential of PTWs for **sustainable and affordable mobility**. In an attempt to make transportation more environmental friendly, research and policy has been dedicated to a modal shift from passenger cars to more sustainable modes. A shift towards bicycles and public transportation has been the main focus. However, these modes have their limitations. Bicycles are only a good alternative to cars for short distance trips and public transportation services remain limited in rural areas. PTWs have many advantages being a flexible mobility solution, offering economic and environmental benefits.

This study fills the research gap on the potential of PTWs for sustainable mobility in Belgium. We first provide an overview of the market for PTWs in Europe and Belgium and we describe new trends and tendencies. Mopeds, scooters and speed pedelecs are becoming increasingly popular in Belgium. These smaller PTWs are mostly used in suburban areas. Motorcycle ownership is most prevalent in rural areas.

The strong rise in small PTWs is driven by a trend towards **electrification** and **flexible urban mobility**. Mopeds and scooters are easy to electrify because they require smaller batteries than cars and these batteries can be swapped relatively easily. E-mopeds are very suitable vehicles for **shared mobility** and **Mobility as a Service (MaaS)** solutions.

The core of this study consists of **a social cost-benefit analysis of a modal shift from passenger cars to PTWs during the period 2025 to 2030**. We assess the impact of two scenarios:

- a **mild modal shift scenario** (Alternative 1) that builds on the projections for PTW transport activity based the European Climate Action Plan and the European Green Deal;
- a **strong modal shift scenario** (Alternative 2) that is based on the traffic and modal shift ambitions of the regional mobility plans.

We compare each of these modal shift scenarios with a Reference Scenario and **we calculate and monetise the impact of such a modal shift on traffic congestion, total costs of ownership, road safety, air and noise emissions, the occupation of public space and the health effects from riding speed pedelecs**. The impact of the modal shift scenarios is projected over the period 2025 to 2050. We calculate **the net present value of all economic and societal costs and benefits** at constant prices of the year 2021.

A summary of the results of this cost-benefit analysis is shown in the table below.

The mobility effects of a modal shift are estimated separately on the primary road network (highways and ring roads), the regional road network and the urban road network. For the primary road network we used fitted **congestion functions** in each region (Brussels, Flanders and Wallonia). To estimate the mobility effects on the regional and urban road networks, we used

VISSIM microsimulations in which we modelled the driving behaviour of the different vehicle types.

We find that a modal shift from cars to PTWs leads to important mobility benefits by **easing traffic congestion which results in significant time savings** for road users. In the mild modal shift scenario, that assumes a strong uptake of PTWs but only a small shift from passenger cars, the mobility benefits are mainly realized on the urban road network. In an urban traffic situation, PTWs move faster than cars. In the strong modal shift scenario, the uptake of PTWs coincides with a decrease in car traffic. This leads to very large mobility effects. The monetary benefits are the largest on the regional road network because this is the most congested road network in Belgium.

	Mild modal shift	**Strong modal shift**
Mobility effects	**€ 1 533**	**€ 31 747**
Primary road network	€ 307	€ 7 829
Regional road network	€ 289	€ 15 476
Urban road network	€ 938	€ 8 442
Cost of ownership	**€ 3 850**	**€ 36 597**
Road safety	**-€ 15 545**	**-€ 60 855**
Emissions	**€ 448**	**€ 7 954**
Air pollution	€ 19	€ 362
Climate change	€ 429	€ 7 592
Noise	**-€ 290**	**€ 3 192**
Space	**€ 37**	**€ 2 129**
Health active modes	**€ 1 752**	**€ 9 423**
TOTAL	**-€ 8 215**	**€ 30 187**
Benefit Cost Ratio (BCR)	**0.48**	**1.50**

A second benefit from the modal shift to PTWs are the savings with respect to private ownership costs. We calculated the total cost of ownership (TCO) per vehicle mode expressed in euro per 100 vehicle kms. **PTWs are cheaper to purchase and to operate than cars, leading to much lower TCOs**.

As a third benefit, we find that **PTWs are a more sustainable mode of transport than passenger cars because they emit less greenhouse gases and other air pollutants**. In addition, the moped segment is already more electrified than the passenger car fleet, further contributing to lower emissions.

The majority of electric mopeds are pedal-assisted mopeds or speed pedelecs. This means that these vehicles are not only environmental friendly and silent, they also require the rider to be active. This active transport mode generates **important health benefits**.

Being several times smaller than cars, **PTWs require less space**. They are allowed to park on the sideway, provided that there remains sufficient space for pedestrians to pass. Their small size and space occupation is a great asset in an urbanised environment where competition for public space is high. We calculate the societal benefit from the static space occupation resulting from the modal shift from cars to PTWs and find this effect to be positive. This is especially the case in the strong modal shift scenario, where we assumed that the uptake in PTWs coincides with a reduction in passenger cars.

A modal shift from cars to PTWs creates one important cost to society. Because PTW riders are more vulnerable than car drivers, an uptake in PTW activity creates **accident costs**. We find that these accident costs are large. In the mild modal shift scenario, the high accident costs result in a negative societal value for the cost-benefit analysis.

It is important to note that the qualification of accident risk and the calculation of accident costs is not straightforward. Following the cost-benefit methodology, we calculate future accident risk based on historical accident statistics. This is problematic because the method is not forward looking. It doesn't take into account the impact of safety plans and regulations, improvements in infrastructure, technological innovations, and changes in rider and driver behaviour. We can take this partially into account by allowing for a decreasing trend in accident risk and by correcting for the safety-in-numbers effect (i.e. when traffic volume increases, accidents increase at a lower rate). However, accident risks might still be overestimated. Therefore, without minimalizing the issue of traffic safety, we advise to interpret the accident costs with caution.

PTWs have a bad reputation when it comes to producing **traffic noise**. Several studies and surveys show that the noise produced by PTWs is not only harmful, but also causes annoyance. Intuitively, one would expect that a modal shift towards PTWs would create high noise costs to society. In this respect, our study brings positive news. **We find that the noise costs resulting from a modal shift to PTWs are very small**. In the high modal shift scenario, we show that noise emissions create even a benefit. This result depends crucially on the assumption that was made with respect to electrification. We expect a strong electrification for mopeds and motorcycles, resulting in a significant noise reduction. E-motorbikes produce very little noise, even less than cars because of their lower weight. In case the high share of electric motorcycles would not be realized and zero-emission vehicles are driven by bio fuels or e-fuels, positive noise costs could arise.

Overall, we find that a strong modal shift from passenger cars to PTWs leads to large benefits to society. **The net present value of the strong modal shift scenario is equal to € 30 187 million**. The benefit-to-cost ratio is equal to 1.5 which means that the value of the benefits are 150% higher than the value of the costs. **The net present value of the mild modal shift scenario is negative, at € -8 215 million**. The reason for this negative NPV are the high accident costs. As stated earlier, these accident costs are to be interpreted with caution.

The table above shows the quantification of the costs and benefits for Belgium. In the report, we calculate the costs and benefits of the modal shift scenarios per region. These results show that **a modal shift from cars to PTWs is most beneficial in Flanders**. This is because traffic congestion is most severe in Flanders. Therefore, the mobility benefits are predominantly realized in that region. At the same time, accident risk is the lowest in this region, leading to relatively smaller accident costs than in Brussels and Wallonia.

List of abbreviations

ABS	Anti-lock bracking system
ACEM	The Motorcycle Industry in Europe
ARAS	Advanced Rider Assistance Systems
BCR	Benefit-Cost Ratio
BEV	Battery electric vehicle
C-ITS	Cooperative Intelligent Transport System
CMC	Connected Motorcycle Consortium
ITF	International Transport Forum
ITS	Intelligent Transport System
MaaS	Mobility as a Service
NPV	Net Present Value
OBIS	On-Bike Information Systems
PMR	Power to mass ratio index
PTW	Powered two-wheeler
SCBA	Social cost-benefit analysis
TCO	Total Cost of Ownership
vkm	Vehicle kilometres

Introduction

Over the past two decades, the use of powered two- and three-wheelers has increased significantly all across Europe. Especially in European cities, the number of powered two-wheelers (PTWs) circulating through the streets has grown fast and steady. Belgium is no exception to this trend. The number of PTW registrations has increased at an accelerating pace of the past few years.

The popularity of PTWs as a transport mode is not surprising because motorized two-wheeled mobility provides an answer to several challenges in passenger transportation. In Europe's highly congested cities, PTW riders benefit from shorter travel times in dense traffic because they are able to manoeuvre between cars. But not only time costs for PTW riders are lower than for car drivers. Most PTWs incur significantly lower purchase, maintenance and operating costs compared to cars. Lower time costs and lower costs of ownership make PTWs attractive as personal transport mode, especially in times when purchasing power is under pressure due to rising commodity and energy prices.

Apart from these private benefits, PTW-use has also benefits for society. Motorcycles, scooters and mopeds emit less greenhouse gases than cars. Fighting climate change is one of the main priorities of the European Commission and national policy makers. Policy actions are taken to reduce the emissions of the transport sector. A modal shift from cars to PTWs can contribute to reducing emissions, especially in the case of electric vehicles.

Another advantage of PTWs is their size. Thanks to their relatively small size, they take up less road space than passenger cars. This means that less public space needs to be reserved for parking area. For the rider, this ease of parking is also beneficial. In rush hours, car drivers may spend a considerable amount of time finding a parking spot, while in the case of PTWs, this problem is negligible (Dorocki & Wantuch-Matla, 2021). Hence, the size advantage enhances the advantages of time savings and emissions. Because motorcycles are easier to park, this saves time compared to a car, and also emissions, as additional travel to search for a parking space is not required.

Since the COVID-19 pandemic, PTWs provide an attractive alternative to public transportation. Many public transport users became reluctant to sit in a bus or tram with many others. Shared mobility solutions such as shared e-scooters and e-mopeds have become a popular type of personal transport.

Despite the growing number of PTWs on our streets and the benefits to society if car trips are swapped for trips with a motorized two-wheeler, PTWs have received little attention from researchers and policy makers. One reason why policy makers have been reluctant to promote PTW use is the accident risk associated with PTWs and their reputation for creating noise hindrance. Because the benefits associated with the use of PTWs are so substantial, it is surprising that policy makers have refrained from implementing measures to tackle the disadvantages associated with PTW-usage. Regional mobility plans and road safety plans in Belgium still pay little attention to this means of transport.

A second reason why PTWs have been overlooked by policy makers is the lack of research on this transport mode. While there is a plethora of studies investigating the consequences of and motivations for car use, only a handful of studies considers PTW usage.

This studies aims to fill this gap and intends to provide policy makers with clear answers to the question whether and to what extent PTW use is beneficial to society. We perform a cost-benefit analysis in which we assess the consequences of two modal shift scenarios. Both modal shift scenarios assume a modal shift from passenger cars to PTWs in Belgium over the period 2025 to 2030. We determine and quantify the costs and the benefits of these modal shift scenarios compared to a business-as-usual reference scenario up to the year 2050.

The first modal shift scenario, Alternative 1, is based on the policy scenarios for the European Green Deal action plan. Alternative 1 assumes a doubling of motorbike kilometres and a 150% increase of moped kilometres over the period 2025-2030. This increase in PTW-use is caused by a mix of modal shift motives, notably a switch from passenger cars, public transportation and autonomous traffic growth.

The second modal shift scenario, Alternative 2, starts from the ambitions set in the regional mobility plans in Belgium. These mobility plans aim for a strong decrease in passenger car kilometres. We apply this reduction of car kilometres by differentiating over road networks (primary roads, regional roads and urban roads). We assume that half of the reduction in car kilometres is picked up by powered two-wheelers.

In addition, each modal shift scenario assumes a faster electrification of the PTW segment than what is foreseen in the reference scenario.

We calculate the impact, costs and benefits of each modal shift scenario on different aspects:

- mobility (impact on congestion),
- total costs of ownership,
- road safety,
- emissions,
- spatial aspects.

Two earlier studies are similar to ours. Kopp (2011) makes a cost-benefit analysis of the increase in two-wheeled motorized traffic in Paris during the period 2000 to 2007. He finds the impact of this rise in PTW use to be overly positive to society, and estimates the net benefits at € 168.1 million. The dominant contributor to this positive societal value are the time savings realized by PTW riders. Kopp's study differs from ours because it is backward looking, while we analyse current trends and policies to create forward looking traffic scenarios. Also, he considers a shorter time period (8 years), while we use traffic forecasts up to 2050 (26 years). We also take into account additional factors such as the impact of noise and space occupation, two factors that were not considered in Kopp's study.

The second related study is done by Oxford Economics (2021) that investigated the economic importance of motorcycles to Europe. The focus of that study is different from our focus, because it mainly analyses the contribution of the motorcycle industry to the European economy (in terms of employment, contribution to GDP,…). A small part of the study investigates the user and environmental benefits of PTW use. The factors considered are time savings, private operating costs and emissions, which all are found to be important. A limitation of the study is that it does not consider the disadvantages of PTW use.

This study is based on an objective evaluation of potential modal shift scenarios from cars to PTWs in Belgium. The analysis is based on data from official, independent sources and we follow the European guidelines for social cost-benefit analysis, where they apply. The modal shift scenarios are built on a synthesis of policy, regulations and trends. Based on the results of this study, we can provide informed policy advice on whether and to what extent PTW-supporting policies are desirable from a societal viewpoint. In addition, we contribute to the debate on the relative effectiveness of cars versus PTWs as a mean of personal transport.

The remainder of this study is structured as follows. In the first chapter, we provide a clear definition of powered two-wheelers and the different vehicle types in this segment. Chapter 2 provides an overview of the European and Belgian market for PTWs and discusses recent trends. In Chapter 3, we briefly discuss relevant policies and regulation. Chapter 4 presents the scenarios that are considered in the cost-benefit analysis. Chapter 5 explains the methodology. The impact of the modal shift scenarios in discussed in Chapters 6 to 11, that respectively cover mobility effects, total cost of ownership, road safety, emissions, noise and space occupation. Other effects which are not calculated in the cost-benefit analysis are qualitatively discussed in Chapter 12. Finally, Chapter 13 concludes and provides policy recommendations based on our findings.

1 Powered two-wheelers: definition and classification

The term powered two (or three)-wheeler (PTW) is used for a range of two or three wheeled vehicles from mopeds (motorized vehicles with an engine below 50 cm^3 and a maximum speed of 45 km/h) to scooters (engine between 50cc and 250cc and small 10-inch wheels) and motorcycles. Powered two-wheelers are part of the L-category vehicles as defined in EU Regulation 168/2013.[1] L-category vehicles include powered cycles, mopeds, motorcycles, tri- and quadricycles.

EU Regulation 168/2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles provides a clear definition of the different types of L-category vehicles. A full overview of this categorisation is provided in Annex 1. Figure 1, copied from Pavlovic and Fragassa (2015) shows the name of each subcategory together with an illustrated example.

Powered two-wheelers must also be distinguished from micro mobility modes, as demonstrated by Figure 2.

In this report, we make a distinction between mopeds and motorcycles. Mopeds comprise the categories L1e and L2e and have the following characteristics:

- two or three wheels and powered by a propulsion,
- engine capacity ≤ 50 cm3 in case of a positive ignition internal combustion engine, or engine capacity ≤ 500 cm3 for a compression ignition engine combustion engine,
- maximum speed ≤ 45 km/h,
- maximum net power ≤ 4 000 W and,
- mass in running order ≤ 270 kg

Motorcycles include the categories L3e to L7e and consist of all two-wheel, three-wheel and four-wheel motorbikes.

In the remainder of this study, we will refer to mopeds, scooters and motorcycles as powered two-wheelers (PTWs). PTWs include all the vehicles in category's L1e to L7e, shown to the right in Figure 2.

[1] https://eur-lex.europa.eu/eli/reg/2013/168/oj

Category		Subcategory		Example
L1e	Light two-wheel vehicle	L1e-A	Powered cycles	
		L1e-B	Moped	
L2e	Three wheel moped			
L3e	Motorcycle	A1, A2, A3		
L4e	Motorcycle with side car			
L5e	Tricycle	L5e-A	Tricycles	
		L5e-B	Commercial Tricycles	
L6e	Light quadricycle	L6e-A	Light quad	
		L6e-B	Light mini car	
L7e	Heavy quadricycle	L7e-A1 L7e-A1	On road quad	
		L7e-B1	Heavy all terrain quad	
		L7e-B2	Heavy all terrain quad side-by-side buggy	
		L7eC	Heavy Quadri-mobile	

Figure 1 Typology of L-cat vehicles Source: Pavlovic and Fragassa (2015)

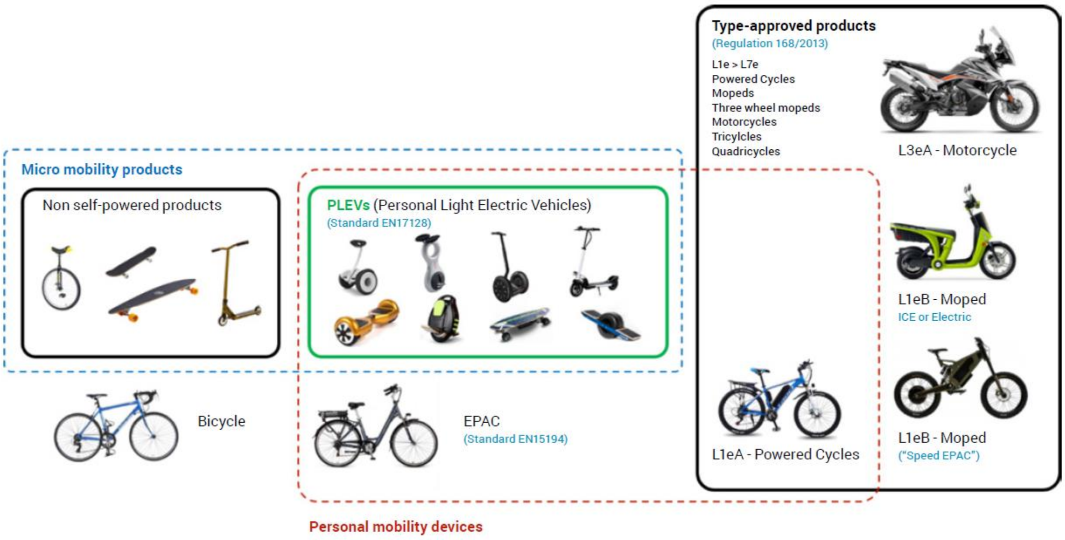


Figure 2 Micro mobilty, PLEVs and Powered two-wheelers
Source: ACEM (2021)

2 Market size and forecast

2.1 Powered two-wheelers: global market outlook and trends

2.1.1 Global and European market

In Europe, powered two-wheelers are most common in southern countries (Greece, Italy and Spain) with more than 100 PTWs per 1,000 people. Figure 3 shows the evolution of PTW ownership for a selection of European countries and the EU average over the period 1994 to 2019. The average number of PTW vehicles per 1,000 people in Europe increased from 39.3 in 1994 to 67.8 in 2019.

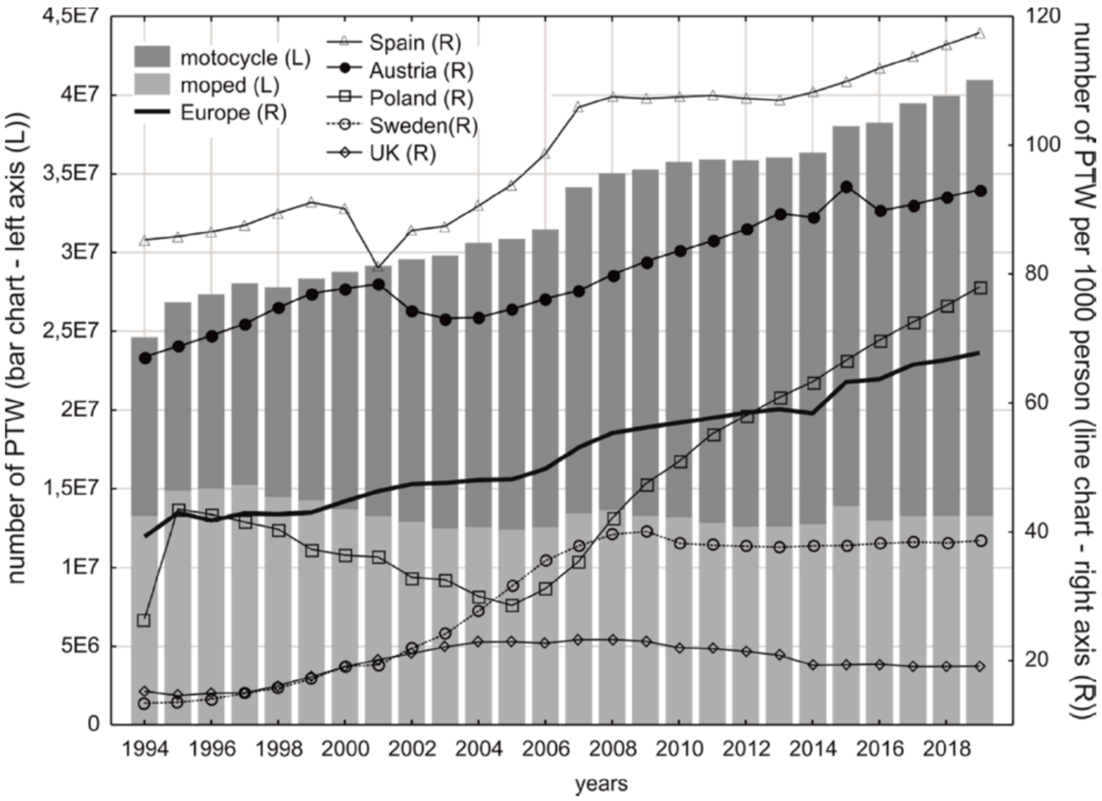


Figure 3 PTW fleet and PTW per 1,000 inhabitants in selected European countries 1994-2019. Source: (Dorocki & Wantuch-Matla, 2021)

The market for powered two-wheelers was able to withstand the COVID-19 crisis quite successfully. Although the industry has been hit by preventive measures such as lockdowns and telework, demand for PTW remained strong as a consequence of the waning popularity of collective transportation. The pandemic has accelerated the demand for individual mobility solutions, which translated to a rising demand for powered two-wheelers.

Projections for global PTW sales vary depending on the source, but there is agreement among analysts that the industry will experience a solid growth in the coming ten years. Fortune Business

Insights (2021) forecasts global motorcycle sales to increase at an annual growth rate of 7.2% in the 2021 to 2028 period. Fact.Mr predicts a more modest compound annual growth rate (CAGR) of 3.5% for the period 2021-2031.[2] Global Market Watch projects a CAGR of 3.8% for 2021-2030.[3]

2.2 Powered two-wheelers in Belgium

This study investigates the impact of a modal shift to powered two-wheelers for Belgium. Therefore, we provide a closer look on the Belgian vehicle fleet and the market for PTWs. We first provide statistics at country level and subsequently zoom in at the three regions, Brussels, Flanders and Wallonia.

2.2.1 Country level

Total vehicle fleet

Figure 4 shows the composition of the Belgian vehicle fleet (excluding agricultural vehicles and special purpose vehicles) from 2014 to 2021. Cars dominate the Belgian fleet. Nevertheless, powered two-wheelers have increased in importance, growing from a 6.8% share to a share of 10% of the total fleet.[4] Because the numbers in Figure 4 do not contain e-bikes with a speed limit up to 25km/h (L1eA category vehicles), the actual share of PTW in the Belgian fleet is even higher.

The motorcycle fleet is larger in absolute numbers than the moped fleet. However, the moped fleet is catching up quickly. In 2017, since registration of all mopeds was mandatory, mopeds accounted for 24% of all L-category vehicles. By the end of 2021, their share has risen to 32% (Figure 5).

---

[2] https://www.factmr.com/report/7/motorcycle-market

[3] https://www.marketwatch.com/press-release/global-motorcycle-market---global-industry-analysis-size-share-growth-trends-and-forecast-outlook-2030-2021-12-21

[4] Data on L1e-category vehicles (powered cycles and mopeds) is incomplete before 2017. Registration of new mopeds is mandatory in Belgium as of March 31, 2014. As of December 10, 2016 all mopeds have to be registered in Belgium, also those purchased before 2014. This means that data on mopeds is only complete as of the year 2017.

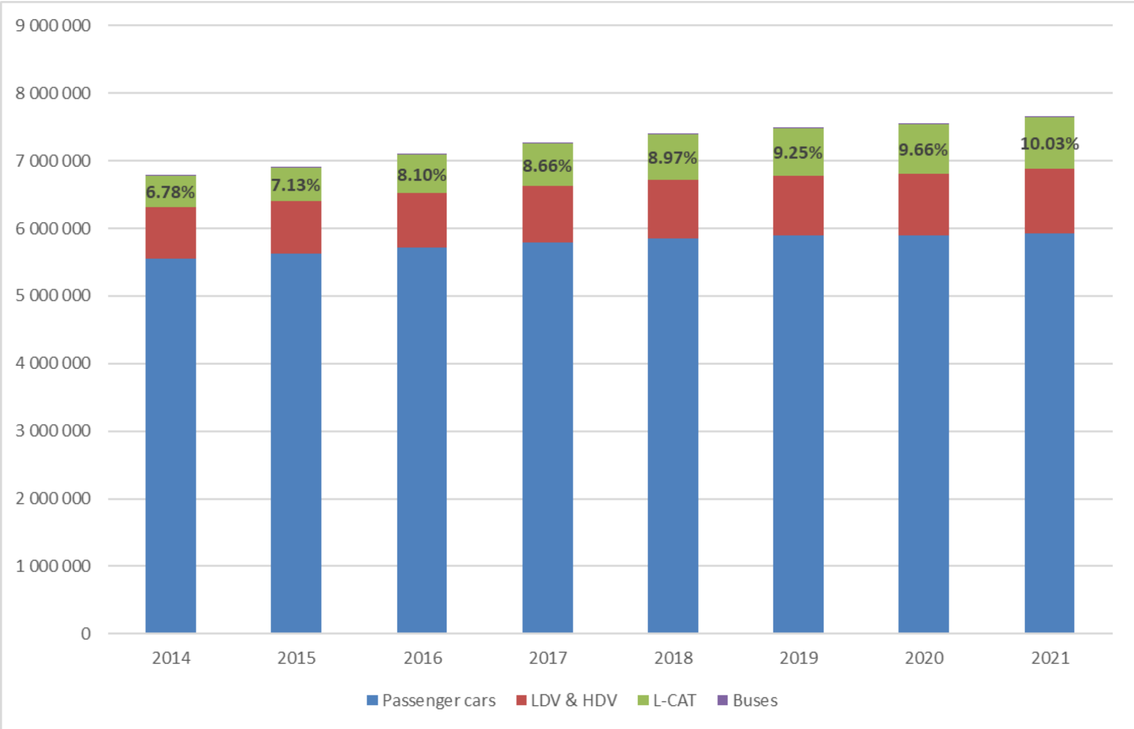


Figure 4 Belgian road vehicle fleet 2014-2021. Source: Febiac and Statbel

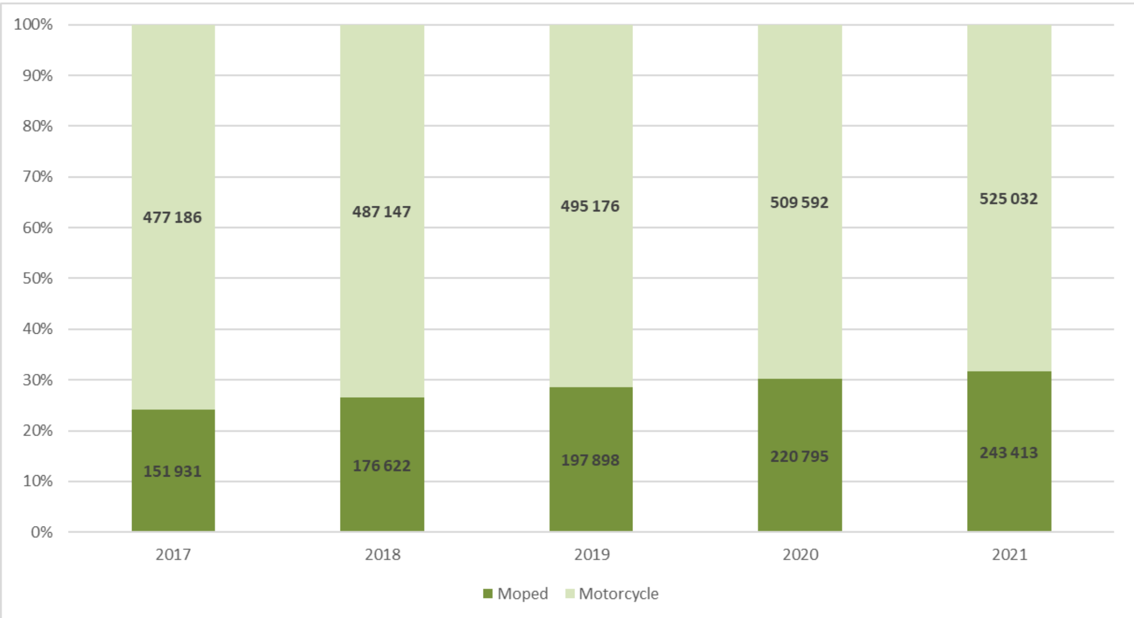


Figure 5 Moped and Motorcycle fleet in Belgium 2017 – 2021. Source: Febiac and Statbel

The classification of mopeds at the Belgian registration office (DIV) is not fully consistent with the European classification. Two-wheeled mopeds with a speed limit up to 45km/h (class B) are often classified with vehicle kind code L2.

According to this definition, 220 795 mopeds and 509 592 motorcycles were registered in Belgium in 2020. Per 1,000 inhabitants, this corresponds to 19.2 mopeds and 44.3 motorbikes. For comparison, the Belgian car fleet has a size of 512 passenger cars per 1 000 inhabitants.

Figure 6 and Figure 7 show respectively the number of registered mopeds and motorcycles in Belgium over time. Note that moped registrations are only complete as of 2017. Both figures show a steady increase in the PTW vehicle fleet in Belgium.

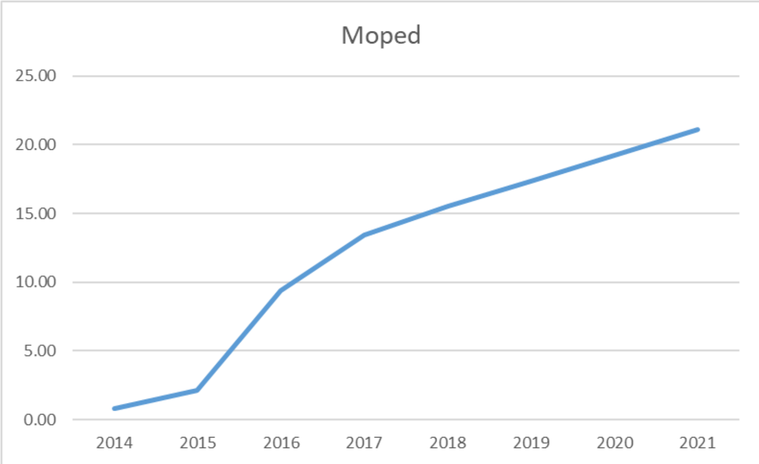


Figure 6 Registered mopeds per 1 000 inhabitants in Belgium

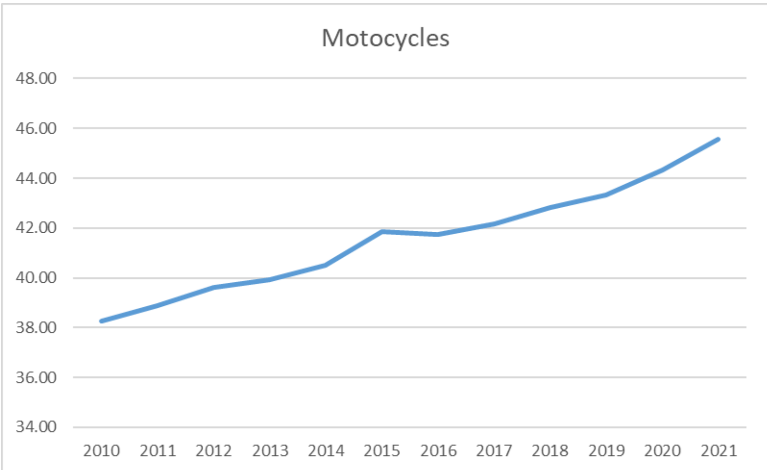


Figure 7 Registered motorcycles per 1 000 inhabitants in Belgium

The number of registered powered two-wheelers experienced a significant growth over the past three years. As shown in Table 1, the number of registered mopeds has increased by 15.7 percent in 2018 and by 11 percent in 2019 and 2020. The number of registered motorcycles has experienced a more modest growth (between 0.99 and 2.36 percent per year).

We observe a disconnect between the growth rates of the passenger car fleet and PTWs. Where PTWs are catching up at a steady pace, the number of registered cars per 1,000 inhabitants grows at a much smaller rate and even had negative growth rate in 2020.

Figures for the 2020 are not representative because it was an abnormal year due to COVID-19. Therefore, it is hard and too early to tell whether the negative growth rate in car registrations and the positive growth rates for PTW reflects a structural modal shift from passengers cars to two wheelers. Nevertheless, the accelerating growth of PTW registrations in Belgium is a clear trend that seems continuous for several years.

Table 1 Yearly growth rates in number of vehicles per 1,000 inhabitants in Belgium

	Mopeds	Motorcycles	Cars
2017	NA	0.99%	0.80%
2018	15.7%	1.60%	0.70%
2019	11.5%	1.16%	0.12%
2020	11.0%	2.36%	-0.54%
2021	10.0%	2.77%	0.42%

Source: DIV and Febiac

New vehicle sales

In terms of number of new vehicle sales per year (Figure 8), the number of new motorcycles is relatively stable at about 25 000 new motorbikes per year. The number of new mopeds has increased considerably over the period 2014-2020. The two most recent years, 2020-2021, seem to show a stagnation in new moped sales. However, this does not necessarily reflect a sluggish demand for mopeds. The industry is faced with supply problems due to the global shortage in semiconductors.

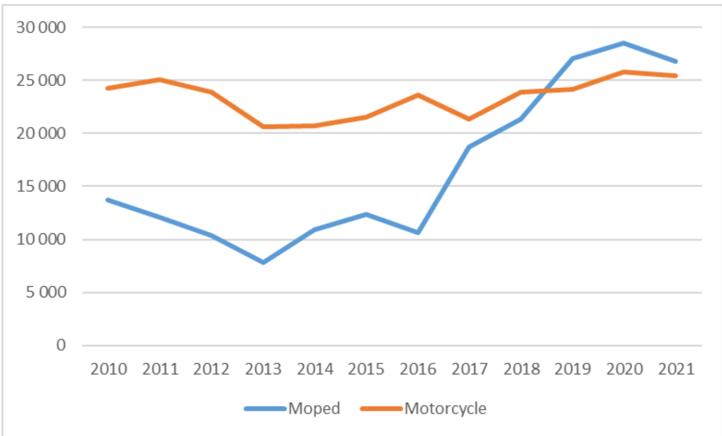


Figure 8 New vehicle registrations per year in Belgium
Source: https://www.acem.eu/market-data and https://www.febiac.be/public/pressreleases.aspx?ID=1400&lang=NL

Sales by fuel type

The majority of powered two-wheelers are fuelled with petrol. According to Febiac, 98,7% of all new motorbike registrations in 2021 had a petrol-based combustion engine.[5] Table 2 shows the number of new PTW registrations in Belgium as of 2010. The table makes a distinction between all type of fuels and electric vehicles (EV). The electrification in the moped segment is noticeable. Since 2019, more than half of the mopeds sold are powered by an electric engine. This is not the case for motorcycles. Only 1.3 to 1.5 percent of the new motorcycles are electric vehicles.

Table 2 New registrations of powered two-wheelers in Belgium

	Moped_all	Moped_EV	EV/Total	Motorc_all	Motorc_EV	EV/TOTAL
2010	13 701	NA	NA	24 270	NA	NA
2011	12 131	6	0.0%	25 043	25	0.10%
2012	10 397	16	0.2%	23 921	44	0.18%
2013	7 830	10	0.1%	20 648	35	0.17%
2014	10 936	86	0.8%	20 681	89	0.43%
2015	12 384	397	3.2%	21 577	95	0.44%
2016	10 599	922	8.7%	23 621	102	0.43%
2017	18 761	5 487	29.2%	21 390	121	0.57%
2018	21 391	10 248	47.9%	23 936	183	0.76%
2019	27 112	15 998	59.0%	24 205	328	1.36%
2020	28 535	14 325	50.2%	25 807	387	1.50%
2021	26 832	15 917	59.3%	25 422	333	1.31%

Source: https://www.acem.eu/market-data and https://www.febiac.be/public/pressreleases.aspx?ID=1400&lang=NL

The majority of the new sales in electric mopeds consists of active modes such as speed pedelecs (powered cycles). In 2019, 91% of all electric moped sales were powered cycles. An important advantage of this type of motorized two-wheeler is that it generates health benefits to the rider.

Sales by size

Comparing the evolution of PTW registrations in Belgium by size segment is only meaningful as of 2017. Before this date, moped registrations were not mandatory. Figure 9 confirms the recent trend of an increasing popularity of small PTWs. While the share of medium sized PTWs has remained fairly constant over the past four years, we observe a decrease in the registrations of new large motorbikes.

[5] https://www.febiac.be/public/pressreleases.aspx?ID=1400&lang=NL

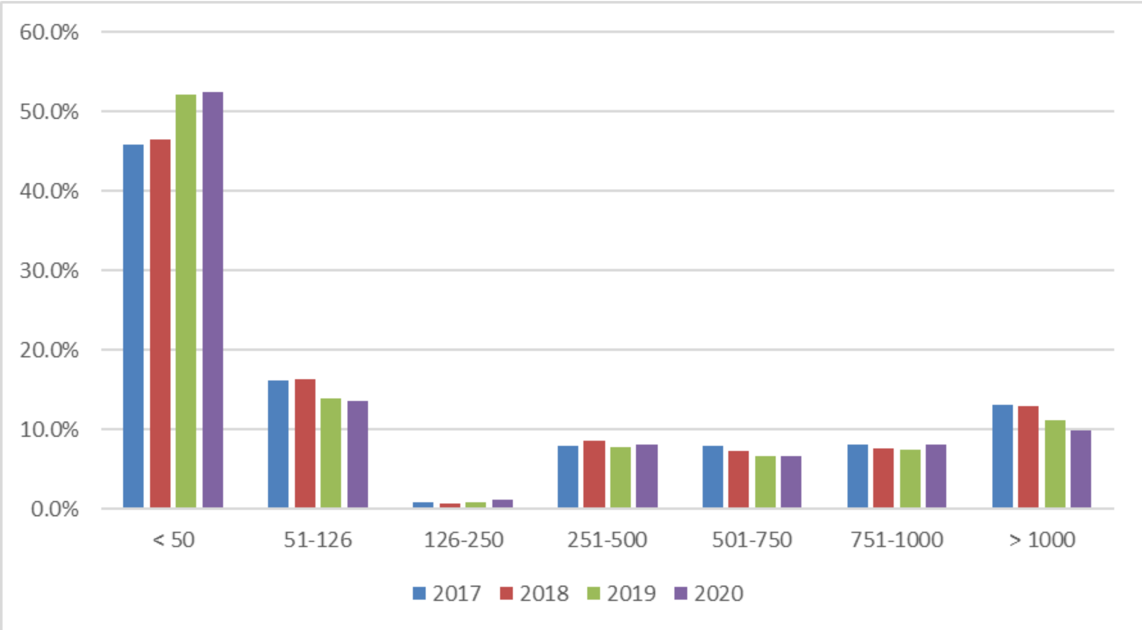


Figure 9 Share of new PTW vehicle registrations by size in cc. Source: Febiac and DIV

When concentrate on the motorcycle segment only (i.e. PTWs with an engine larger than 50cc), we have data for a longer time horizon. More than one fourth of all new motorcycle sales are motorcycles with max 125 cc (Figure 10). The popularity of this type of motorbike can be explained by the fact that they are compact and easy to handle, which makes them well suited for urban traffic. In addition, people who own a car driver's license, do not need to obtain a separate license to drive this type of motorcycle.[6]

Over the past decade, the largest motorcycles with an engine exceeding 1000 cc have decreased in popularity, confirming the short horizon trend.

[6] People who obtained a car driver's license after 2011, have to complete a mandatory training of 4 hours and need to have at least two years of driving experience before they can drive a motorcycle with an engine of max 125 cc. People who obtained a car driver's license before or up to 2011 are exempted from the training.

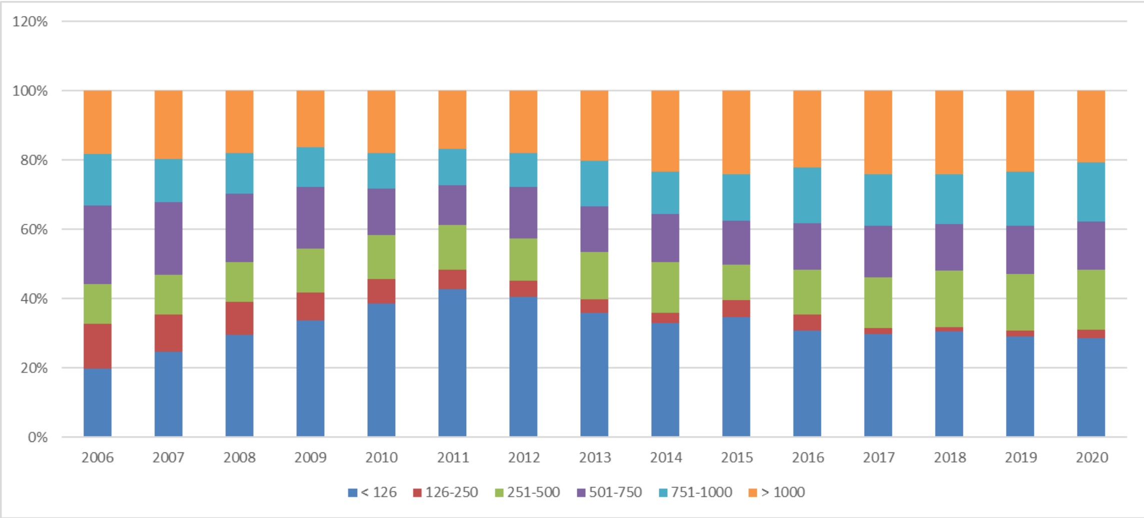


Figure 10 Share of new motorcycle sales per cc per year. Souce: Febiac

2.2.2 Regional and local level

According to the literature, there is a difference between urban and rural areas with respect to PTW use and market share. The most significant increase in PTW use over the last two decades is mainly documented in highly urbanized areas and cities (Rose & Delbosc, 2016). Especially mopeds and scooters are predominantly used in urban environments (Delhaye & Vandael Schreurs). In rural areas, PTWs are more often used for leisure trips. In urbanized areas, PTWs are also a popular transport mode for commuting.

We investigate the relation between PTW-ownership and the level of urbanisation in two ways. First, we calculate the correlation between PTW-ownership (measured per 1000 inhabitants) and population density per municipality. Next, we calculate the average PTW-ownership per degree of urbanisation (city, towns and suburbs and rural areas).

When we calculate the correlation between population density per municipality and the number of registered PTW per 1,000 inhabitants, we find a negative relationship. The correlation between population density and PTW ownership is equal to -0.21 for mopeds and -0.45 for motorbikes. However, the scatterplots in Figure 11 and Figure 12 show that this correlation is influenced by a few outliers.

When we trim the dataset to remove the 5% outliers, we find the relationship between moped ownership and population density to be inverted u-shaped. More specifically, moped ownership initially increases with population density, but then decreases. This means that in the most crowded areas like city centres, moped ownership is lower than in the suburbs and towns. This can be explained by the fact that city centres typically offer a multitude of transport modes, and public transportation services in suburbs are generally lower than in city centres.

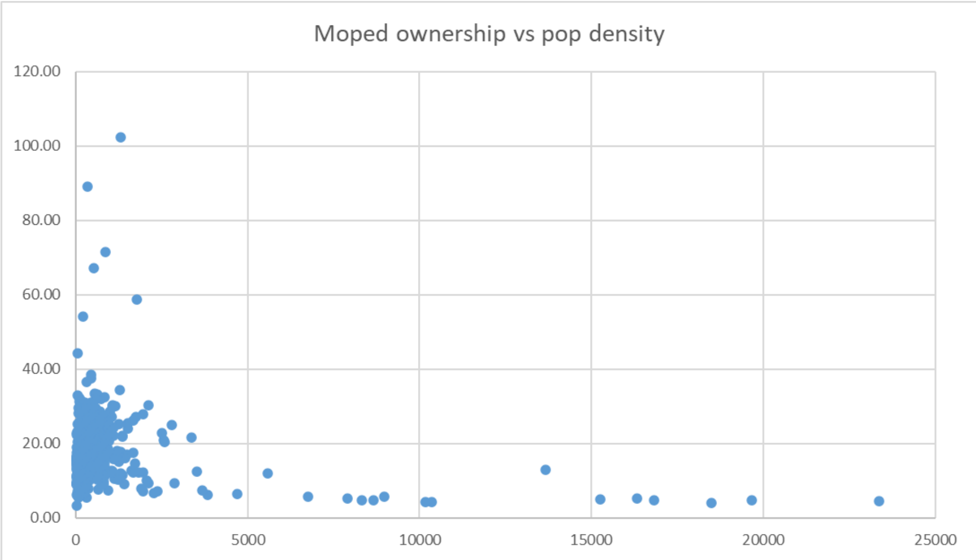


Figure 11 Scatterplot number of mopeds per 1000 inhabitants (Y-axis) vs population density (X-axis)

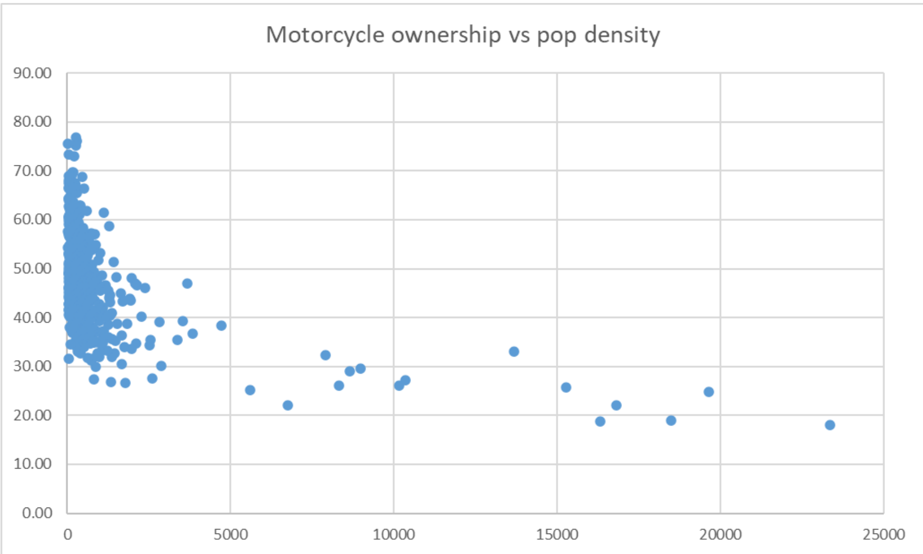


Figure 12 Scatterplot number of motorcycles per 1000 inhabitants (Y-axis) vs population density (X-axis)

To get a better look at the relation between PTW-ownership and urbanisation levels, we group Belgian municipalities per degree of urbanisation according to the Eurostat database. More specifically, we distinguish locations based on the share of local population living in urban clusters and in urban centres into three groups:[7]

1. Cities: densely populated areas
2. Towns and suburbs: intermediate density areas
3. Rural areas: thinly populated areas

Next, we calculate the average PTW ownership per 100 inhabitants per level of urbanisation, as shown in Table 3. In line with our findings based on population density, ownership of mopeds and

[7] https://www.eea.europa.eu/data-and-maps/data/external/degree-of-urbanisation-degurba/

motorbikes is lowest in cities. Mopeds are most common in towns and suburbs, while the ownership of motorbikes is highest in rural areas.

Table 3 PTW ownership per 100 inhabitants per degree of urbanisation

Degree of Urbanisation	Moped	Motorcycle
Cities	1.21	3.22
Towns and suburbs	2.14	4.64
Rural areas	1.68	5.19
TOTAL (Belgium)	**1.90**	**4.78**

Source: Own calculations based on DIV and Statbel

Table 4 shows the communities with the highest number of registered powered two-wheelers (in number of vehicles per 1,000 persons) in Belgium. For mopeds, only one city is part of this list, notably Leuven. A remarkable observation is that all communities in the top ten list of moped ownership are located in the Flemish region.

For motorcycle ownership, nine of the top ten communities are located in Wallonia. The only Flemish community is Wellen, in Limburg. All top ten communities with respect to motorcycle ownership are located in more rural areas.

Table 4 Top ten communities in Belgium with respect to moped (left) and motorcycle (right) ownership

	Moped		**Motorcycle**
Aartselaar	102.2	Olne	76.8
Lommel	89.0	Lasne	76.1
Stabroek	71.6	Vresse-sur-Semois	75.6
Knokke-Heist	67.1	Wellen	75.2
Leuven	58.9	Herbeumont	73.4
Kluisbergen	54.1	Itter	73.0
Zuienkerke	44.3	Theux	69.8
Lanaken	38.4	Marchin	69.7
Wielsbeke	37.4	Donceel	69.0
Zandhoven	36.5	Erezée	68.9

Source: Own calculations based on DIV and Statbel

When we look at total PTW use in terms of vehicle kilometres, we can confirm that there is a strong difference in the activity of motorcycles and mopeds across the Belgian regions. Overall, motorcycles are the dominating type of powered two-wheeler. This is especially the case in Wallonia, where 83% of all PTW-vehicle kilometres are motorcycles in 2020 (compared to 79% in 2006) (Figure 14). The picture is completely different in Brussels. In 2020, mopeds covered nearly half of all PTW-vehicle kilometres (43%). The relative importance of mopeds in Brussels has increased steadily over the years. In 2006, mopeds accounted had a share of 34% in all PTW vehicle kilometres (Figure 13). In Flanders, the picture is mixed. Although motorcycles are still the dominant PTW vehicle type, riding 63% of the PTW-vehicle kilometres in 2020, their share is declining over the last five years, reflecting an uptake in mopeds (Figure 15).

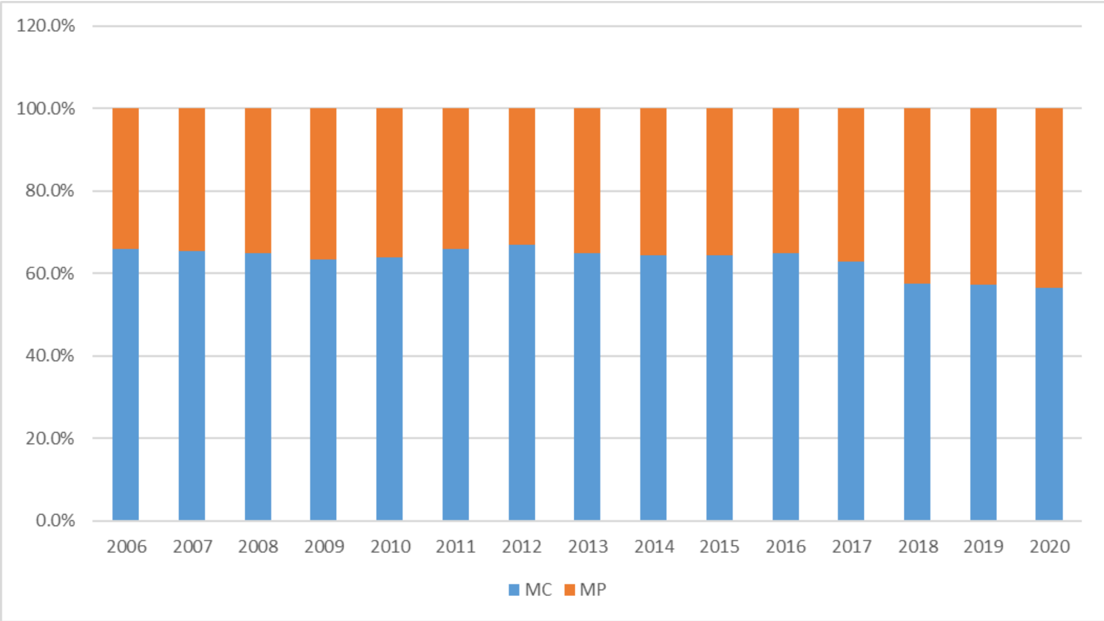


Figure 13 Motorcycle (MC) versus moped (MP) use in Brussels 2006-2020.
Source: Own calculations based on MAM database

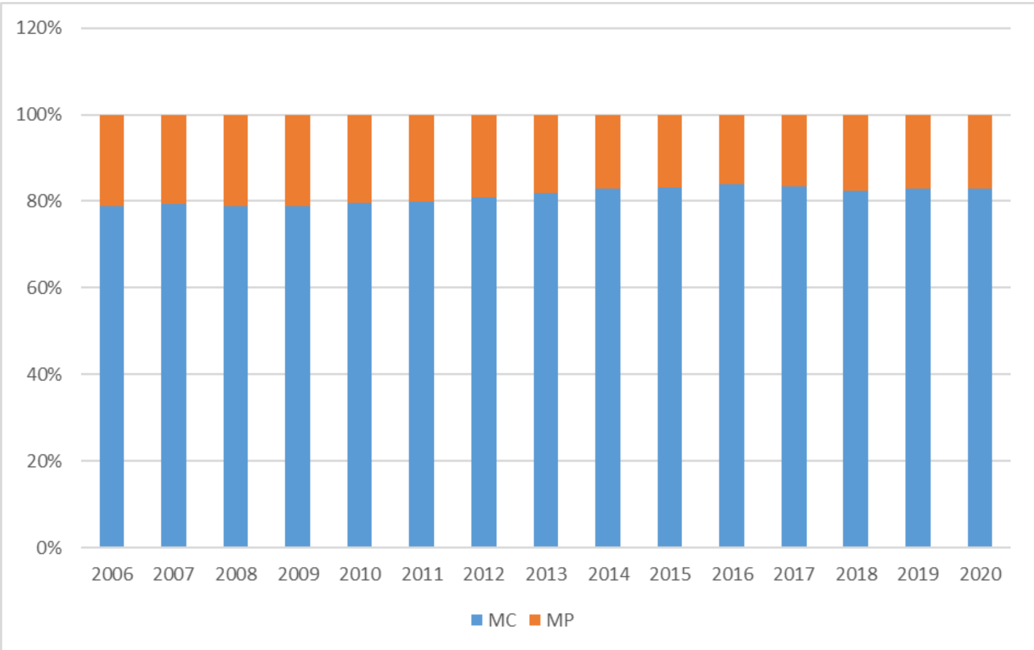


Figure 14 Motorcycle (MC) versus moped (MP) use in Wallonia 2006-2020.
Source: own calculations based on MAM database

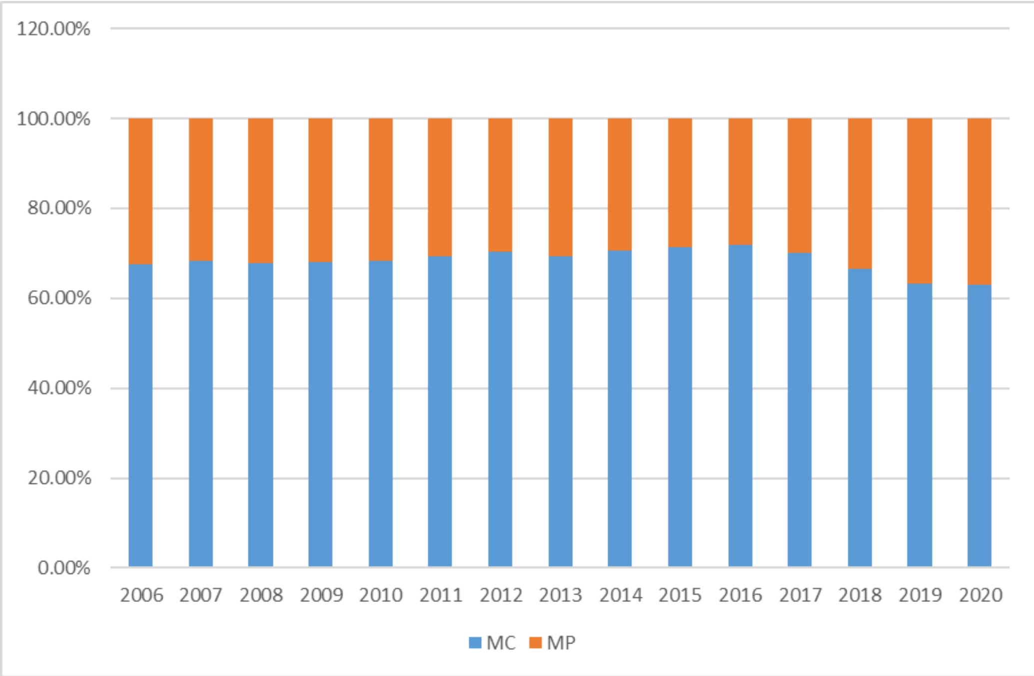


Figure 15 Motorcycle (MC) versus moped (MP) use in Flanders 2006-2020.
Source: own calculations based on MAM database

2.3 Trends

The market for powered two-wheelers is rapidly changing. In this section we briefly discuss the main trends that will impact future PTW ownership and use in Belgium over the coming decades. We respectively focus on electrification, shared mobility and mobility as a service (MaaS), urbanisation, and technological innovations.

2.3.1 Electrification

Powered two-wheelers are very suitable for electrification due to their light weight and relatively small driving distances. This means they which require smaller batteries compared to passenger cars. A recent step forward in the electrification of PTWs, is the development of standardized, swappable batteries. Four of the biggest motorcycle makers (Honda, Yamaha, KTM and Piaggio) joined forces in September 2021 to form the Swappable Batteries Motorcycle Consortium (SBMC) which aim is to a develop a swappable battery system for mopeds and motorcycles.

In 2021, already 44% the global two- and three-wheeler sales and 25% of the existing fleet are electric vehicles, according to Bloomberg NEF.[8] The market leader with respect to PTW electrification is China, but EV market shares are also increasing rapidly in other Asian countries such as Taiwan, Vietnam and India. Other markets like Europe and the U.S. are expected to follow suit quickly. In Europe, electric two-wheelers are most popular in the segment of electric bikes (L1e), because these do not require a driver's license or insurance.

[8] https://about.bnef.com/electric-vehicle-outlook/

Based on a stated policies scenario, the International Energy Agency (IEA, 2021) predicts that electric PTWs will account for one third of the total fleet in 2030. Global sales are expected to double over the period 2020 to 2030, with electric PTWs accounting for more than half of all PTW sales. In a Sustainable Development Scenario in which global climate goals as set in the Paris Agreement are met, electric PTWs would account for 40% of the total stock by 2030. Global sales are expected to increase faster than in the stated policies scenario, notably from $20 million in 2020 to over $60 million in 2030, corresponding to almost 75% of all sales (Figure 16).

Bloomberg estimates the share of electric PTW vehicle sales to increase to 49% in 2030, increasing to respectively 83% in 2040 and 98% in 2050. In a more optimistic, net zero emission scenario, vehicle sales of electric PTWs will rise to a share of 58% in 2030, 99% in 2040 and 100% in 2050 (Figure 17).[9]

The fast rise in sales of electric PTWs is driven by five factors:

- The deployment of electric scooters for mobility sharing services,
- Rising traffic concerns and congestion in European cities,
- EU and national policies to reduce greenhouse gas emissions,
- Behavioural changes among drivers towards mobility caused by environmental concerns,
- Economic benefits such as lower operating costs and financial incentives by governments.

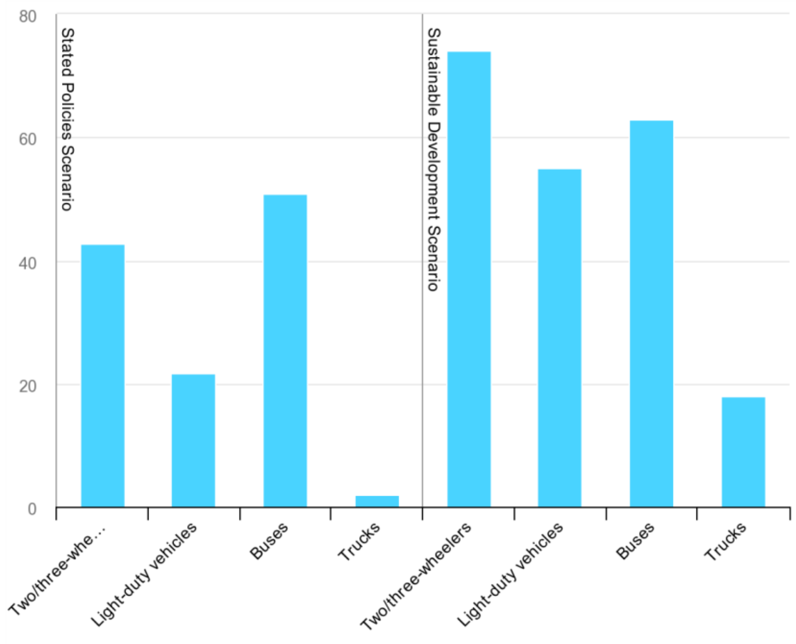


Figure 16 Electric vehicle share of vehicle sales by mode and scenario in Europe, 2030
Source: IEA Global EV Outlook 2021

[9] https://about.bnef.com/electric-vehicle-outlook/

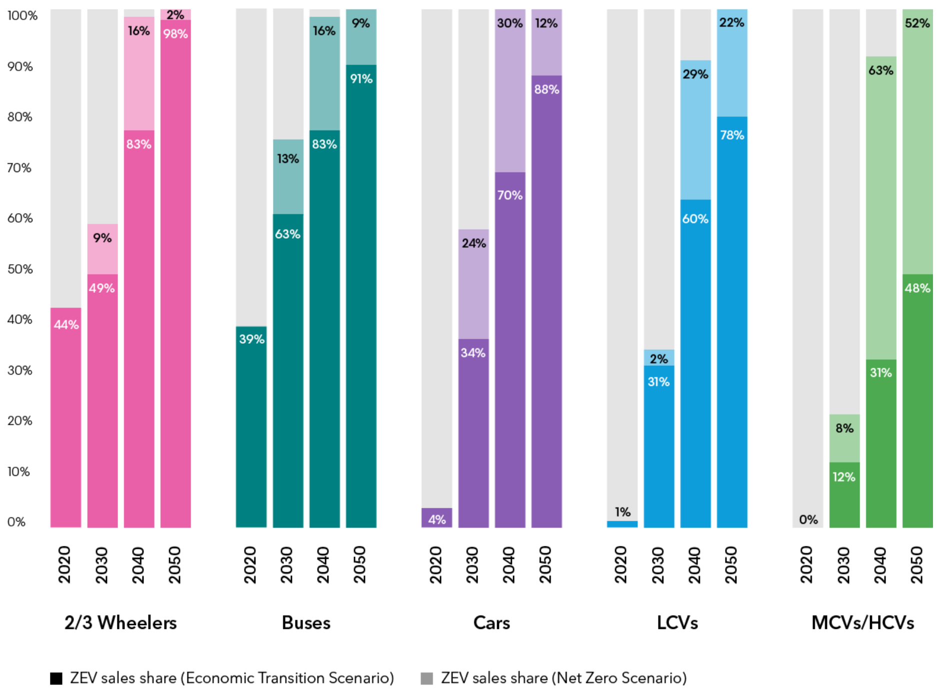


Figure 17 Share of zero-emission vehicle sales - Source: Electric Vehicle Outlook 2021, BNEF

2.3.2 Shared mobility and Mobility as a Service (Maas)

Mobility as a Service (MaaS) involves the combination of different forms of transportation into a single mobility service that is accessible on demand. The idea of MaaS is to offer more efficient and sustainable transport by providing the right modes in the right place and by connecting them intermodally. Shared mobility can be a part of MaaS.

Pioneer cities in shared mobility in Belgium are Brussels and Antwerp. Several other cities offer shared micromobility solutions like steps. In Brussels and Antwerp, moped sharing services are also offered. The market leaders in this segment are Felyx[10] and Go Sharing[11].

[10] https://felyx.com/be/en/brussels
[11] https://nl.go-sharing.com/en/

Figure 18 E-moped sharing solutions Felyx (left) and Go Sharing (right)

Research has shown that cities that implement Low Emission Zones (LEZ) experience a significant increase in shared mobility solutions in parallel with a drop in private (motorized) vehicle use. For example, a study on the impact of the LEZ in Madrid on modal choice shows a 28.5% decrease in private car use, while the use of shared mobility solutions (car sharing, scooter sharing, etc.) grew from 3.8 to 8.4% (Tarriño-Ortiz et al., 2022).

In Belgium, several LEZ are already in place, notably in Antwerp, Brussels and Ghent. As of 2023, a LEZ will be implement in the whole Walloon. Therefore, we expect shared mobility solutions to rise fast in these areas.

2.3.3 Urban transportation: the future is on two wheels

Two and three-wheelers have always been a popular transport mode in highly urbanized areas, especially in Asia. There is an abundance of literature on motorcycle and scooter use in South Asian countries. However, the conclusions of these studies are usually hard to apply to a European setting. Nevertheless, since the beginning of the 21st century, European cities have experienced an unprecedented rise in the use of motorized two-wheelers. According to Kopp (2011), the share of PTWs in total traffic in Paris has increased by 36% between 2000 and 2007. Similarly, Marquet & Miralles-Guasch (2016) show that Barcelona experienced a significant increase in PTW use since the beginning of the 21st century. Over the period 2004 to 2012, the share of motorcycles in the number of registered road vehicles has increased from 17.5% to 22.2%. Over the same period, the number of motorcycle trips in Barcelona increased with 18.6%. The city ranks the highest in Europe in terms of motorbikes per capita.

Drivers spend an increasing amount of time in traffic jams, especially in highly urbanised areas. Experts expect a large modal shift from passenger cars to two wheelers in the next few years, thanks to the success of the e-bike. A study by ISPO estimates that bicycle traffic in major cities worldwide will increase by 18 percent by 2030, compared to 2021.[12] The study does not make a distinction between engine-powered and muscle-powered bikes, but an important share of powered two-wheeler trips is to be expected, especially if these are battery electric.

2.3.4 Technological innovation

The industry is consistently investing in new technologies that should improve PTW rider's safety and driving experience. The aim of this section is not to provide a complete overview of all new

[12] https://www.ispo.com/en/trends/five-major-urban-mobility-trends-future

and forthcoming technologies. Instead, we just want to draw attention to the fact that there is a process of continuous innovation going on and we focus on a few of these innovations.

Cooperative systems

Intelligent Transport Systems (ITS) involves the application of information and communication technology to transport. By the use of sensors, computers and satellites, information is shared between the ICT system and the vehicle. ITS can be considered as cooperative systems because they require to communicate with other systems. This is on contrast to stand-alone systems such as ant-lock braking systems (ABS) (Delhaye and Marot, 2015).

For a system to qualify as ITS, the following three conditions need to apply (Delhaye and Marot, 2015):

- The system includes information technology
- The system includes some form of electric data exchange between the vehicle, the road or roadside infrastructure, the driver or other traffic participant.
- The system has relevance to transport.

Cooperative Intelligent Transport Systems (C-ITS) are currently being developed at a fast pace, but motorcycle-specific aspects are underrepresented. A group of manufacturers, suppliers, researchers and associations has joined force in the Connected Motorcycle Consortium (CMC).[13] CMC publishes studies on the implementation of PTWs in a C-ITS system.

Connected motorcycles are motorbikes that are equipped with an intelligent board computer that connects riders through C-ITS. The innovative technology can inform the rider about traffic conditions, potholes, road curves, oil level, tire pressure, and battery life. It also enables remote monitoring by tracking stolen vehicles, collecting data for performance analytics, and offering operational information, roadside assistance, and over-the-air (OTA) updates.[14] The main advantage of C-ITS enabled motorcycles is their potential to improve driver safety. Because C-ITS warns drivers of potentially dangerous situations, the technology helps to prevent accidents.

Stand-alone systems

Stand-alone systems do not require a communication with other systems. Their main aim is to reduce rider workload and errors. For motorcycles, stand-alone vehicle information systems are typically referred to as Advanced Rider Assistance Systems (ARAS) or On-Bike Information Systems (OBIS).

ARAS/OBIS should improve road safety by preventing accidents and contributing to collision reduction. They are also designed to improves the driving experience and to make life easier for riders. Examples are traction control systems, tyre pressure monitoring systems, proximity activation systems, automatic stability control, etc. Recent innovations in ARAS include devices that provide for adaptive cruise control, forward collision warnings and blind spot detection (ACEM, 2020).

[13] https://www.cmc-info.net/

[14] https://www.imarcgroup.com/connected-motorcycle-market

Driver acceptance

In a survey on PTW-rider profiles in Belgium, Delhaye and Vandael Schreurs (2021) show that 80% of the Belgian PTW riders believes that new technology can help in reducing the number of accidents. Nevertheless, the same survey reports that many PTW riders feel that new technologies cause distraction. When focusing on the specific type on technological innovation, the survey outcomes show that technologies offering a turn left assist and a traffic jam warning are considered most valuable.

3 Policy and regulation

In this chapter, we discuss policies and regulations that are relevant to powered two-wheelers in Belgium. A general finding is that policy makers have given PTWs little attention until today. We identify three reasons for this:

- There is a lack of studies on the potential of PTWs for urban travel
- Until recently, PTWs represented a negligible share of the vehicle fleet
- High accident statistics maker policy makers reluctant to stimulate PTW use

There is an abundance of studies and policies on the management of traffic congestion and reducing pollution that focuses exclusively on cars, public transport, walking and cycling. The potential role of powered two-wheelers in fighting traffic congestion and air pollution has been largely overlooked, especially in the context of western cities. The little number of studies that do exist, focus on cities in Southeast Asia, which transport systems and traffic scenarios cannot be applied to a European setting. Hence, the lack of studies on the role of PTWs as a transport mode is a first reason why policy makers have given PTWs little attention in the mobility plans and the design of road infrastructure.

A second reason why PTWs have received little attention by researchers and policy makers is their small share in total traffic, which has definitely been the case in Belgium. However, PTW use is increasing rapidly, especially in urban environments. Therefore, in one of its research reports, the OECD/ITF emphasized the need to assign attention to PTWs as part of transport policy and to integrate PTW vehicles in mobility plans (OECD/ITF, 2015).

Third, we find that most PTW policies and regulations have a safety focus because the main challenge from a policy perspective remains the high accident statistics related to PTW use. As a result, much less attention of policy makers has been given to the potential role of PTWs for urban travel.

In the following sections, we discuss the policy implications for PTWs from regional mobility plans, road safety plans and noise standards.

3.1 Mobility planning

Each Belgian region has developed a mobility plan, in which the ambitions and action plans are laid out with respect to future mobility (up to 2030) in the respective region.

Brussels

The Brussels mobility plan, Good Move, is the most developed. The ambition of the Good Move-plan is to reduce the number of passenger car kilometres by 21% the capital region. This will be obtained by stimulating "multimodal road specialization", with less traffic in the city centre. More specifically, the Good Move scenario aims to achieve the following change in vehicle kilometres:

- A decrease in motorized traffic with 35% on local roads
- A decrease in motorized traffic with 10% on primary roads
- An increase of 18% in motorized traffic on motorways

The Good Move plan also focuses on shared mobility and MaaS services. This provides an important opportunity for the implementation of shared two-wheelers in the city.

Next to the mobility plan, the Brussels region is a Low Emission Zone (LEZ). In contrast to other LEZs in Belgium, which do not apply to PTWs, the Brussels' LEZ also targets motorized two-wheelers. More specifically, mopeds with a Euro standard below 5 will be prohibited in Brussels as of January 2025. As of 2028 all fossil fuel mopeds will be banned in Brussels. This will have a significant impact on the pace of electrification of the moped fleet in Brussels.

For motorcycles, the LEZ rules differ per category and fuel type. All diesel-powered motorcycles will be banned as of 2025. For motorcycles with a petrol engine, the following rules apply:

- Category L3 to L5: vehicles below Euro 3 are banned as of 2025, Euro 3 standard banned as of 2028, Euro 4 standard banned as of 2030. Euro 5 motorcycles remain allowed.
- Category L6 and L7: vehicles without Euro standard are banned as of 2028, Euro 4 standard banned as of 2030, Euro 5 banned as of 2035.

The Brussels government is also considering to implement road pricing, called SmartMove. In a system of road pricing, registration and circulation taxes are dropped. Instead, drivers pay taxes based on the kilometres driven with their vehicle.

The main objective of a road pricing system like SmartMove is to fight congestion. The potential contribution of PTWs in easing congestion is confirmed by the design of the SmartMove system. In this system, PTWs would pay much lower charges than passenger cars. More specifically, SmartMove implies:

- No charge for mopeds with a speed limit up to 45km/h
- A lower fee for motorcycles than cars. The SmartMove fee is based on the engine power of the vehicle. Because most motorcycles have a fiscal horsepower below 7, they don't pay the starting amount. The kilometre charge will therefore be determined solely on the basis of the amount per kilometre, calculated according to the distance and time of travel.

The reason why powered two-wheelers pay less in a system of road pricing is that they take up less road space than cars and therefore they contribute less to congestion. In the Brussels' SmartMove system, powered two-wheelers will pay only one fourth of the charge paid by passenger cars.[15]

If the road pricing system in Brussel would be approved and implemented, it can potentially lead to a sharp increase in PTW activity in the Brussels region. However, the implementation of SmartMove is politically debated. The governments of Flanders and Wallonia are opposed to SmartMove, because it would lead to extra chargers for Flemish and Walloon commuters to the capital region.

Flanders

Several policy plans (Flemish Mobility Plan, Flemish Energy and Climate Plan[16], Clean Air Plan 2030[17]) refer to the modal shift ambition for 2030 of the Flemish government.[18] This modal shift

[15] https://smartmove.brussels/en

[16] https://energiesparen.be/vlaams-energie-en-klimaatplan-2021-2030

[17] https://omgeving.vlaanderen.be/sites/default/files/atoms/files/1%20VR%202019%202510%20MED.0359-2%20Luchtbeleidsplan.pdf

ambition involves a significant reduction in the use of passenger cars and an increase in sustainable mobility modes. More specifically, the Clean Air Plan and the Energy and Climate Plan state that the share of passenger cars in the total number of trips should decrease to maximum 60%. The share of sustainable transport modes (by foot, (e-)step, (e-)bike or speed pedelec, by shared mobility or public transport) should increase to at least 40% of all trips. For specific transport regions (Flemish periphery around Brussels, Antwerp and Ghent) the aimed share for sustainable transport modes is even 50% of all trips.

The Clean Air Plan has also specific goals with respect to the reductions of the total kilometres driven. More specifically, the aim is to reduce the number of vehicle kilometres driven by passenger cars of 15% by 2030, compared to 2015.

There is no explicit mentioning of PTWs in the Flemish mobility plan.

Flanders has currently two LEZ zones, in Antwerp and Ghent. Motorcycles and mopeds are exempt from the LEZ rules in these zones, that are predominantly targeted to cars and trucks.

Wallonia

In 2019, the Walloon government approved the regional mobility plan with ambitions and action points to improve mobility on the Walloon territory by 2030.[19] The plan explicitly aims to reduce car usage from 83% to 60% by 2030.

This decrease in car kilometres should be achieved by investing in shared mobility and MaaS solutions, stimulating car sharing, micromobility and bicycle use. Similar to the Flemish mobility plan, we find that PTWs are largely overlooked. They are not explicitly mention in the plan.

As of 2023, the Wallonia will become a low emission zone, applicable to cars and trucks. The LEZ rules do not apply to powered two-wheelers.[20] Therefore, PTWs can be an alternative to replace older passenger cars. Especially for people with a lower income or people that do not want to purchase a new car, riding a PTW may become more attractive. Hence, we may expect an uptake in PTW usage in the Walloon area as of 2023.

3.2 Road regulations and safety plans

Policy plans and regulations concerning powered two-wheelers usually have a safety focus. Here, we distinguish between road regulations, that focus on the driving and parking behaviour of PTW riders and safety regulations and plans.

The purpose of this section is not to provide a full overview of all safety rules and standards. We only focus on the aspects that are relevant for this study.

---

[18] https://omgeving.vlaanderen.be/sites/default/files/atoms/files/Afsprakenkader%20modale%20verdeling%20personenvervoer.pdf

[19] http://mobilite.wallonie.be/files/eDocsMobilite/politiques%20de%20mobilit%c3%a9/SRM_PERSONNES_2019.pdf

[20] https://www.walloniebassesemissions.be/fr/

Road and safety regulations

Driver's license

For powered bicycles and mopeds with a maximum speed of 25km/h, no driver's license is required. Riders of mopeds with a maximum speed up to 45km/h, an engine size up to 125 cc and a maximum power of 11 kW need to have a driver's license type A1.

For motorcycles, a driver's license A2 (maximum horse power of 35 kW) or A (above 35 kW) is required.

PTW riders who are in the possession of car driver's license B for at least two years are allowed to ride a PTW. However, this depends on the year the license B was obtained. People who obtained the driver's license B before December 31st, 1998 are allowed to ride a PTW that requires A1, A2 and A. People who obtained their license B before May 1st, 2011 are allowed to ride a PTW that requires a A1 license. People who obtained a driver's license B after May 1st, 2011 can obtain an A1 license after successfully completing four hours training at an officially recognized driving school.

The allowance to ride a PTW with a car driver's license B holds only for Belgium. To ride a PTW abroad, an A, A1 or A2 license is mandatory.

Driving behaviour

Motorcycles drive on the main road, like cars. In contrast to cars, they should not keep right in the lane, but they should drive on 2/3rd of the lane (that is, more to the centre of the road). This increases the visibility of motorcycles of other road users. Mopeds with a speed below 25km/h should always use the bicycle path. Mopeds with a speed up to 45km/h can use the bicycle path and the main road.

Lane filtering by motorcycles is allowed on motorways when traffic is congested, that is when cars drive at a speed of 50km/h or below. Provided that road signalisation allows, PTWs can use bus lanes.

Parking

PTWs are allowed to park on the sidewalk, provided that their remains sufficient space for pedestrians to pass. When they park on the road, they don't need to park parallel to the road. PTWs can park sideways, provided that the vehicle doesn't surpasses the parking marks.

Gear

Motorcycle riders (>50 cc) and their passengers should wear protective gear. This includes a helmet, gloves, a jacket and pant with long sleeves and ankle-protecting shoes.

For mopeds with a speed limit up to 45km/h the protective gear only consists of a helmet.

Road safety plans

Regional action plans have been developed to improve road safety and reduce the number of victims. In Flanders, the Road Safety Plan 2021-2025 aims to drastically reduce the number of fatalities on the Flemish roads.[21] The plan focuses mainly on "active road users", notably cyclists and pedestrians. Nevertheless, reducing the number of accidents involving powered two-wheelers is one of the nine action points of the plan. More specifically, the Flemish Road Safety Plan aims to reduce the number of traffic accidents with 25% in 2025 compared to 2019. By 2030, traffic accidents should be reduced by 50% and the plan aims for zero fatalities and serious injuries by 2050 (dubbed All For Zero).

Similarly, the Agence Wallonne pour la Sécurité Routière (AWSR) has developed a road safety plan for Wallonia. The ambitions of the plan are comparable to those in Flanders, with an aimed reduction of deadly accidents of 50% by 2030 and zero fatalities in road traffic by 2050.[22]

The Brussels Road Safety Plan is even more ambitious than those of Flanders and Wallonia, striving for zero deaths and zero seriously injured victims in traffic accidents by 2030.[23]

The policy actions that should improve traffic safety include the mandatory technical inspection of motorcycles upon purchase and after an accident (as of January 1, 2023), an extended and improved educational offer for PTW drivers, sensibilisation and risk awareness campaigns and intensified and optimised control and enforcement of the road regulation.

A remarkable observation is that the regional road safety plans focus on educating and raising risk awareness of the motorcycle rider. Nevertheless, most research on the accident types involving motorcycles show that the most frequent type of accidents are collisions with a car driver who should have waited for the PTW, indicating problems with the perception of PTW's.[24]

In November 2021, the federal safety plan "All For Zero" was presented at the States General meeting. This plan sets the clear ambition to a 50% reduction of road accidents with serious injuries by 2030 and zero deaths on the roads by 2050.[25]

3.3 Noise standards

Traffic noise is an important concern in Europe, especially in densely populated areas. Exposure to noise can lead to health problems and feelings of annoyance. The negative health effects of noise exposure have been wildly documented and can be objectively measured. Exposure to loud noise can lead to health issues such as heart diseases and hypertension. Traffic noise is can also be a source of annoyance. However, the relationship between the noise level (measure in dB(A)) and annoyance is not always clear cut. How annoyance should be accounted for when considering noise effects on society has been a long debate in the literature. We come back to this issue into more detail in Chapter 10. Here, we focus on international motorcycle sound laws and standards, without going into a normative discussion.

The United Nations Economic Commission for Europe sets the standards for motorcycle noise emissions UNECE Regulation 41.[26] EU Regulation No 168/2013 and 134/2014 refers to the UNECE standard for sound limits. The relevant regulation for each PTW type is shown in Table 5.

---

21 https://www.vlaanderen.be/verkeersveiligheidsplan-vlaanderen-2021-2025

22 https://www.awsr.be/awsr/

23 https://mobilite-mobiliteit.brussels/sites/default/files/2022-01/Gewestelijk%20actieplan%20verkeersveiligheid%202021-2030.pdf

24 https://ec.europa.eu/transport/road_safety/statistics-and-analysis/statistics-and-analysis-archive/powered-two-wheelers/powered-two-wheelers_en

25 https://all-for-zero.be/nl/all-for-zero/

Table 5 UNECE and EU regulations for sound emissions of PTWs

Regulation	**L-Category**
UNECE Regulation No 63: Sound emission of mopeds	L1
UNECE Regulation No 41: Sound emission of motorcycles	L3
UNECE Regulation No. 9: Sound emission of three- and four-wheel vehicles	L2, L4, L5, L6, L7
UNECE Regulation No. 92: Replacement exhaust systems	L1, L2, L3, L4, L5
Regulation (EU) No. 168/2013 and 134/2014: Approval and market surveillance of two- or three-wheel vehicles and quadricycles	L1, L2, L3, L4, L5, L6, L7

Source: Dittrich et al (2018)

The regulations describe in detail how sound tests should be performed and under what conditions approval is obtained.

According to UNECE Regulation 41 for new motorcycles, sound should be measured based on a pass-by test at a predetermined speed and acceleration with wide open throttle (WOT) and maximum engine load. The WOT test results in a sound level L_{WOT}. The WOT pass-by test is combined with a constant speed test. The total sound level is calculated as a mix of the WOT and constant speed test and the resulting sound level is determined as L_{URBAN}.

Regulation 41 also specifies a stationary test to determine the sound level close to exhaust.

UNECE Regulation 63 for new mopeds describes two sound tests: a pass-by test and a stationary test.

The maximum sound levels set by the UNECE Regulations are shown in the table below.

Table 6 Maximum limits of sounds levels UNECE Regulation

UNECE Regulation No. 63 (new mopeds)	
Category	*Maximum noise-level*
<= 25 km/h	66 dB(A)
> 25 km/h	71 dB(A)
UNECE Regulation No. 61 (new motorcycles)	
Power-to-mass ratio index (PMR)	*Limit value for Lurban*
PMR <= 25	73 dB(A)
25 < PMR <= 50	74 dB(A)
PMR > 50	77 dB(A)

[26] https://unece.org/transport/vehicle-regulations-wp29/standards/addenda-1958-agreement-regulations-41-60

4 Scenarios

In this study we develop two alternative scenarios for powered two-wheeler (PTW) use in Belgium. The scenarios differ with respect to PTW uptake in the period 2025-2030 ("the shock period"). The economic and social impact of the change in vehicle kilometres across modes will be computed from 2025 to 2050.

The alternative scenarios will be tested against a reference scenario. The reference scenario contains traffic predictions for Belgium over the period 2018 to 2050. The reference scenario takes into account all EU and national transport, energy and climate policies decided up to December 2019. Below is a description of the reference scenario and the two alternative scenarios.

4.1 Reference scenario

To build the reference scenario for passenger transport and vehicle fleet in Belgium, we need to make predictions about the vehicle kilometres per transport mode. Because we need information about the fleet composition, especially with respect to fuel type, we also need to make assumptions about the share of each vehicle type (per fuel) in the total sales.

The vehicle kilometres (vkm) for each combination of vehicle type, size, fuel and Euro class are calculated by the MAM projection tool based on the following three inputs:

- the vehicle stock
- the total vkm per vehicle type from traffic statistics
- info on the average yearly kilometres driven from GOCA/CARPASS.

Based on projected vehicle kilometres and average vehicle lifetimes (calculated from scrappage functions), we calculate the vehicle fleet per region (Brussels, Flanders, Wallonia).

The MAM database contains actual vkms driven and the actual vehicle stock (from DIV) up to 2019. The future vkms driven per vehicle type in the reference scenario are based upon the traffic projections for Belgium in the EU Reference Scenario 2020 (European Commission, 2021). The EU Reference Scenario provides an energy and transport outlook for all EU countries up to 2050. It is the baseline scenario upon which the policy scenarios for implementing the Green Deal and the Fit-for-55 action plan are built.

The Reference Scenario incorporates transport, climate and energy policies at EU and county level, whose implementation intensifies until 2030 and continues afterwards, assuming no additional measures apply between 2030 and 2050.[27] The Reference Scenario is a business-as-usual scenario based on all policies decided up to December 2019.

Table 7 shows the projected transport activity for Belgium as modelled in the Reference Scenario. We only show passenger transport here. Transport activity is expressed in gross person kilometres. For all transport modes, an increase in demand is expected. Note that the Reference Scenario forecasts a significant uptake for powered two-wheelers. Transport activity by PTW is expected to

[27] https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en

increase by 16.65% over the period 2025 to 2030, compare to a 3.63% increase in passenger car activity.

Table 7 EU Reference Scenario 2020 (REF2020) – transport activity growth rates PRIMES Model

Transport activity	**2018-2025**	**2025-2030**	**2030-2035**	**2035-2040**	**2040-2045**	**2045-2050**
Passenger transport activity (Gpkm)	**+15.12%**	**+4.49%**	**+1.88%**	**+1.92%**	**+1.61%**	**+1.72%**
Buses and coaches	+28.63%	+0.70%	-0.85%	+0.83%	+0.56%	+0.36%
Passenger cars	+5.63%	+3.63%	+1.38%	+0.88%	+1.15%	+1.27%
Powered two-wheelers	+13.22%	+16.65%	+9.01%	+8.62%	+4.52%	+4.42%
Rail	+63.35%	+5.78%	+4.67%	+3.75%	+4.04%	+3.86%
Intra-EU aviation	+73.03%	+12.22%	+4.51%	+7.36%	+2.95%	+3.42%
Inland waterways and domestic maritime	+74.50%	+3.20%	+4.54%	+3.03%	+2.73%	+2.64%

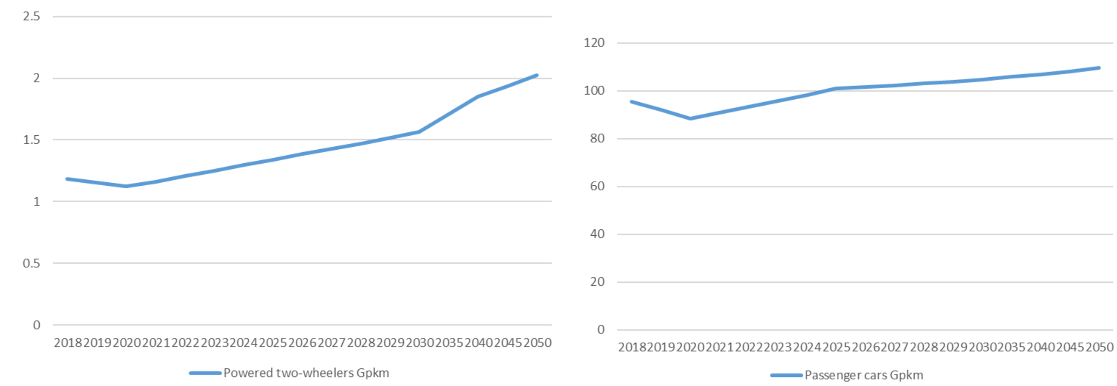


Figure 19 Passenger transport activity for motorcycles (left) and passenger cars in Belgium. Source: EU Reference Scenario 2020

Apart from projections in mileages, we also need to make assumptions about the fuel mix of the vehicle stock. We assume a different pace of electrification for mopeds and motorcycles, which is in line with current trends and predictions from other studies. More specifically, we assume that 75% of all new mopeds will have an electric engine in 2025. The remaining 25% will have a petrol engine. In 2030, only electric mopeds will be sold. For Brussels, we expect an even faster electrification. We assume a 90% share of electric mopeds in all moped sales in 2025. This is because the LEZ regulations will prohibit mopeds with an internal combustion engine as of 2028.

For motorcycles we estimate that electric vehicles will represent a share of 50% of all new sales in 2030. The remaining vehicles are assumed to have a petrol engine. Full electrification of the motorbike segment is expected by 2050.

4.2 Alternative scenarios

In the alternative scenarios, we assume a faster uptake of PTWs than in the reference scenario and a modal shift from passenger cars to PTWs. For each scenario, we start from a different viewpoint. We build two scenarios, a mild modal shift scenario (Alternative Scenario 1) and a strong modal shift scenario (Alternative Scenario 2).

In the first alternative scenario, we focus on PTW activity and build the scenario upon the predictions for PTW resulting from the EU Green Deal Policy Scenarios (EC, 2020).

In the second alternative scenario, we start from the regional mobility plans in Belgium. These mobility plans imply no targeted policies for PTW. Instead, they focus on a strong reduction of car kilometres.

The ambition of the Good Move mobility plan of Brussels is to reduce the number of passenger car kilometres by 21% the capital region. In Flanders, the aim of the Clean Air Plan and Energy and Climate Plan is reduce the number of vehicle kilometres driven by passenger cars of 15% by 2030, compared to 2015. The regional mobility plan of Wallonia strives for a reduction of passenger car usage from 83% to 60% by 2030. A decrease in car kilometres implies that part of the car trips will be done with other transport modes, preferably sustainable ones.

For both alternative scenarios, we have to make assumptions on the modal shift. Not all suppressed car trips will result in PTW trips. Some drivers will use public transport, go by foot or won't undertake the trip at all. Vice versa, an increase in PTW use does not imply an equal decrease in car use. The literature shows that new PTW trips reflect a mix of trips that were previously done by car, public transport, another mode or that didn't occur at all.

Based on a study of the rise of PTW in Paris over the period 2000 to 2007, Kopp (2011) shows that the increase in PTW vehicle kilometres (vkm) results from people shifting from public transportation (53%) or private cars (26.5%). 20% of the increase in vkm is an exogeneous growth in PTW use.

Kämper et al. (2016) analyse the modal shift induced by e-bike users in Germany. The authors show that 45% of the e-bike mileage replaces passenger car kilometres, while 32% of the distance was originally covered with a conventional bicycle.

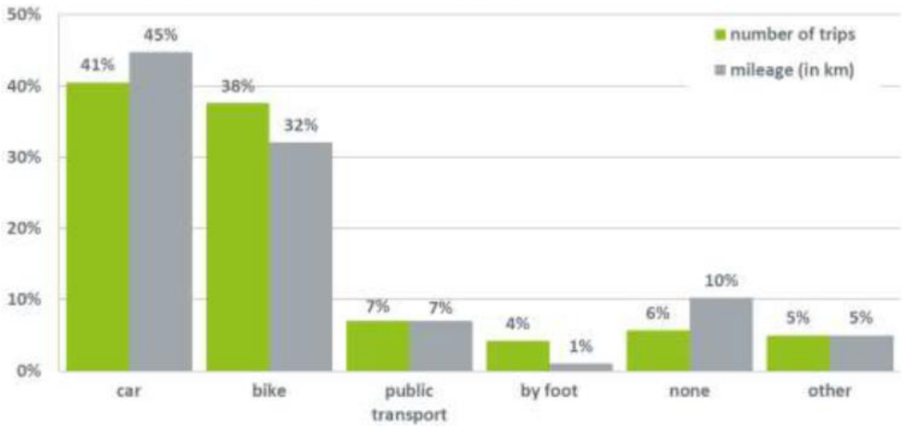


Figure 20 Modal shift induced by e-bikes. Source: Kämper et al (2016)

In a study for the U.K. Department of Transport, WSP Civils (2004) investigated the impact of five policies to stimulate motorcycle use on modal choice in Cambridge. The tested policies were the following:

1. Permitting motorcycles to use bus lanes
2. Increasing the cost of car parking for motorcycle owners by 50%

3. Road pricing for cars: a 10p per mile charge for car travel by motorcycle owners
4. Increased motorcycle ownership by 50%
5. Combination of 3 & 4: increased motorcycle ownership + road pricing for cars

The study found that only road pricing (potentially in combination with increased motorcycle ownership) leads to a significant modal shift from car travel to motorcycles. A road charge for car travel led to a 10.8% decrease in car trips and a 6.2% increase in motorcycle trips.

Table 8 Overview scenarios

	Reference scenario	Alternative 1	Alternative 2
Underlying policy	Current transport policies Business as usual	Green deal impact on PTWs	Regional mobility plans
vkm cars '25 -'30	3.63%	1.98%	-18.18%
vkm PTW '25 -'30	16.65%	+100% MC +150% MP	+ 273% MC + 750% MP
Share EV new sales	2025: 75% MP 2030: 100% MP, 50% MC 2050: 100% MP, 100% MC	2025: 90% MP 2030: 100% MP, 75% MC 2050: 100% MP, 100% MC	2025: 90% MP 2030: 100% MP, 75% MC 2050: 100% MP, 100% MC
Modal shift		50% of increase PTW is modal shift from passenger cars	50% of decrease passenger cars is modal shift to PTW

Table 8 provides an overview of the assumptions made in the three scenarios. A detailed description of the modal shift scenarios is provided below.

Alternative Scenario 1: mild modal shift

In the context of the European Climate Target Plan and the Green Deal, the European Commission published a "Sustainable and Smart Mobility Strategy and Action Plan" (European Commission, 2020).[28] The plan is based on specific milestones to achieve a zero or low emission vehicle fleet and a strong increase in rail transport and inland waterways by 2050.

The Sustainable and Smart Mobility Strategy and Action Plan assesses the impact of different policy scenarios relative to the EU Reference Scenario with respect to their impact on the transport sector. The policy scenarios are designed to meet the targets of the 2030 Climate Target Plan and the European Green Deal, notably a 55% reduction in greenhouse gas emissions by 2050 compared to 1990.

To achieve this climate target, the green deal scenarios are constructed around a specific measures that either focus on carbon pricing (through an expansion of the EU ETS), regulatory measures (e.g. more stringent CO_2 emission standards for vehicles, support for urban sustainable mobility) or a mix between both. These policies reflect, amongst others, specific measures to support multimodal mobility and investments in sustainable urban transport. The projections of these green deal policy scenarios result in a higher transport activity for powered two-wheelers than the Reference Scenario.

[28] European Commission, Directorate-General for Mobility and Transport (2020). Commission Staff Working Document Sustainable and Smart Mobility Strategy – putting European transport on track for the future, SWD/2020/331 final.

We build Alternative Scenario 1 based on the projections for traffic activity for powered two-wheelers in the green deal policy scenarios.[29] Because we want to isolate the effect of a stronger uptake in PTW activity and we do not intend to evaluate the Green Deal scenario perse, we only focus on the impact of the Green Deal implementation in PTWs.

Alternative Scenario 1 differs from the Reference Scenario with respect to the following:

- Aggregated to the Belgian level, vehicle kilometres for motorcycles increase by 100% over the period 2025-2030, in line with the Green Deal policy scenarios.
- We simulate a 150% increase in moped kilometres over the period 2025-2030, which results from a confirmation of the current increasing popularity of mopeds over motorcycles and the regional stimulating policies for these vehicle types.
- The increase in motorcycle and moped vehicle kilometres represents the following modal shift:
    - 16.65% is the expected increase in PTW activity which is also incorporated in the Reference scenario
    - 50% results from a modal shift from cars to PTW
    - 35.35% results from a modal shift from public transportation to PTW
- We assume a faster electrification of the PTW segment, in line with the Sustainable Development Scenario as projected by IEA and the Net Zero Scenario of BNEF. More specifically, the share of electric mopeds in total moped sales increases to 90% by 2025 and 100% by 2030. For motorcycles, we expect electric vehicles to have a share of 75% in 2030 and 100% in 2050.

Alternative Scenario 2: strong modal shift

Alternative Scenario 2 is built based on the change in passenger car activity. Passenger car activity is expected to change in line with the ambitions set by the regional mobility plans. We assume a different reduction rate of car kilometres per road type:

- A decrease of 10% on motorways
- A decrease of 20% on regional roads
- A decrease of 30% on (urban) local roads

At the regional level, this corresponds to a decrease in car kilometres in Brussels, Flanders and Wallonia of 21.6%, 17.8% and 18.4% respectively, which is of comparable magnitude to the ambitions set in the regional mobility plans. Aggregated to the country level, this corresponds to a 18.2% decrease in car kilometres over the period 2025-2030.

We assume that half of the decrease in car kilometres is substituted by an increase in PTW kilometres as follows:

- On motorways: half of the car reduction in car kilometres is replaced by motorcycle kilometres
- On regional roads: half of the reduction in car kilometres is replaced by mopeds (60%) and motorcycles (40%)
- On local roads: half of the reduction in car kilometres is replaced by mopeds (70%) and motorcycles (30%).

[29] https://energy.ec.europa.eu/data-and-analysis/energy-modelling/policy-scenarios-delivering-european-green-deal_en

We assume a faster electrification of the PTW segment, in line with the Sustainable Development Scenario as projected by IEA and the Net Zero Scenario of BNEF. More specifically, the share of electric mopeds in total moped sales increases to 90% by 2025 and 100% by 2030. For motorcycles, we expect electric vehicles to have a share of 75% in 2030 and 100% in 2050.

4.3 Comparison of the three scenarios

To get a better understanding of the three scenarios, we compare the outcomes of each scenario with respect to traffic volumes and vehicle fleet composition over the projected horizon 2025-2050.

Vehicle kilometres

The scenarios differ from each other in the "modal shift period" 2025 to 2030. The reference scenario already foresees a larger increase in PTW vkms than in car kilometres. In Alternative Scenario 1, the uptake in PTW activity is more pronounced, but there is still a quite mild modal shift. Alternative Scenario 2 represents a strong modal shift scenario, with a significant reduction in car kilometres that is only partly substituted by PTW kilometres.

Table 9 Changes in vehicle kilometres in the modal shift period 2025-2030

Vehicle kilometres	Reference Scenario	Alt Scenario 1	Alt Scenario 2
Passenger cars	+3.63%	+1.98%	-18.18%
Powered two-wheelers	+16.65%	+100.00% MC +150% MP	+ 273% MC + 750% MP

Figure 21 to Figure 23 show the relative shares of each road transport mode in the three scenarios. Modal shares are expressed in vehicle kilometres. In all scenarios, passenger cars remain overly dominant. In the reference scenario, the vkm shares for cars, motorcycles and mopeds are respectively 75%, 1.7% and 0.6% in 2050. In Alt 1, these shares are equal to 73%, 2.9% and 1.3%. In Alt 2, the shares of car, motorcycle and moped kilometres in 2050 are equal to 64%, 5.9% and 5.0%.

The numbers in the figures are aggregated for Belgium. There are regional variations in the modal shares based on the level of urbanisation. This is further illustrated in Chapter 6 where we calculate the mobility impact per road type and region.

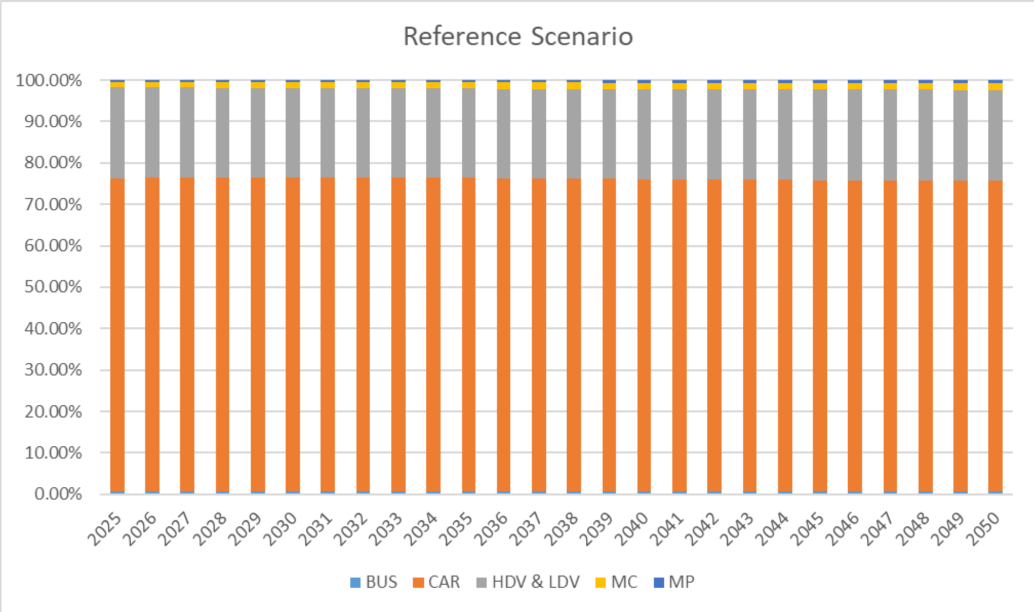


Figure 21 Vehicle kilometre shares reference scenario

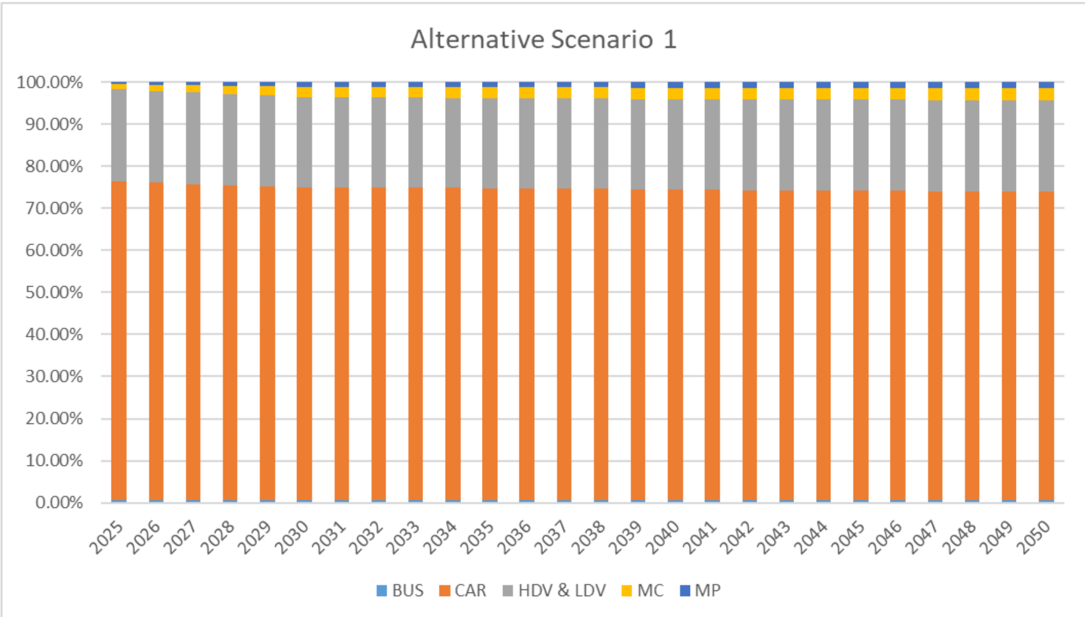


Figure 22 Vehicle kilometre shares Alternative Scenario 1

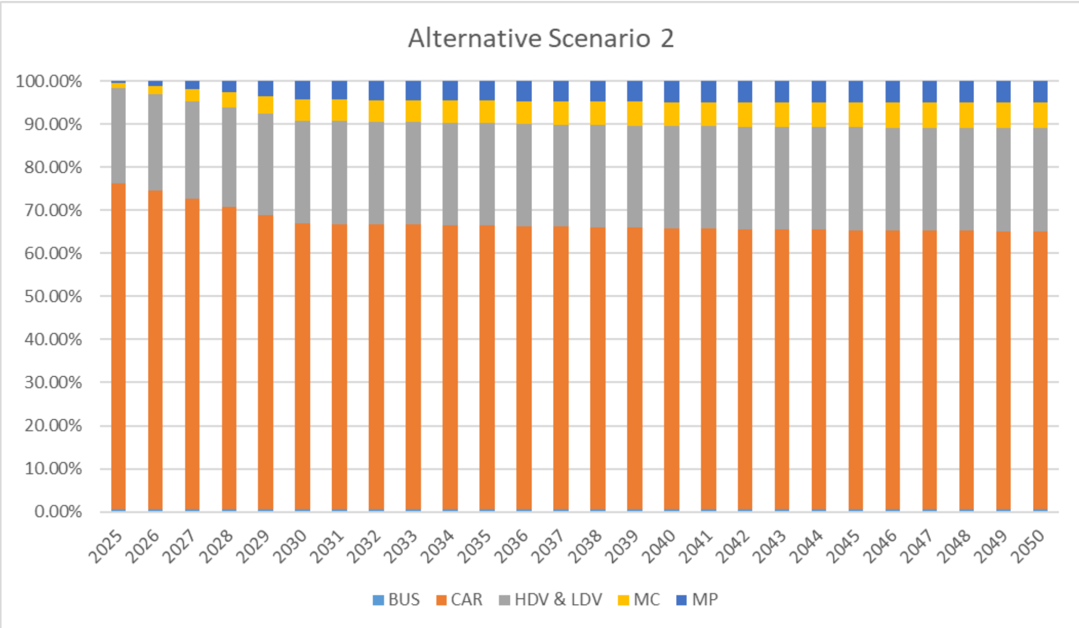


Figure 23 Vehicle kilometre shares Alternative Scenario 2

The modal share per scenario is different when its expressed in number of vehicles instead of vehicle kilometres. This is because the total mileage per year that is driven by a PTW is lower than that of a car. PTW riders typically make trips of shorter distance than cars. This is especially the case for mopeds riders. Therefore, the share of PTW in the total vehicle fleet is larger than the mileage share of these vehicles.

Figure 24 to Figure 26 show the modal shares relative to the total vehicle fleet in the three scenarios. Note that the modal shift shock is concentrated in the 2025-2030 period. After that, modal shares remain fairly constant.

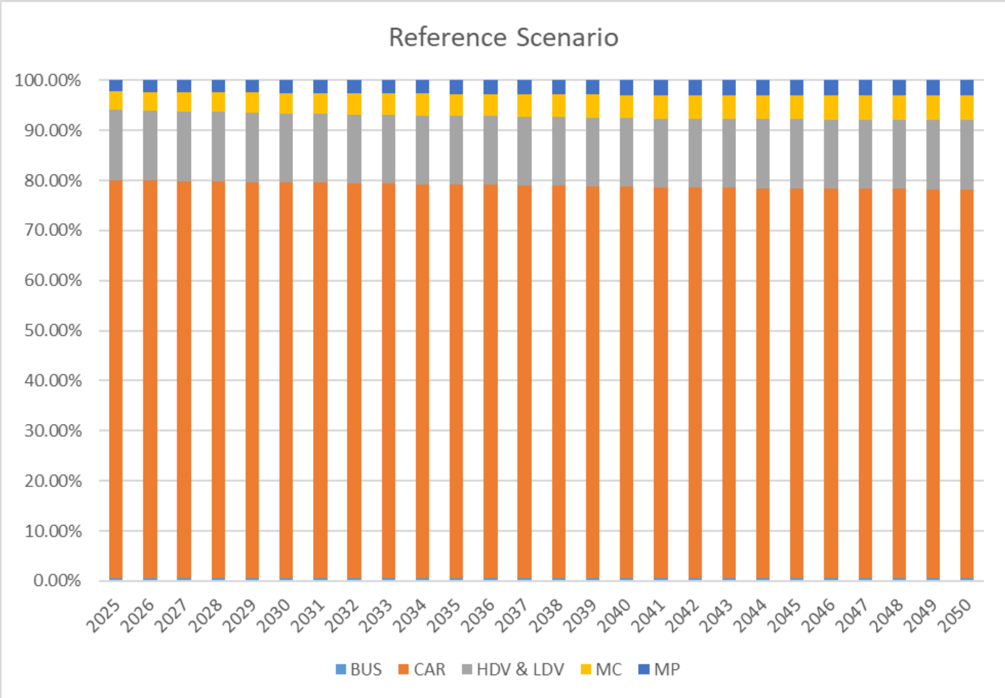


Figure 24 Vehicle fleet shares Reference scenario

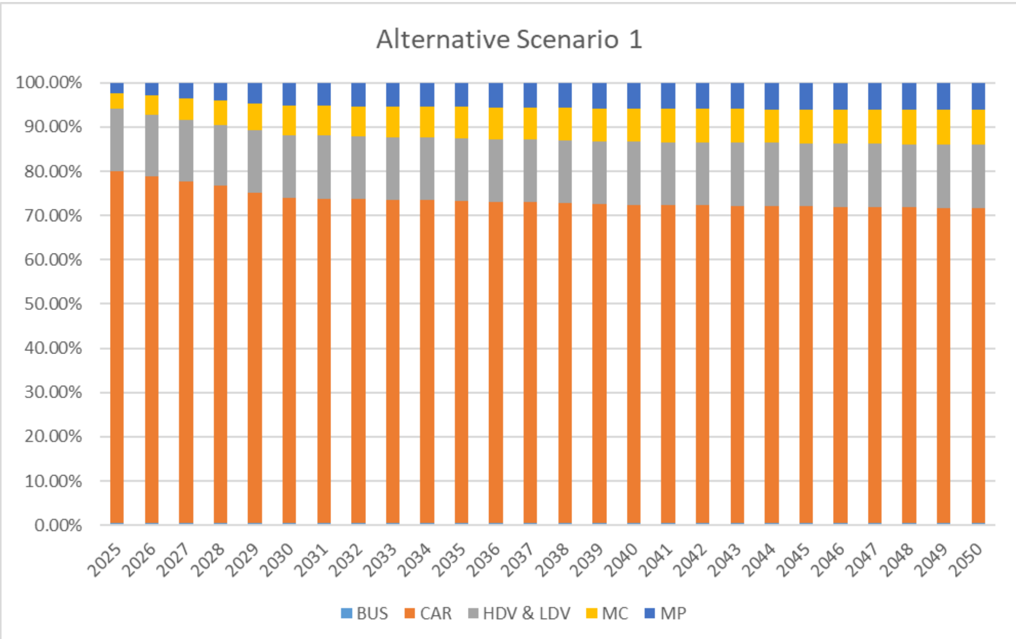


Figure 25 Vehicle fleet shares Alternative Scenario 1 – mild modal shift

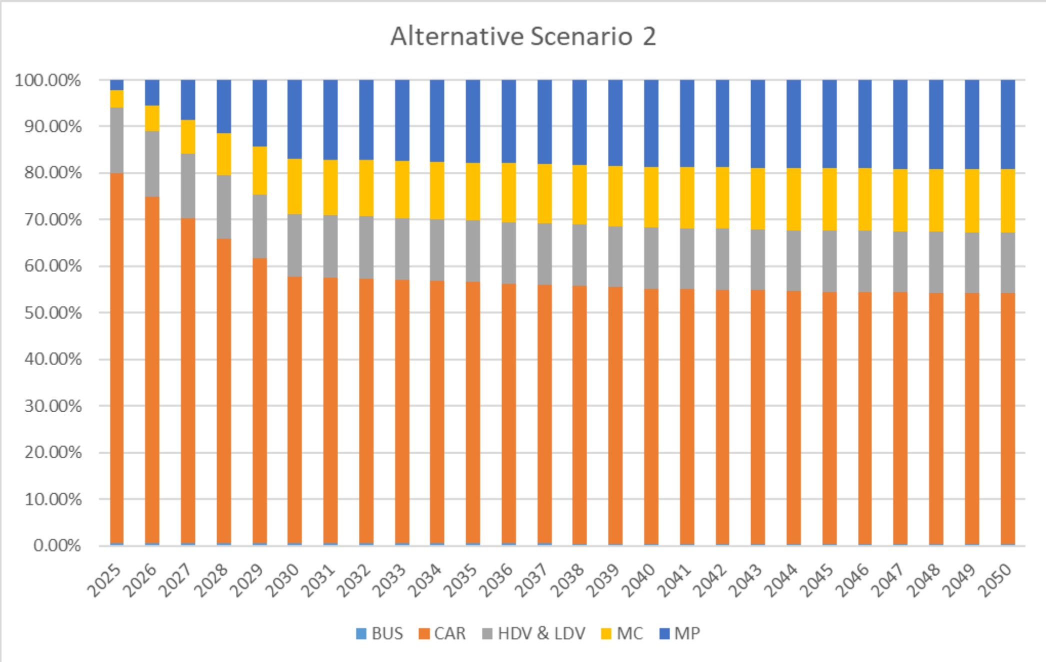


Figure 26 Vehicle fleet shares Alternative Scenario 2 – strong modal shift

PTW vehicle fleet by type, size and fuel

Apart from assumptions on vehicle kilometre per mode, the scenarios differ from the reference scenario with respect to the pace of electrification and the relative share of moped versus motorcycle kilometres.

Table 10 Share of electric vehicle in new vehicle sales

	Reference Scenario			Alt Scenario 1			Alt Scenario 2		
	2025	2030	2050	2025	2030	2050	2025	2030	2050
Moped	75%	100%	100%	90%	100%	100%	90%	100%	100%
Motorcycle		50%	100%		75%	100%		75%	100%

Figure 27 shows the evolution of the powered two-wheeler kilometres per fuel type in each scenario. The figure also makes a distinction between motorcycles (MC) and mopeds (MP). Several observations can be made from the figure. First, there is significant increase in PTW kilometres in the two alternative scenarios compared the reference scenario. This is especially the case for Alternative Scenario 2.

Second, the electrification pace of mopeds is much faster than that for motorcycles. Nearly all moped kilometres will be electric in 2050, in all three scenarios. For motorcycles, the electric share is equal to 77% in 2050 in the reference scenario. In the two alternative scenarios this is equal to 87%.

Third, the relative share of motorcycles versus mopeds differs across the scenarios. By 2050, moped kilometres account for 27% of PTW kilometres in the reference scenario. In Alternative

Scenario 1, this proportion has increased to 31.6%. In Alternative Scenario 2, moped kilometres correspond to 45.6% of all PTW kilometres driven in Belgium.

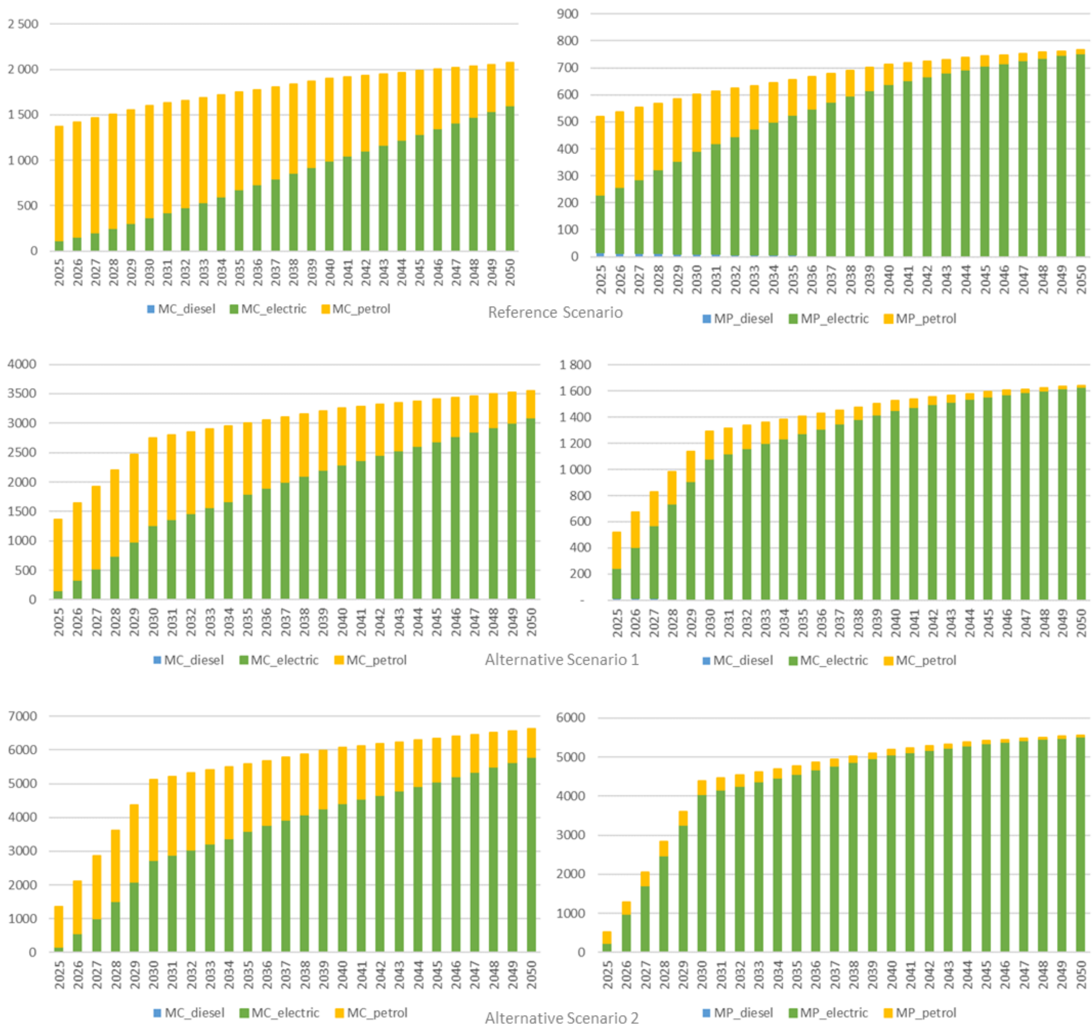


Figure 27 Motorcycles (MC) and mopeds (MP) by fuel type per scenario (in million vkm)

To further illustrate the different shares of mopeds and motorcycles in the total PTW fleet,

Table 11 shows the share of PTW vehicle kilometres in 2050 for each scenario, split up by size segment. The size segments are based on the COPERT classifications. The COPERT database distinguishes between mopeds (< 50cc), small motorcycles (50<cc<=250), medium motorcycles (250<cc<=750) and large motorcycles (> 750cc).

Each alternative scenario assumes a more rapid growth of small two wheelers by 2050. Within the motorcycle segment (PTWs with an engine exceeding 50cc), the size segments remain relatively constant.

Note that the distinction in size categories as shown in the table below is not applicable to e-motorbikes. This is because the power of e-motorbikes is measured based on the battery size (kw).

Table 11 PTW vehicle kilometres by size (COPERT size classes) in 2050

	Reference	Alternative Scenario 1	Alternative Scenario 2
< 50cc	27.3%	31.9%	46.1%
50<cc<=250	24.2%	22.5%	17.6%
250<cc<=750	23.6%	22.3%	17.8%
>750cc	24.9%	23.3%	18.6%

5 Social Cost Benefit Analysis

With a **social cost benefit analysis (SCBA)**, we assess the societal value of a change in the modal share of powered two-wheelers in Belgium. For and extended version of the description of the SCBA methodology, we refer to the European guidelines for cost benefit analysis of DG Regio (2014).[30] Here, we focus on what is of significant importance for the project at hand.

In a SCBA, we calculate present value of all current and future costs and benefits of a scenario. More specifically, a SCBA takes into account the following effects:

- Direct effects (private costs and benefits)
- Indirect effects (if relevant)
- External effects
- Project costs (not relevant here, because a modal shift scenario does not require upfront investment costs)

The effects are calculated over a specific time horizon and subsequently discounted to calculate their present value, which is the **total monetary value (economic and social)** of a project or a scenario.

In a cost benefit analysis, we use the concept of **Net Present Value** (NPV) to calculate the current societal value of future costs and benefits. The NPV method consists of the discounting of all cost and benefits:

$$NPV = \sum_{t=0}^{T} \frac{(B_t - C_t)}{(1 + SDR)^t}$$

where B and C are respectively equal to the benefits and the costs and SDR is the social discount rate.

The implication of discounting future cost and benefits is that we assign a higher value to costs and benefits that occur earlier in time. For the baseline analysis, we use **a social discount rate of 3%** as recommended by European guidelines for SCBA.

The cost and benefits resulting from each scenario are calculated over a **specific time horizon**. Here, we estimate costs and benefits for **the period 2025 to 2050**. Setting an end date at 2050 is somewhat arbitrary because the effects of a change in modal share across transport modes are expected to be permanent. An alternative approach would be to work with a perpetual time horizon. This means that the cost and benefits are calculated for the infinite future (perpetuity). In that case, we should make traffic predictions over a very long time period. Estimates so far in the future are not very reliable. Therefore, we work with a limited time horizon. This only leads to a small underestimation of the total effects. In practice, the present value of long term costs and benefits converges to zero because of discounting.

[30] https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf

In the SCBA, we work with a **fixed price level**, notably **prices for the year 2021** based on the harmonised index of consumer prices obtained from Statbel. Where necessary, in the previous steps we will convert key figures from older studies to the correct price level.

In general, the effects of a modal shift from cars to powered two-wheelers fall into four groups.

Direct effects

The **direct effects** on the transport system follow from the differences in costs (time and monetary) of transport and the transport flows in the baseline scenario and the alternative scenarios. As far as direct effects are concerned, we therefore expect the following elements:

- Mobility effects that take the form of time gains or losses caused by a change in congestion levels and/or average speed.
- Effects on monetary costs in scenarios such as purchase costs, maintenance costs and fuel costs.

We will calculate the economic and social value of the mobility effects and the private operating costs of each alternative scenario and compare these effects with those in the reference scenario.

Indirect effects

Indirect impacts are those that occur outside the project. These are mainly the impact on government revenues and the wider economic effects (GDP and employment).

Apart from direct effects, a modal shift towards PTWs can have repercussions on other modes of transport, the rest of the economy and on the population, for instance in terms of GNP per sector, unemployment and income per income percentile, etc.

Indirect economic effects are effects generated outside the transport market. The existence of these indirect effects is confirmed in the literature, but there is much discussion about the order of magnitude of these effects. These indirect effects on the wider economy are less easy to quantify. After all, many indirect effects are rather redistributive. It is, however, an effect that can count on much interest.

Because there is a risk of double counting, we only include indirect effects if they are expected to be significant and if they can be quantified. This is in line with the approach of DG Regio (2014) which also warns against double counting and the lack of robust techniques. Given the fact that the share of powered two-wheelers in the total transport system is Belgium is small, we do not expect large indirect effects of an increase in PTWs modal shares. Therefore, we opt not to calculate the indirect effects in this project.

External effects

The **external effects** are the effects on the environment (local residents, nature, agriculture, ...) and for which there is no compensation. In the end, society as a whole pays. More specifically, in this project we will focus on the external effects of transport flows which includes the effects of:

- emissions (air quality and climate change)
- noise pollution,
- road safety,
- occupation of public space

6 Mobility

When people shift from driving a car to a powered two-wheeler, they occupy less road space, thereby contributing to easing traffic congestion. Apart from being smaller than cars, PTWs travel faster because PTW riders can use lane-filtering with other vehicles. PTWs do not stand in traffic jams. In case of a queue, for example at traffic lights, PTWs join traffic much faster than cars thanks to their lower weight, smaller size and high driving dynamics.

Several studies have demonstrated that travel times by PTWs in an urban environment are much lower than those of cars. For example, a recent survey carried out in Poland shows that travel time of PTWs in large cities is half that of cars (Dorocki & Wantuch-Matla, 2021). Marquet & Miralles-Guasch (2016) investigate the factors behind the rise of PTWs in Barcelona and report that 35.3% of the PTW riders motivate their modal choice by the fact that motorbikes are "faster than public transport".

Kopp (2011) calculates the time savings that can be realized when switching from a specific transport mode to a PTW for trips within Paris or trips between Paris and the suburbs. These time gains turn out to be significant, ranging from 27% time savings when switching from RER to PTW, to 386% time savings when switching from traveling on foot to PTW. A modal switch from passenger car to PTW results in 45% time savings within Paris and 39% time saved for a trip between Paris and the suburbs.

We measure the impact of the modal shift scenarios described in Chapter 4 on traffic congestion and resulting time savings. Because the traffic situation and traffic mix differs considerably depending on the road type, we calculate the congestion effects separately for motorways, regional roads and local roads. We do this for the three regions, Flanders, Wallonia and Brussels.

6.1 Road congestion costs on the primary road network

The primary road network consists of motorways and the ring roads around the big cities, as shown in Figure 28.

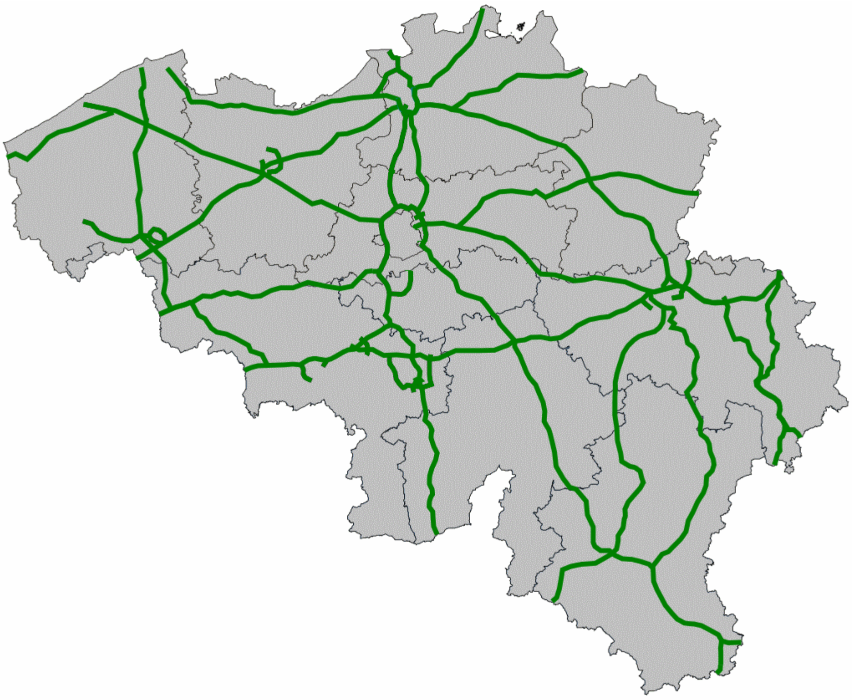


Figure 28 Primary road network Belgium

6.1.1 Congestion and lost vehicle hours

To estimate the impact of congestion on the primary road network, we first calculate the average travel time per kilometre during an average working day. Because traffic volumes vary considerably during the day, we make a distinction between the following time frames:

- Morning rush hour: 7 am – 10 am (3 hours)
- Day: 10 am – 4 pm (6 hours)
- Evening rush hour: 4 pm – 7 pm (3 hours)
- Late evening: 7 pm – 11 pm (4 hours)
- Night: 11 pm – 7 am (8 hours)

For each regional area, average travel times per time of the day are calculated based on fitted congestion functions. A congestion function describes the relation between travel times (T) and traffic volume. We use the Bureau of Public Records congestion function, that has the following functional form:

$$T = T_{ff}\left(1 + \alpha\left(\frac{q}{C}\right)^{\beta}\right)$$

where T_{ff} = travel time with free float speed (seconds)

q = traffic volume (vehicle kilometre per hour)

C = maximum road capacity (vehicle kilometre per hour)

$\alpha,\ \beta$ = parameters

To estimate travel times on the Belgian motorways, we use congestion functions that were fitted in earlier studies. For Flanders, the parameters of the congestion function are based on Delhaye et al

(2017). For Brussels and Wallonia, we use the congestion functions estimated in Maerivoet and Yperman (2008).

The parameters of the congestion functions are shown in Table 12. The average free float speed, (T_{ff}), is expressed in seconds. It corresponds respectively to 97 km/h, 104 km/h and 106 km/h on motorways in Flanders, Wallonia and Brussels.

Table 12 Parameters of the congestion functions of the primary road network

	T_{ff}	C	α	β
Flanders	37.22	5 664 245	0.562	5.682
Wallonia	34.59	2 977 611	0.075	1.000
Brussels	33.90	22 251	0.330	1.239

Source: Delhaye et al (2017) and Maerivoet and Yperman (2008)

To estimate the congestion function, vehicle kilometres are expressed in person car equivalents (PCE). Heavy duty trucks and buses are equal to 2 PCE, while motorcycles correspond to 0.5 PCE. This is because motorcycles can split lanes in case of slowing traffic.

Next, we calculate the time lost per vehicle, V, which is equal to the difference between the actual travel time and the travel time at free float speed:

$$V = max\{0, T - T_{ff}\}$$

where V = the average time lost

T = the average travel time

T_{ff} = travel time at free float speed

Once the time lost per vehicle is determined, we compute the Lost Vehicle Hours (LVH), that are equal to the average number of hours that all vehicles lose due to congestion or reduced speed.

More specifically, lost vehicle hours are equal to the product of traffic volume and average time loss:

$$LVH = \frac{qV}{3600}$$

where LVH = average number of lost vehicle hours (vehicle hours/hour)

q = traffic volume (vehicle kilometres/hour)

V = time lost (hours/kilometre)

To determine the initial vehicle kilometres per time of the day and per region, we start from the counted vehicle kilometres in Delhaye et al (2017) (Flanders) and Maerivoet and Yperman (2008) (Brussels and Wallonia). Since these numbers are based on historical data, we calculate corresponding values up to 2019 based on vkm growth rates reported in the MAM database.[31]

[31] We don't use vehicle kilometres for the years 2020 and 2021 because these are non-representative years caused by the Covid-19 crisis.

The Transport Database of the Federal Planning Agency reports the vehicle kilometre per transport mode and road type on the Belgian road network up to 2017. This data permits to calculate the modal shares on the primary road network in each region. We assume that the modal shares have remained constant since 2017. Future modal shares are determined based on the traffic forecasts of each scenario. The initial modal shares on the primary road network are shown in Table 13.

Table 13 Modal share on the Belgian primary road network.

	Flanders	Wallonia	Brussels
Passenger car	74.3%	75.5%	84.7%
HDV	13.9%	12.3%	4.5%
LDV	10.9%	11.2%	8.9%
Motorcycle	0.6%	0.7%	0.6%
Moped	0.0%	0.0%	0.0%
Bus	0.2%	0.3%	1.2%

Source: Federal Planning Bureau

The lost vehicle hours per weekday in each scenario are shown in Figure 29 to Figure 31. Most of the traffic congestion is located on Flemish territory. The share of traffic congestion in Flanders also intensifies over time. In 2025, 75% of the LVH are in Flanders, while in 2050 this share has increased to 82%.

In Alternative Scenario 1, lost vehicle hours are only slightly lower than in the reference scenario. In 2030, LVH in Alt1 are 1.6% lower than in the reference scenario. However, the lower levels of congestion lead to an induced traffic demand. By 2050, LVH in scenario Alt 1 are only 0.8% lower than in the reference scenario.

In Alternative Scenario 2, we observe a significant drop in LVH during the period 2025-2030. This is the period where we assumed the modal shift between cars and motorcycles taking place. The scenario assume a 10% drop in car kilometres during this period, which corresponds to a decrease of approximately 2.09% per year. Motorcycle kilometres increase in turn, but they don't compensate fully for all car kilometres. As a result, traffic flows more smoothly and LVH are lower. After this initial modal shift, traffic volumes increase again for all modes, as do LVHs.

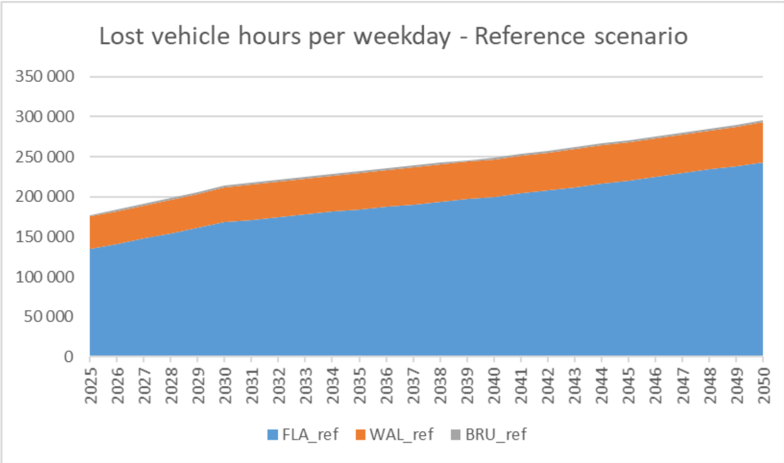


Figure 29 LVH per weekday on the primary road network in Belgium - Reference scenario

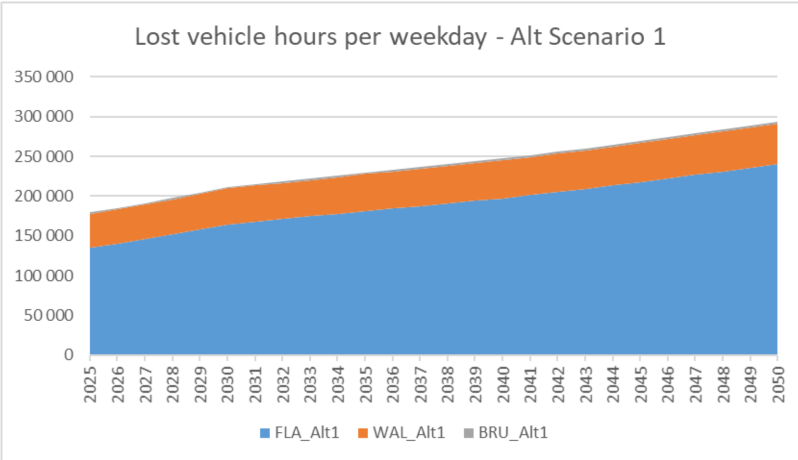


Figure 30 LVH per weekday on the primary road network in Belgium - Alternative scenario 1

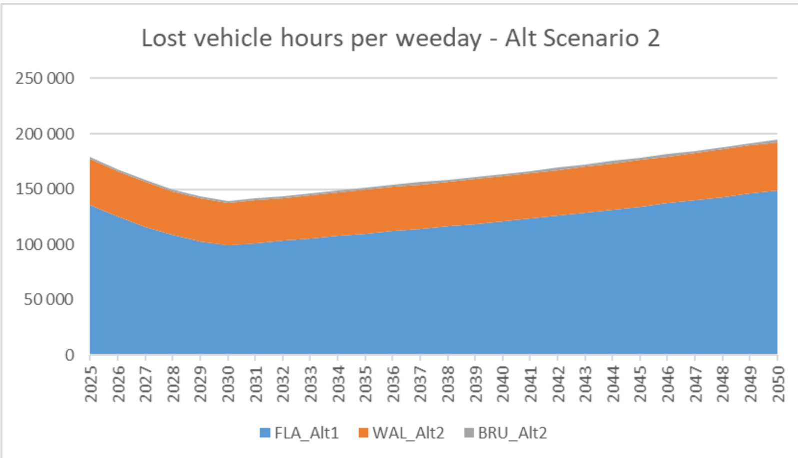


Figure 31 LVH per weekday on the primary road network in Belgium - Alternative scenario 2

6.1.2 Economic costs of congestion

We estimate the external benefits of a modal shift from cars to PTWs by calculating the total congestion costs per year over the period 2025 to 2050 in each scenario.

Total congestion costs per year, IC, are calculated as follows:

$$IC_{year} = 230 * LVH_{day} * [sh_{mode} * OF_{mode} * VOT_{mode}]$$

where LVH_{day} = the average lost vehicle hours per working day

sh_{mode} = the share of each transport mode on the road type

OF_{mode} = the occupancy factor of each mode

VOT_{mode} = the value of time per mode (freight versus passenger transport)

Note that we assume 230 working days per year, which is consistent with the assumptions reported for the estimation of the TomTom congestion index and the calculations in DG MOVE (2020). During weekends, we assume traffic to flow freely. Occupancy rates are set equal to 1.39 for passenger cars and 20 for buses, following Delhaye et al (2017).

To express the effects of a change in lost vehicle hours in monetary terms, the average travel time has to be multiplied with the "value of time". Value of time is determined based on research on the willingness to pay for travel time reduction in passenger transport. The value of time for passenger transport reflects the value of travellers allocated to:

- time savings (higher speed)
- improvement in comfort condition of the travel time (e.g. more fluent traffic flows)

A recent and renowned study by the UK Department for Transport (DfT) estimates the value of time for different transport modes, distances and travel motives. The time valuations (expressed in € 2020 prices) are shown in Table 14.

Table 14 Value of time (in €/hour) for different passenger transport modes, 2020

Distance	Commuting	Non commuting	Business trips (=employer pays the costs)				
			All modes	Car	Bus	Other public transport (tram, metro)	Rail
All	15,64	7,14	25,43	23,35	Not available	11,62	38,52
<32 km	11,54	5,05	11,59	11,45		11,62	14,10
32 to 160 km	16,95	9.05	22,39	22,11		11,62	40,44
>160 km	19,95	12,93	39,92	35,91		11,62	40,44

Source: Batley et al (2019)

We convert the time valuations in Table 14 to one central value of time based on the frequency of different travel motives over all transport modes. The frequency of travel motives is obtained from the most recent Study on Mobility Behaviour (OVG 2015-2016). We express the values in prices of 2021.[32]

Table 15 Overall value of time passenger transport, € 2021

Commuting	Business travel	Other	Overall value of time (weighted average by motive)
€ 16,02/hour	€ 26,05/hour	€ 7,31/hour	€ 11,00/hour
23%	9%	68%	

Source: Own calculations based on Batley el al. (2019)

When passengers lose time in congestion, additional costs arise. An example are schedule delay costs. Therefore, a weighting factor is applied to in-vehicle unit value of time spent in congestion. Following the recommendations of the EC's Economic Appraisal Vademecum 2021-2027, we multiply the value of time with a factor 1.5 to account for the extra costs of in-vehicle weighting time.[33] Hence, the average value of time for transport by passenger car is equal to €16.5/hour.

The value of time for freight in Belgium is determined by DG MOVE (2020) in prices of the year 2016. We convert these values to 2021 prices:

Table 16 Value of time for freight road long distance trips

	2016	2021
Value per tonne	1.1	1.2
Value per HGV	33.4	36.4

Source: DG MOVE (2020)

Table 17 shows the calculated economic benefit from time savings in the modal shift period 2025-2030. In Alt 1, economic benefits rise to € 21.6 million in 2030, almost all realized in Flanders (97%). In Alt 2, the estimated benefits are significantly higher, mounting up to even € 446.8 per year in 2030. 90.9% of these benefits are realized in Flanders, 8.7% in Wallonia and 0.5% in Brussels.

Table 17 Economic benefit of time savings on the primary road network per year 2025-2030

	2025	**2026**	**2027**	**2028**	**2029**	**2030**
Alternative Scenario 1						
Flanders	0	5 426 834	10 466 730	14 927 311	18 569 606	21 097 245
Wallonia	0	325 032	558 947	683 872	679 010	520 165
Brussels	0	18 666	32 948	41 943	44 596	39 678
Total	**0**	**5 770 531**	**11 058 625**	**15 653 126**	**19 293 212**	**21 657 089**
Alternative Scenario 2						
Flanders	0	96 271 903	185 035 106	266 448 083	340 350 325	406 143 046
Wallonia	0	8 979 944	17 426 106	25 263 074	32 391 549	38 681 411
Brussels	0	525 899	1 004 798	1 425 355	1 771 385	2 019 726
Total	**0**	**105 777 745**	**203 466 010**	**293 136 512**	**374 513 259**	**446 844 183**

[32] OVG 5.4 - Tabel 122: Verdeling van het gaakpppd volgens motief

[33] https://ec.europa.eu/regional_policy/en/information/publications/guides/2021/economic-appraisal-vademecum-2021-2027-general-principles-and-sector-applications

We then calculate the economic benefit of each modal shift scenario over the full horizon 2025-2030 and discount yearly cost and benefits to the present using the net present value formula. The results are shown in Table 18. We find that the modal shift scenarios lead to substantial economic benefits on the primary road network. This is especially the case for Flanders, where congestion on the primary road network is severe. In Alternative Scenario 1, that assumes are relatively mild modal split, a total benefit of € 306.6 million is realized in Belgium. In Alternative Scenario 2, this benefit is estimated at a staggering € 7 829 million.

Table 18 Net Present Value economic benefit time savings on the primary road network 2025-2030

	Flanders	Wallonia	Brussels	**Total**
NPV_Alt1	€ 304 346 416	€ 1 933 239	€ 319 761	**€ 306 599 417**
NPV_Alt2	€ 7 184 191 464	€ 613 169 016	€ 31 728 361	**€ 7 829 088 841**

Note that the time savings in Alt 2 cannot be fully allocated to an increase in PTW-use. First and foremost, this scenario assumes a decrease in car kilometres. Only half of these car kilometres is picked up by PTW activity.

6.2 Road congestion costs on the regional and urban road network

To estimate the mobility effects of a modal shift on the regional and urban road network, we use microsimulations modelled with VISSIM software. The advantage of microsimulations is that we can program the traffic flow and have a detailed view on the mobility effects on each road user. The VISSIM software allows to simulate non-lane based traffic.

6.2.1 Case studies

Studying the mobility effects of a modal shift with microsimulations implies that we cannot observe the overall Belgian road network. Instead, we focus on two representative case studies representing a typical regional road and an urban (local) traffic situation.

The regional network consists of the R11, which connects the airport of Deurne with Wijnegem. It is mostly two lanes wide, and is lined with ribbon development. It also provides access to a large shopping mall and several major car dealers, furniture shops, etc. Moreover, it contains the on- and offramp complex to the E313 in Wommelgem, which is often heavily congested.

Figure 32 R11 at Wommelgem - Source: Google Maps

The local urban network is based on the Bredabaan in Antwerp. A major part of the network consists of one lane in each direction, cycling lanes on both sides of the road, and a strong presence of public transport on a segregated bus- and tram lane. Along the road, there are several shops and housing, and many small roads give out on the Bredabaan. At junctions with major roads, such as the Ringlaan and the Horstebaan, traffic signals are present.

The traffic situation at Bredabaan is diverse. In the southern part, the traffic situation is highly urban with single lanes and a dense mix of public transport, motorised and non-motorized traffic (Figure 33). In the northern part, the road evolves to a two lane street, but with many intersections (Figure 34).

Figure 33 Bredabaan south - Source: Google Maps

Figure 34 Bredabaan north - Source: Google Maps

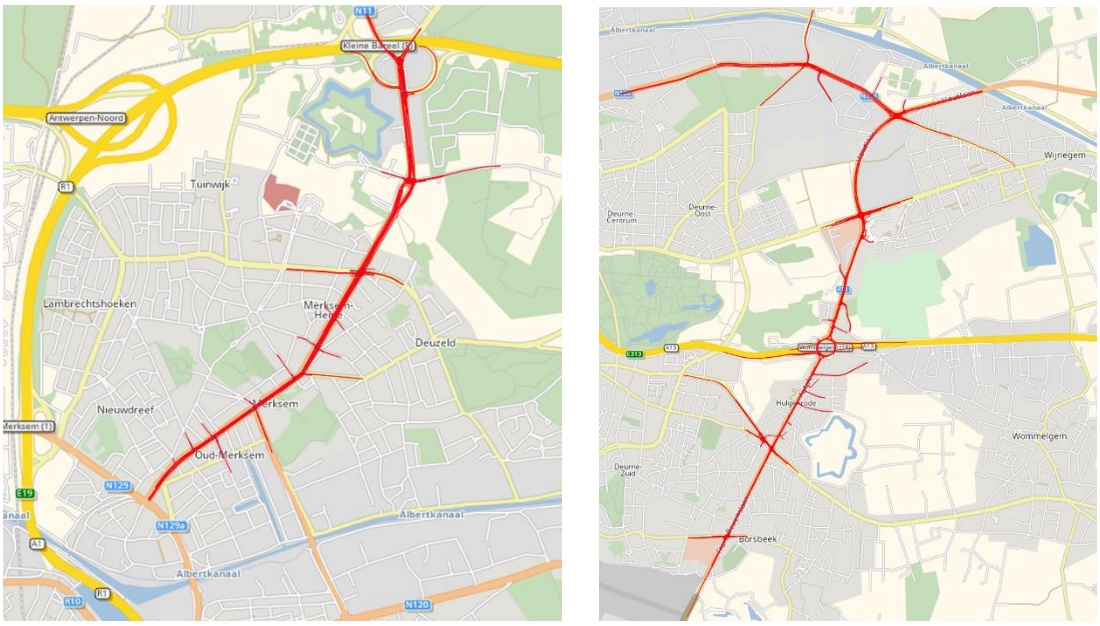


Figure 35: The selected networks for the urban environment (Left) and the regional roads (Right), Own figure from VISSIM.

The choice for two case studies is based on the sufficient presence of traffic demand and the representation of the road network. Both segments suffer from congestion in morning and evening rush hour, but have relatively free floating traffic the rest of the day. In the simulations, it is assumed that motorcycles behave similar to cars in uncongested circumstances. In congested traffic, however, PTWs will try to overtake other vehicles in order to speed up their journey. Therefore, it is in congested networks that PTW are expected to make the most significant difference. The main time savings from the modal shift are expected to come from the fact that more PTWs result in less cars. Furthermore, PTWs are typically able to accelerate faster when the traffic signal turns green, resulting in a reduced impact on other modes compared to cars.

The input to the network is based on traffic counts during 2 hours in the morning rush hour and 2 hours in the evening rush hour. These input figures rescaled to the base year 2025 based on the traffic forecast of the reference scenario discussed in Section 4.1. The traffic intensities in the different scenarios are calculated starting from the base case, and increased as prescribed in the two alternative scenarios discussed in Chapter 4.

Figure 36 and Figure 37 show respectively the modal share of each transport mode on the selected regional and local road segments in the reference scenario and the two alternative scenarios. Unsurprisingly, the share of PTWs is the largest in Alternative Scenario 2.

On regional roads, the share of motorcycles increases from 2% in the reference scenario to 4.2% in Alt 1 and 6% in Alt 2. For mopeds, the increases is even more pronounced. Their share in the reference scenario is equal to 1.5%. In Alternative scenario 1 it increases to 3.8% and in Alternative scenario 2 to 10.6%.

A similar trend is observed for the modal shares in on the urban road segments. The relative increase in the modal share of mopeds is stronger in Alternative 2. In the reference scenario, mopeds account for only 0.3% of the traffic. In Alternative 1, their share has increased to 1.3%, while in Alternative, 2 they represent a share of 10.8%. For motorcycles, we observe a similar pattern as for regional roads. The modal share of motorcycles increases from 1.5% in the reference scenario to 3% in Alternative 1 and 6.2% in Alternative 2.

The increase in modal share of PTWs is mainly attributed to a decrease in the share of passenger cars. Note that the alternative scenarios assume that part of the modal shift comes from a change in public transport use. However, we don't assume a change in the number of trams and buses apart from the growth rates already incorporated in the reference scenario. Instead, we assume the modal shift to have an impact on occupancy rates on public transport modes.

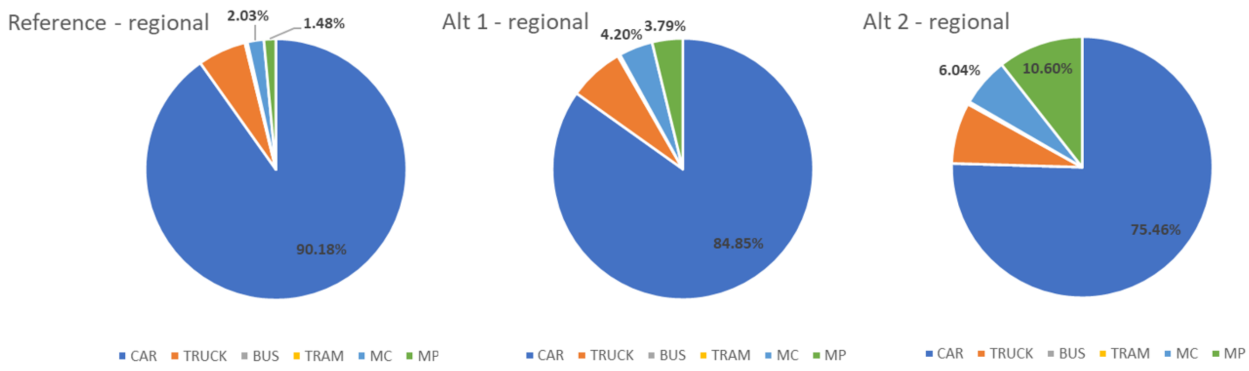


Figure 36 Modal shares regional road network

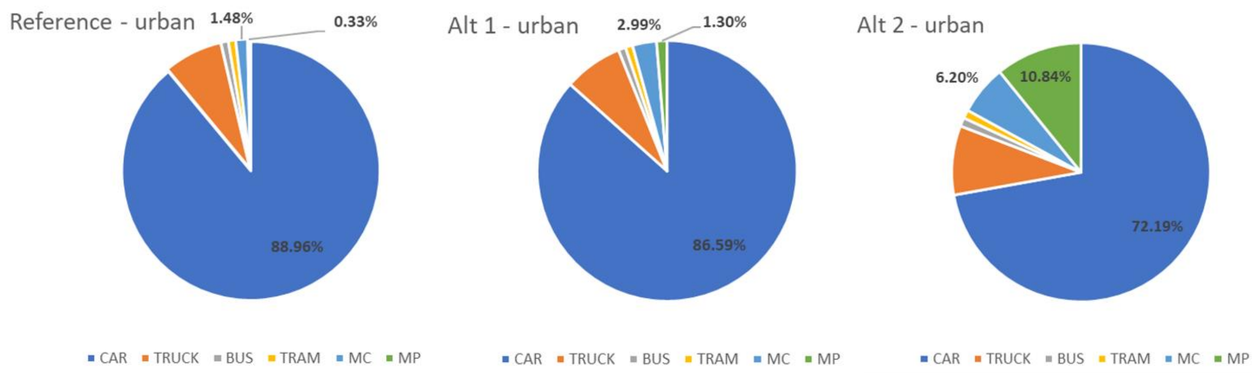


Figure 37 Modal shares local urban road network

6.2.2 *Modelling PTW driving behaviour*

Motorcycles

In free-flow traffic conditions, motors behave similarly to cars. However, two motors are able to share a lane, thereby postponing breakdown of the road. In congested traffic conditions, the motorcycle rider's behaviour is vastly different from other modes. Motorcycles are able to overtake other road users on the same lane when the speeds are low enough. On motorways, this often happens while the other road users are also moving, using the wider lanes. On urban and local networks, as traffic is mostly dominated by traffic signals, motorcycles will navigate through stopped traffic. This allows for smaller gaps between the vehicles when overtaking. On the contrary, the lanes are often smaller, and especially on one-lane streets, there is often insufficient lateral space to pass other road users.

Apart from their ability to pass other vehicles to reach the front of the traffic queue, motorcycles are also able to accelerate faster from the front of the queue. Consequently, following vehicles will not be hindered as strongly as when they were following a car. In VISSIM, this faster acceleration is modelled based on the empirically measured acceleration and deceleration, as proposed by Kumar et al (2020). The desired speed of the motorcycle rider is assumed equal to the speed for car drivers, namely 50 km/h on the urban network and 70 km/h on the regional network.

For lane filtering, the default settings of VISSIM do not allow for vehicles to pass others in the same lane. However, by defining alternative driving behaviours, it is possible to allow the overtaking of vehicles, when sufficient lateral distance is available. By trial-and-error, a threshold is defined for this distance such that motorcycles overtake only when realistic. An overview of the parameters used in this microsimulation can be found in Annex 2.

Mopeds

In Belgian law, it is allowed for mopeds and speed pedelecs to choose whether they drive on the public road or on the cycling path when the road's speed is limit is 50 km/h. This is, however, a behaviour that is not easily implemented in the simulation. Therefore, it is assumed that they strictly travel on the cycling path. This assumption is justified as the drivers will only drive on the road if there is no congestion. At times of free-flow there will only be a negligible impact on other drivers, and therefore no significant delays will be added.

The simulated networks do not have a cycling path that lines the full road network, and only at intersections all paths are modelled. To extrapolate the resulting travel times and delays, it is assumed that no time will be lost between intersections, and that the average distance travelled by moped is equal to the average distance travelled by cars. Assuming a free-flow travel speed for mopeds of 35 km/h (assuming an equal proportion of class A and class B mopeds), the total travel time can be extrapolated.

Mopeds have the ability to accelerate faster than cyclists. However, the difference and the impact of this difference on delays is much smaller than for motorcycles. Therefore, it is assumed the same as the default cyclists in VISSIM. The desired speed of mopeds will however be significantly higher. For this, a distribution between 30 km/h and 45 km/h is chosen. The lower bound represents the electrically supported bikes and class A mopeds, whereas 45 km/h is the legal speed limit for speed pedelecs and class B mopeds.

Calibration

As there is no data available to estimate the model parameters when motors overtake stationary traffic, these parameters in VISSIM are estimated by trail-and-error. Therefore, the part of the delay attributable to lane filtering may be measured imprecisely. As a robustness check and to understand the importance in the total result of the vehicle hours lost, a sensitivity analysis is performed on this parameter for the urban context.

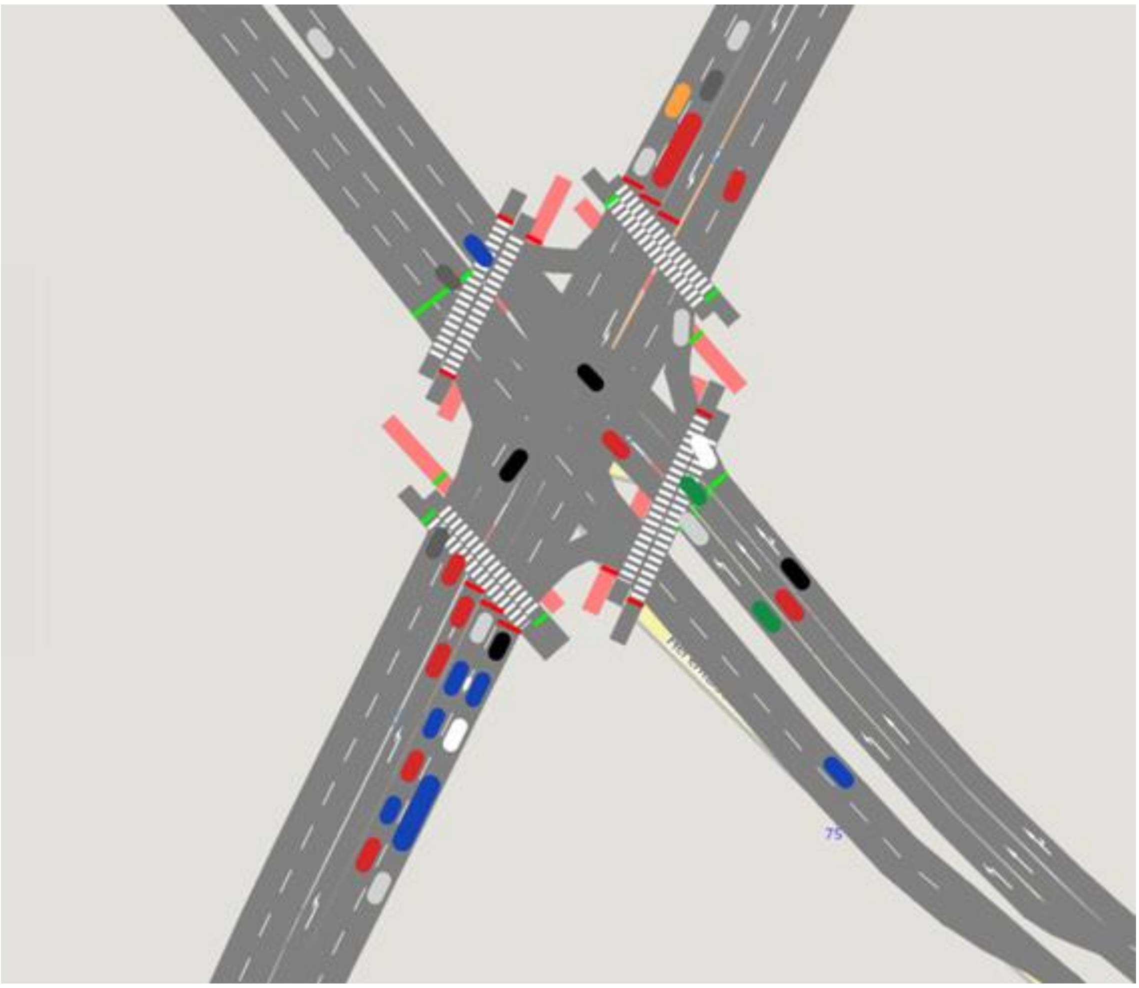


Figure 38 Snapshot of the VISSIM simulation

6.2.3 Impact modal shift scenarios on mobility

Mobility patterns are simulated for each scenario during four hours: 2 hours during morning rush hour and 2 hours during evening rush hour. In line with the assumptions made for the primary road network, we assume that each peak hour period lasts three hours, notably from 7 am to 10 am in the morning and from 4 pm to 7 pm in the evening. Hence, we rescale the mobility effects to a three-hour timeframe. We assume free floating traffic during the rest of the day. Note that this means that we slightly underestimate the time savings realized by the modal shift because PTWs accelerate faster at traffic lights.

Results of the case studies

Table 19 shows the impact of the modal shift to PTW on the **regional road network**. In Alternative 1, we find no significant impact on total travel times and lost vehicle hours. In Alternative 2, that involves a stronger modal shift scenario, the time gains are much stronger. During morning rush hour, travel times decrease by 39% and lost vehicle times decrease by 60%

compared to the situation in the reference scenario. During the evening peak, we also observe significant time gains in Alternative Scenario 2.

Table 19 Total mobility impact on the regional road network

	Reference	Alternative 1	Alternative 2
Total travel time (hours) – regional road network			
Morning	2 469	2 481 (+0.5)	1 514 (-39%)
Evening	2 597	2 633 (+1.4%)	1 867 (-28%)
Lost vehicle hours – regional road network			
Morning	1 364	1 356 (-0.5%)	544 (-60%)
Evening	1 286	1 294 (+0.6%)	716 (-44%)

When we look at the overall traffic flows on the **local road network** resulting from the modal shift scenarios, we notice a smaller effect than on the regional roads (Table 20). In Alternative 1, time gains, expressed in total travel time or lost vehicle hours, are small compared to the reference scenario. In Alternative 2, we find much larger time gains in both rush hour periods. Travel time decreases by 27% to 28% and lost vehicle hours decrease by 44% compared to the reference scenario.

Our findings concerning the mobility impact of PTWs in an urbanized environment are similar to the results reported by Kopp (2011) for the Paris case. Kopp (2011) estimates that times savings from a modal shift from passenger cars to PTWs are in a range of 39% to 45% for the Paris region.

Table 20 Total mobility impact on urban road network

	Reference	Alternative 1	Alternative 2
Total travel time (hours) - urban road network			
Morning	1 124	1 124 (0.0%)	811 (-28%)
Evening	1 476	1 382 (-6.4%)	1 066 (-28%)
Lost vehicle hours - urban road network			
Morning	470	469 (-0.3%)	265 (-44%)
Evening	645	645 (0.0%)	360 (-44%)

To get a better insight in the impact of the modal shift scenarios on the transport modes, Figure 39 and Figure 40 show the speed of each mode during the peak hours (averaged over the morning and evening rush hour) in each scenario. The average speed of mopeds is hardly affected by the modal shift. This is intuitive because mopeds can use separate bicycle lanes and are less sensitive to changes in traffic volume on other lanes. For passenger cars, motorcycles, trucks and buses, we find that average speed increases when there is a substantial modal shift from cars to PTWs. For example, the average speed of passenger cars on the regional road network increases from 29 km/h in the reference case to 39 km/h in Alternative Scenario 2.

A second observation from the figures is that powered two-wheelers move faster on urban roads than passenger cars. This is because they can navigate through traffic when there is a queue. Small PTWs like mopeds have higher average speeds on the urban network than motorcycles. Even in the reference case, PTW have a higher speed on the urban road network than cars. This explains the rise of this vehicle type in cities.

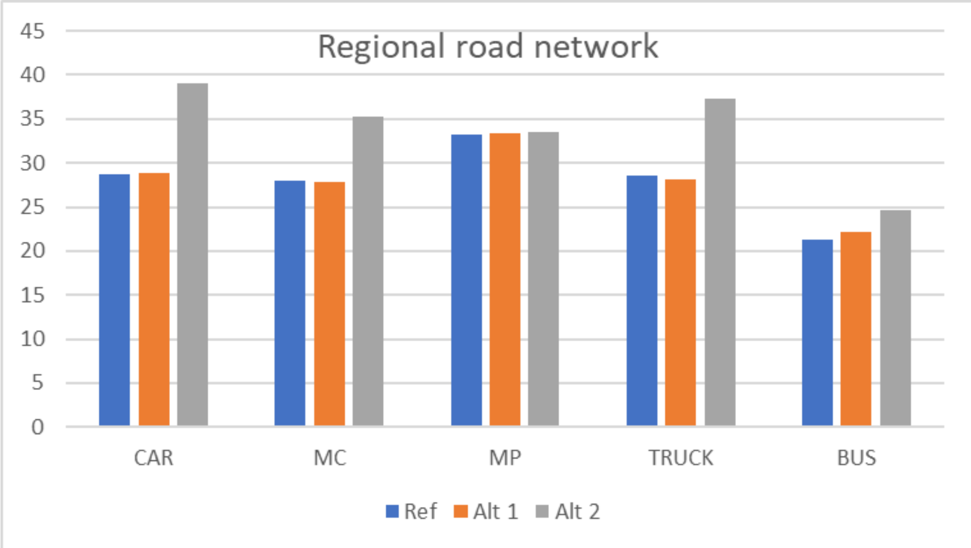


Figure 39 Average speed (km/h) per transport mode on the regional road network 2030

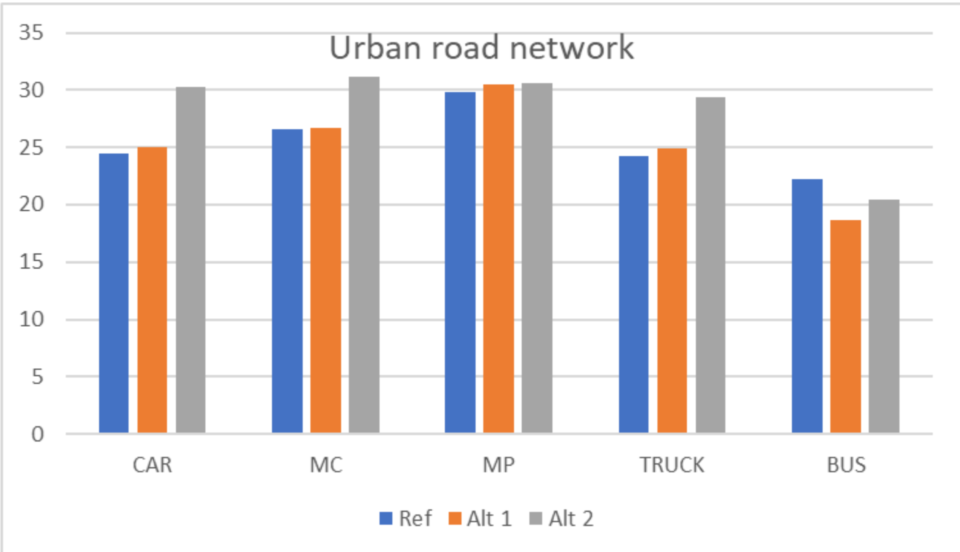


Figure 40 Average speed (km/h) per transport mode on the urban road network 2030

Knock-on effects

When a transport mode becomes more attractive, demand for this alternative will increase. The modal shift scenarios result in shorter travel times and will attract extra traffic. This extra traffic will be made up of journeys that previously were not made and journeys that previously were made in a different manner.

Using the concept of "price elasticity" we can estimate how much extra traffic is attracted when the traffic situation improves, i.e. when transport costs falls. Price elasticity describes the percentage change in demand in response to a percentage change in price. The price of personal transportation is made up of two components, the time cost and the vehicle cost.

Many studies exist on the estimation of price elasticities for transportation. We use the elasticities calculated in the most recent study of Litman (2021). Price elasticities differ per motive and level of urbanisation as shown in the Table below. The share of business trips and personal trips is based on the Flemish Survey on Mobility Behaviour. A price elasticity of -0.55 implies that when the cost of a car trip decreases by 1%, demand for this trip will increase by 0.55%.

Table 21 Price elasticity passenger transport

	urban	**inter-urban**
Car business (32%)	-0.49	-0.56
Car personal (68%)	-0.58	-0.67
Car total	-0.55	-0.63

Source: Litman (2021)

We calculate the costs for an average trip on the urban and regional road networks of our case studies. This cost consists of a vehicle cost and a time cost. Both cost factors change over the modal shift period 2025 to 2030.

The vehicle cost is equal to the total cost of ownership (TCO) of the vehicle. This concept is further elaborated on in Chapter 7. We compute the TCO for cars following the methodology in Delhaye et al. (2017) but with updated prices and cost price projections up to 2050. TCO are expressed at constant prices for the year 2021. The TCO of a passenger car in 2025 (calculated as a weighted average over different fuel types) is equal to €0.41/km. In 2030, this cost is equal to €0.43/km. The cost increase is mainly caused by expected fuel price rises (see Chapter 7).

In section 6.1.2, we determined the time value for a traveller with a passenger car at €16.50/hour. We multiply this by the occupancy rate of 1.39 travellers per vehicle, giving us a time value of €22.9/hour per vehicle.

Table 22 shows the elements in the calculation of the induced demand for car trips on the regional road network. The time cost per vehicle for an average trip is calculated as the product of the time value per vehicle and the average travel time per vehicle. The table shows that the time cost decreases in both alternative scenarios compared to the reference scenario. The lower time cost is partly offset by increased private vehicle costs. The vehicle costs per trip are equal to the TCO per km times the average distance in km.

The total cost of a trip on the regional road network is equal to € 1.92 in the reference scenario. In the two alternative scenarios, this cost is respectively €1.94 (Alt 1) and €1.72 (Alt 2), which corresponds to a price increase of 1.2% in Alt 1 and a price decrease of 10% in Alt2. Note that the price increase in Alt 1 is the result of the rising private vehicle costs, which are larger than the reduced time costs. Taking into account the price elasticity for inter-urban trips of -0.63, this leads to an induced demand -0.8% and +6.4% respectively. Because the induced demand in Alt 1 is very small, we do not consider this in the subsequent analysis.

Table 22 Induced demand for trips by car on the regional road network.

Regional	# vehicles	travel time (h)	av distance (km)	**time cost/veh**	**private cost/veh**	**total cost**	% price	**induced demand**
Reference	26 157	1 436	1.59	**€ 1.26**	**€ 0.66**	**€ 1.92**		
Scenario 1	25 593	1 396	1.59	**€ 1.25**	**€ 0.69**	**€ 1.94**	1.2%	**-0.8%**
Scenario 2	19 968	864	1.69	**€ 0.99**	**€ 0.73**	**€ 1.72**	-10%	**+6.4%**

Table 23 shows the induced demand on the urban road network caused by the modal shift scenarios. The total cost of a trip is equal to € 1.51 in the reference scenario. In Alternative Scenario 1, the time savings for passenger car travellers are fully offset by the price increase in vehicle costs. The total trip costs change only slightly (0.1%), hence there is no induced travel demand.

In Alternative Scenario 2, the cost of a trip drops by 9%. Taking into account the price elasticity for urban trips of -0.55, this leads to 4.8% extra car traffic.

The finding of less additional car traffic generation on the urban network compared to the regional road network can be explained by the fact that on the urban road, the modal shift is mainly towards mopeds. Motorcycles increase as well, but to a smaller extent. Mopeds interact to a less with cars than motorcycles because they use separate lanes (bicycle paths).

Table 23 Induced demand for trips by car on the urban road network

Urban	# vehicles	travel time (h)	av distance (km)	**time cost/veh**	**private cost/veh**	**total cost**	% price	**induced demand**
Reference	13 313	607	1.11	**€ 1.05**	**€ 0.46**	**€ 1.51**		
Scenario 1	13 087	585	1.12	**€ 1.03**	**€ 0.48**	**€ 1.51**	0.1%	**+0.0%**
Scenario 2	8 965	343	1.16	**€ 0.88**	**€ 0.50**	**€ 1.38**	-9%	**+4.8%**

Table 24 shows the average LVH per workday including the knock-on effects, for each transport mode. For motorcycles and mopeds, there's an increase in LVH due to the larger number of vehicles on the street. Overall, we conclude that both modal shift scenarios result in a decrease of LVH, with the biggest impact in Alternative Scenario 2.

Table 24 Lost vehicle hours per day per transport mode - including induced demand

	Regional			**Urban**		
	Ref	Alt 1	Alt 2	Ref	Alt 1	Alt 2
CAR	2 341	2 284	1 208	846	793	402
MC	47	92	72	13	24	32
MP	4	9	20	1	3	22
TRUCK	194	199	126	80	78	54
BUS	7	6	5	9	11	9
TOTAL	**2 592**	**2 590**	**1 431**	**950**	**908**	**520**
%CHANGE		**-0.06%**	**-44.77%**		**-4.49%**	**-45.34%**

The change in LVH translates into corresponding changes in average speeds. In the high modal shift scenario (Alt 2) traffic flows more smoothly and average speed is higher for each vehicle type and road type.

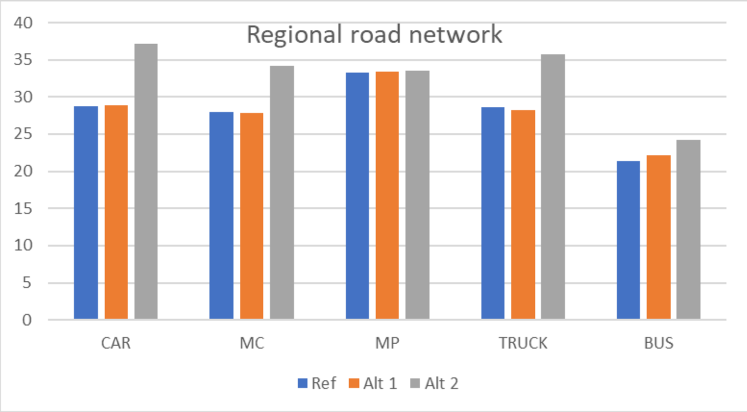


Figure 41 Average speed (km/h) on the regional road network including knock-on effects

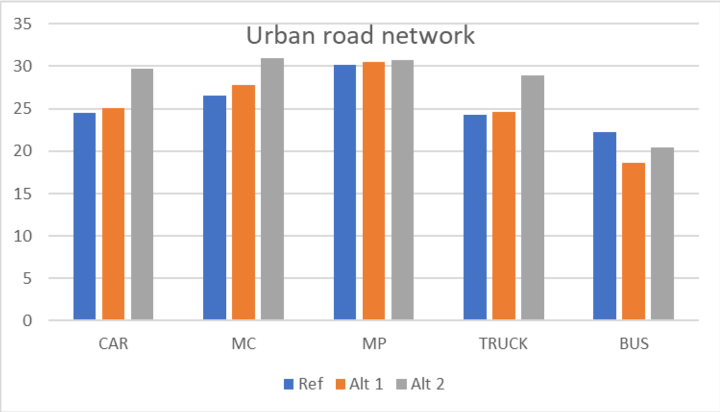


Figure 42 Average speed (km/h) on the urban road network including knock-on effects

Extrapolation to the total regional and urban road network

In this section we compute the impact on lost vehicle hours for the two alternative scenarios when the modal shift is achieved throughout the Belgian regional and urban road network. We extrapolate the effects of the modal shift that emerged in the case studies to the entire regional and urban network in the three regions.

Calculating the impact per region is important, because traffic volumes and congestion depend crucially on the local circumstances. Based on the analysis of the primary road network, we already know that the majority of traffic congestion occurs in Flanders. Maerivoet and Yperman (2008) estimate the lost vehicle hours on the different road networks in Belgium up to 2020. They show that 72% of all lost vehicle hours are in Flanders, 23% in Wallonia and 5% in Brussels.

Table 25 Share of lost vehicle hours per road type and per region

	Primary road network	Regional road network	Urban road network	Total
FLA	21.2%	55.1%	23.8%	100%
WAL	23.2%	50.2%	26.6%	100%
BRU	16.9%	74.0%	9.1%	100%

Souce: Maerivoet and Yperman (2008)

Table 25 shows the share of lost vehicle hours per road type and per region. The majority of the vehicle hours lost occur at the regional road network. This is especially the case for Brussels. Given the information in Table 25, we can apply the following scaling factors to the LVH on the primary road network to get an estimate of the LHV on the total regional and urban road networks in the three regions:

	Regional road network	Urban road network
FLA	2.6	1.1
WAL	2.2	1.1
BRU	4.4	0.5

Next, we compute the impact of the modal shift scenarios on the total LVH on each road type and in region by applying the percentage change in LVH resulting from the microsimulations and shown in Table 24.

To calculate the total congestion costs, we need the following input:

- The total time cost for passenger transport and freight
- The modal shares of each vehicle type on each road type up to 2050
- The occupancy rates per vehicle

The total costs of congestion are then calculated in the same way as for the primary road network. That is, total congestion costs per year are equal to:

$$IC_{year} = 230 * LVH_{day} * [sh_{mode} * OF_{mode} * VOT_{mode}]$$

Table 26 shows the total net present value in 2025 of all time savings resulting from Alternative Scenario 1 over the period 2025 to 2030. The majority of the time savings (88%) are realized in Flanders, while 12% of the time savings are realized in Wallonia. For Brussels, the impact is relatively small. The total monetary value of time gains thanks to alleviating congestion in Belgium is estimated at € 1 533 million.

When we compare the allocation of the time savings per road type, we observe that most time savings are realized on urban roads. Overall, 61% of the time savings are on the urban road network, 19% on the regional road network and 20% on the primary road network.

Table 26 Total NPV of time savings - Alternative Scenario 1

	Primary road	Regional road	Urban road	Total
Flanders	€ 304 346 416	€ 248 910 355	€ 793 160 734	**€ 1 346 417 506**
Wallonia	€ 1 933 239	€ 36 962 725	€ 142 316 577	**€ 181 212 542**
Brussels	€ 319 761	€ 2 913 916	€ 2 611 502	**€ 5 845 179**
Belgium	**€ 306 599 417**	**€ 288 786 996**	**€ 938 088 814**	**€ 1 533 475 227**

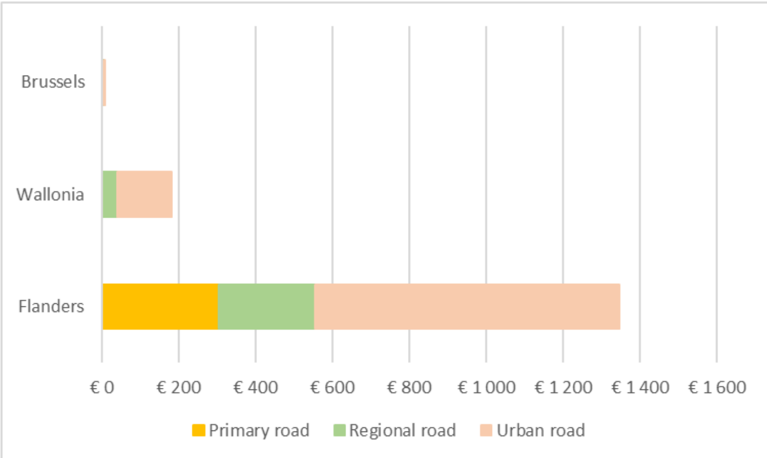


Figure 43 NPV of time savings (million €) - Alternative Scenario 1

Table 27 shows the monetary value of all time gains realized by the high modal shift scenario, Alternative 2. Unsurprisingly, the benefits are several times higher than in Alternative 1. This is because this scenario combines a reduction in passenger car kilometres with a strong shift to powered two-wheelers. The total benefit for Belgium is € 31 747 million, more than 20 times higher than the benefit that was realized in Alternative 1.

Table 27 Total NPV of time savings - Alternative Scenario 2

	Primary road	Regional road	Urban road	Total
Flanders	€ 7 184 191 464	€ 13 366 170 574	€ 7 139 155 336	**€ 27 689 517 374**
Wallonia	€ 613 169 016	€ 1 955 497 483	€ 1 279 529 744	**€ 3 848 196 244**
Brussels	€ 31 728 361	€ 154 256 810	€ 23 480 347	**€ 209 465 518**
Belgium	**€ 7 829 088 841**	**€ 15 475 924 867**	**€ 8 442 165 427**	**€ 31 747 179 136**

In this Scenario, the biggest time gains are realized on the regional road network, notably 49% of all benefits on country level. The rest of the benefits are equally spread over the primary road network and the urban road network.

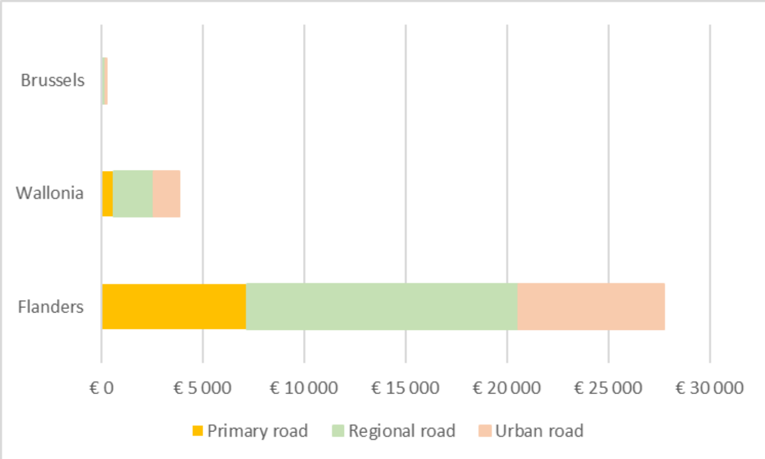


Figure 44 NPV of time savings (million €) - Alternative Scenario 2

Sensitivity analysis

The sensitivity analysis assesses one of the main parameters of the VISSIM modelling. More specifically, we compute the effects on the resulting travel times when the minimal margins used for lane filtering are doubled.

In the final model, the motorcycles only overtake vehicles when there is a non-zero margin available at standstill. If this vehicle to be passed is a bus or a truck, the minimal margin should be 0.10 m at standstill. The sensitivity analysis assesses what the effects on the resulting travel times are if these margins are increased to 0.10 m and 0.15 m respectively. For both the final model and the sensitivity analysis, the minimal margin at 50 km/h is taken to be 0.50 m, independent on the vehicle type.

This analysis is performed only for the urban environment during the morning peak. The results, summarized in Table 28, show that the effect of changing this parameter is rather small. Evidently, the most significant impact is measured for the motorcycles, as they will now less frequently pass the queue. On the other hand, the effects on other modes are negligible. This confirms that, while lane filtering by motorcycles has an effect on the time gains, the main difference comes from the decreasing number of cars.

Table 28: Relative changes in total travel time and vehicle hours lost when increasing the safety margin, compared to the final model.

	Reference	Alternative 1	Alternative 2
Total travel time (hours) – urban road network			
Car	+0.54%	+0.61%	+0.56%
Motorcycle	+1.57%	+1.18%	+1.25%
Lost vehicle hours – urban road network			
Car	+1.22%	+1.25%	+1.38%
Motorcycle	+5.28%	+4.34%	+4.36%

7 Total cost of ownership

Passenger transport involves costs to the drivers. Total Cost of Ownership (TCO) is equal to the sum of all costs involved in the purchase, operation and maintenance of a vehicle during its lifetime. The private ownership costs vary significantly per transport mode.

We calculate the total ownership and use costs per 100 km for each vehicle type. The total private costs include the following cost items:

- Purchase costs: purchase price, registration taxes, …
- Recurring fixed costs: maintenance costs, insurance, circulation taxes,…
- Variable costs: fuel costs

We only consider TCO for cars and powered two-wheelers because the modal shift scenarios are focused on these transport modes. For the calculation of the total operating costs of cars, we refer to Delhaye et al. (2017). We use the same methodology, with updated costs up to 2021.

The different cost items considered in the calculation of the TCO of powered two-wheelers are described below.

7.1 Purchase costs

Purchase price

Purchase prices for motorcycles are retrieved from "Le repaire des motards", website portal containing prices of new and second hand motorcycles.[34] We collect prices for all new motorcycles and calculate the average price per cc-category. The average price of a motorcycle in Belgium is computed as the weighted average price per cc-category (Table 29). The average price of a motorcycle in Belgium on February 1, 2022 is equal to **€ 10 348**.

Table 29 Prices of motorcycles (incl. VAT), Feb 1, 2022

cc category	Average price	Share in vehicle fleet
50<cc<=125	3 755	36%
125<cc<=250	6 993	4%
250<cc<=500	6 808	14%
500<cc<=750	9 526	13%
750<cc<=1000	15 116	13%
> 1000	22 481	20%

Source: http://www.lerepairedesmotards.com/guides/cote-moto-occasion.php and MAM database

For electric motorbikes, we obtain prices from Egear of all e-motorbikes currently available for sale in Belgium (Table 30).[35] The average price of an e-motorbike in Belgium, including VAT is equal to **€ 11 177**.

The average price of a conventional motorbike and an electric motorbike is not very high. The reason for this is that the e-motorbikes currently offered in Belgium are relatively small bikes. The

[34] http://www.lerepairedesmotards.com/guides/cote-moto-occasion.php

[35] https://www.egear.be/elektrische-motorfietsen/

only large motorbike in Table 28 is the Harley Davidson. This should not be problem. First, the price of e-motorbikes is expected to decline and become at par with conventional motorbikes (see below). Second, the overrepresentation of smaller motorbikes is to some extent a response to the higher demand for small bikes compared to large ones.

Table 30 Prices of e-motorbikes in Belgium, December 31 2021
Source: https://www.egear.be/elektrische-motorfietsen/

Brand	Price	Range (km)
BMW	16 500	100
Eccity	7 500	115
Energica	20 000	190
Govecs	8 500	90
Harley Davidson	34 000	152
KTM	11 700	80
Kumpan	6 000	150
Niu	4 500	70
Torrot	4 500	100
Vectrix	8 900	260
Vespa	6 700	100
Zero	13 000	320
Ydra EV	3 500	150

We assume no real price changes for vehicles with an internal combustion engine.[36] There is general consensus that the average price of electric vehicles (cars and PTWs) will decrease in the coming years. We follow the Electric Vehicle Outlook 2021 by BloombergNEF and Transport & Environment (2021) that investigates scenarios and trends for electrification of road transport up to 2050. According this study, the purchase price of electric vehicles will gradually decrease from 2020 to 2030. The prices of electric and fossil fuel vehicles are expected to hit parity in 2026. After 2026, we assume no real price change for electric vehicles.

Prices of petrol-driven mopeds are retrieved from scooterprijs.nl[37] and prices of e-mopeds and e-bikes are obtained from Egear. For the petrol-driven mopeds, we collected prices of 41 new models, covering 10 different brands. Egear publishes the prices of all 20 e-mopeds available for sale in Belgium. We also include the prices of 20 e-bike brands. Prices of e-mopeds and e-bikes are comparable. The average price of a petrol-driven moped in Belgium is equal to € 1 918. The average purchase price of an e-moped/e-bike is equal to € 2 855.

The purchase prices mentioned above include a 21% VAT rate.

Gear

In order to ride a motorcycle, specific gear is required such as a helmet, a jacket and gloves. For L1e vehicles (e-bikes and mopeds with a speed limit up to 25km/h), wearing a helmet is not required, but highly recommended. As of January 1, 2023, a helmet will also be mandatory for L1e vehicles.

[36] The cost benefit analysis works with fixed prices of the year 2021. Hence, we do not consider inflation effects. We only take real effects into account when they apply.
[37] https://www.scooterprijs.nl/scooters/agm.html

The price of motorcycle gear may vary depending on brand an quality. Febiac estimates the price of standard gear at € 700 (in 2019).[38] Other sources refer to similar costs for gear in a range of € 600 to € 1600.[39] We estimate the total cost for gear as the average of this range, at € 1 100 in 2021 (including VAT). For mopeds, only a helmet is required, which can be purchased for € 80 on average.

Registration tax

Owners of a motorbike need to pay a registration tax based on the fiscal horse power of the vehicle. Registration taxes are charged by the regional governments. The amount charged for second hand vehicles is lower and reduces with the age of the vehicle. There is no registration tax charged for mopeds, e-bikes or electric scooters.

License plate

Mopeds with a maximum speed of 45km/h and motorcycles need a license plate. A Belgian license plate costs € 30.

Technical inspection

Until today, powered two-wheelers are exempt from a mandatory periodic technical inspection, as is required for passenger cars and other motorized vehicles. However, as of January 1, 2023, all motorcycles with an ICE engine larger than 125 cc and all electric motorbikes with a power of at least 11 kw are subject to a mandatory technical inspection at time of purchase (new or second hand) and after an accident. This inspection upon purchase is not applicable to mopeds. There will be no periodical technical inspection for motorcycles.

Therefore, unlike for passenger cars, technical inspection for motorcycles is considered a non-recurrent cost. For cars, technical inspection is a recurrent fixed cost.

The charge of a motorcycle inspection is not yet determined. Therefore, we assume the same charge as for passenger cars, which is currently equal to € 38.90 for petrol cars.[40]

7.2 Recurring fixed costs

Maintenance costs

Maintenance costs depend largely on the brand, the dealer, the vehicle characteristics and mileage. Therefore, it is hard to estimate maintenance costs precisely. Following Delhaye et al (2017), we assume yearly maintenance costs to be equal to 3.5% of the purchase price for internal combustion engines (ICE). Electric vehicles have lower maintenance and repair costs than ICE vehicles.[41]

Following van Vliet et al (2011), we assume yearly maintenance and repair costs of electric vehicles to be 25% lower than those for ICE vehicles, notably EV maintenance and repair costs are set at 2.6% of the purchase price per year.

[38] https://www.febiac.be/public/pressreleases.aspx?ID=1185&lang=NL
[39] Motorrijdenexpert, bikersrights, bikesaddicts, motorcyclehabit, FBTO
[40] https://www.autoveiligheid.be/autokeuring/tarieven
[41] https://www.greencars.com/post/what-does-it-cost-to-maintain-an-electric-car

Insurance

Drivers of a powered two-wheeler must take out civil liability insurance. The insurance premium generally depends on the driver's age and residence, the vehicle type, and the driver's accident history.

The average cost for insurance of motorcycles and mopeds is obtained from autoverzekering-berekenen.be.[42] For motorcycles the average insurance premium is equal to € 294 per year in 2021. For mopeds, the average insurance premium is € 138 per year.

Circulation tax

An annual circulation tax is required for motorcycles with an engine exceeding 251 cc. Electric motorbikes are exempt from circulation taxes in Flanders. The amount of the circulation tax is the same in the three regions. For the period July 1, 2021 to June 30, 2022 the circulation for motorcycles is equal to € 60.32. An annual indexation applies.

7.3 Variable costs

Fuel costs

Fuel consumption of a motorcycle increases with the size of its engine. Light motorcycles typically consume 2.5 to 3 litres per 100 kilometres, while heavy motorcycles consume more than 4 litres per 100 kilometres.[43]

For the base year 2021, we assume the following petrol consumption per vehicle category, which are the technical assumptions used in the EU Reference Scenario:

cc	litre/ 100km
Moped	2.9
50-250	3.2
250-750	4.4
> 750	5.4

For the other road vehicle types we also follow the technical assumptions of the EU Reference Scenario. Fuel price projections are taken from the EU Reference Scenario, as shown in the table below.

Table 31 Fuel price change projections 2021-2025

	2021-2025	2026-2030	2031-2035	2036-2040	2041-2045	2046-2050
CNG	8.69%	6.04%	1.86%	3.26%	1.62%	0.28%
Diesel	8.57%	5.98%	2.45%	1.50%	1.63%	2.23%
Electricity	0.53%	0.33%	-0.21%	-0.21%	-0.70%	-0.70%
Petrol	8.57%	5.98%	2.45%	1.50%	1.63%	2.23%

Source: EU Reference Scenario 2020

[42] https://www.autoverzekering-berekenen.be/motoren/bromfietsverzekering-tarieven.html and https://www.autoverzekering-berekenen.be/motoren/prijs-motorverzekering-belgie.html

[43] https://www.febiac.be/public/pressreleases.aspx?ID=1185&lang=NL

7.4 Total operating costs for the modal shift scenarios

Table 32 shows the TCO in euro per 100 vehicle kilometres per vehicle type for the three regions. We consider three vehicle types (privately-owned) passenger cars (CAR), motorcycles (MC) and mopeds (MP). For motorcycles, the cost is calculated as a weighted average of the motorcycles per size segment. Weights are determined based on vehicle registration at DIV.

When comparing the transport modes, we find that passenger cars come at a higher TCO compared to powered two-wheelers. The cheapest transport mode, unsurprisingly is the moped.

Ownership costs differ per region because of taxation differences across the regions. For example, electronic motorcycles are exempt from circulation and registration taxes in Flanders. In Brussels and Wallonia the lowest tariff applies, € 61.5 per vehicle.

Table 32 Total cost of ownership (€/100 vkm) per mode, 2021

	Flanders	**Wallonia**	**Brussels**
CAR_CNG	35.10	38.67	37.31
CAR_diesel	39.04	38.63	37.02
CAR_diesel_pluginh	48.73	51.09	50.26
CAR_electric	39.27	40.53	39.35
CAR_H2	67.58	68.84	67.66
CAR_LPG	34.53	36.89	35.87
CAR_petrol	37.70	38.70	36.89
CAR_petrol_pluginh	49.19	50.72	50.72
MC_diesel	32.11	33.41	33.41
MC_electric	25.70	26.95	26.95
MC_petrol	32.56	33.93	33.93
MP_diesel	19.15	19.15	19.15
MP_electric	19.97	19.97	19.97
MP_petrol	19.46	19.46	19.46

For comparison, a recent study by Oxford Economics (2021) compares the operating cost of a particular passenger car (Fiat Panda) with that of a motorcycle (Honda SH125). They report an operating cost for the passenger car equal to €38.55/100 vkm and an operating cost of €16.45/100 vkm for the motorcycle. This cost difference is larger than our cost calculations. For passenger cars, the study uses a relatively high fuel consumption rate of 9.4l/100 km, while our model assumes a consumption of 8.6l/100 km for an average petrol car in 2021. Apart from that, the study only covers one particular model and fuel type. Also it only takes into account operating costs and ignores purchase and maintenance costs.

Figure 45 shows the estimated evolution of TCO per vehicle mode in the reference scenario and the two alternative scenarios. Note that the costs for passenger cars is expected to be the same in the three scenarios. The average cost per vehicle mode is calculated as a weighted average per fuel type.

The TCO for passenger cars is significantly higher than for motorcycles (MC) and mopeds (MP). For motorcycles, the average TCO are expected to be lower in the two modal shift scenarios because of the higher share of electric motorcycles in this scenario. Although the purchase cost of e-motorbikes is higher than those of conventional motorbikes, TCO are lower due to the difference in fuel prices and maintenance costs. For mopeds, the TCO is similar in the three scenarios. This is because there is already a large share of e-mopeds in the reference scenario.

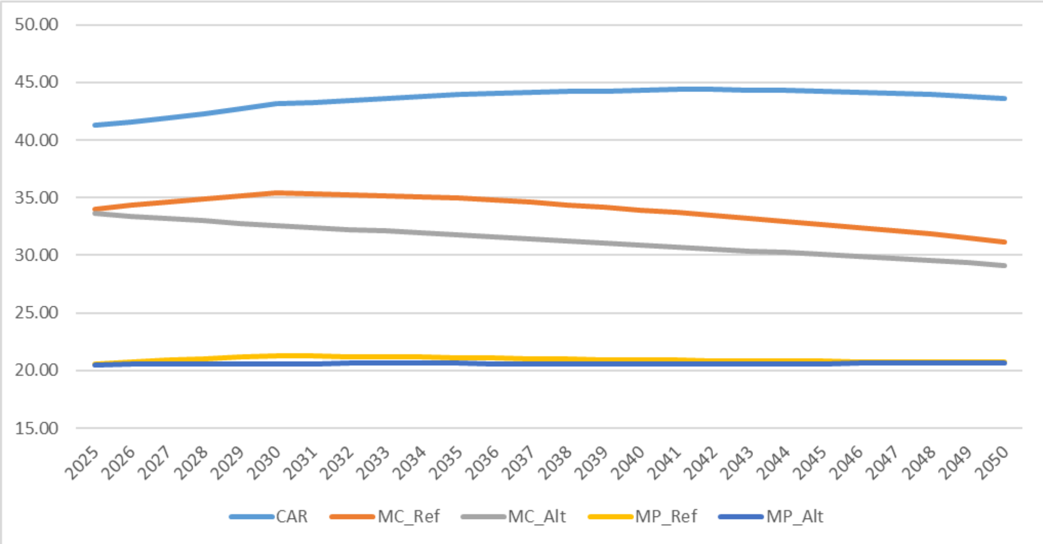


Figure 45 Evolution of the average TCO per transport mode in the different scenarios

A modal shift from cars to powered two-wheelers will, in most cases lead to cost savings for the user. For mopeds, the cost savings are significant. Any type of moped has lower TCO than a passenger car. For motorcycles, cost savings depend on the fuel type of the car and the respective motorcycle. Electric motorcycles have a lower TCO than cars. However, in the initial years, the electrification process of passenger cars will be faster than that of motorcycles. For example, in the reference scenario, 39.1% of the car kilometres will be electric by 2030. For motorcycles, this is only 24.1%. In the alternative scenarios, vehicle kilometres of electric motorcycles will have a share of 46.1% (Alt 1) and 54.3% (Alt 2).

Overall, a modal shift from cars to motorcycles will lead to a small increased cost in the first years, when most motorcycles have a combustion engine. In the later years, when the majority of the motorcycles are electric, cost savings will be realized.

The total effect of the modal shift scenarios on total ownership costs is calculated per vehicle type as the change in vehicle kilometres in each scenario times the TCO of the vehicle type.

$$Total_{TCO,PTW} = \left(vkm_{ref,PTW} - vkm_{alt,PTW}\right) \times TCO_{PTW}$$

Note that a switch from a passenger car to a powered two-wheeler does not necessarily mean that the car will be sold, or that people refrain from buying a new car. Hence, not the full ownership cost will be saved if people exchange trips by car to trips by two-wheelers. Counting the full TCO of cars as cost savings results in an overestimation of the benefit. About 50% of the TCO of cars comprise upfront or fixed costs (purchase cost, insurance, taxes). If we assume that a modal shift to PTWs leads to car scrappage in only 10% of the cases, we can consider only 60% of the TCO as cost saving. The total effect of a decrease in car kilometres is thus calculated as follows:

$$Total_{TCO,CAR} = \left(vkm_{ref,CAR} - vkm_{alt,CAR}\right) \times 0.6 \ \times TCO_{CAR}$$

Table 33 shows the total benefits (positive) and costs (negative) per region and vehicle type realized by each of the modal shift scenarios with respect to changes in total cost of ownership. As expected, significant cost savings are realized thanks to the lower number of passenger car kilometres. There is an additional cost for motorcycles and mopeds in the alternative scenarios compared to the reference scenario, but this is only a fraction of the total TCO saved by less car use. The overall result is unambiguously positive. In Alternative Scenario 1, total cost savings for Belgium are estimated at € 3 849 million. In Alternative Scenario 2, total cost savings are equal to € 36 597 million.

Table 33 NPV of the impact of the modal shift scenarios on total cost of ownership

	Flanders	**Wallonia**	**Brussels**	**Belgium**
Alternative Scenario 1				
CAR	€ 7 508 300 741	€ 4 210 984 799	€ 242 508 292	**€ 11 961 793 833**
MC	-€ 2 836 866 198	-€ 2 730 289 704	-€ 111 667 864	**-€ 5 678 823 766**
MP	-€ 1 700 195 073	-€ 637 431 987	-€ 95 369 736	**-€ 2 432 996 796**
Total	**€ 2 971 239 470**	**€ 843 263 109**	**€ 35 470 692**	**€ 3 849 973 271**
Alternative Scenario 2				
CAR	€ 42 328 329 780	€ 24 489 698 544	€ 1 836 116 119	**€ 68 654 144 442**
MC	-€ 10 559 077 842	-€ 7 531 323 044	-€ 544 506 191	**-€ 18 634 907 078**
MP	-€ 7 401 291 900	-€ 5 433 547 686	-€ 587 141 913	**-€ 13 421 981 500**
Total	**€ 24 367 960 037**	**€ 11 524 827 813**	**€ 704 468 014**	**€ 36 597 255 864**

8 Road safety

With respect to accidents, powered two-wheelers have a bad reputation. According to a study based on European accident statistics, the risk of death per kilometre travelled by a PTW is 20 times higher than that for car travel.[44]

As discussed in Chapter 3, reducing the number PTW accidents has become one of the priorities in regional safety plans.

Apart from policy interventions to improve traffic safety, accident risk is also expected to decrease thanks to technological innovations. The introduction of powered two-wheelers equipped with intelligent board computers connected through Cooperative Intelligent Transport Systems (C-ITS) will potentially lower the number of accidents because drivers are warned of dangerous situations.

Accident risk over time

Thanks to an increase of safety standards, policy measures to increase traffic safety and infrastructural and technological improvements, accident risk on the Belgian road network has decreased significantly over time. According to the European Transport Safety Council, the number of road deaths in Belgium has decreased by 43% over the period 2010 to 2020.[45] Delhaye and Vandael Schreurs (2021) show that the number of accidents involving powered two-wheelers follows a similar declining trend in Belgium. Over the period 2011 to 2020, the number of PTW deaths decreased from 123 to 77 per year (-37%), while the number of injured PTW riders decreased from 4084 to 2256 victims (-45%) (Delhaye & Vandael Schreurs, 2021).

Because of the several lockdown periods during the Covid-19 crisis, 2020 does not serve as a good benchmark to calculate accident statistics. Road accidents were significantly lower that year because of the lower traffic volumes. Hence, we take accident statistics of 2019 as a starting point. For the period 2010 to 2019, the number of fatalities on the Belgian roads has decreased by 24%. When we focus on PTWs, we find that the number of deaths has decreased by 17.5% while the number of injured persons decreased by 26.8%.

Safety-in-numbers

One of the main hurdles for people to switch from cars to powered two-wheelers and for policy makers to incentivise PTW use is the relatively high accident rate. This high accident rate is caused by the characteristics of the vehicle (light weight, vulnerability of the rider), the driver's behaviour and by the so called "**low-prevalence effect**". The low-prevalence effect means that rare targets (<5% prevalence) are often not detected by other road users (Beanland et al , 2014). Based on an analysis of more than 500 accidents involving PTWs (75%) and bicycles (25%), Brown et al. (2021) report that errors of observation ("looked but failed to see") contributed to 38% of the accidents. Delhaye and Vandael Schreurs (2021) surveyed Belgian PTW riders, who report that 55% of the accidents are caused by manoeuvres of other road users.

[44] https://trimis.ec.europa.eu/project/powered-two-wheeler-integrated-safety
[45] https://etsc.eu/

Several studies have demonstrated the concept of **safety-in-numbers**, which means that the number of accidents increases less than proportional to traffic volume. Safety-in-numbers is the opposite of the low-prevalence effect. Elvik and Goel (2019) performed a meta-analysis on the safety-in-numbers effect, assessing the findings of 45 studies. They conclude that there is general empirical evidence for a safety-in-numbers effect for vulnerable road users. However, there is a wide dispersion in the size of the effects and the safety-in-numbers effect is stronger for pedestrians than for powered two-wheelers and bicycles.

The relationship between PTW traffic volume and the number of accidents is non-linear of the following basic form:

$$ACC = e^{\beta_0} MC^{\beta_1} MP^{\beta_2}$$

where ACC denotes the number of accidents involving PTWs, MC is the number of motorcycles and MP is the number of mopeds. Variations of this model also include the number of pedestrians and cyclists and a set of predictor variables that can also influence the number of accidents.

The safety-in-numbers principle implies that driving behaviour of other road users adapts, if one transport mode becomes relatively more important than before. This improves overall traffic safety. In addition, extra vehicles lead to busier roads, which leads to more careful driving. This also deceases accident risk.

8.1 Calculation of accident risk

To calculate the social and economic costs of accidents, we need to make projections about two statistics:

- **The accident risk**: the expected number of accidents with deaths, serious injured and slightly injured victims per vehicle kilometres over the period 2025 – 2050
- The **external cost of accidents** with deaths, serious injured and slightly injured victims over the period 2025 – 2050

Official statistics on accidents are subject to an underestimation of the accident risk because a number of accidents remain unreported. The data on deathly accidents are the most reliable. In this case, a police report is most likely. Data for slightly injured are subject to the biggest underestimation, especially for vulnerable road users (pedestrians and (motor)cyclists).

Based on a recent survey of PTW riders in Belgium, Delhaye and Vandael Schreurs (2021) show that the majority (64.3%) of accidents with PTWs are unilateral. When these unilateral accidents only result in material damage or slight injuries, police intervention is usually absent. Therefore, we assume that most of these unilateral accidents remain unreported.

To control for the underreporting of accidents, we apply an adjustment factor to reported accident statistics for Belgium as reported by DG Move (2020).

Table 34 Adjustment factor for underreporting

	Slight injuries	Serious injuries	Deaths
Passenger cars	2	1.25	1
Motorcycle, moped	3.2	1.55	1

Source: DG MOVE (2020)

Table 35 shows the accident risk per mode and region for 2019. Accident risk is calculated as the number of victims per one million vehicle kilometres. The vulnerability of PTW riders is demonstrated by the figures: the accident risk for motorcycles and mopeds is several times higher than the risk for passenger cars. There is also quite some variation among the regions. The risk for accidents with slight injuries is the highest in Brussels, while the risk for a fatal accident with cars and mopeds is much lower in Brussels than in the other two regions.

Table 35 Accident risk (# victims per 1 million vkm) per region and mode 2019

	Flanders	Wallonia	Brussels
	Slight injuries		
CAR	0.512	0.540	1.122
MC	5.771	4.517	52.225
MP	19.328	16.667	32.096
	Serious injuries		
CAR	0.019	0.021	0.017
MC	0.693	0.342	1.297
MP	0.996	0.529	0.363
	Deaths		
CAR	0.003	0.006	0.002
MC	0.056	0.079	0.139
MP	0.044	0.034	0.000

Source: Own calculations based on Statbel and MAM-database

Over the past decade, the decline in accident risk has been more significant for passenger cars than for powered two-wheelers. This is because most safety standards and mobility plans are focused on passenger cars, bikers and pedestrians. PTWs have been largely overlooked. As a result, PTWs are generally considered as very unsafe because they have relatively high accident rates per number of kilometres driven compared to passenger cars. However, under the influence of several EU actions and initiatives, recent mobility and safety plans prioritize on improving road safety for PTWs.[46]

To take into account the general trend in declining accident risk, we assume a yearly decrease in the risk of deaths, seriously injured and slightly injured of respectively 3.6%, 4% and 4.8%. This corresponds to the overall trend over the 2010-2019 as demonstrated in Table 36.

Table 36 Evolution of accident risk (# accidents per million vkm) per mode 2010-2019

	Death		Seriously injured		Slightly injured	
	Risk reduction 2010-2019	Risk reduction per year	Risk reduction 2010-2019	Risk reduction per year	Risk reduction 2010-2019	Risk reduction per year
CAR	-37.4%	-5.1%	-57.9%	-9.2%	-36.1%	-4.9%
MC	-32.2%	-4.2%	-23.0%	-2.9%	-27.2%	-3.5%
MP	-21.2%	-2.6%	-34.2%	-4.5%	-37.8%	-5.1%
Overall	**-28.0%**	**-3.6%**	**-30.5%**	**-4.0%**	**-35.6%**	**-4.8%**

Source: Own calculations based on Statbel

46 https://ec.europa.eu/transport/road_safety/eu-road-safety-policy/priorities/safe-road-use/making-roads-safer-motorcycles-and-mopeds_en

We also adjust the accident risk of PTWs by the safety-in-numbers principle. For a transport mode to be considered by other road users, it needs to represent a certain part of the total traffic volume. Currently, the share of motorcycles and mopeds on the Belgian roads is low, which means that they are not (sufficiently) taken into account by other road users. This affects their traffic behaviour and creates an unsafe environment. Based on the low-prevalence effect, we assume a critical minimum share of 5% of total traffic for road users to be considered. As soon as this critical share in traffic is reached, we assume an accident risk elasticity equal to -0.25, as recommended in DG MOVE (2020). The risk elasticity implies that an increase in vehicle kilometres of 1% results in a decrease in accident risk of 0.25%.

8.2 External costs of accidents

We calculate the costs of accidents per vehicle type based on the **Value of a Statistical Life (VSL)** and the **Value of a Statistical Serious Injury (VSSI)**. Both concepts are used to make an economic evaluation of the impact of respectively fatal accidents and accidents with serious injuries. VSL and VSSI are estimated based on the risk to die or to lose a healthy life year and on the willingness to pay to reduce this risk. Differently put, the VSL is the willingness to pay for fatal risk reduction and therefore the economic value to society to reduce the statistical incidence of premature death in the population by one. This willingness to pay is usually based on stated preference studies (i.e. survey analysis) or revealed preference studies (e.g. payments for health insurance).

DG MOVE (2020) determines the VSL based on a meta-analysis by the OECD (2012). This meta-analysis is largely influenced by the HEATCO (2006) study, that determines the VSL for the European Union at € 3,6 million (2016 prices). Note that the VSL as reported by DG MOVE is outdated. The VALOR study by Schoeters et al. (2021) provides a revision of the VSL for four countries (Belgium, France, Germany and the Netherlands). In VALOR, Schoeters et al. (2021) use a stated preference method to estimate the Willingness-To-Pay (WTP) for reducing risk of fatal and serious injuries in road accidents. For Belgium, the VSL is determined at € 5,9 million and the VSSI is calculated at € 0,94 million (2020 prices). The costs of slight injuries are valued at 1% of the VSL, in line with the recommendations of HEATCO.

Note that DG MOVE and VALOR calculate the VSL slightly differently. In DG MOVE, external costs such as productivity losses and consumption losses are also included in the VSL. This is not the case in VALOR. On the other hand, VALOR considers all medical costs as relevant, while DG MOVE only includes 30% of the medical costs. The remainder of the medical costs are considered by DG MOVE as private costs, which are already included in the insurance premium

Table 37 shows the average value of a statistical life in Belgium as reported by Schoeters et al. (2021). We convert the values to prices for the year 2021. The societal accident cost of a fatality is equal to € 6 084 719. A victim with serious injuries costs € 962 902 and a slight injured victim costs € 60 847.

Table 37 Value of a statistical life in Belgium - VALOR

	Slight injuries	Serious injuries	Deaths
VSL_2020	59 400	940 000	5 940 000
VSL_2021	60 847	962 902	6 084 719

Source: Schoeters et al. (2021)

The total accident costs (AC) per vehicle type i in year t are calculated as follows:

$$AC_{i,t} = \Delta vkm_{i,t} * (1 + E) * \left(risk_{i,D} * cost_D + risk_{i,SI} * cost_{SI} + risk_{i,SYI} * cost_{SYI}\right)$$

where $\Delta vkm_{i,t}$ represents the predicted change in vehicle kilometres according to the alternative scenario for vehicle type i in year t; $risk_{i,D}$, $risk_{i,SI}$ and $risk_{i,SYI}$ is the risk of an accident with respectively deaths, seriously injured or slightly injured victims per vkm driven by vehicle type *i*; and $cost_D$, $cost_{SI}$, $cost_{SYI}$ represents the external costs of a death, seriously injured or slightly injured victim. E is equal to the accident risk elasticity, which is -0.25 for all vehicle categories with a minimum share of 5% in total road traffic and zero otherwise.

8.3 Impact of the modal shift scenarios on external accident costs

Table 38 shows the net present value of the total external accident costs for the modal shift scenarios. As expected, accident costs are high when there is a substantial shift from passengers cars to powered two-wheelers. In Alternative Scenario 1, the NPV of accident costs to society is equal to € 15 545 million. In Alternative Scenario 2, the NPV of accidents costs is equal to € 60 855 million.

Table 38 NPV of total external accident costs resulting from the modal shift scenarios

	Flanders	Wallonia	Brussels	**Total**
Alt Scen 1	-€ 9 129 094 034	-€ 5 276 686 017	-€ 1 139 636 206	**-€ 15 545 416 257**
Alt Scen 2	-€ 33 072 869 717	-€ 22 603 910 639	-€ 5 178 442 120	**-€ 60 855 222 476**

These high accident costs are one of the main reasons why policy makers find it hard to implement PTW-stimulating policies. At the same time, the calculation of the costs underlines the importance of implementing measures to improve safety for PTW riders. As shown in Chapter 2, the number of PTW users is on the rise and is expected to increase at an accelerating pace. In addition, we showed in the previous chapters that PTWs can play an important role in easing congestion, which is an important problem in Belgium.

Therefore, one of the main priorities of policy makers should be to make the Belgian roads safer for PTWs. This can be done by optimizing road infrastructure such that it accommodates PTW rides (e.g. self-explaining and forgiving roads), involving other road users in sharing responsibility for the safety of PTW riders and making the needs of PTWs an explicit part of transport and safety policies (OECD, 2015).

An important step in improving safety for PTWs is set in the regional road safety plans. With the All For Zero approach, a systemic approach is taken to eliminate road deaths and serious injuries by

2050.[47] To understand the implication of achieving All For Zero, we calculate the societal accident costs of the modal shift scenarios assuming that All For Zero is achieved by 2050. That is, we let the accident risk for fatalities and serious injuries decline gradually from their 2025 values to a zero risk in 2050.

The table below shows the NPV of the accident costs resulting from the modal shift scenarios with a zero risk for serious and fatal accidents in 2050. The NPV of external costs has more than halved in both scenarios. There are still costs to society due to the higher accident rates for powered two-wheelers. This is a risk inherent to the vehicle type because PTW riders do not have the protected shell that car drivers have.

Table 39 NPV of total external accident costs resulting from the modal shift scenarios and All For Zero

	Flanders	Wallonia	Brussels	**Total**
Alt Scen 1	-€ 4 160 857 525	-€ 1 703 929 672	-€ 395 611 079	**-€ 6 260 398 276**
Alt Scen 2	-€ 14 251 091 725	-€ 6 869 264 221	-€ 1 739 794 681	**-€ 22 860 150 627**

47 https://all-for-zero.be/

9 Emissions

Emissions have a negative impact on public health, the climate, ecosystems, or more generally on the environment. External emission costs attribute a monetary value to this environmental damage.

A modal shift from cars to powered two-wheelers is likely to have a reducing effect on emission costs because air pollution caused by PTWs is smaller than for cars. For example, Table 40 copied from ACEM (2021), shows the average CO2 emission factors in urbanised areas for motorcycles and cars per European Emission Standard class (COPERT).

Table 40 Average urban CO_2 emission factors per COPERT class - Source: ACEM

CO_2 (g/km)	Euro 0	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6c	Euro 6d
Motorcycle/moped(125cc)	91	73	66	53	53	53		
Motorcycle (250cc-750cc)	134	118	109	187	144	144		
Motorcycle (750cc)	152	148	146	186	144	144		
Petrol car	228	224	220	219	224	216	210	213
Diesel car	234	209	214	204	201	196	193	193

Emission factors express the emission of a particular pollutant per vehicle kilometre driven (unit: g/km). We calculate the impact of the emissions of the following pollutants:

- CO_2: carbon dioxide
- NOx: nitrogen oxides
- $PM_{2.5}$: fine particulates with a diameter smaller than 2.5 micrometres
- NMVOC: non-methane volatile organic compounds

The impact of emissions are calculated based on a bottom-up approach. We first calculate the total emissions per pollutant (in tonne), vehicle type and country by using the average emission factors from the COPERT database and the projected vehicle kilometres per vehicle type. We then multiply the total emission per pollutant with the cost factor per tonne.

We use the COPERT 5.5.1 database and calculate the emissions for each vehicle category, classified by fuel type and size. For PTWs, we use the following classifications:

Table 41 PTW vehicle types considered for emission calculations

Type	Size class	Segment_COPERT5
Motorcycle	<=50cc	Motorcycles 2-stroke >50 cm^3
Motorcycle	50<cc<=250	Motorcycles 4-stroke
Motorcycle	250<cc<=750	Motorcycles 4-stroke 250 - 750 cm^3
Motorcycle	>750cc	Motorcycles 4-stroke >750 cm^3
Moped	Petrol_2-stroke	Mopeds 2-stroke
Moped	Petrol_4-stroke	Mopeds 4-stroke
Moped	not_petrol	Micro-car

To calculate the external costs of emissions, we make a distinction between the emission of greenhouse gases (CO_2) and other air pollutants. The emission of greenhouse gases leads to climate change costs while the other pollutants lead to air pollution costs. We discuss each of them in turn.

Air pollution costs

The emission of air pollutants (NOx, $PM_{2.5}$ and NMVOC) leads to the following damages (DG MOVE, 2020):

- Health effects: The inhalation of small particulates (PM) and nitrogen oxides (NOx) increases the risk of respiratory and cardiovascular diseases. This leads to medical costs, production loss due to illness and in extreme cases even to death.
- Crop losses: The emission of NOx creates ozone which can damage agricultural crops.
- Material and building damage: The emission of acidic substances such as NOx causes corrosion. In addition, fine particulates and dust damage building surfaces.
- Biodiversity loss: Acidic substances such as NOx and SO_2 cause acidification of soil, precipitation and water. Air pollutions like NOx and NH_3 result in the eutrophication of ecosystems.

The air pollution cost factors reported by DG MOVE are based on the NEEDS-model (2008) that applies an impact-pathway approach to calculate damage costs. Because the NEEDS-model is based on outdated data, the model is adjusted with more recent concentration response functions and population statistics, to match the current EU context.

Table 42 shows the average air pollution costs (in € 2021 prices per kg) for the air pollutants under consideration in this study. The damage costs comprise the health costs and damage caused to crops, infrastructure and biodiversity.

Table 42 External costs of non-CO2 air pollutants in Belgium - Source: DG MOVE (2019)

	NOx (urban)	NOx (rural)	PM2.5 (average)	NMVOC
External costs (€_2021/kg)	28.5	16.5	205	3.9

Source: DG MOVE (2020)

The damage cost of NOx emission differs considerably depending on the degree of urbanisation. We calculate a regional specific damage cost based on the degree of urbanisation of each region, as classified by Eurostat.[48]

Table 43 External costs of NOx emissions per region (€_2021/kg)

	Urban	Rural	NOx
Flanders	73%	27%	25.3
Wallonia	24%	76%	19.3
Brussels	100%	0%	28.5

Source: Own calculations based on Eurostat and DG MOVE (2020)

The figures below show the total air pollutant emitted by road traffic in Belgium for the three scenarios. A first observation is that emissions are expected to drop significantly in all scenarios.

[48] https://ec.europa.eu/eurostat/web/degree-of-urbanisation

This is consequence of the expected electrification of the vehicle fleet in Belgium, which is in line with the EU and national policies.

As a result of the general electrification trend, the difference between the scenarios with respect to air pollution is not very big. However, we observe a noticeable decrease in the emission of fine particulars and non-methane volatile organic compounds in Alternative Scenario 2 compared to the reference scenario and Alternative Scenario 1.

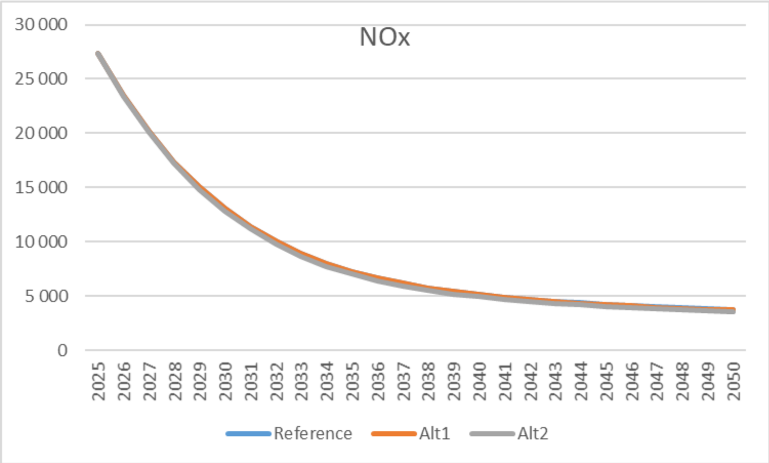


Figure 46 Total NOx emissions road transport (in tonne) 2025-2050

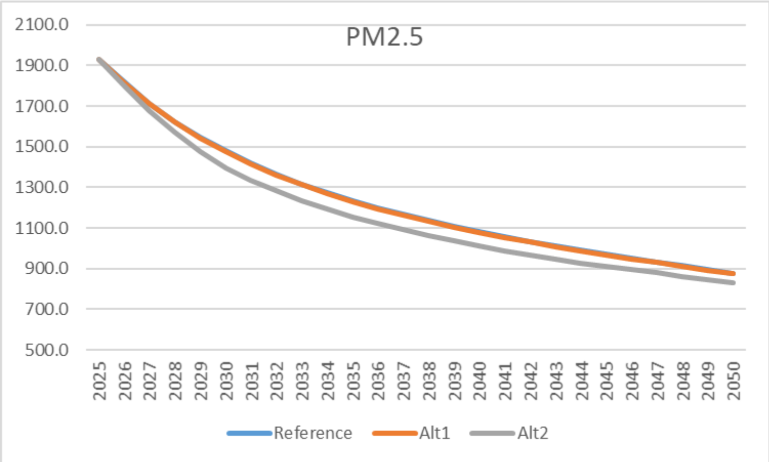


Figure 47 Total PM2.5 emissions road transport (in tonne) 2025-2050

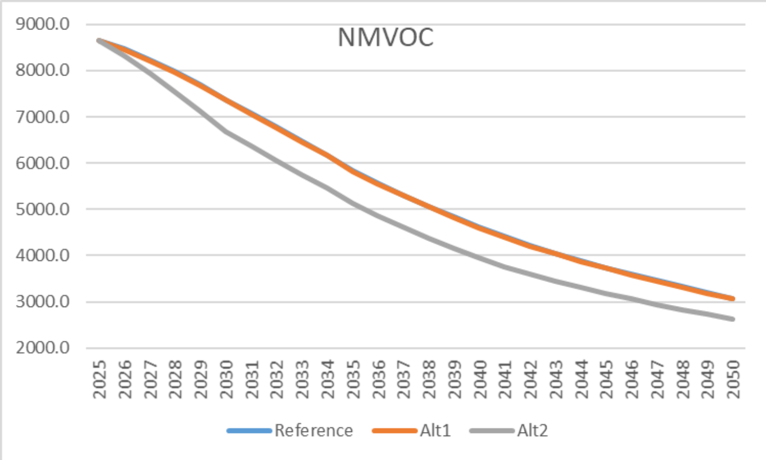


Figure 48 Total NMVOC emissions road transport (in tonne) 2025-2050

Climate change costs

Climate change costs measure the damage caused by emitted greenhouse gases. Road transport results in the emission of CO_2, N_2O and CH_4 (methane). The emission of these gases leads to global warming and climate change. In this study, we calculate the impact of the modal shift scenarios on total CO_2 emissions.

A recent publication by the European Commission provides an update of the cost of carbon that should be used in cost benefit analysis for the evaluation of transport and infrastructure projects.[49] It measures the cost of meeting the goal set in the Paris Agreement (the 1.5° target). The shadow cost of carbon is published in prices of the year 2016. We convert the cost to 2021 prices.

Table 44 Shadow cost of carbon per year in €/tonne CO_2 emission

	2020	2025	2030	2035	2040	2045	2050
CO_2_2016	80	165	250	390	525	660	800
CO_2_2021	87.3	180.0	272.8	425.5	572.8	720.1	872.9

Source: EC 2021/C 373/01 (2021)

[49] Commission Notice — Technical guidance on the climate proofing of infrastructure in the period 2021-2027 (OJ C, C/373, 16.09.2021, p. 1, CELEX: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021XC0916(03))

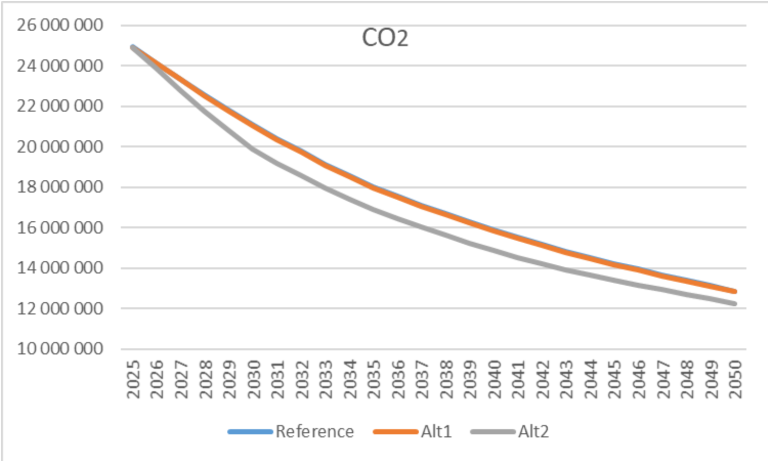


Figure 49 Total CO_2-emissions road transport (in tonne) 2025-2030

Figure 49 shows the total CO_2 emissions of road transport in Belgium for the three scenarios. Similar to the other air pollutants, there is a strong decrease in CO_2 emissions in all scenarios and the difference between the scenarios seems small. However, given the importance of CO_2 emissions of road transport, a small relative reduction in emissions signifies a large reduction in absolute numbers.

For example, Alternative Scenario 1 results in a CO2 emission reduction of -0.25% in 2030 compared to the reference scenario. This corresponds to a reduction of 52 318 tonne, which has a total climate change cost saving of € 14 270 636. In Alternative Scenario 2, CO_2 emissions are 5.7% lower than in the reference scenario in 2030, which means that 1 204 204 tonnes of CO_2 are emitted less, corresponding to a cost saving of € 328 467 047.

External costs of emissions

Table 45 shows the NPV of the change in emissions caused by the modal shift scenarios. Overall, both scenarios result in net benefits for Belgium. The total monetary benefit of reduced emissions is equal to € 448 million in Alternative 1 and € 7 954 million in Alternative 2.

Remarkable is the large difference among the regions. While for Flanders and Wallonia the impact on emissions is overly positive, this is not the case for Brussels. The reason of the increased emission costs in Brussels is the implication of the LEZ regulations. LEZ rules in Brussels are stricter for cars than for motorcycles. As a result, an increase in motorcycle use will lead to a longer use of fossil fuel vehicles than in the reference scenario.

Table 45 NPV of emissions as a result of the modal shift scenarios

	Flanders	**Wallonia**	**Brussels**	**Belgium**
Alternative Scenario 1				**€ 447 896 619**
Air pollution	€ 16 384 885	€ 2 645 615	-€ 121 840	**€ 18 908 660**
Climate change	€ 358 701 237	€ 70 769 301	-€ 482 579	**€ 428 987 959**
Alternative Scenario 2				**€ 7 953 681 727**
Air pollution	€ 283 717 646	€ 78 224 532	-€ 257 664	**€ 361 684 514**
Climate change	€ 6 026 208 357	€ 1 569 804 094	-€ 4 015 238	**€ 7 591 997 213**

10 Noise

Increasing traffic volumes lead to higher noise levels. With growing population numbers and an increase in urbanisation, more people are getting exposed to noise. Exposure to noise leads to negative health effects (hypertension, sleep deprivation, …) and annoyance. Although the electrification of the vehicle fleet promises a reduction of traffic noise, noise costs will remain because of the large traffic volumes.

Measuring noise costs

Noise is measured in decibel (dB). In general a frequency weighting is applied to correct for the sensitivity of the human ear to deep and very high tones. This A-weighting is denoted by dB(A). The threshold above which noise is considered problematic (for health reasons and/or annoyance), is 50 to 60 dB(A).

Noise costs differ considerably depending on the time of the day at which the noise takes place. Noise during the evening (19:00-23:00) and night (23:00-07:00) is more disturbing than noise during daytime. Therefore, noise is measured in Lden, which is a weighted average of the noise produced during the day, evening and night:

$$L_{den} = 10 \cdot \log \frac{12 \cdot 10^{\frac{L_{day}}{10}} + 4 \cdot 10^{\frac{L_{evening}+5}{10}} + 8 \cdot 10^{\frac{L_{night}+10}{10}}}{24}$$

More specifically, noise during the evening gets a penalty of +5 dB(A), while noise during the night is increased by +10 dB(A).

The World Health Organisation advises a maximum noise level of 53 dB Lden and 45 dB Lnight for road transport. For rail transport maximum tolerated noise levels are determined at 54 dB Lden and 44 dB Lnight.

The average noise cost is composed of health costs and annoyance costs. Annoyance costs increase with the noise level. The threshold value for annoyance is set at 50 dB(A). Although motorcycles produce less noise than cars, they trigger more annoyance. Especially in quiet, rural areas, the motorcycle noise is found to be more annoying (Lechner et al, 2020).

There is a lot of controversy in the literature on how and to what extent annoyance should be taken into account in noise emission costs. One reason is that computing health costs and annoyance costs separately holds a risk of double counting. Health costs are calculated based on the cost of illness and the Value Of Life Year (VOLY). Annoyance costs can be calculated based on stated preferences (surveys), revealed preferences, or the environmental burden of disease method. Each of these methods result in very different valuations for annoyance.

DG MOVE (2020) uses annoyance valuation based on a stated preference approach which leads to a considerably higher valuation of annoyance costs than what is found by other methods. Because the impact of annoyance costs is especially strong for motorcycles, we note that the costs calculated in this section must be considered with caution.

DG MOVE (2020) reports noise costs per transport mode for the EU28. Average noise costs in 2021 prices are shown in the table below.

Table 46 External costs of road traffic noise for the EU28 (€2021/dB/person/year)

Lden (db(A))	Annoyance	Health	Total
50-54	15.3	3.3	18.5
55–59	30.5	3.3	33.8
60–64	30.5	6.5	37.1
65–69	58.9	9.8	68.7
70–74	58.9	14.2	73.1
≥ 75	58.9	19.6	78.6

Source: DG MOVE (2020)

Table 47 shows the average noise cost per road transport vehicle type in Belgium, expressed in eurocent per vehicle kilometre. Motorcycle noise costs are among the highest of all vehicle types. The average noise costs of a motorcycle are considered comparable as those of a heavy-duty truck and they are 6.5 times higher than noise costs produced by a passenger car.

DG MOVE (2020) states that the cost estimates for motorcycles should be interpreted with caution because they are highly influenced by the quality of the transport data that was collected for this vehicle type. In addition, the study only calculates the noise costs for motorcycles, while mopeds are not considered.

Table 47 Average noise costs for road traffic in Belgium, € 2021 prices

	Average costs (€-cent per vkm)
Pass car petrol	2.1
Pass car diesel	2.2
Pass car total	2.2
Bus	13.5
Coach	13.5
Motorcycle	14.4
LDV	2.7
HDV 3.5 - 7.5 t	8.6
HDV 7.5 - 16 t	11.9
HDV 16 - 32 t	13.6
HDV > 32 t	15.4

Source: DG MOVE (2020)

We adjust the cost estimates in the table above to take into account the costs of electric vehicles. A study by COMPETT (2015) on the noise caused by electric vehicles shows that the noise reduction potential of electric vehicles is negligible as soon as the vehicle's speed exceeds 30km/h. At higher speeds, the tyre type and road type are dominating the noise emission. This is especially true for cars, because of their weight. Hence, noise emission costs for cars are quite insensitive to the fuel type.

For motorcycles, scooters and mopeds, the situation is different. The noise reduction potential of an electric PTW compared to a combustion engine PTW is significant. This is shown in Figure 50.

The electrification of scooters can lead to a noise reduction up to 20 dB per vehicle. The noise from e-motorbikes is so low that other road users can hardly recognize their presence by sound, to the extent that the possibility of adding sounds to warn pedestrians of approaching electric motorbikes has been studied. Therefore, we set the noise cost of e-motorbikes equal to that of a passenger car, notably € 2.2 euro cent per km.

For mopeds, speed pedelecs and e-bikes, the noise reduction is even more pronounced. Noise levels produced by e-mopeds do not exceed the 50 dB(A) threshold. Therefore, external noise costs of e-mopeds can be ignored.

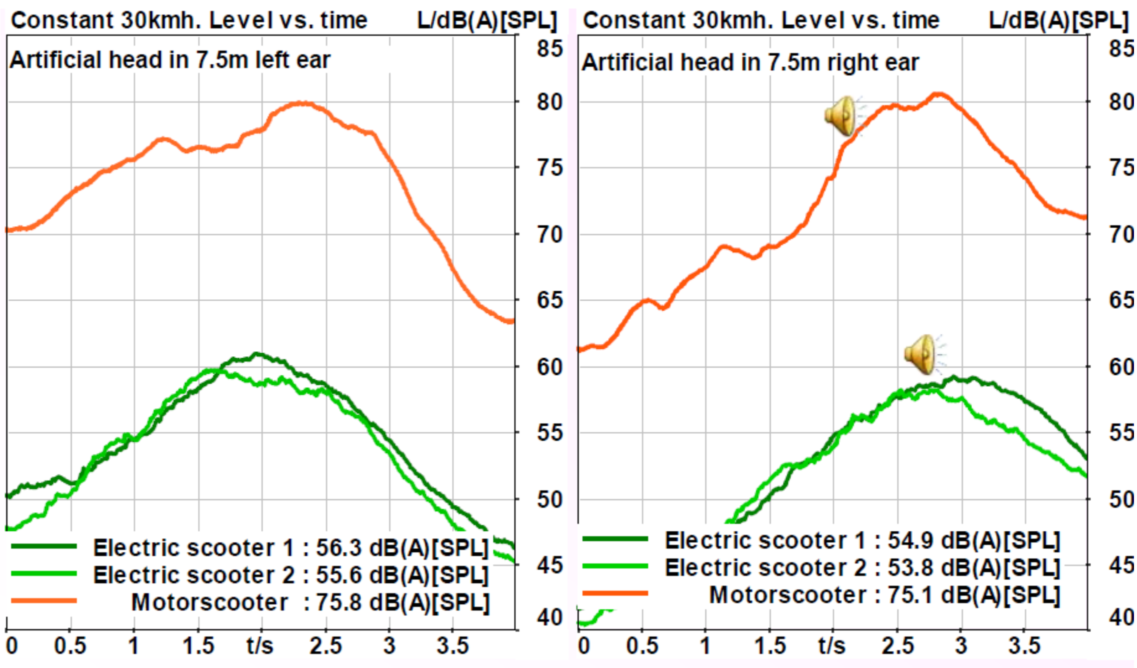


Figure 50 Noise reduction potential of electric scooters - Source: GmbH (2012)

Impact modal shift scenarios on external noise costs

We calculate the impact of the modal shift scenarios on noise costs in Belgium by multiplying the change in vehicle kilometres per vehicle type in the Alternative Scenario compared to the reference scenario by the average noise cost per kilometre for the respective vehicle type.

On the one hand, the alternative scenarios assume a reduction in car kilometres. Therefore, lower noise costs are expected from car traffic. On the other hand, noise costs increase due to the increase in PTW-activity. For mopeds, these costs are small, given the fast electrification of this vehicle type.

Table 48 shows the net present value of the noise costs (-) and benefits (+) for each scenario compared to the reference scenario over the period 2025 to 2030. In Alternative Scenario 1, there is a net noise cost of € 289.6 million. In Alternative Scenario 2, the noise reduction from the car fleet outweighs the increased noise emissions by PTWs. Hence, there is a net benefit of € 3 192 million.

Note that the noise costs may be overestimated, and likewise, noise benefits may be underestimated due to the high valuations for annoyance costs. Also, as we will show in the concluding Chapter 13, noise costs represent only a small share of the total costs and benefits of a modal shift from cars to PTWs. This is mainly due to the expected electrification of the fleet, which will reduce noise emissions of PTWs considerably.

Table 48 NPV of noise costs (-) and benefits (+) for Belgium 2025-2030

	Flanders	Wallonia	Brussels	**Total**
Alt Scenario 1	-115 175 158	-173 008 688	-1 450 625	**-289 634 472**
Alt Scenario 2	1 752 896 662	1 269 969 947	169 427 840	**3 192 294 449**

11 Space occupation

Transport modes and transport infrastructure (roads, parking space) take up space. Due to growing population numbers and rising urbanisation rates, the competition for space has intensified over the years. This is especially the case in highly urbanised areas. But also in rural areas, giving up space for transport infrastructure has become controversial. In the wake of global climate change, the costs of destroying or fragmenting open space have increased considerably.

Because space has become a rare resource, especially in cities, urban planners from many cities are investigating how to optimise street space such that it better fits the changing needs of society. For example, cities like Brussels and Ghent have implemented car-free zones. Many modern cities are looking for solutions that imply less space for cars, but more urban open space for recreational activities.

Powered two-wheelers can play a role in space-related decisions. Thanks to their small size, they occupy less space than passenger cars. A recent report by the International Transport Forum (ITF, 2022) analyses space consumption of mobility modes. The study distinguishes static space consumption and dynamic space consumption. **Static space consumption** is the amount of space that is required for parking and vehicle storage. Required static space is linearly related to the size of the vehicle. **Dynamic space consumption** is the space occupied by vehicles in movement. It depends on vehicle size and speed.

In this study, we only calculate the impact of a modal shift scenario on static space consumption. Table 49 shows the static space consumption per transport mode and configuration. The most space consuming parking options are car parks, because additional space is needed to access the park and to manoeuvre in the park. In case of on-street parking, powered two-wheelers occupy 80% less space than cars.

Table 49 Static space consumption per person, transport mode and configuration

Mode and configuration	Space consumption per vehicle (m²)	Occupancy rate	Space consumption per person (m²)
Car (on-street, parallel)	10	1.39	7.2
Car (on-street, angled)	12	1.39	8.6
Car (car park)	25	1.39	18.0
PTW (on-street)	1.5	1	1.5
PTW (car park)	2.5	1	2.5
Bicycle (stand)	0.8	1	0.8
Bicycle (two-level rack)	0.6	1	0.6
Bus (12 m)	70	20	3.5
Bus (12 m, peak hour)	70	50	1.4

Source: Own calculations based on Héran et al. (2011)

Used public space for vehicle storage

To determine the amount of public space occupation, we need to know how many vehicles are parked on public areas during the day. In a survey by TML (2022) on the potential for electric vehicles, respondents were asked about the location of their when not in operation (and for how many hours per day. The survey was held among a representative sample of 2,500 Belgian households. Based on the survey responses, we calculate the location shares of cars in Belgium, as shown in the table below.

For most of the day, vehicles are parked at private property, at home or at work. The proportion of vehicles parked at a public parking space differs considerably per region. In Flanders, only 19% of the vehicles are parked at public space (on the street or at a parking lot) during the day. In Wallonia this share is 26%. In Brussels, 41% of the vehicles are parked on a public parking space, if not driving. This is intuitive because many houses in the capital do not have garage or driveway.

Table 50 Storage locations for vehicles (when on driving) during the day

	FLA	WAL	BRU
Private parking	71%	65%	52%
Parking provide by employer	10%	10%	8%
Public parking	4%	6%	4%
On the street	15%	20%	37%
Total private parking	**81%**	**74%**	**59%**
Total public parking	**19%**	**26%**	**41%**

Source: TML (2022)

We calculate the amount of public space (in m²) used by vehicle parking in each region as follows:

$$Space\ \ occupation = cons\ per\ veh\ (m^2) * \#\ vehicles * share\_public\_parking$$

Differently put, the total public space occupation (in m²) is equal to the static space consumption per vehicle (in m²), multiplied by the vehicle fleet and the share of public space used per region.

Costs of occupation of public space

The calculation of the cost of public space is not straightforward. Apart from the land cost, one should also take into account the opportunity cost. If a parking is built, the space cannot be used for other purposes to serve the community. In addition, in rural areas, road infrastructure implies the loss of nature and a fragmentation of open space. Hence, the cost of public space occupation depends to a great extent on the location.

Unfortunately, we have no information on the opportunity costs for the use of public space. Therefore, we can only partially account for this effect. We compute the cost of public space as the cost of the infrastructure (investment + maintenance costs). Vermeiren et al (2019) calculate the average annual costs of road infrastructure in Flanders.[50] They take into account investment and maintenance costs and convert these into annual costs in euro per meter. Costs are computed separately for infrastructure in rural and urban areas. The average lifetime of infrastructure is determined at 31 years.

We convert the infrastructure costs in Vermeiren et al (2019) to a unit of € per m² and express the costs in fixed prices of the year 2021. Based on the different degrees of urbanisation in the three regions, we compute yearly road infrastructure costs per region. The results are shown in the table below.

[50] https://omgeving.vlaanderen.be/maatschappelijke-kosten-van-verspreide-bebouwing-becijferd

Table 51 Cost of road infrastructure per year (€/m², 2021 prices)

	€/m²
FLA	22.72
WAL	20.14
BRU	24.12

Because road infrastructure and maintenance costs are higher in urban areas compared to rural areas, the infrastructure cost is highest in Brussels and lowest in Wallonia.

We calculate the cost and benefits from the modal shift scenarios on public space occupation by multiplying the difference in space occupation in each scenario relative to the reference scenario by the cost of road infrastructure.

Table 52 shows the monetary benefit of public space occupation resulting from the modal shift scenarios. Alternative Scenario 1 leads only to a very small reduction in the number of cars relative to the reference scenario, while there is an increase in the number of PTWs. Therefore, the space benefits realized by this scenario are relative small. Alternative Scenario 1 leads to a total economic benefit of € 36.7 million. 52% of these benefits are realized in Brussels, where the cost of public space is the highest.

Alternative Scenario 2 involves a lower number of passenger cars on the streets. At the same time, there is a substantial increase in PTW, but because these vehicles require less space than cars, the net benefit is still overly positive. For the whole country, the net benefit is estimated at € 2 129 million. In this scenario, 50% of the benefit is realized in Flanders. This is because the car fleet in Flanders decreases proportionally more than in Brussels in this scenario.

Table 52 NPV of space occupation benefits realized by the modal shift scenarios

	Flanders	Wallonia	Brussels	**Belgium**
Alt Scen 1	€ 14 259 513	€ 3 546 010	€ 18 869 994	**€ 36 675 517**
Alt Scen 2	€ 1 073 238 977	€ 639 287 916	€ 416 913 956	**€ 2 129 440 849**

Note that the calculated space occupation benefits involve a potentially strong underestimation. The reasons for this are the following:

- We only accounted for the use of public space. Vehicles also have a private storage costs (garage, driveway) at home and at work. Private storage costs for PTWs are smaller than for passengers cars.
- The cost of public space is assumed constant over the years. However, given the scarcity of public space, we may expect the cost of space to increase at a higher rate than the national inflation rate. This real price change is not taken into account.
- Dynamic space occupation is not taken into account.

12 Other effects

This studies considers the main effects of a modal shift from cars to PTWs on society. Apart from the impact investigated in this report, such a modal shift may have additional effects. We discuss these effects briefly in this section

Health effects

A modal shift from cars to active transport modes such as bikes creates positive health effects for the user. Part of the PTWs considered in this study are active transport modes, notably electric bikes and speed pedelecs. In this study, these active modes are classified as electric mopeds. Research has demonstrated that these vehicle types bring positive mental (enjoyment, clear head/fresh feeling and added attention) and physical (sweat, exercise, and physical condition) health effects (De Geus & Hendriksen, 2015; Van den Steen et al, 2019).

The physical effort needed to ride a conventional bike is higher than an e-bike. But because e-bikers ride longer trips compared to cyclists, the physical activity gains are similar for e-bikers and riders of conventional bikes (Castro et al., 2019).

The health benefits resulting from our modal shift scenarios are potentially large. This is because a large majority of the e-moped fleet (up to 90%) are powered bicycles.

Delhaye et al (2017) estimate the health benefits for riding a powered bicycle in Belgium at € 0.266 per kilometre driven.[51] Converted to prices for the year 2021, this corresponds to an average external health benefit of € 0.29/km.

Because we have no information on the future share of e-mopeds that are e-bikes and speed pedelecs, we make the conservative assumption that 50% of the electric mopeds require pedalling. Note that currently, up to 90% of all e-mopeds sold is an electric bicycle.

Table 53 Total health benefits from riding active modes

	Flanders	Wallonia	Brussels	Belgium
Alternative Scenario 1	€ 1 221 036 885	€ 458 500 516	€ 72 196 960	**€ 1 751 734 361**
Alternative Scenario 2	€ 5 190 138 943	€ 3 788 193 793	€ 444 392 159	**€ 9 422 724 895**

Table 53 shows that the health benefits from the active modes in our modal shift scenarios are indeed important. In the mild modal shift scenario, health benefits are equal to € 1 751 million. In the strong modal shift scenario, the health benefits are equal to € 9 422 million.

Synthetic fuels

In the design of the modal shift scenarios, we made assumptions about the greening of the vehicle fleet. We assumed that the required reduction in greenhouse gas emissions will be achieved by an electrification of the vehicle fleet.

[51] Delhaye E., De Ceuster G., Vanhove F., Maerivoet S. (2017) Internalisering van externe kosten van transport in Vlaanderen: actualisering 2016, studie uitgevoerd in opdracht van de Vlaamse Milieumaatschappij, MIRA, MIRA/2016/02 door Transport & Mobility Leuven.

An alternative to electric motorcycles are motorcycles powered by synthetic fuels (e-fuels). E-fuels are climate neutral and can be used in a motorcycle with a traditional engine. In addition, no battery is needed, so there is no range anxiety for the rider.

The advantages offered by e-fuels imply that the future motorcycle fleet may not be fully electric, but a mix of electric motorbikes and motorcycles powered by e-fuels. This is something that was not taken into account in this study. We could not take a scenario for e-fuels into account because there is no price data for this type of fuel yet.

The impact of a scenario with e-fuels on the results will be small. Whether the PTW is powered by an electric battery or by e-fuels has no impact on the scenario results for the mobility effects, road safety, emissions or space occupation. The only impact is on the private ownership costs and the noise costs. With respect to costs, e-fuels are more expensive that conventional fuels. However, with the price of conventional costs rising and the expected production costs for e-fuels decreasing, the difference in fuel costs we become smaller over time. According to the e-fuel Alliance, e-fuel will cost between € 1.34 and € 1.36 per litre in 2025, compared to an expected cost of € 1.22 per litre for conventional fuel.[52]

With respect to noise emissions, we assume that motorcycles with conventional and e-fuels will produce the same noise level. Therefore, noise emission costs will be higher in a scenario with more e-fuelled motorcycles and less electric motorcycles.

Time savings from parking space search costs

To calculate the time savings from a modal shift from cars to powered two-wheelers, we only considered the time savings that are realized during an average trip. What we did not take into account are the potential time savings that are realized when riders search for a parking space. The literature shows that the time spent on searching for parking can be significant in urbanized areas.

To get an idea of the magnitude of the effect, we refer to a study by Economica (2015). The study estimates that the economic value of time savings resulting from parking space searching are equal to €2.5 million per year if 54,500 Austrians commuters would switch from using cars to motorcycles. Over a period of 25 years, this corresponds to savings with a present value equal to €43.5 million.

[52] https://www.efuel-alliance.eu/efuels

13 Conclusions and policy implications

In this final chapter we put everything together and present the overall result of the cost benefit analysis. Based on our findings, we discuss the policy implications of our study and provide some initial policy recommendations with respect to powered two-wheelers.

13.1 Overview of the cost-benefit analysis

We investigated the impact of two modal shift scenarios, in which we assumed a transition from passenger car use to PTW-use in Belgium. We calculated the impact of each scenario with respect to different aspects, notably mobility, total cost of ownership, road safety, air and noise emissions, the occupation of public space and health impacts.

The effects of each scenario are compared to a reference scenario that already incorporates the expected effect the transport and energy policies that are currently in place. Hence, we are able to identify the isolated impact of the modal shift assumptions.

The two alternative scenarios differ considerably with respect to the magnitude of the modal shift that is assumed. In Alternative Scenario 1, we assume a significant increase in PTW activity, notably the increase in activity that can be expected based on the European Commission's Green Deal action plan. We assume that only a part of this increase in PTW-activity leads to decreased passenger car use. Hence, Alternative Scenario 1 can be considered as a **mild modal shift scenario**.

Alternative Scenario 2 is based on the ambitions of the regional mobility plans. We assume a similar decrease in passenger car kilometres as is aimed for in the mobility plans designed by the Brussels, Flemish and Walloon governments. Half of this reduction in passenger car activity is then assumed to be picked up by powered two-wheelers. This scenario leads to a very strong increase in PTW kilometres and can be considered as a **strong modal shift scenario**.

The impact of each scenario is calculated on yearly basis, over a total time horizon of 25 years (2025-2050). The yearly costs and benefits resulting from each scenario in comparison with the reference case are discounted to the base year (2025) using the Net Present Value formula and applying a discount rate of 3%.

We present the outcomes of each Alternative Scenario in turn.

13.1.1 Alternative Scenario 1

Table 54 shows the results of the social cost-benefit analysis (SCBA) of the **mild modal shift scenario**. The effects of the SCBA can be split up between direct effects and external effects.

Direct effects

The direct effects are the effects for the users of the transport modes. In this case, the direct effects are the mobility effects, the total cost of ownership and the health benefits from active modes. We find that the direct effects of the mild modal shift scenario are positive for the three regions in Belgium.

The total mobility effect is estimated at € 1 533 million. A modal shift from cars to PTWs leads to less traffic congestion and a higher average speed on the Belgian road network. The impact is different per road type. 61% of the mobility benefits are realized on the urban road network. In urban areas, PTWs move faster than cars, generating significant time savings for the users. Respectively 20% and 19% of the mobility benefits are realized on the primary and regional road network.

When people choose a powered two-wheeler as a transport mode instead of a car, they will benefit from much lower purchase and operating costs. We find that the impact of the modal shift scenario on the total cost of ownership is very large. The total economic benefit is estimated at € 3 850 million. The majority of these benefits are realized in Flanders (77%), where the share of kilometres driven is the largest.

Powered bicycles, in our study classified as e-mopeds, generate a positive health effect for the user. Although the effort needed to ride an e-bike or speed pedelec is lower than a traditional bike, the average distance covered is larger. Therefore, health benefits are found to be similar. Most e-bikes are registered in Flanders. Hence, most of the health benefits are realized in that region. The health benefits in Flanders are equal to € 1 221 million, compared to a total benefit of € 1 752 million that is realized in the whole country.

Table 54 Results of the SCBA, in million euro - Alternative Scenario 1

	Flanders	**Wallonia**	**Brussels**	**Belgium**
Mobility effects	**€ 1 346**	**€ 181**	**€ 6**	**€ 1 533**
Primary road network	€ 304	€ 2	€ 0	€ 307
Regional road network	€ 249	€ 37	€ 3	€ 289
Urban road network	€ 793	€ 142	€ 3	€ 938
Cost of ownership	**€ 2 971**	**€ 843**	**€ 35**	**€ 3 850**
Road safety	**-€ 9 129**	**-€ 5 277**	**-€ 1 140**	**-€ 15 545**
Emissions	**€ 375**	**€ 73**	**-€ 1**	**€ 448**
Air pollution	€ 16	€ 3	€ 0	€ 19
Climate change	€ 359	€ 71	€ 0	€ 429
Noise	**-€ 115**	**-€ 173**	**-€ 1**	**-€ 290**
Space	**€ 14**	**€ 4**	**€ 19**	**€ 37**
Health active modes	**€ 1 221**	**€ 459**	**€ 72**	**€ 1 752**
TOTAL	**-€ 3 316**	**-€ 3 890**	**-€ 1 009**	**-€ 8 215**
Benefit Cost Ratio (BCR)	**0.64**	**0.29**	**0.12**	**0.48**

External effects

The external effects of the modal shift scenarios are the effects that do not only impact the user, but that have an effect on the whole society. These effects are the impact on road safety, air and noise emissions, and the impact on the occupation of public space.

A mild modal shift scenario from passenger cars to PTWs creates two costs for society: there will be a higher number of accidents and there will be higher noise costs than in the reference scenario. Among these two costs, accident costs are a true concern. PTW riders are more vulnerable than passenger car users, which leads to more severe accidents. The total accident cost is valued at €

15 545 million. It is so large that it overshadows the benefits calculated for this scenario. However, the estimated accident costs should be interpreted with caution. Accident risks are based on current accident incidences which are based on a low share of PTWs on the streets, the current road infrastructure, technology and behaviour of road users. The literature shows that accident rates decline over time. In addition, accident rates increase less than proportionally with traffic intensity. This is especially the case when a vehicle type surpasses a critical minimum share in total traffic. In our analysis, we tried to account for these effects, but future accident risk may still be overestimated.

In the next section, we discuss the impact of improved road safety as ambitioned in the All For Zero approach as specified in the Federal Road Safety Plan. If the ambition set in road safety plans is met, total accident costs will be more than halved. This would result in a positive outcome for the cost-benefit analysis.

Noise costs are estimated at € 290 million. The noise cost will mainly impact Flanders and Wallonia. Noise costs are fairly small because of the expected electrification of the vehicle fleet. In addition, as discussed in Chapter 10, noise costs depend to an important extent on the valuation of annoyance costs. Therefore, these results should be interpreted with caution.

The other external effects resulting from a mild modal shift from cars to PTWs, emissions and public space occupation are positive. Because PTWs emit less air pollutants and greenhouse gases than cars, they can contribute to cleaner air and lower climate change costs. The total benefit for Belgium is estimated at € 448 million.

PTWs require less space for parking. We find that a mild modal shift to PTWs implies that less public space is required for vehicle parking. This is especially important in highly urbanised areas like Brussels. The total benefit of this effect is estimated at € 37 million.

Result SCBA – Alternative Scenario 1

Overall, the result of the SCBA of a mild modal shift from passenger cars to powered two-wheelers is negative. The Net Present Value is estimated at € - 8 215 million. This negative NPV is caused by the high accident costs associated with PTW use. Therefore, to fully capitalise the benefits that come with a modal shift to PTWs, policy makers should prioritise on reducing accident risk.

The benefit-to-cost ratio (BCR) differs significantly across the regions. For Flanders, the BCR is 0.64, which is the highest for the three regions. This means that most of the benefits of a modal shift are realized in Flanders. The BCR in the other regions is much lower, notably 0.29 for Wallonia and 0.12 in Brussels.

A reason for the low BCR in Brussel is that the region has already implemented transport policies that are expected to have an impact on passenger car and PTW-use. For example, Brussels has implemented a strict Low Emission Zone that also applies to motorcycles and mopeds. The impact of these LEZ rules are already incorporated in the reference case.

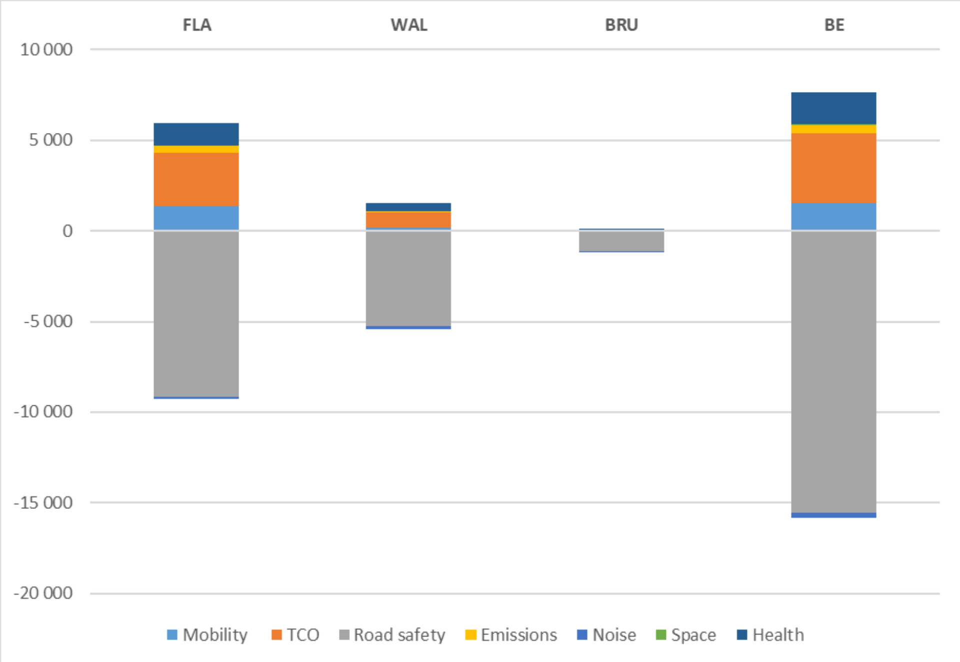


Figure 51 Result of the SCBA by region - Alternative Scenario 1

13.1.2 Alternative Scenario 2

Table 55 shows the overall result of the SCBA for the **strong modal shift scenario**. Again, we subsequently discuss the direct and external effects resulting from this scenario.

Direct effects

The direct effects of a strong modal shift from passenger cars to powered two-wheelers consist of a mobility effect, an impact on total ownership costs and health benefits for the users of active modes. These direct effects are found to be substantial.

A strong modal shift from cars to PTWs leads to less congestion on the Belgian roads. We find that the reduction of total Lost Vehicle Hours per day is significant and the average speed of traffic during the morning and evening peak hours is higher than in the reference case. This all leads to important time savings and significant economic benefits. The total monetary benefits of these time savings are valued at € 31 747 million.

In contrast to Alternative Scenario 1, the main advantage with respect to time savings is on the regional road network that accounts for 49% of the total mobility benefits. This makes sense, because earlier studies show that the regional road network in Belgium contains the most congestion. Having less cars on this network results in a significant improvement of the traffic situation. The urban road network enjoys 27% of the mobility benefits and the primary road network accounts for 24% of all time savings.

As expected, a strong modal shift to PTWs also leads to significant private ownership cost savings. The total cost savings are estimated at € 36 597 and are predominantly realized in Flanders (67%) and Wallonia (31%) where vehicle ownership and kilometres driven is proportionally higher than in Brussels.

Because the majority of e-mopeds sold are powered bicycles, we find that there are significant health benefits associated with riding these active modes. The total health benefit is estimated at € 9 423 million, which is realized for 55% in Flanders, 40% in Wallonia and 5% in Brussels.

Table 55 Results of the SCBA, in million euro - Alternative Scenario 2

	Flanders	**Wallonia**	**Brussels**	**Belgium**
Mobility effects	**€ 27 690**	**€ 3 848**	**€ 209**	**€ 31 747**
Primary road network	€ 7 184	€ 613	€ 32	€ 7 829
Regional road network	€ 13 366	€ 1 955	€ 154	€ 15 476
Urban road network	€ 7 139	€ 1 280	€ 23	€ 8 442
Cost of ownership	**€ 24 368**	**€ 11 525**	**€ 704**	**€ 36 597**
Road safety	**-€ 33 073**	**-€ 22 604**	**-€ 5 178**	**-€ 60 855**
Emissions	**€ 6 310**	**€ 1 648**	**-€ 4**	**€ 7 954**
Air pollution	€ 284	€ 78	€ 0	€ 362
Climate change	€ 6 026	€ 1 570	-€ 4	€ 7 592
Noise	**€ 1 753**	**€ 1 270**	**€ 169**	**€ 3 192**
Space	**€ 1 073**	**€ 639**	**€ 417**	**€ 2 129**
Health active modes	**€ 5 190**	**€ 3 788**	**€ 444**	**€ 9 423**
TOTAL	**€ 33 311**	**€ 115**	**-€ 3 238**	**€ 30 187**
Benefit Cost Ratio (BCR)	**2.01**	**1.01**	**0.38**	**1.50**

External effects

Similar to the result in Alternative Scenario 1, the main disadvantage of an increased use of powered two-wheelers are the high accident costs. Again, road safety costs are found to be substantial. The total cost is estimated at € 60 855 million. However, in contrast to the mild modal shift scenario, the accident costs are no longer overshadowing the positive effects of the modal shift.

Remarkably, in a strong modal shift scenario, we find the impact on noise emissions to be positive. The reason for this is twofold. First, noise from passenger car traffic will be lower than in the reference scenario because of the lower number of car kilometres. Also, noise will be lower thanks to the electrification of the vehicle fleet. The noise reduction capacity of electric passenger cars is not very large, given their heavy weight. In contrast, electric motorcycles and especially mopeds are much lighter which will lead to lower noise emissions. Still, we advise to interpret the noise costs with caution due to the reasons discussed in Chapter 10.

The economic benefits with respect to lower emissions and less public space occupation are more substantial in the strong modal shift scenario compared to a mild modal shift. The monetary benefits of reduced air pollution and climate change costs are estimated at € 7 954 million. Note that Brussels counts as an exception. Here we find net emission costs, albeit small. This is the result of the LEZ rule that bans fossil fuel-driven motorcycles at a later date than fossil fuel cars.

Lastly, benefits are created by freeing public space. The total space occupation benefits are equal to € 2 129 million. Note that we applied a quite conservative approach to calculate the space occupation gains. Actual economic savings might be larger.

Result SCBA – Alternative Scenario 2

A strong modal shift from passenger cars to powered two-wheelers has a positive value to society. The result of the SCBA is convincingly positive. The NPV, that represents the present value of the net benefits and costs is equal to € 30 187 million.

The Benefit to Cost Ratio for Belgium is equal to 1.50, which implies that total benefits are one and a half as high as total costs. There is however, much dispersion across the regions. Flanders is able to reap most of the benefits of a strong modal shift scenario. The BCR is equal to 2.01, which is very high. The main reason for this is that Flanders has the biggest share in congestion and vehicle kilometres driven. At the same time, the costs in Flanders are proportionally lower thanks to the lower accident risk for PTW in this region.

The BCR in Wallonia is equal to 1.01. For Brussels the BCR is only equal to 0.38 and the NPV for this region is negative. There are two explanations for this. First, accident rates in Brussels are relatively high. Especially accidents with slight injuries occur more often than in Flanders. This is also true for Wallonia, although to a lesser extent. Second, Brussels cannot benefit from the emission advantage coming from more PTWs in the same way as the other regions. With the LEZ rules already in place, a strong modal shift to PTWs will not contribute to lower emission in addition to what is already foreseen in the reference scenario. On the contrary, as fossil fuelled motorcycles are banned at a later date than passenger cars, a modal shift to PTWs will initially lead to slightly higher emissions.

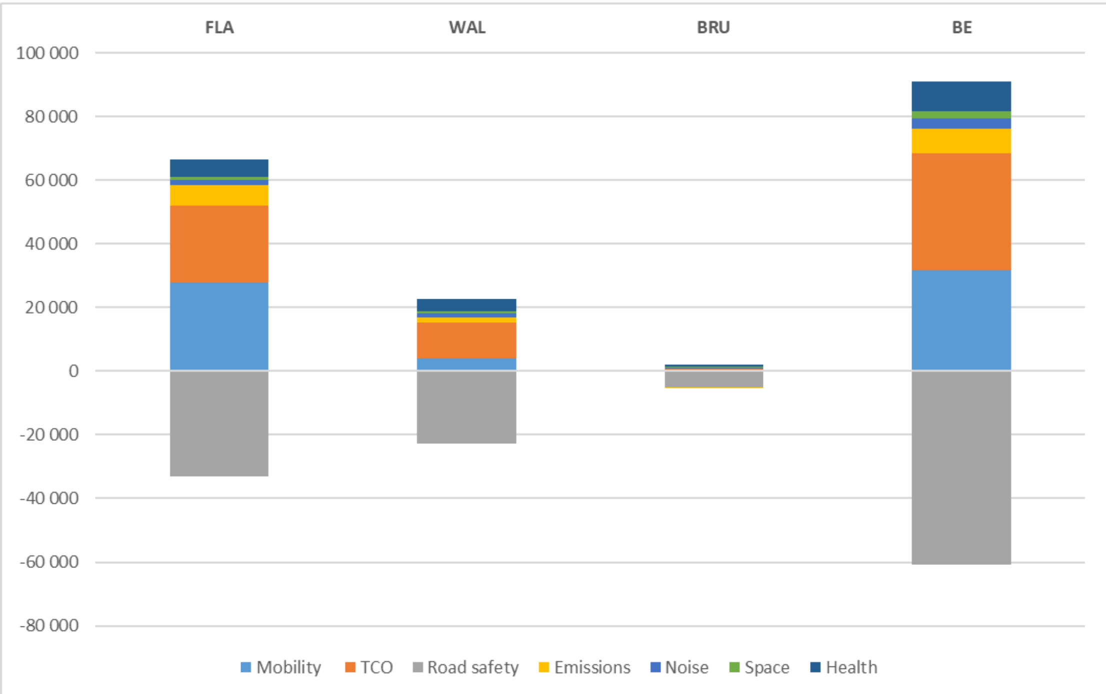


Figure 52 Result of the SCBA by region - Alternative Scenario 2

13.2 Policy implications

In this study, we calculated the benefits and the costs that result from a modal shift from passenger cars to powered two-wheelers in Belgium. We find that the potential gains and costs to society are significant. The policy maker's challenge is to capitalize the gains while simultaneously minimizing the costs. This study intends to support policy makers in this decision by quantifying each effect resulting from a switch from passenger cars to PTWs.

What this study doesn't do, is determining which policy interventions are the most effective to reap the benefits of a modal shift and to control the costs. However, based on our results and best practices in other countries, we are able to provide some recommendations.

A first implication of our study is that policies to discourage passenger car use and encourage PTW use lead to significant benefits to society with respect to time savings, economic savings, and health and environmental benefits.

The question is then, how to stimulate people to make the switch from car travel to PTW rides? **A critical action point will be to improve road safety for PTWs**. Accident statistics show that the primary cause of accidents involving PTWs are human errors of other road users. Therefore, educating PTW riders and improving vehicle safety standards will not be sufficient to bring accident numbers down. Instead, a systemic approach is needed that changes the behaviour of all road users and that foresees in infrastructure that accommodates all road users.

This systematic approach to road safety is prescribed in the **Safe System approach** by the International Transport Forum (ITF, 2016). The Safe System approach is based on four principles:

- People make mistakes that can lead to crashes,
- The human body has a limited physical ability to tolerate crash forces before harm occurs,
- A shared responsibility exists amongst those who design, build, manage and use roads and vehicles and provide post-crash care to prevent crashes resulting in serious injury or death,
- All parts of the system must be strengthened to multiply their effects, and if one part fails, road users are still protected.

A Safe System follows a holistic and proactive approach and requires constant management of the dynamic interaction between operating speeds, vehicles, road infrastructure and road user behaviour. The idea of the Safe System is shown in the figure below.

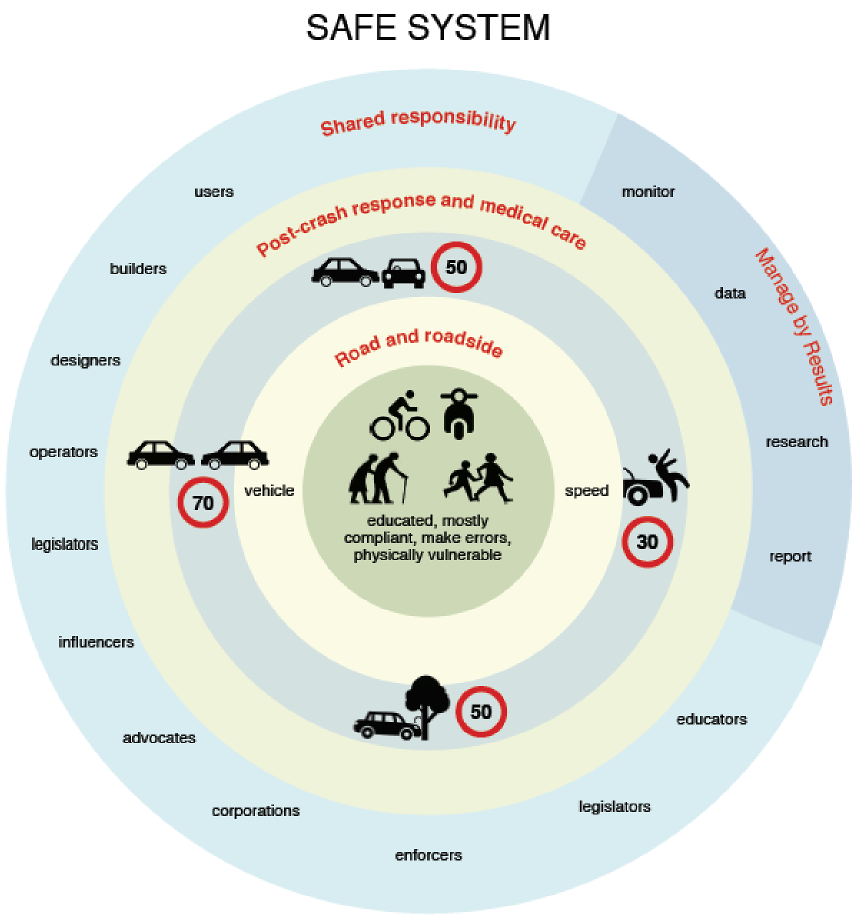


Figure 53 The Safe System – Source: ITF (2016)

Belgium is currently at an early phase of the Safe System approach. Recently the States General has launched the All For Zero challenge that aims for an elimination of all fatal and serious road accidents. All For Zero is already incorporated in the regional road safety plans in Belgium. We calculated that achievement of All For Zero would decrease the road accident costs in each of the modal shift scenarios by more than half. This means that the SCBA of the mild modal shift scenario would be positive for Flanders.

On a smaller scale, we can draw lessons from road safety actions taken by cities with a more motorcycle-dominated traffic mix like Barcelona and several South Asian cities. Several studies show that the most effective measures are infrastructure related. Examples are separate motorcycle lanes (or allowing PTWs to use bus lanes), the "scooter box" (a setback-waiting space for motorcycles at signalized intersections), or two-stage left-turn traffic control measures for left-turning motorcycles (Hsu et al, 2003).

The second implication of our work is that PTWs help to ease traffic congestion and reduce travel time, which is especially a concern in Flanders. In urban traffic, PTWs move faster than cars. We show that even without a significant reduction of passenger cars, a higher share of PTWs in urban areas reduces the lost vehicle hours (LVH) by 4.5% per day. A strong modal shift from cars to PTWs leads to a reduction in LVH of 45% on the urban road network. On the primary and regional road networks a significant decrease in LVHs can be obtained as well, provided that there is a sufficiently large modal shift from cars to PTWs.

Although the potential time savings realized by a modal shift from passenger cars tot PTWs are large, these can be further exploited by extra policy measures. Examples of such policies, which were found to be successful in other studies, are the provision of bus lanes for powered two-wheelers, the exemption from fees (parking, toll zones), or allowing mopeds to drive through car-free traffic routes (Dorocki & Wantuch-Matla, 2021).

A third implication of our results is that PTWs are significantly cheaper in terms of total cost of ownership (TCO) than passenger cars. This means that **PTWs can be an important factor in making mobility affordable and accessible to all.** PTWs have an important role to play in inclusive and sustainable mobility policies.

The Flemish government reduced the TCO of electric PTWs significantly by providing a subsidy upon the purchase of an e-vehicle from 2016 to the end of 2019. Although an econometric analysis should confirm the effectiveness of this premium, data shows that the incentive was successful to promote sustainable PTW use in Flanders, especially in the case of mopeds. Of all new e-mopeds sold in Belgium during this period, 96% were registered in Flanders (Table 56). For e-motorcycles as well, the majority of the new vehicles was registered in Flanders. However, these figures are less reliable given the low overall numbers. Only a few e-motorcycle models were available on the market during this period.

Table 56 Share of new electric powered two-wheeler purchases by region

	E-Motorcycles				E-Mopeds		
	2016	**2017**	**2018**	**2019**	**2017**	**2018**	**2019**
FLA	83.2%	64.8%	75.3%	78.2%	95.6%	96.6%	95.6%
BRU	5.8%	19.1%	13.6%	9.9%	1.5%	1.1%	2.7%
WAL	11.0%	16.1%	11.1%	11.9%	2.9%	2.3%	1.8%

Source: Statbel and DIV

A necessary condition to further stimulate the use electric vehicles is the availability of sufficient recharging points. E-PTWs can be recharged using a conventional plug, at a charging station or by swapping the battery. The latter recharging option implies that e-PTWs can be recharged much faster and in a more flexible way than cars. It also means that **e-PTWs can be easily used in modern, sustainable transport systems such as Mobility-as-a-Service (MaaS)**. PTWs are more flexible than cars in a MaaS system and they allow for longer and faster trips than active modes (cycling and walking) (Eccarius & Lu, 2020).

A fourth implication of this study is that the traditional concern of excessive noise emissions in case of higher PTW activity is expected to become less important in the future. Because the majority of the PTW fleet is expected to electrify, and e-PTWs produce considerably lower noise than conventional PTWs, **noise emissions will gradually decrease in the near future**. It should be noted, that a different greening process of PTWs could change this result. For example, if emission standards are achieved by e-fuels instead of battery electric vehicles, this finding might no longer hold. Whether this is the case, this should be investigated by future research.

Lastly, **this social cost-benefit analysis shows that the impact of a modal shift from passenger cars to PTWs in Belgium is very regional-specific**. The opportunities for such a modal shift are the biggest in Flanders. This region has the most congestion, the highest traffic activity, yet at the same time the lowest accident rates. Although Brussels has the strongest degree of urbanisation, our results show that a modal shift from cars to PTWs is the least desirable in this region.

To summarize, the rapid growth in powered two-wheeler adoption rates in Belgium leads to important social benefits. PTWs can play a key role in designing sustainable and inclusive mobility systems, especially in urban areas. This mode of personal transport leads to significant time savings, lower user costs, reduced emissions and a more efficient allocation of public space. Investments in improving road safety remain crucial to fully reap the benefits of this transport mode.

1 Annex : L-category vehicles

Cat	Category name	Sub-category	Subcategory name
L1e	**Light two-wheel powered vehicle**	L1e-A	Powered cycle
		L1e-B	Two-wheel moped
L2e	**Three-wheel moped**	L2e-P	Three-wheel moped for passenger transport
		L2e-U	Three-wheel moped for utility purposes
L3e	**Two-wheel motorcycle**	L3e-A1	Low-performance motorcycle
		L3e-A2	Medium-performance motorcycle
		L3e-A3	High-performance motorcycle
		L3e-AxE	Enduro motorcycles
		L3e-AxT	Trial motorcycles
L4e	**Two-wheel motorcycle with side-car**		
L5e	**Powered tricycle**	L5e-A	Tricycle
		L5e-B	Commercial tricycle
L6e	**Light quadricycle**	L6e-A	Light on-road quad
		L6e-B	Light quadri-mobile
		L6e-BP	Light quadri-mobile for passenger transport
		L6e-BU	Light quadri-mobile for utility purposes
L7e	**Heavy quadricycle**	L7e-A	Heavy on-road quad
		L7e-A1	A1 heavy on-road quad
		L7e-A2	A2 heavy on-road quad
		L7e-B	Heavy all terrain quad
		L7e-B1	All terrain quad
		L7e-B2	Side-by-side buggy
		L7e-C	Heavy quadri-mobile
		L7e-CP	Heavy quadri-mobile for passenger transport
		L7e-CU	Heavy quadri-mobile for utility purposes

2 Annex: VISSIM-parameters

In typical VISSIM-simulations, PTWs are neglected, especially in European context. Their share in the traffic mix is relatively small, and their behaviour is not well recorded. For this project, the motorcycles and mopeds are included as new vehicle types. Next, a new driving behaviour is specified where lane filtering is allowed for motorcycles. The two modes are discussed below.

2.1 Motorcycles

2.1.1 Vehicle type

The motorcycles are modelled as a type of car. They have a significantly higher maximal and desired acceleration and deceleration rate compared to cars, as shown in Figure 54 - Figure 57[53].

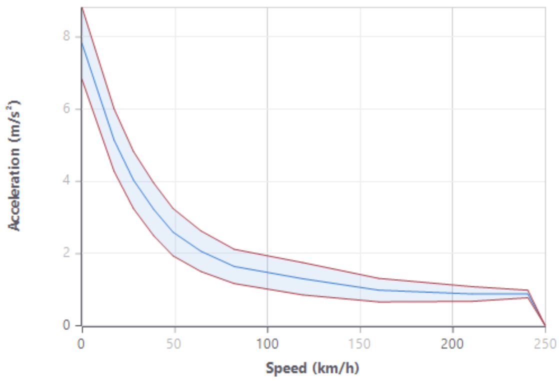


Figure 54 Maximal acceleration of motorcycles

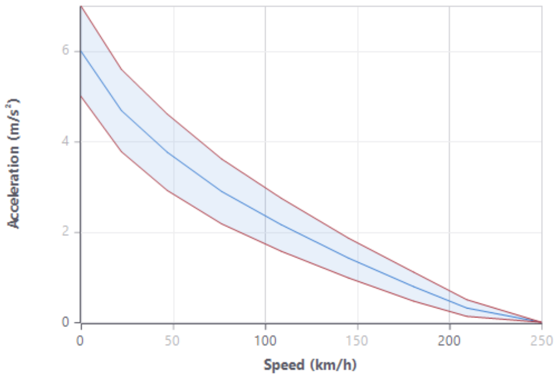


Figure 55 Desired acceleration of motorcycles

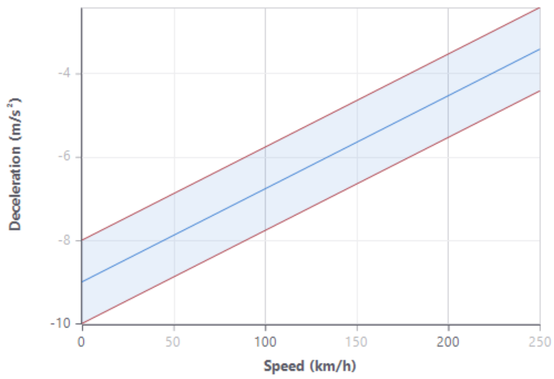


Figure 56 Maximal deceleration of motorcycles

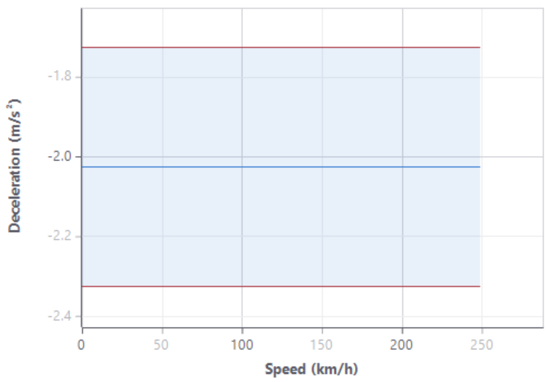


Figure 57 Desired deceleration of motorcycles

[53] *Modelling Motorcycles Driving Cycles and Emissions in Edinburgh*. Ravindra Kumar. 2019.

2.1.2 *Driving behaviour*

Secondly, the driving behaviour for all links is modified to a newly defined one. This new behaviour is nearly a copy of the standard behaviour, except for the lateral behaviour. It uses the Wiedeman74 car following model with VISSIM's default parameters.

The parameters used for the lateral driving behaviour can be seen in Figure 58. Most notably, the minimum lateral distance for a vehicle to pass another vehicle ranges from 0.00 m to 0.50 m, depending on the speed of the vehicle. If the other vehicle is a bus or a truck (HGV), however, more space is required for the motorcycle to pass.

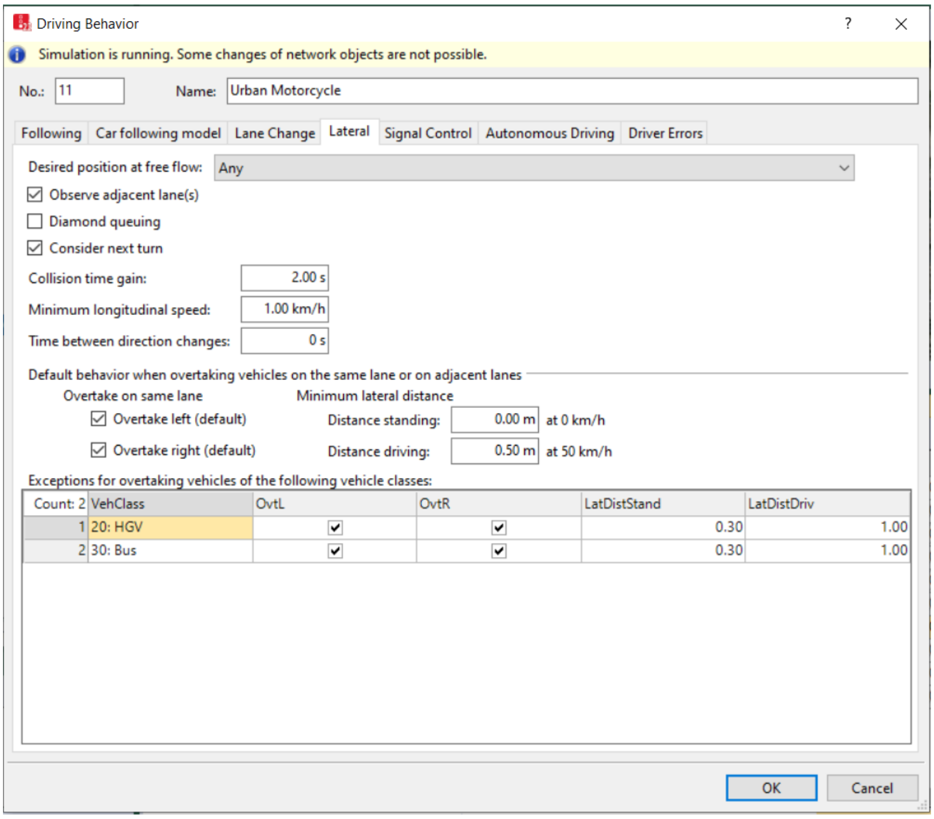


Figure 58 Parameters for the lateral driving behaviour from VISSIM

2.2 Mopeds

The implementation of mopeds is more straightforward. They are modelled as normal bikes, with a higher desired speed. In reality, they also have a higher acceleration and deceleration, but their effects on the results are expected to be minimal.

For the desired speed distribution, a linear relation is expected between 30 and 45 km/h, as both electric bikes and speed pedelecs or mopeds are included as mopeds in the analysis.

References

- ACEM (2021). Decarbonisation of Transport: Powered Two-Wheelers (PTWs) on the road to 2050. https://www.acem.eu/policy-areas/environment/acem-position-paper-decarbonisation-of-transport-powered-two-wheelers-ptws-on-the-road-to-2050
- ACEM (2021). Micromobility: The case of the Personal Light Electric Vehicle. ACEM Position Paper. https://www.acem.eu/policy-areas/mobility/acem-position-paper-micromobility-the-case-of-the-personal-light-electric-vehicle
- ACEM (2020). The safe ride to the future 2.0. The motorcycle industry's commitment to road safety. https://roadsafetystrategy.acem.eu/assets/Files/ACEM-Safe-Ride-to-the-Future-2.0-Strategy.pdf
- Batley et al (2019). New Appraisal values of travel time saving and reliability, Transportation 46: 583-621.
- Beanland, V., Lenné, M.G. & Underwood, G. (2014). Safety in numbers: Target prevalence affects the detection of vehicles during simulated driving. Attention, Perception, & Psychophysics76, 805–813.
- BloombergNEF and Transport & Environment (2021). Hitting the EV Inflection Point. Electric vehicle price parity and phasing out combustion vehicle sales in Europe. May 2021.
- Brown, L. et al. (2021). Investigation of accidents involving powered two wheelers and bicycles – A European in-depth study, Journal of Safety Research 76, 135-145.
- Castro A. et al (2019). Physical activity of electric bicycle users compared to conventional bicycle users and non-cyclists: Insights based on health and transport data from an online survey in seven European cities, Transportation Research Interdisciplinary Perspectives 1, 100017.
- Commission Notice — Technical guidance on the climate proofing of infrastructure in the period 2021-2027 (OJ C, C/373, 16.09.2021, p. 1, CELEX: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021XC0916(03))
- COMPETT (2015). Noise form electric vehicles – measurements. https://www.vejdirektoratet.dk/api/drupal/sites/default/files/publications/noise_from_electric_vehicles_0.pdf
- De Geus, B., Hendriksen, I. (2015) Cycling for Transport, Physical Activity and Health: What about Pedelecs? Cycl.Futures Res. Pract. 28, 17–31.
- Delhaye, A., Marot, L. (2015), Traffic Management and ITS, Deliverable 6 of the EC/MOVE/C4 project RIDERSCAN.
- Delhaye, A., Vandael Schreurs, K. (2021). Overzicht van het G2W-gebruik in België – Profilering van Belgische bestuurders van gemotoriseerde tweewielers, Brussel, België: Vias Institute – Kenniscentrum verkeersveiligheid
- Delhaye E., De Ceuster G., Vanhove F., Maerivoet S. (2017) Internalisering van externe kosten van transportin Vlaanderen: actualisering 2016, studie uitgevoerd in opdracht van de Vlaamse Milieumaatschappij, MIRA, by Transport & Mobility Leuven.
- Dittrich M., Papadimitriou G., Ntziachristos L., Steven H., Durampart, M. (2018). Developments in Regulations for Sound Emission of L-category vehicles, Euronoise 2018 - Conference Proceedings.
- Dorocki, S., Wantuch-Matla, D. (2021). Power Two-Wheelers as an Element of Sustainable Urban Mobility in Europe, Land 10, 618.

- Eccarius, T., Lu C.-C. (2020) Powered two-wheelers for sustainable mobility: A review of consumer adoption of electric motorcycles, International Journal of Sustainable Transportation, 14:3, 215-231.
- Economica, (2015). Die Ökonomische Bedeutung der Motorradwirtschaft in Österreich.
- Elvik, R. and R. Goel (2019). Safety-in-numbers: an updated meta-analysis of estimates, Accident Analysis and Prevention 129, 136-147.
- European Commission, Directorate-General for Mobility and Transport (2020). Commission Staff Working Document Sustainable and Smart Mobility Strategy – putting European transport on track for the future, SWD/2020/331 final
- European Commission, Directorate-General for Mobility and Transport, Essen, H., Fiorello, D., El Beyrouty, K. (2020). Handbook on the external costs of transport : version 2019 – 1.1, Publications Office. https://data.europa.eu/doi/10.2832/51388
- European Commission, Directorate-General for Climate Action, Directorate-General for Energy (2021), Directorate-General for Mobility and Transport, De Vita, A., Capros, P., Paroussos, L., et al., EU reference scenario 2020 : energy, transport and GHG emissions : trends to 2050, Publications Office, 2021, https://data.europa.eu/doi/10.2833/35750
- Fortune Business Insights. (2021) Motorcycle Market Size, Share & COVID-19 Impact Analysis, by Type, by Propulsion Type, and Regional Forecast, 2021-2028.
- GmbH (2012). Noise of electric and combustion powered scooters. PTW noise levels, resulting annoyance and potential for reduction. Presentation at 2012 Annual Polis Conference, session on acoustically green cities (CityHush workshop)
- HEATCO (2006). Developing Harmonised European Approaches for Transport Costing and Project Assessment (HEATCO). Deliverable D5: Proposal for harmonised guidelines, Stuttgart: IER University of Stuttgart.
- Héran, F et al (2011), La consommation d'espace-temps des divers modes de déplacement en milieu urbain. Recherche complémentaire, Ministère de l'équipement et des transports, France, http://isidoredd.documentation.developpement-durable.gouv.fr/documents/Temis/0063/Temis-0063282/17652_2011.pdf
- Hsu, T. P., Dao, N. X., & Ahmad, F. M. S. (2003). A Comparative Study on Motorcycle Traffic Development of Taiwan, Malaysian and Vietnam. Journal of the Eastern Asia Society for Transportation Studies, 5, 179–193.
- IEA (2021). Global EV Outlook 2021. Accelerating ambitions despite the pandemic. Available at: https://www.iea.org/reports/global-ev-outlook-2021
- ITF (2022). Streets That Fit: Re-allocating Space for Better Cities, International Transport Forum Policy Papers, No. 100, OECD Publishing, Paris.
- ITF (2016). Zero Road Deaths and Serious Injuries. Leading a Paradigm Shift to a Safe System, OECD Publishing, Paris.
- Kämper, C., Helms, H. & J. Jöhrens (2016). Modal shifting effects and climate impacts through electric bicycle use in Germany, Journal of Earth Sciences and Geotechnical Engineering, 6 (4), 331-345.
- Kopp, P. (2011). The unpredicted rise of motorcycles: A cost benefit analysis. Transport Policy 18, 613-622.
- Kumar, R., Saleh, W. and Bosewell, C. (2010), Modelling motorcycle emissions and driving cycle in Edinburgh, World Journal of Science, Technology and Sustainable Development, 7 (4), 357-368.
- Lechner, C., Schnaiter, D., Siebert, U., Böse-O'Reilly, S. (2020). Effects of Motorcycle Noise on Annoyance-A Cross-Sectional Study in the Alps. International journal of environmental research and public health, 17(5), 1580.

- Litman, T. (2021). Understanding Transport Demand and Elasticities. How prices and other factors affect travel behavior. Victoria Transport Policy Institute. Available at: https://www.vtpi.org/elasticities.pdf
- Maerivoet, S., Yperman, I. (2008). Analysis of Traffic Congestion in Belgium. Available at: https://www.tmleuven.be/en/project/congestieprobleem
- Marquet, O., Miralles-Guasch, C. (2016) City of Motorcycles. On how objective and subjective factors are behind the rise of two-wheeled mobility in Barcelona. Transport Policy, 52, 37–45.
- OECD (2012). Mortality Risk Valuation in Environment, Health and Transport Policies, Paris.
- OECD (2015). "Executive summary", in Improving Safety for Motorcycle, Scooter and Moped Riders, OECD Publishing, Paris, https://doi.org/10.1787/9789282107942-1-en
- OECD/ITF (2015). Improving Safety for Motorcycle, Scooter and Moped Riders, OECD Publishing, Paris.
- Oxford Economics (2021). The Economic Importance of Motorcycles to Europe. Report for ACEM. https://www.oxfordeconomics.com/recent-releases/The-Economic-Importance-of-Motorcycles-to-Europe
- Pavlovic, A., Fragassa, C. (2015). General considerations on regulations and safety requirements for quadricycles. International Journal for Quality Research. 9. 657-674.
- Rose, G., Delbosc, A. (2016). Powered-two-wheelers for city commuting: Insight from Australia's three largest capital cities. Journal of Transport Geography 54, 325-335.
- Schoeters, A., Large, M., Koning, M., Carnis, L., Daniels, S., Mignot, D., Urmeew, R., Wijnen, W., Bijleveld, F., van der Horst, M. (2021). Monetary valuation of the prevention of road fatalities and serious road injuries – Results of the VALOR project.
- Tarriño-Ortiz, J. Gómez, J., Soria-Lara, J.A., Vassallo, J.M. (2022). Analyzing the impact of Low Emission Zones on modal shift, Sustainable Cities and Society, 77, 103562.
- Van den Steen, N., B. Herteleer, J. Cappelle, L.Vanhaverbeke,. (2019). Motivations and Barriers for Using Speed Pedelecs for Daily Commuting. World Electric Vehicle Journal, 10. 87.
- van Vliet, O. Brouwer, A.S., Kuramochi, T., van den Broek, M. Faaij, A. (2011). Energy use, cost and CO2 emissions of electric cars, Journal of Power Sources, 196 (4), 2298-2310.
- WSP Civils (2004). Motorcycles and congestion: The effect of modal shift. Phase 3 – Policy testing. Available at: http://mwigan.com/mrw/ewExternalFiles/04%200800%20WSP%20Dft%20MC%20PolicyTest.pdf