Effect of shared electric mopeds on CO_2 emissions

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Management summary

The use of shared electric mopeds is on the rise, especially in the Netherlands. Felyx, a Dutch provider of shared electric mopeds, anticipates that they will boost sustainable mobility and contribute to liveability and accessibility in cities. Felyx wants to gain insight into the impact of its e-mopeds on CO_2 emissions in comparison with other modes of transport to better understand their impact on the environment.

This study determines the effect on Well-to-wheel CO_2 emissions in Rotterdam, Brussels and Berlin of the use of Felyx's e-mopeds compared to other modes of transport. Rotterdam was selected as the study city, based on the number of Felyx's e-mopeds in service, the balanced distribution between availability of mopeds and demand (in comparison with other Dutch cities) and the resulting data quality. Furthermore, due to the fact that e-mopeds have been available in Rotterdam for several years, this mode of transport has become an important transport option. Brussels and Berlin were added at the request of Felyx.

In Rotterdam, users of e-mopeds (mainly students, tourists, freelancers, commuters and expats in the age range of 25-40) have indicated that their alternative mode of transport would have been public transport or a passenger car 50% of the time. The other 50% is primarily apportioned between cycling, walking and taxis. Taking into account the CO_2 emissions per passenger kilometre of the various transport modes, this study finds that shared electric mopeds reduced the CO_2 emissions of urban transport in Rotterdam by almost 500 tonnes CO_2 in the period from October 2020 to September 2021. This is a reduction of almost 86% compared to a situation where the Felyx user would have chosen for another mode of transport. Most emissions are reduced when electric mopeds replace car rides and the use of public transport as these have the highest specific CO_2 emissions.

Compared to Rotterdam, the total impact of Felyx's mopeds in Brussels is less (61 tonnes of CO_2 emissions). This is mainly due to the smaller moped fleet. However, the impact per moped is larger as the CO_2 emissions of the electricity used in Belgium is less compared to the Netherlands as well as Germany. This results in a CO_2 reduction of 93%.

In Berlin Felyx has only been active since July 2021. Therefore, a calculation has been made for 2022 based on the projections provided by Felyx. This resulted in an expected CO_2 reduction of almost 430 tonnes; a saving of 84% compared to the usage of alternative transport modes.

The sensitivity analysis shows that the estimated emission reduction depends primarily on the alternative mode of transport. When mopeds replace car trips or the use of public transport, emission reductions increase the longer the trip. When alternative modes are electrified (which is largely already the case for public transport in Rotterdam), the emission reductions become smaller than estimated here.

1 Introduction

1.1 Growth ambitions of Felyx

Shared electric mopeds[1] are increasingly popular, especially in the Netherlands which has the highest growth rate of available shared mopeds in the world in 2020 (One world, 2021). Felyx, a Dutch provider of shared electric mopeds, has played a key role in this growth due to its fleet of 6,000 mopeds in the Netherlands, Belgium and Germany.

Felyx wants its electric mopeds to boost sustainable mobility and contribute to the liveability and accessibility of cities. Insight into the impact of mopeds on traffic, mobility and emissions is needed to introduce the concept in cities where Felyx is not yet active or to grow the concept in cities where Felyx already has a fleet of mopeds. Felyx is aware of the impact of mopeds on traffic and mobility, and it would like to complement this with insight into CO_2 emissions to share this with relevant stakeholders.

1.2 Aim of this study

The aim of this study is to determine the effect on CO_2 emissions in Rotterdam, Brussels and Berlin through the use of Felyx's mopeds. The main research question is: what are the CO_2 emissions of Felyx's shared electric mopeds compared to other modes of transport in Rotterdam, Brussels and Berlin?

1.3 Scope

In this study we focus on Well-to-wheel[2] CO_2 emissions. Other emissions generated when using a vehicle, such as NO_x and PM, are not included in this study. We consider the battery logistics (i.e. transport of charged batteries to be swapped with the empty and the subsequent return transport to the charging station) as part of Well-to-wheel emissions. The impact resulting from the production, repair and disposal of the moped (i.e. a Life Cycle Analysis) is not included in this study.

We focus specifically on the impact of Felyx's moped fleet and not on the impact of shared electric mopeds in general. The reason for this is that our analysis is based on data provided by Felyx. We will not make any statements about the applicability of the data to all shared electric mopeds in the Netherlands. As shared electric mopeds are mostly used in larger cities, we use trips in Rotterdam as a basis. We explain why Rotterdam has been selected as the city for our analysis in Section 2. In addition, we apply the method used for Rotterdam to replicate the analysis for Felyx's moped fleet in Brussels and Berlin.

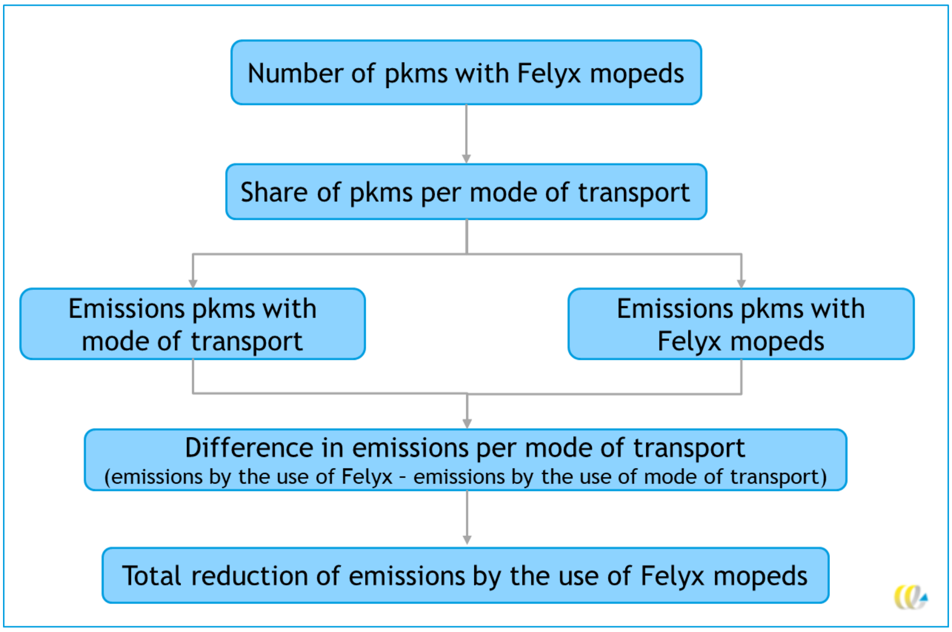
1 In this report the term *moped* is used for a motorized two-wheeler with saddle and a platform on which the operator's feet can rest. Sometimes the term *scooter* is referred to a moped as well, but *scooter* is also used to refer to a (electric) kickbike which is also used as a shared vehicle in other countries. In addition, in the remainder of this report, we will use the term *mopeds* when we discuss shared electric mopeds.

2 Well-to-wheel emissions are all emissions related to fuel (or in the case of Felyx: electricity) production, processing, distribution, and use. In the case of gasoline, emissions are produced while extracting petroleum from the earth, refining it, distributing the fuel to stations, and burning it in vehicles.

1.4 Methodology

To answer the research question we have executed our research in four steps. First, Felyx provided us with trip data to calculate the number of kilometres driven with Felyx mopeds. Second, we performed a literature study where we focussed on mobility (e.g. who uses mopeds and which mode of transport would have been used if a moped had not been used?) and emissions (i.e. which CO_2 emissions apply for each mode of transport?). As a third step, we have combined all this information to calculate the pkm[3] emissions for Felyx mopeds and the other modes of transport. The difference between these two figures provides insight in the amount of CO_2 that has not been emitted. These steps are shown in Figure 1. As a fourth and final step, we have adjusted input variables in our calculation model to perform a sensitivity analysis. The sensitivity analysis is only executed for Rotterdam as it will provide similar results for the other cities.

Figure 1 - Overview of methodology



1.5 Outline of the report

The report continues in Section 2 with an analysis of mobility in Rotterdam, Brussels and Berlin. We discuss the introduction of the shared moped, discuss our case selection (i.e. city) and profiles per mode and mode choice. Section 3 details the results of the calculations of CO_2 emissions. In Section 4 we present our main conclusions.

[3] A *pkm* stands for passenger kilometre, which is a unit to express passenger transport quantity.

2 Mobility analysis

2.1 The shared moped and app

Shared mopeds are one of the new forms of personal urban transportation that have emerged in the last couple of years. Felyx uses an app to locate the nearest moped, which can be reserved for 15 to 45 minutes (the first 15 minutes are free). The moped is activated to start the ride and also deactivated after the ride by the app. Felyx's shared moped service is currently available in the Netherlands in Groningen, Haarlem, Amsterdam, Den Haag, Delft, Rotterdam, Den Bosch and Eindhoven.

Felyx uses two types of mopeds: ones which can travel with a maximum speed of 25 km/h and ones with 45 km/h. In the Netherlands, *moped* is defined as a 'snorfiets' (25 km/h) and a helmet does not need to be worn, while those defined as 'brommer' (45 km/h) do require a helmet. Although 25 km/h mopeds are allowed in the Netherlands, the municipality of Amsterdam has made it compulsory to wear helmets on all mopeds in the city centre (Gemeente Amsterdam, 2021). In Belgium (ANWB, 2021a) and Germany (ANWB, 2021b), all moped users have to wear a helmet. Felyx is also active in Brussels and Berlin. In these cities Felyx only offers 45 km/h mopeds.

2.2 Selection of case city

Case city choice

The focus of this study is an analysis of the environmental effects of shared mopeds of Felyx. In order to compare shared mopeds with other modalities, one city has been chosen for the scope of this analysis. It is important that this city resembles other cities in the Netherlands. It is intended that the outcome of this case study is reflective of shared moped use and is also comparable to other cities where Felyx is active. We discussed this choice of case city in correspondence with Felyx.

The city of Rotterdam was selected for the analysis. Rotterdam is a large city in the Netherlands. Felyx has been active in Rotterdam longer than in the other Dutch cities. Currently the number of Felyx mopeds in Rotterdam has reached around 1,200; far more than in any other Dutch city. An important aspect here is the amount of data that is available about Felyx mopeds in Rotterdam due to the number of years Felyx has been active in the city and the number of mopeds. The validity of the analysis is directly related to the amount and quality of data to conduct an analysis. In the case of Rotterdam, the amount and quality of the data is sufficient for an analysis. Furthermore, unlike Amsterdam, until recently the municipality of Rotterdam did not impose a maximum limit on the number of shared mopeds, which has resulted in a much better balance between the availability of mopeds and the demand.

One other reason to choose Rotterdam over any other city in the Netherlands is the number of mopeds and the number of years they have been in use. The adoption of a new technology takes time to reach a certain base level where enough people have become familiar with the availability of the mopeds and gain experience with the technology.

The number of years shared mopeds have been available and the physical number of mopeds in Rotterdam creates a sound comparison with other familiar mobility types, such as bicycles, cars and public transport. This lowers barriers for adaptation and the acceptance of shared mopeds as an alternative means of mobility. This aspect is most significant in Rotterdam.

In addition to Rotterdam, on Felyx's request also Brussels and Berlin are selected as city to analyse the impact.

Characteristics of mobility

Rotterdam

In Rotterdam a substantial number of different modes of transport is available. The city has a large network of public transport; including bus, tram, metro and trains and shared bicycles such as the *OV-fiets*. Furthermore, the city is accessible by passenger car and taxi, and there are parking options in the city centre.

When a shared moped is used, it replaces one of the other modes of transport. Recently, the Municipality of Rotterdam conducted a questionnaire about the use of shared mopeds (Gemeente Rotterdam, 2021). Table 1 presents the percentage of modes of transport which are replaced by the shared moped. Public transport is the largest mode which is replaced, followed by passenger cars and bicycles, and then walking.

Brussels

Just like Rotterdam, Brussels has numerous transport modes available. Traffic in the city is heavy. Modes such as public transport and two-wheelers are often faster than by car. From January 2021 onwards, Brussel has become a '30 city'. This means speed limits of 30 km/h for all road users, except for certain major roads (50 or 70 km/h) and residential areas (20 km/h) (Visit.Brussels, 2021). In 2021, close to 1% of passenger cars were electric in Belgium (Egear, 2021).

Public transport in Brussels, such as metro, tram and bus, is organised by the STIB/MIVB. Approximately 76% of passenger kilometres in Brussels are by tram/metro and 24% by bus (STIB/MIVB, 2021). In 2021, 5% of busses are electric in Brussels (STIB/MIVB, 2021). No data was found about the amount of passenger kilometres within Brussels by train. Therefore, we assume that this will be limited and have set the share of rail withing public transport on 0%.

Berlin

Berlin has several transport modes for getting around the city. The public transport system is comprehensive and there are plentiful types of transportation by shared mobility. In 2021 0,6% of cars in Germany were electric (Statista, 2021).

Public transport is offered by train (S-Bahn), metro (U-Bahn), tram (Straßenbahn) and bus (Omnibus). Approximately 29% of passenger kilometres are by train, 44% by metro/tram and 27% by bus (BVG, 2021, S-Bahn Berlin, 2021). In 2021, 9% of busses are electric in Berlin (BVG, 2021).

Split of alternative modes

As the market for shared urban mobility is relatively new, limited literature is available on alternative transport modes that would have been used instead of mopeds. The majority of data from surveys and scientific researches are based on scooters (Aguilera-García et al., 2021).

For our selected cities, we have found only for Rotterdam specific figures of alternative modes that would have been used instead of the shared moped. For Brussels and Berlin we estimated the influence of trip distance on preferred alternatives, since shared scooters cover less distance than shared mopeds. Furthermore, when longer distances are covered in one trip the alternative modes are different than in shorter trips for scooters (Reck et al., 2022). Therefore, we used several sources (Aguilera-García et al., 2020, Aguilera-García et al., 2021, Christoforou et al., 2021, Fearnley et al., 2020, Laa & Leth, 2020, Moreau et al., 2019, Reck et al., 2022, Tier, 2021) to create an image of alternative transport modes when shared mopeds are not used. Data from researches in Brussels (Moreau et al., 2019) and several large German cities including Berlin (Laa & Leth, 2020) are used as input to scale the percentages from shared scooter to shared moped.

Table 1 - Percentage of transport modes which are replaced by shared moped rides

Modes of transport		Percentage of replaced mode by shared mopeds		
		Rotterdam	Brussels	Berlin
1	Public transport	27%	32%	34%
2	Passenger car	23%	29%	18%
3	Bicycle	23%	14%	19%
4	Walking	10%	12%	12%
5	Taxi	7%	8%	11%
6	Private moped	5%	1%	1%
7	Not travelling	3%	3%	2%
8	Other	2%	1%	3%

Source: Gemeente Rotterdam (2021), Moreau, et al. (2019) and Laa & Leth, (2020).

Travel distances per modality in high density urban areas (Netherlands)

From the data provided by Felyx, the average distance of rides is 3.1 km for 25 km/h mopeds and 3.8 km for 45 km/h mopeds in the Netherlands. How do these travel distances fit into the transport mode distribution in high density urban areas? According to data from CBS, on distances between 1 to 3.7 km the majority of trips are taken by bicycle, walking and passenger car (CBS, 2021a). In the 3.7 to 7.5 km category, the distribution shifts towards passenger cars and public transport, although travelling by bicycle remains the most efficient mode of transport. For the purpose of this study it would have been useful to have similar figures for Belgium and Germany to know whether the situation is comparable. Unfortunately, we have not been able to find these.

Table 2 - Number of trips per person per day, per mode of transport in high density urban areas in the Netherlands (all reasons)

Year	Mode of transport	Total	0 to 1 km	1 to 3.7 km	3.7 to 7.5 km
2019	**Total**	**2.58**	**0.37**	**0.89**	**0.50**
	Passenger car	26%	3%	17%	28%
	Train	5%	-	-	-
	Bus/tram/metro	7%	-	3%	12%
	Bicycle	31%	27%	51%	38%
	Walking	19%	68%	21%	8%
	Other	3%	-	3%	4%
2020	**Total**	**2.12**	**0.38**	**0.77**	**0.41**
	Passenger car	26%	3%	18%	29%
	Train	2%	-	-	-
	Bus/tram/metro	4%	-	3%	7%
	Bicycle	29%	21%	43%	32%
	Walking	28%	71%	29%	17%
	Other	3%	-	3%	5%

Source: CBS (2021a).

2.3 Travel distances/profiles per modality

User profile and travel motives for shared mopeds from literature

In the Netherlands shared mopeds are used for commuting, recreation, collecting groceries and, to a lesser degree, to travel to school or study (KiM, 2021). The mopeds are mainly used in high density urban areas and are mainly used by millennials (birth year 1981 till 1996). According to KiM, (2021), providers of shared mopeds focus on students, tourists, freelancers, commuters and expats as their target groups.

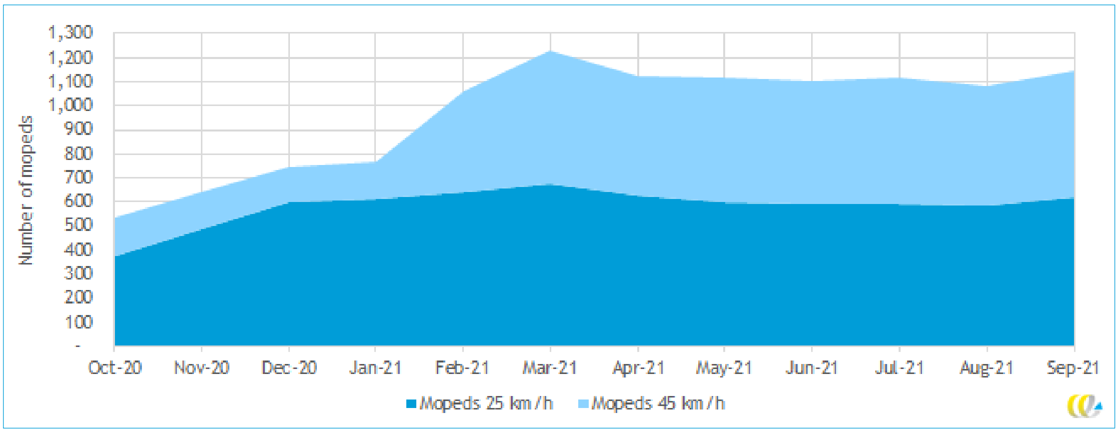
Average trip lengths are 2.3 kilometres and half of the trips are less than 2 kilometres. Around 14% of the trips start or end 200 metres from a train station (KiM, 2021). According to KiM, (2021), shared mopeds are mainly used as an alternative to walking and cycling. According to the Gemeente Rotterdam, (2021), the average trip length of shared mopeds is 2.0 kilometres. A similar picture can be seen in other European countries. Although there seems to be a stronger connection with public transport. For example, Tier, a provider of shared urban e-mobility, indicated that 50% of their trips start or end within 100 metres of a public transport station (Tier, 2021).

Details of Felyx moped rides

Rotterdam

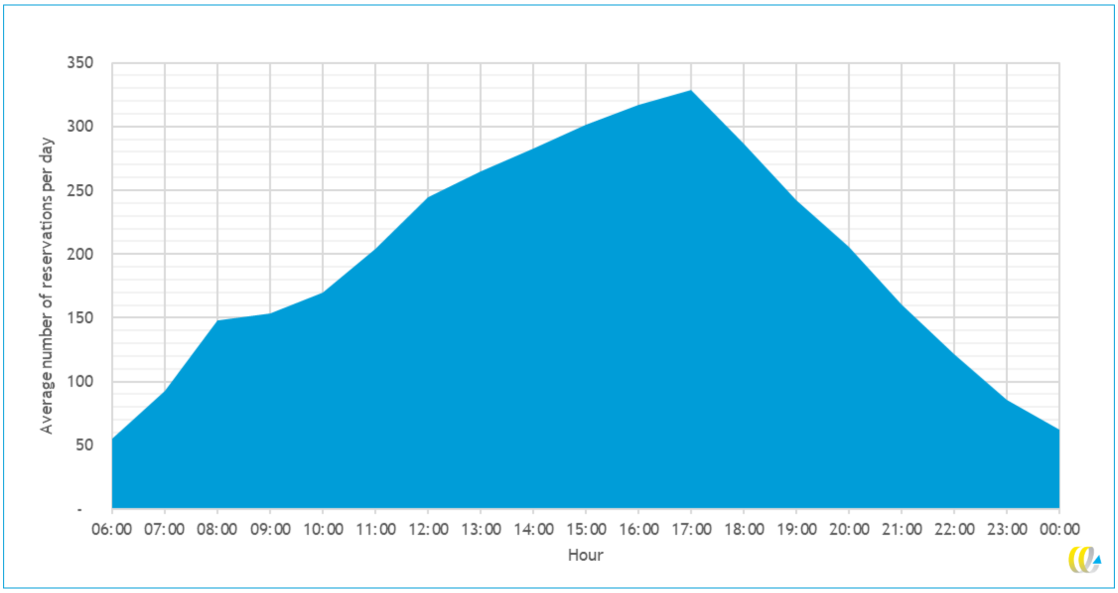
In 2021, Felyx increased the number of mopeds available in Rotterdam to around 1,200 to meet the increasing demand. In particular, 45 km/h mopeds were added to the fleet.

Figure 2 - Number of Felyx mopeds in Rotterdam



According to Felyx's data, the average age of users is 29.4 years. This corresponds with literature, where especially millennials (KiM, 2021) are shown to be users of shared mobility. Taking the average of the number of reservations per time of day, the maximum of reservations peaks at 17:00 hours. An early peak at 08:00 hours indicates reservations which are made for the purpose of commuting or reaching a mobility hub, such as a public transport station. The number of reservations in the afternoon rush-hour is significantly higher than in the morning. A steady rise in reservations towards the afternoon and into the evening indicates Felyx mopeds being also used for other reasons, such as recreation and visiting.

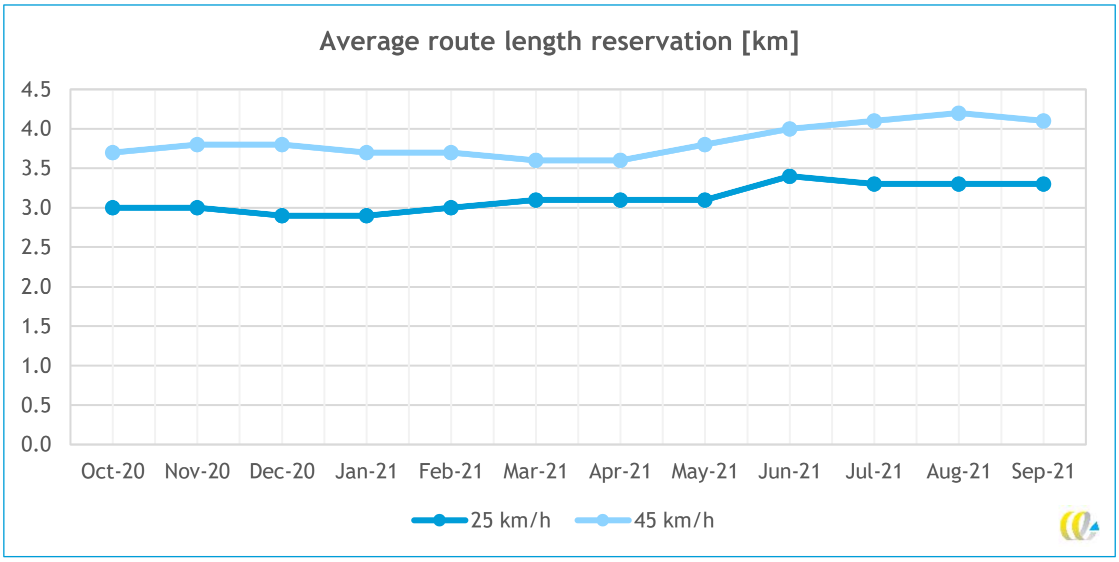
Figure 3 - Average number of reservations per day per hour from October 2020 to September 2021



The average distance covered per reservation is higher for 45 km/h mopeds than of 25 km/h mopeds. Between October 2020 and September 2021, the average trip length was around 3.1 km for 25 km/h mopeds and 3.8 for 45 km/h mopeds. These are longer distances than reported by KiM (2021) and Gemeente Rotterdam (2021), although Felyx issued a statement

(Felyx, 2020) in which it indicated that their recorded travel distances are longer than those reported by KiM (2021).

Figure 4 - Average travelling distances with Felyx mopeds in Rotterdam between October 2020 and September 2021

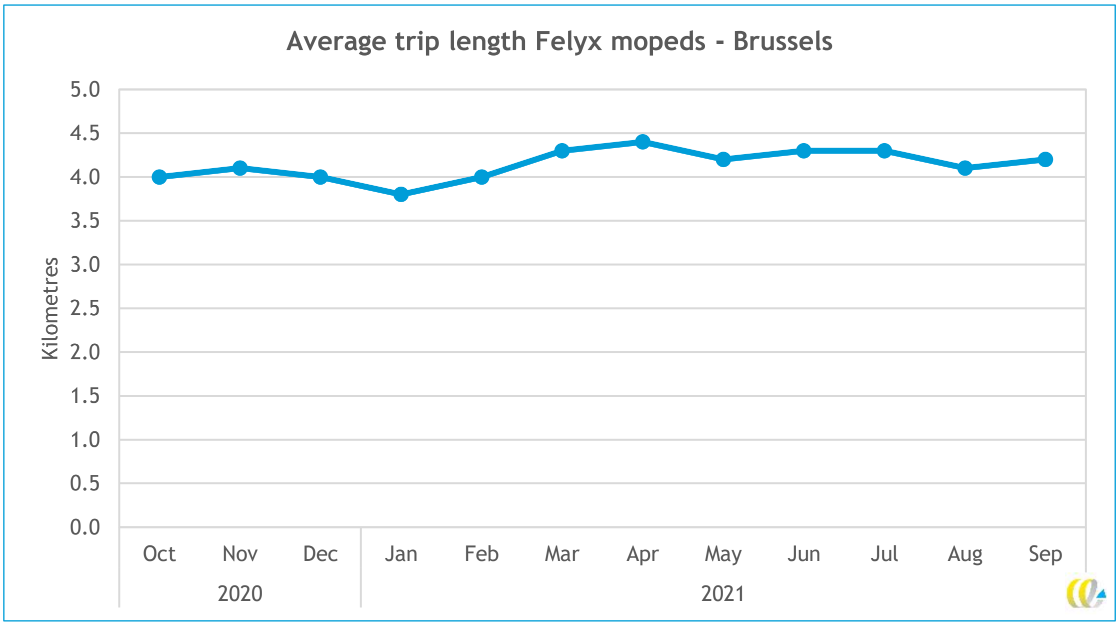


Brussels

In Brussels the moped fleet of Felyx consists of 190 mopeds, substantially smaller than the fleet in Rotterdam. Other differences compared to Rotterdam exist as well, although less significant. The average trip length is 4.1 km, which is slightly longer than the trip length of 45 km/h mopeds in Rotterdam. The average age of the users is 33.3 years old, which is older than in Rotterdam.

Based on the reservations made throughout the day, we found that the pattern in Brussels is comparable to the pattern seen in Rotterdam (Figure 5). Although the peak is reached one hour later (i.e. 18:00 hours).

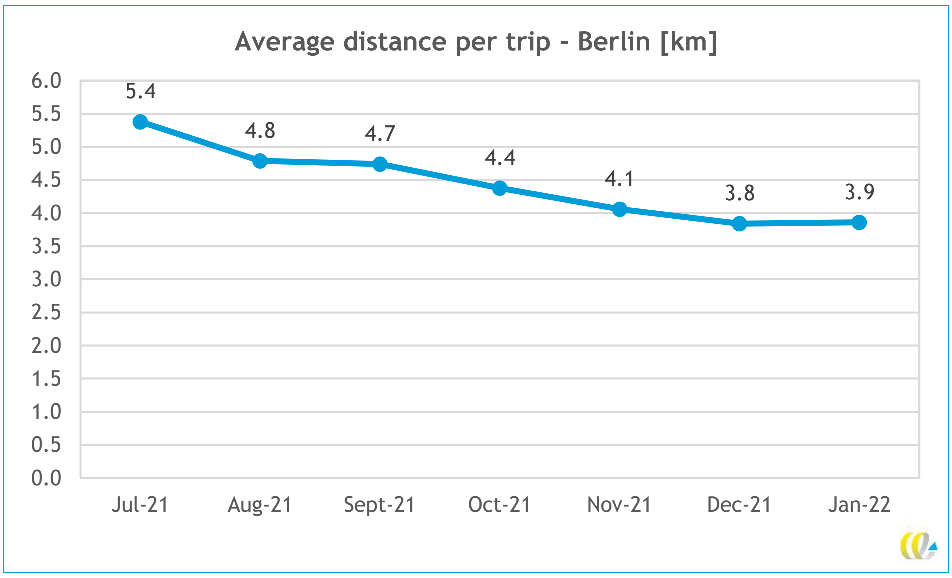
Figure 5 - Average travelling distances with Felyx mopeds in Brussels between October 2020 and September 2021



Berlin

Since Felyx has only been active in Berlin since July 2021, there is no full year of data available. Based on the data from July, August and September 2021, we found that the average age of passengers is 31.4 years, which is in between that of Rotterdam and Brussels. The average ride length shows a declining trend. It started with relatively long distances in July 2021 but as of November 2021 the average ride length settles at around 4 km, which is comparable with Rotterdam (3.8 km/ride) and Brussels (4.1 km/ride). Therefore, we have used 4.0 km/ride for Berlin in our calculations.

Figure 6 - Average travelling distances with Felyx mopeds in Berlin between July 2021 and January 2022



Felyx provided CE Delft with a projection of the expected number of rides for 2022.
In September 2021 Felyx had 1,472 active shared mopeds in Berlin. Felyx indicated that their fleet will be increased with 370 mopeds in 2022 to total around 1,840 mopeds.

In the projection of Felyx, the highest amounts of rides are expected in August and September, as can be seen from Figure 7. When we take an average of rides per day for these months we get approximately 5,000 rides per day. With an expected amount of 1,840 mopeds in this period, this results in 2.7 rides per day per moped. This is comparable to the number of rides per day in Rotterdam (2.6) and Brussels (2.5).

Figure 7 - Projected number of rides per month in Berlin in 2022, provided by Felyx

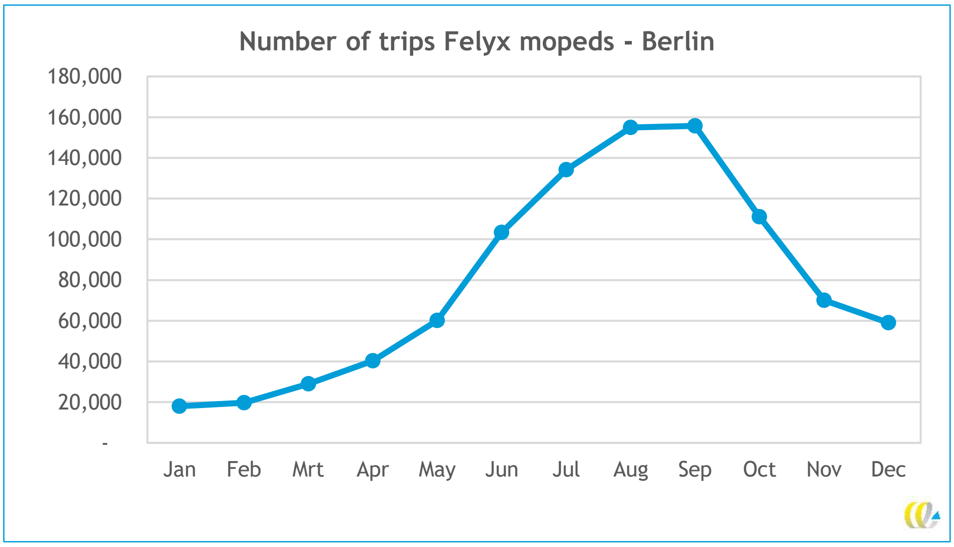
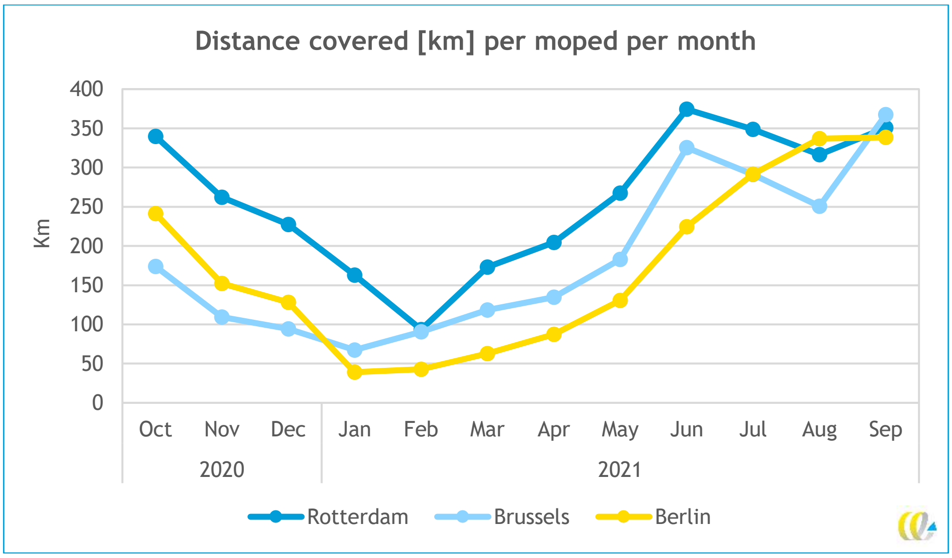


Figure 8 presents the distance covered per moped per month. Note that Berlin is based on the projected number of rides per month, not specifically on 2021/2022 (Figure 7), and an average ride length of 4.0 km. Average distance per month follows the same trajectory for Rotterdam, Brussels and Berlin.

Figure 8 - Average distance calculated per moped



2.4 CO_2 emission of transport modes

Emissions of modes

The emissions associated with the modes can be divided into the user phase and energy production. The user phase is defined as Tank-to-wheel (TTW) and energy production as Well-to-tank. Together they represent the total of emissions associated with the mode of transport in Well-to-wheel (WTW).

The emissions can be determined at vehicle level, though it is important to include the average number of passengers or capacity used per mode (CE Delft, 2014). This allows the emissions per passenger kilometre to be determined, which enables an accurate and sound comparison between transport modes. Table 3 presents these various factors. For Felyx mopeds, the average number of passengers is 1.46 (MopedSharing, 2021). We take passenger number per vehicle kilometre from CE Delft (2014) for Rotterdam, Brussels and Berlin.

Table 3 - Average number of passengers or occupied capacity per mode of transport in the Netherlands

Mode of transport	Average number of passengers per vehicle km	Average percentage of passenger capacity occupied
Bicycle/electric bicycle	1.10	-
Private moped	1.10	-
Felyx moped*	1.46	-
Bus	9.00	-
Tram/metro	-	14%
Train	-	29%
Car	1.39	-
Taxi	1.50	-

Source: CE Delft, (2014).

* MopedSharing, (2021).

The emissions can be calculated by using the factors for passenger kilometres. TTW and WTT combined provide the total emissions (WTW). For Felyx mopeds, battery distribution is added. Energy use (CE Delft, 2014) is used as an input and updated with current emission factors for the Netherlands (CE Delft, 2020). For Belgium and Germany, a similar calculation[4] is used to determine CO_2 emissions for electricity generation. For Belgium this is approximately 226 and Germany 446 grams CO_2 per kWh generated for the entire energy generation chain, lower than in the Netherlands (475 grams CO_2 per kWh). The used CO_2 emissions per transport mode can be found in Annex A.1.

Battery Swap Operation

An important aspect of shared mopeds is that the batteries need to be replaced by fully charged ones. The mopeds themselves are not parked at a charging station or at home where charging is possible. Felyx uses its own electric vans to distribute the batteries to the mopeds. Felyx calls this distribution 'Battery Swap Operation' (BSO).

The CO_2 emissions resulting from the BSO are based in the situation in Rotterdam and comparable for the situation in Brussels and Berlin. In Rotterdam, four vans are used to distribute the batteries. Every van makes four trips per day. The length of an average trip is 40 km, during which around 30 batteries are distributed. Since two batteries are included in every moped, this equates to fifteen mopeds per trip. Per day, 240 mopeds are equipped with charged batteries in Rotterdam and the total distance driven for distribution is 640 km.

The vans used by Felyx are electric vans of Nissan and Toyota. The Nissan[5] uses 0.27 kWh/km, which equates to 106 CO_2/km if we use an WTW emission factor of 475 g/kWh CO_2.

A total of 24.7 tons of CO_2 is emitted (WTW) for 233,600 km in battery distribution per year (640 km x 365 days). For 1,200 mopeds in Rotterdam, this equates to 20.5 kg of CO_2 per year per moped. Between October 2020 and September 2021, on average one Felyx moped covers 4,729 km. The battery distribution of 20.5 kg of CO_2 can be divided by the average total distance driven per moped. The end result is 4.3 grams of CO_2 per kilometre, which can be attributed to battery distribution. This amount is added to the emission factor of

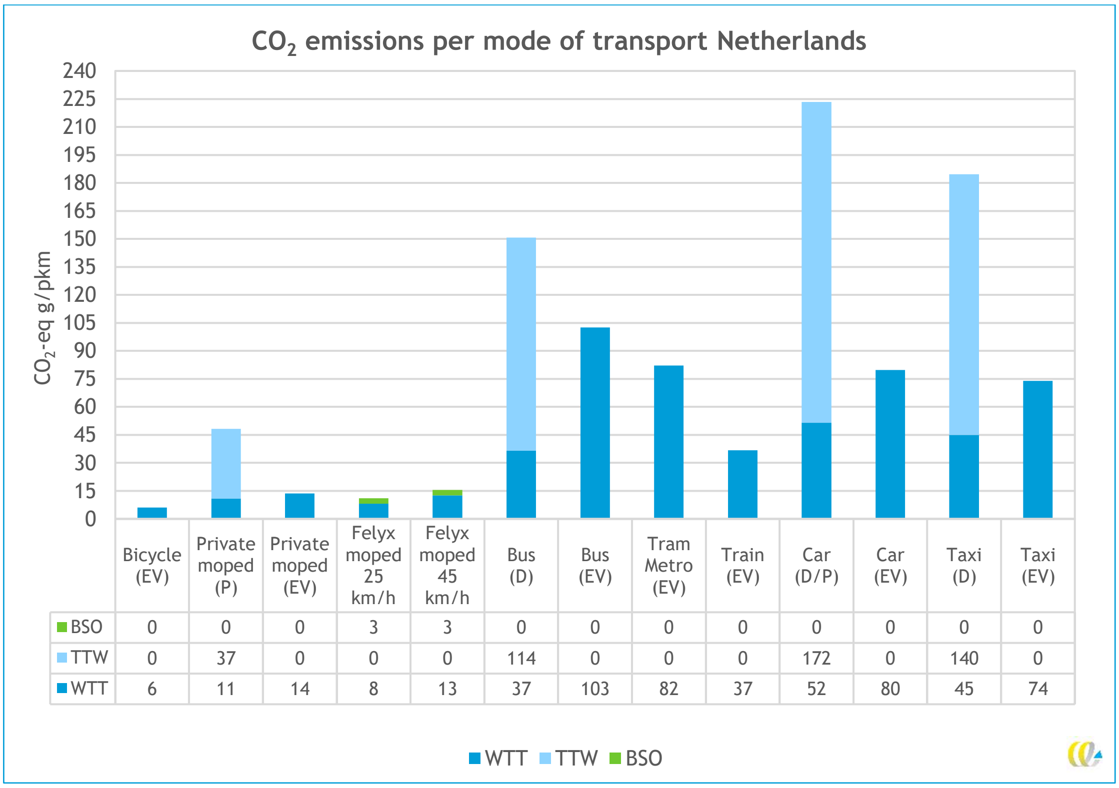
[4] Sources: Eurostat, (2022); EEA, (2021); CE Delft, (2020); CO_2 emissiefactoren, (2021).

[5] Nissan e-NV200, range 180 km, battery capacity 40 kWh.

shared mopeds. Correcting for average passengers per moped trip, this is 3.0 grams of CO_2 emission per passenger kilometre.

Figure 9 provides an overview of the CO_2 emissions and occupancy per mode together with the CO_2 emissions resulting from the BSO for the Netherlands. Similar results have been found for Belgium and Germany, these figures are included in Annex A.1.

Figure 9 - CO_2 emissions for different modalities, in passenger kilometres in the Netherlands



	Bicycle (EV)	Private moped (P)	Private moped (EV)	Felyx moped 25 km/h	Felyx moped 45 km/h	Bus (D)	Bus (EV)	Tram Metro (EV)	Train (EV)	Car (D/P)	Car (EV)	Taxi (D)	Taxi (EV)
BSO	0	0	0	3	3	0	0	0	0	0	0	0	0
TTW	0	37	0	0	0	114	0	0	0	172	0	140	0
WTT	6	11	14	8	13	37	103	82	37	52	80	45	74

BSO = Battery Swap Operation, TTW = Tank-to-wheel, WTT = Well-to-tank, BSO = Battery Swap Operation, EV = Electric vehicle, P = Petrol, D = Diesel.
Sources: CE Delft, (2015); CE Delft, (2020); CBS, (2021).

3 Impact on CO_2 emissions

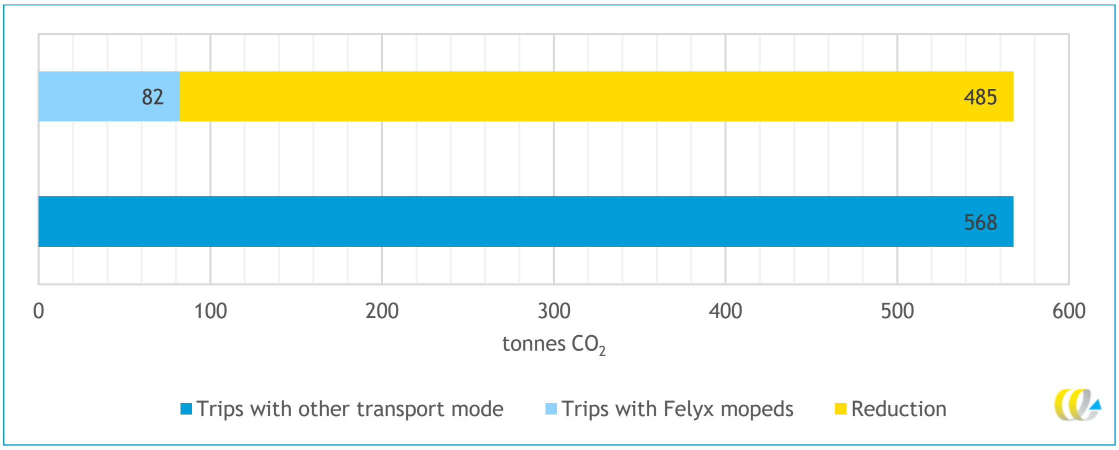
3.1 Impact of one year of Felyx mopeds

The aim of this study is to determine the effect on CO_2 emissions in Rotterdam, Brussels and Berlin from the use of Felyx shared electric mopeds. We calculated this effect for Rotterdam and Brussels between October 2020 and September 2021, based on the parameters discussed in Section 2. For Berlin we use the forecasted usage of the Felyx mopeds for 2022.

Rotterdam

The use of Felyx mopeds in Rotterdam resulted in a CO_2 reduction of 485 tonnes between October 2020 and September 2021, see Figure 10. In one year, 4.6 million kilometres were travelled with Felyx mopeds instead of with other modes of transport in the city of Rotterdam. If these 4.6 million kilometres were travelled with other modes of transport, the CO_2 emissions would have been 568 tonnes. The use of Felyx mopeds resulted in 82 tonnes of CO_2 emissions; a reduction of almost 86%[6].

Figure 10 - Effect on CO_2 emissions in Rotterdam by the use of Felyx mopeds between October 2020 and September 2021

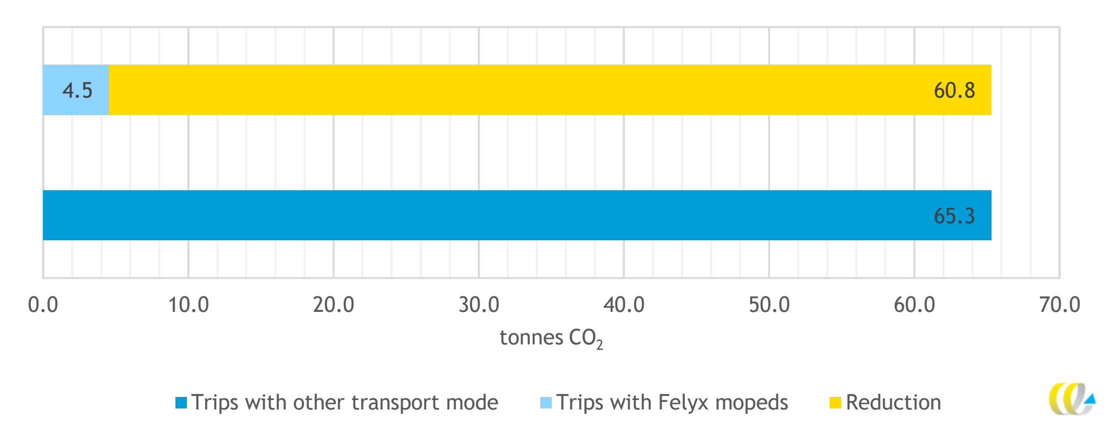


Brussels

The amount of Felyx mopeds in Brussels is substantially smaller than in Rotterdam. As a result the CO_2 reduction is also substantially smaller: 61 tonnes between October 2020 and September 2021. During these twelve months 420 thousand kilometres were travelled with Felyx mopeds instead of with other modes of transport in the city of Brussels. If this amount would have been travelled with other modes of transport, the CO_2 emissions would have been 65 tonnes. The use of Felyx mopeds resulted in 5 tonnes of CO_2 emissions; a reduction of almost 93%.

[6] This reduction also includes public transport. Although a trip with a moped does not directly replace public transport as it does with other transport modes, we do assume that continued moped use does influence public transport schedules in the long term.

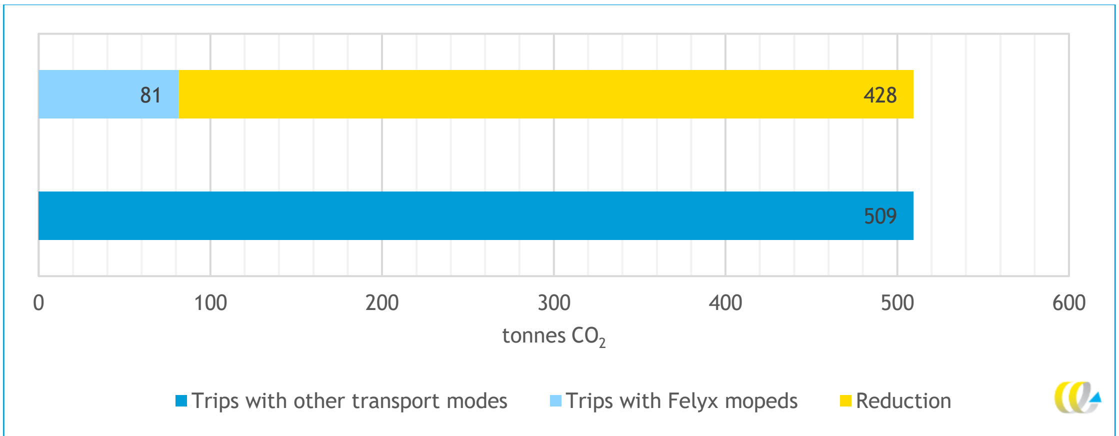
Figure 11 - Effect on CO_2 emissions in Brussels by the use of Felyx mopeds between October 2020 and September 2021



Berlin

Based on the projections of the moped usage in Berlin 2022, a reduction potential of 482 tonnes has been calculated. For 2022 3.8 million travelled kilometres are projected with Felyx mopeds instead of with other modes of transport in the city of Berlin. This will result in 81 tonnes of CO_2 emissions, instead of 509 tonnes of CO_2 emissions if other modes of transport are used; a reduction potential of almost 84%.

Figure 12 - Projected effect on CO_2 emissions in Berlin by the use of Felyx mopeds between October 2021 and September 2022



3.2 Emissions per mode of transport

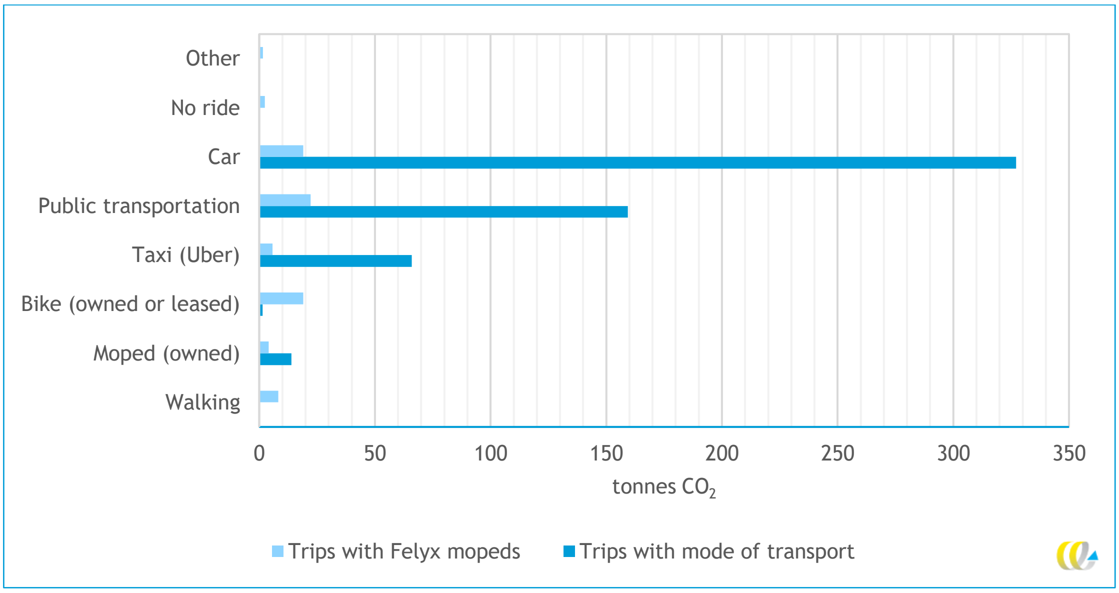
Rotterdam

The reduction of 485 tonnes CO_2 in Rotterdam is based on replacing kilometres travelled with different modes of transport. We made a comparison in CO_2 emissions between travelling with Felyx mopeds and these modes of transport. The result is presented in Figure 13. The largest reduction in CO_2 emissions comes from the replacement of car trips.

This is due to the large share of car trips that are being replaced (23%) and the high emissions that result from travelling by car. Additionally, a significant reduction comes from replacing trips made with public transport and taxi.

On the other hand, CO_2 emissions increase if the kilometres travelled by mopeds replace kilometres from cycling. The same applies to 'walking', 'no ride' and 'other' where no CO_2 emissions are emitted if Felyx mopeds are not used. Although the replacement of trips with these modes of transport by Felyx mopeds results in an increase of CO_2 emissions, the increase is not as high as the decline in CO_2 emissions from replacing car trips and trips by public transport or taxi.

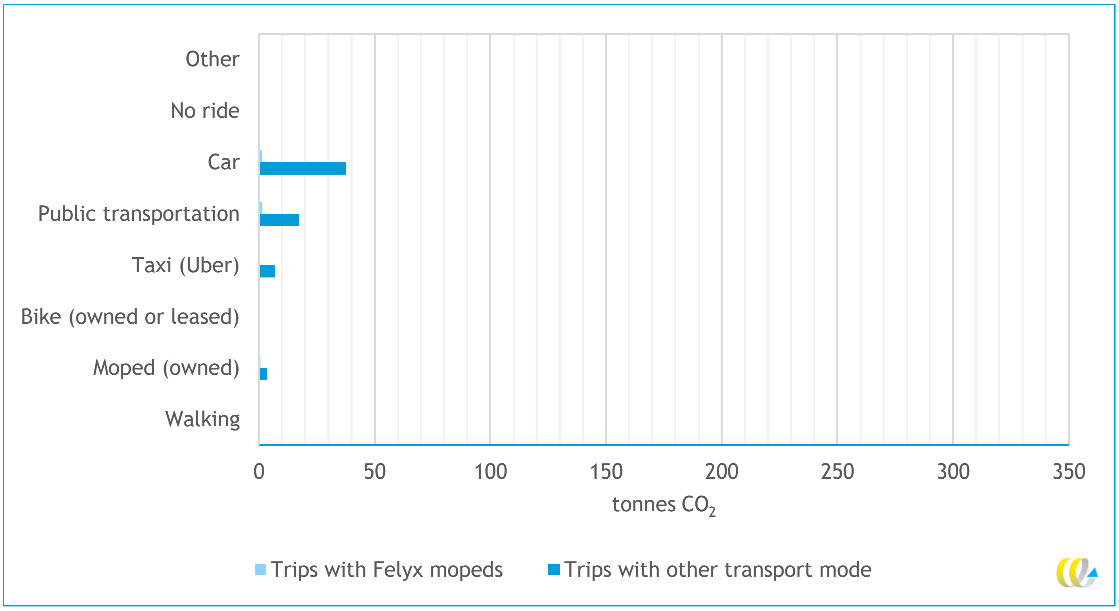
Figure 13 - Comparison of CO_2 emissions in Rotterdam per mode of transport between October 2020 and September 2021



Brussels

Compared to Rotterdam the total emissions in Brussels per mode of transport are relatively small (see Figure 14). This is mainly due to the fact that in Brussels less mopeds are available which, in the end, results in a smaller impact. The main contributor of CO_2 emissions in case trips would have been made with another mode of transport is, just like in Rotterdam, the car.

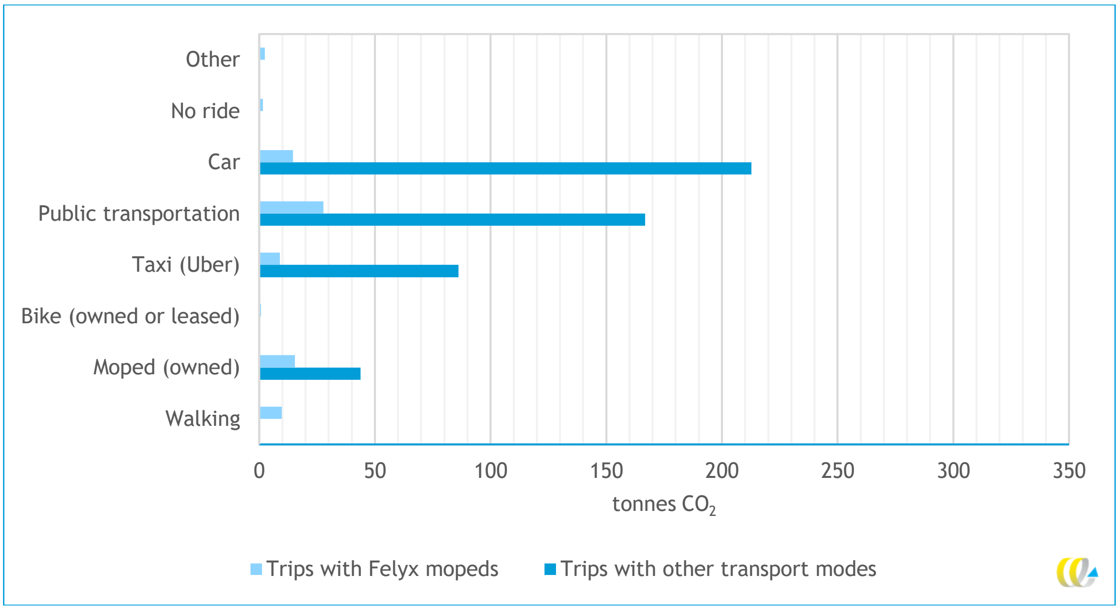
Figure 14 - Comparison of CO_2 emissions in Brussels per mode of transport between October 2020 and September 2021



Berlin

The projected results per mode of transport for Berlin are shown in Figure 15. The results are closer to the outcome for Rotterdam. This is logical since the amount of travelled kilometres on Felyx mopes in Berlin (3.8 million) is much closer to the amount of travelled kilometres in Rotterdam (4.6 million). The impact by car is smaller due to the fact that the share of car transport is smaller in Berlin (18%) compared to Rotterdam (23%). On the other hand, the share of public transport in Berlin (34%) is larger compared to Rotterdam (27%). In addition, the share of diesel powered busses and a large share of bus transport in the total public transport mix cause the relatively high impact of public transport compared to Rotterdam.

Figure 15 - Comparison of CO_2 emissions in Berlin per mode of transport for 2022



3.3 Impact per moped

Rotterdam

We have calculated the reduction in CO_2 emissions per moped between October 2020 and September 2021 per month. The number of Felyx mopeds in Rotterdam increased during this period (Figure 2). Therefore, we have calculated the CO_2 emissions and corresponding reduction of Felyx's fleet in Rotterdam and divided the emissions by the number of mopeds to calculate the emissions per moped.

Figure 16 and Figure 17 show a clear seasonal effect in emissions per moped. During the winter the number of kilometres travelled per moped is less than during the summer. As a consequence, the amount of saved emissions per moped declines compared to the emissions during the summer. In addition, the impact per 25 km/h moped is bigger than the impact from a 45 km/h moped. This is also caused by fewer kilometres travelled with 45 km/h mopeds than with 25 km/h mopeds.

Figure 16 - Impact per moped in Rotterdam between October 2020 and September 2021 - 25 km/h moped

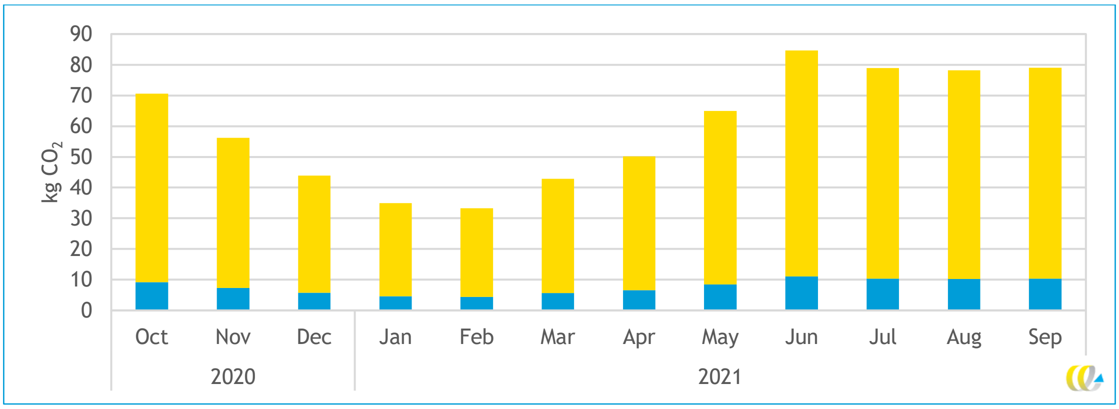
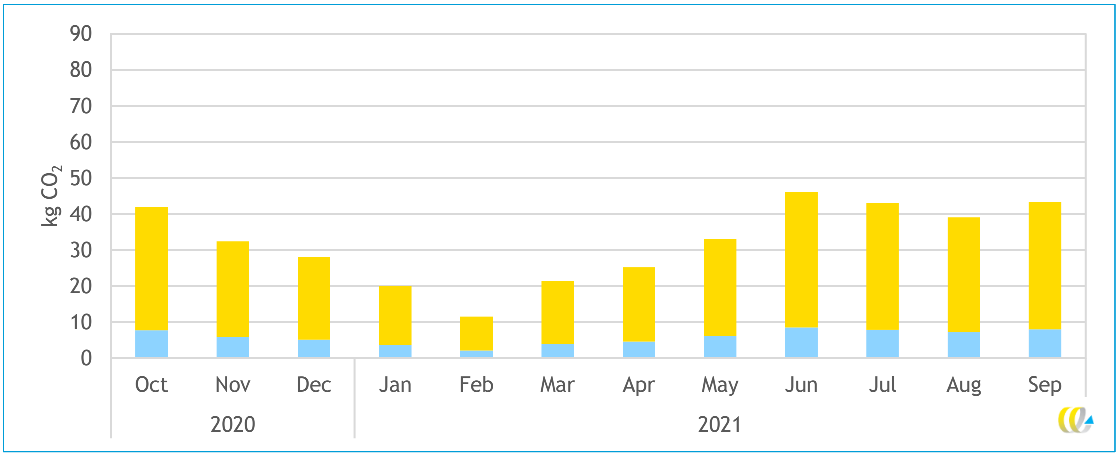


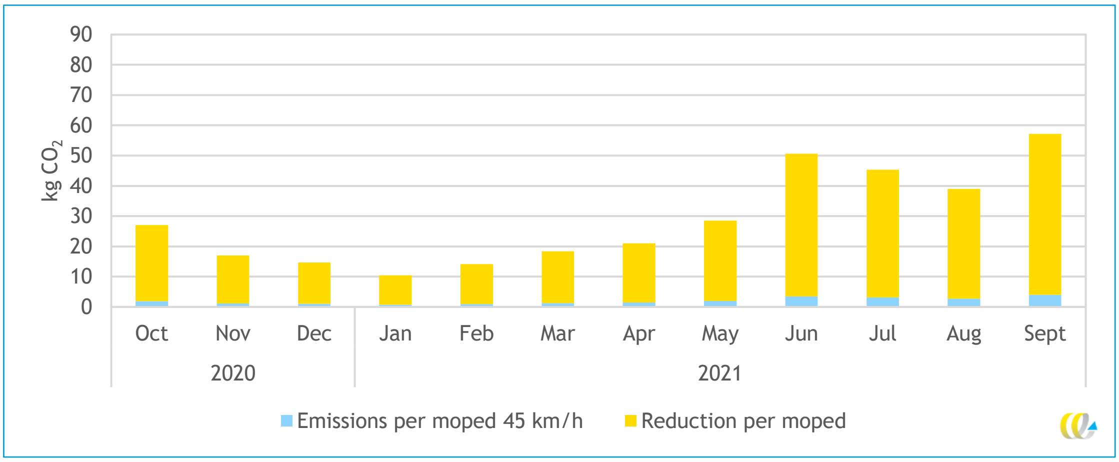
Figure 17 - Impact per moped in Rotterdam between October 2020 and September 2021 - 45 km/h moped



Brussels

In Brussels the same seasonal effect is seen (Figure 18). In Brussels the biggest impact is made between June and September. Due to the low CO_2 emissions of the electricity mix in Belgium, the impact per moped easily becomes bigger as the amount of trips increases when compared to Rotterdam and Berlin.

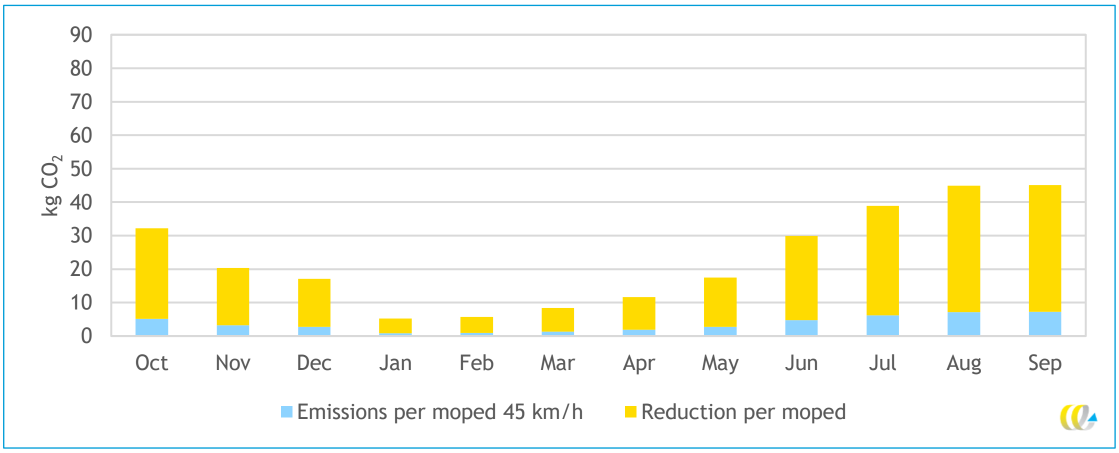
Figure 18 - Impact per moped in Brussels between October 2020 and September 2021



Berlin

The same seasonal pattern is expected for Berlin in 2022. We have placed the last three months of 2022 (i.e. October, November and December) at the beginning of Figure 19 to make it easier to compare with the previous two figures.

Figure 19 - Projected impact per moped in Berlin between October and September



3.4 Sensitivity analyses

We conducted five sensitivity analyses for Rotterdam to show the effect of certain parameters on the results. In this paragraph we describe the analyses and the corresponding results. The changes in parameters and assumptions can be found in Annex A.

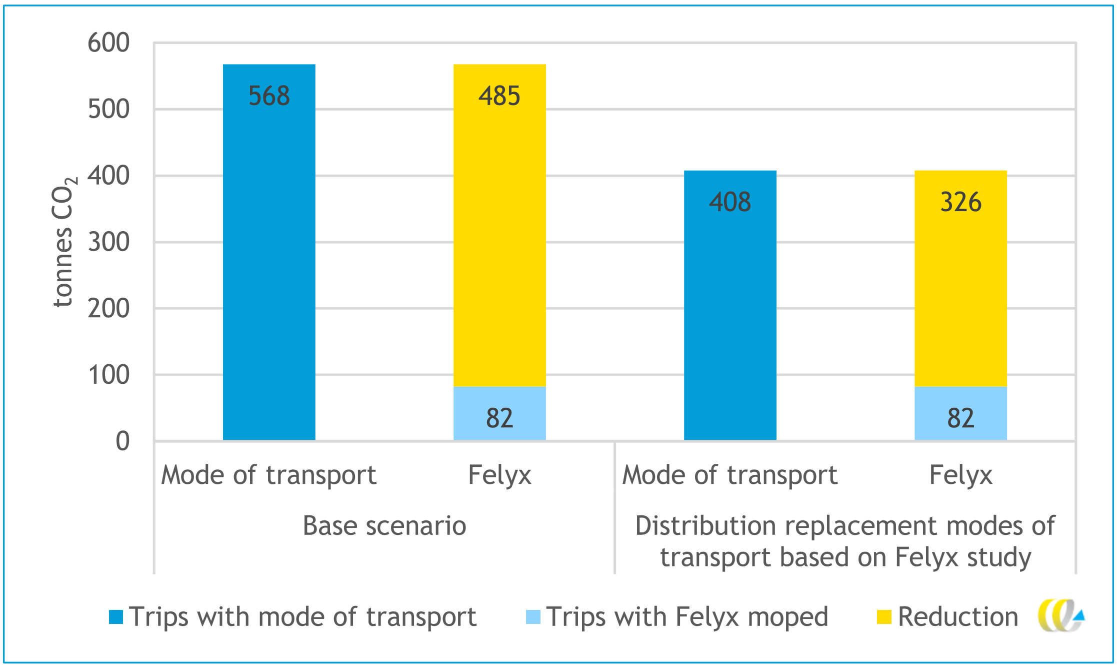
Sensitivity Analysis 1: other distribution of modes of transport

In the first sensitivity analysis we changed the parameters of the distribution of modes of transport which are replaced by trips by Felyx mopeds. In the base scenario, we used study by Gemeente Rotterdam (2021) to calculate the reduction of CO_2 emissions due to the use of Felyx mopeds. In this sensitivity analysis we used the parameters from Molgo (2019). The results of the sensitivity analysis are displayed in Figure 20.

The change in parameters results in lower emissions from the trips with modes of transports that are replaced. This changes from 568 tonnes CO_2 in the base scenario to 408 tonnes in the new scenario. This is mainly caused by the difference in the proportion of car trips which are replaced (23% in the base scenario and 10% in the new scenario). Another reason for the decline in CO_2 emissions is the increased proportion of trips that replace active modes (walking and cycling). Therefore, an increase or decrease in the replacement of car trips or active mode trips is directly related to the CO_2 emissions from these modes of transport.

The number of kilometres travelled with Felyx mopeds has remained the same and thus the emissions from trips with Felyx mopeds remain the same in both scenarios (82 tonnes CO_2). The reduction of CO_2 emissions is less in the new scenario because of the change in parameters.

Figure 20 - Results of Sensitivity Analysis 1: ‘other distribution replacement modes of transport’

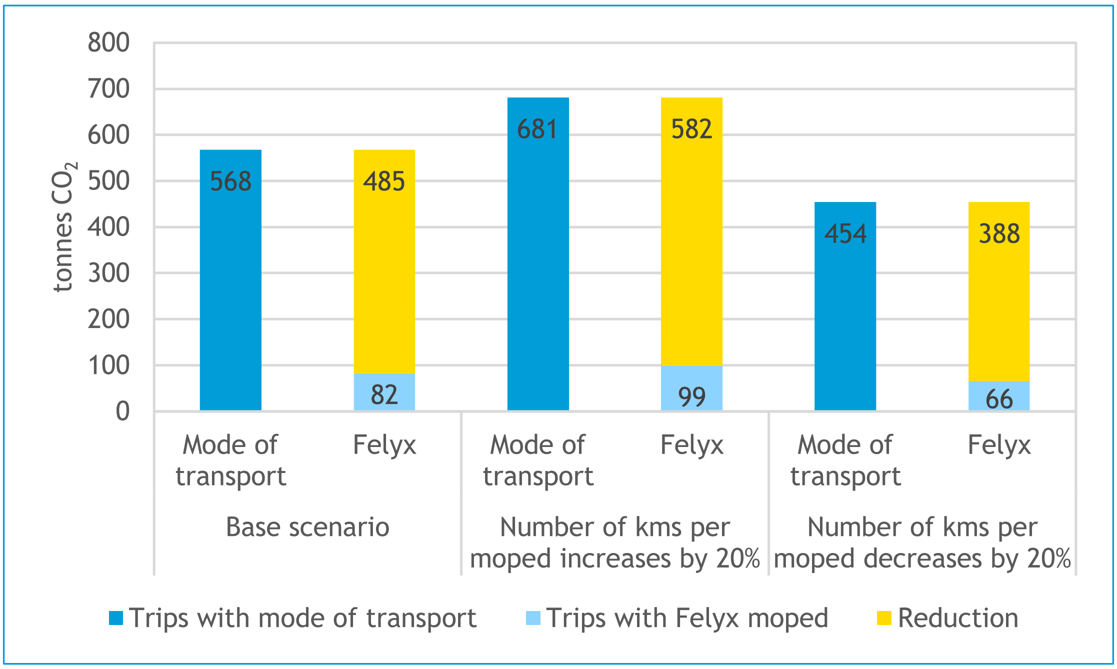


Sensitivity Analysis 2: increase and decrease number of kms with Felyx mopeds

The total distance driven with Felyx mopeds in Rotterdam between October 2020 and September 2021 is about 4.6 million kilometres. In this sensitivity analysis we have increased this number by 20% and also decreased it by 20%. We used an increase and decrease of 20% because these values are assumed to be realistic based on the current fleet of mopeds and the demand in Rotterdam. In the case of more pronounced changes, for example a 100% increase, other factors (such as market saturation) must be taken into account to determine the effect on CO_2 emissions. We have not changed the number of mopeds, but only increased and decreased the number of kilometres driven per moped. The results are displayed in Figure 21.

An increase in kilometres of 20% also results in an increase in the CO_2 emissions by 20%. This applies not only to the emissions resulting from kilometres travelled by the other modes of transport, but also to the emissions from travelling by Felyx mopeds. Logically, the reduction of CO_2 emissions also increases by 20%. The opposite applies to a decrease of 20% in kilometres: in that case all emissions decrease by 20%.

Figure 21 - Results of Sensitivity Analysis 2: 'increase and decrease number of kms by Felyx mopeds'

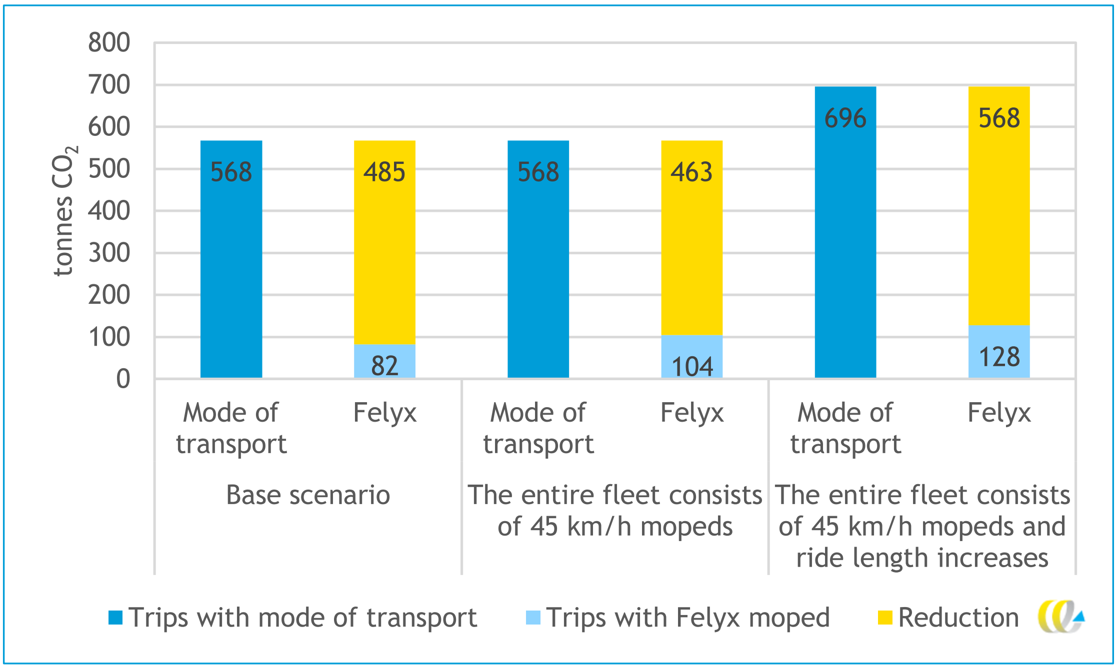


Sensitivity Analysis 3: The entire fleet consists of 45 km/h mopeds

The emissions from 45 km/h mopeds are 26g CO_2/pkm, while the emissions from 25 km/h mopeds are 21g CO_2/pkm. Between October 2020 and September 2021, the number of 45 km/h mopeds has increased from 164 mopeds to 521 mopeds and the number of 25 km/h mopeds has increased from 374 to 621. Over time, Felyx wants to focus on 45 km/h mopeds and therefore only wants to introduce 45 km/h mopeds to the fleet and replace the 25 km/h mopeds. In this sensitivity analysis, we have replaced all 25 km/h mopeds in Rotterdam by 45 km/h mopeds. We know from Figure 4 that the average trip length of a 45 km/h moped is longer than with 25 km/h mopeds (3.8 km and 3.1 km respectively).

Therefore, we have also conducted an analysis where all 25 km/h mopeds are replaced by 45 km/h mopeds and the average trip length increases from 3.1 km to 3.8 km.
Figure 22 shows that replacing the 25 km/h mopeds with 45 km/h mopeds, causes an increase of almost 27% in CO_2 emissions from trips with Felyx mopeds. The additional increase in the average trip length means that the CO_2 emissions from trips with Felyx mopeds increase by 56% compared to the base scenario. However, an increase in the average trip length also increases the number of kilometres to be replaced by other modes of transport. Consequently, CO_2 emissions from the other modes of transport increase as well as the reduction of CO_2 emissions. The reduction in this scenario is 82%, while the reduction in the base scenario is 85%.

Figure 22 - Results of Sensitivity Analysis 3: 'the entire fleet consists of 45 km/h mopeds'

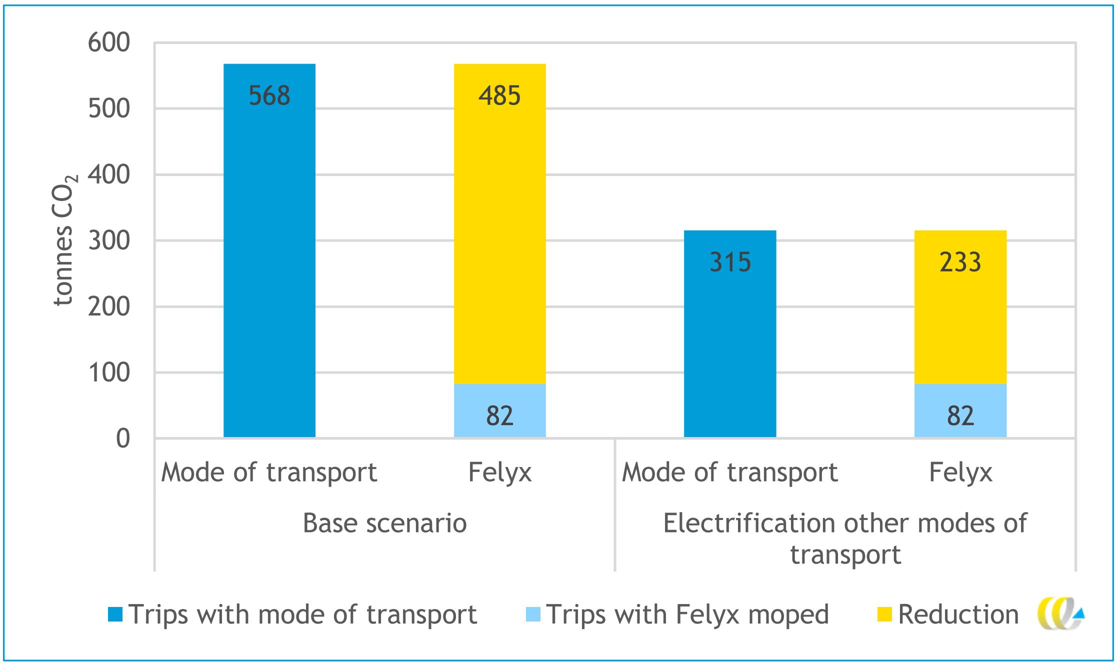


Sensitivity Analysis 4: Full electrification of all other modes of transport (except for cycling)

In the base scenario, we have conducted the analysis showing the proportion of electric and fossil powered vehicles for each mode of transport. The proportion of electric powered vehicles will increase in the near future in the Netherlands (Partijen Bestuursakkoord, 2020; RVO, 2021). In this sensitivity analysis, we investigate the effect on CO_2 emissions of full electrification of all the other modes of transport, except for cycling.

CO_2 emissions from electric powered vehicles are lower than emissions from fossil powered vehicles. Thus, we expect the emissions from the kilometres travelled with modes of transport other than Felyx mopeds to decrease as a result of electrification. Compared to the base scenario the decrease is almost 45%, see Figure 23. As a consequence, the reduction when travelling with Felyx mopeds decreases by almost 52%. Hence, in the case of electrification of other modes of transport, the impact of Felyx mopeds decreases during the user phase.

Figure 23 - Results of Sensitivity Analysis 4: 'full electrification of all other modes of transport (except for cycling)'



Sensitivity Analysis 5: impact of the use of green energy

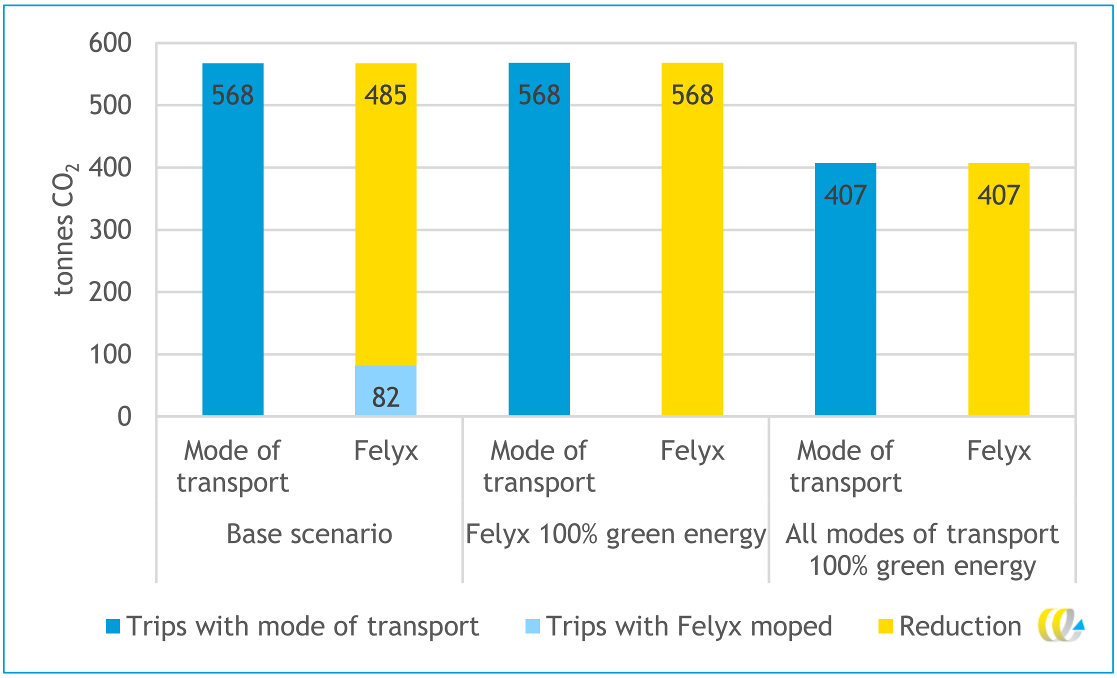
In the base scenario we used the Dutch energy mix for all electric powered vehicles (CE Delft, 2020). This energy mix is applied to all modes of transport, including Felyx's electric mopeds. However, Felyx has a contract for green energy from the production of electricity, which has a positive impact on CO_2 emissions. When green energy is used, the source of the energy comes from sustainable sources such as wind and solar power. As a consequence, electricity from these sources does not cause any CO_2 emissions during the user phase.

In practice, green energy in the Netherlands is not only from sustainable sources but from a mixture of sustainable sources and coal. To take into account the impact of Felyx on CO_2 emissions from the production of electricity, we conducted a sensitivity analysis where emissions from electricity used by Felyx are set to zero. Additionally, we compiled a second scenario where all electric powered vehicles are powered by green energy. The results are displayed in Figure 24.

In the scenario where Felyx only uses zero emission electricity, the total reduction of CO_2 emissions from the use of Felyx mopeds would increase by 82 tonnes CO_2. If all modes of transport change to green energy for electric powered vehicles, the amount of CO_2 emissions from trips with other modes of transport decreases.

In the case of full electrification of all modes of transport and a full change to green energy, CO_2 emissions from the user phase become zero for all modes of transport. In that case, other emissions become more important such as emissions from production and recycling. With an increase in electrification (see Sensitivity Analysis 4) and an increase in green power, this is a realistic scenario for the near future.

Figure 24 - Results of Sensitivity Analysis 5: 'impact of the use of green energy'



4 Conclusions

To determine the impact of Felyx mopeds, this report focusses on the question: what are the CO_2 emissions of Felyx's shared electric mopeds compared to other modes of transport in Rotterdam?

With trip data from Felyx in combination with data from literature on transport mode choice and emissions, we have been able to calculate the CO_2 emissions that are prevented when Felyx mopeds are used.

4.1 Conclusions

Based on the current parameters, trips with Felyx mopeds resulted in a reduction of 485 tonnes CO_2 between October 2020 and September 2021 in Rotterdam. This is a reduction of almost 86%, which is mainly due to the replacement of car trips and trips by public transport as these have the largest impact on CO_2 emissions. Although the replacement of active mode trips (i.e. walking and biking) by trips with Felyx mopeds results in an increase of CO_2 emissions, the impact is limited.

Between October 2020 and September 2021 a reduction of 61 tonnes CO_2 emissions has been realised in Brussels (93%). In Berlin a reduction of 428 tonnes of CO_2 emissions is projected for 2022 (84%).

From the sensitivity analyses we know that many parameters influence the impact from Felyx mopeds. The parameters that have a substantial impact on CO_2 emissions are the use of other modes of transport if a moped is not used and an increase or decrease in the number of kilometres driven per moped. Based on how the parameters are adjusted, it results in an increase or decrease of the reduction realised. In any case, there does not seem to be a scenario in which the reduction of CO_2 emissions due to the use of Felyx mopeds changes into an increase of CO_2 emissions by using Felyx mopeds when compared to the total CO_2 emissions of other transport modes.

Another parameter we reviewed in the sensitivity analysis is the electrification of other modes of transport in the future. An increase of an overall electrification substantially reduces the difference in CO_2 emissions of Felyx mopeds compared to the other transport modes. However, the use of Felyx mopeds will still have a positive impact on CO_2 emissions in Rotterdam (i.e. the estimated reduction is still 52%). Finally, we reviewed the impact of green energy. Over time, this will likely lead to zero emissions during the use phase of Felyx mopeds. When green energy is also used by all other modes of transport in combination with full electrification, there is no longer any difference in emissions during the use phase. In this situation other emissions (i.e. during production or recycling) will become dominant.

4.2 Recommendations

This study focusses solely on CO_2 emissions. It is possible to extent this and also include PM and NO_x. In addition, we have indicated that due to electrification and the use of sustainable energy sources, CO_2 emissions in the use phase will become zero. In such a situation, Life Cycle emissions (i.e. during production and recycling) will become the norm for all transport modes. Therefore, it will become interesting to perform a Life Cycle Analysis.

Based on the results for Rotterdam, statements could be made for other cities as well. However, as cities differ in size, available modes of transport and number of inhabitants, the use of Felyx mopeds will also differ. Therefore, the results for Rotterdam will not be 100% applicable for other cities. This should be taken into account when making statements about other cities based on the results presented in this report. In order to customize the results for other cities, a more generic model needs to be developed in which parameters can be adjusted to give a more precise indication of the potential CO_2 reduction.

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A Parameters used for the analysis

A.1 Emission data

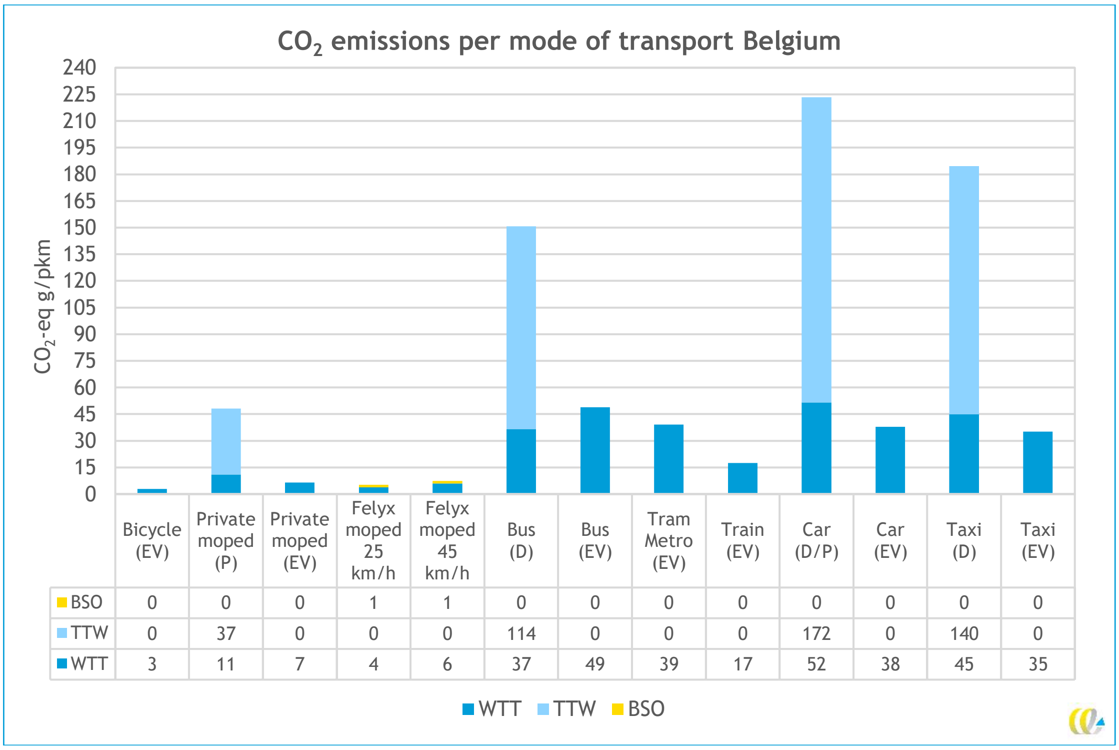
Table 4 - CO_2 emissions (gram) per passenger kilometre (pkm). Fossil fuel vehicles same for all three countries. CO_2 emission electricity production the Netherlands (475 grams/kWh), Belgium (226 grams/kWh) and Germany (446 grams/kWh)

			The Netherlands				Belgium				Germany			
Mode of transport	**Fuel type**	**Passenger km/ vehicle km**	**CO_2 WTT (g/pkm)**	**CO_2 TTW (g/pkm)**	**CO_2 BSO[1] (g/pkm)**	**CO_2 total (g/pkm)**	**CO_2 WTT (g/pkm)**	**CO_2 TTW (g/pkm)**	**CO_2 BSO[1] (g/pkm)**	**CO_2 total (g/pkm)**	**CO_2 WTT (g/pkm)**	**CO_2 TTW (g/pkm)**	**CO_2 BSO[1] (g/pkm)**	**CO_2 total (g/pkm)**
Walking	-	1.00	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
Bicycle	-	1.00	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**
E-Bike	Electric	1.00	6	0	0	**6**	3	0	0	**3**				**6**
Private moped (25/45 km/h)[2]	Petrol	1.10	11	37	0	**48**	11	37	0	**48**	11	37	0	**48**
Private moped (25/45 km/h)[2]	Electric	1.10	14	0	0	**14**	7	7	0	**7**	6	0	0	**6**
Felyx moped (25 km/h)	Electric	1.46	8	0	3	**11**	5	4	1	**5**	8	0	3	**10**
Felyx moped (25 km/h)	Electric	1.46	13	0	3	**16**	7	6	1	**7**	12	0	3	**15**
Bus	Diesel	9.00	37	114	0	**151**	37	114	0	**151**	37	114	0	**151**
Bus	Electric	9.00	103	0	0	**103**	49	0	0	**49**	96	0	0	**96**
Tram/metro[3]	Electric	14%	82	0	0	**82**	39	0	0	**39**	77	0	0	**77**
Train[3]	Electric	29%	37	0	0	**37**	17	0	0	**17**	34	0	0	**34**
Passenger car[4]	Petrol/diesel	1.39	52	172	0	**223**	52	172	0	**223**	52	172	0	**223**
Passenger car	Electric	1.39	80	0	0	**80**	38	0	0	**38**	75	0	0	**75**
Taxi	Diesel	1.50	45	140	0	**185**	45	140	0	**185**	45	140	0	**185**
Taxi	Electric	1.50	74	0	0	**74**	35	0	0	**35**	69	0	0	**69**

1: BSO = Battery Swap Operation; 2: 25 km/h and 45 km/h average; 3: Capacity of mode of transport taken by passengers on average; 4: Weighted average on kilometres per fuel type 2020 (CBS, 2021b).

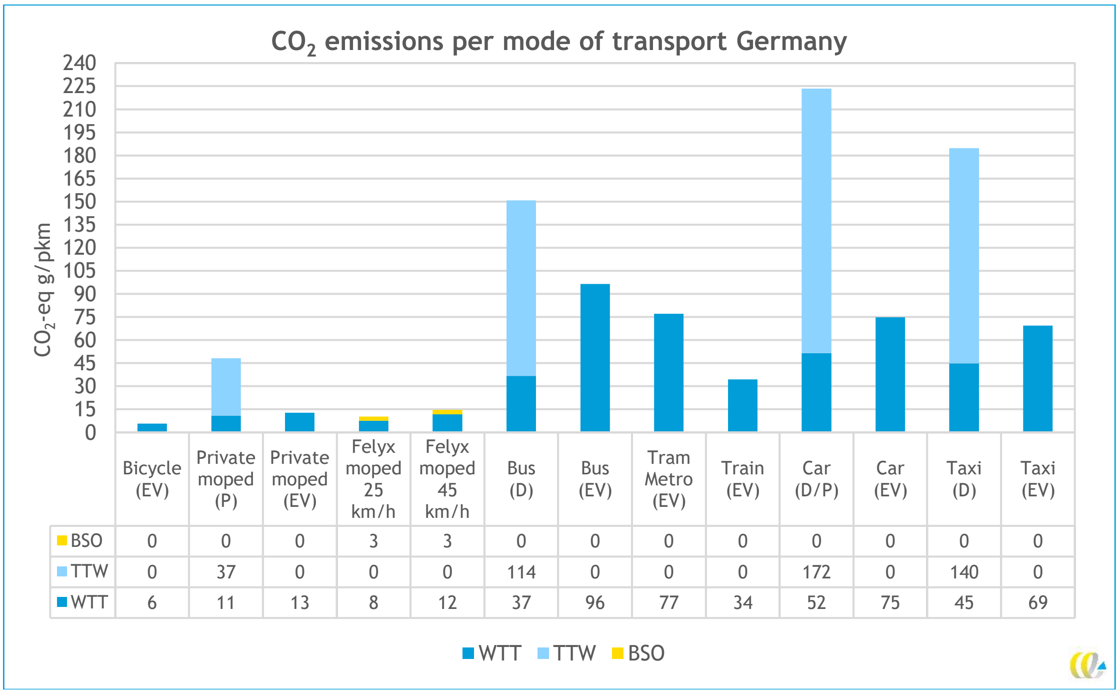
g/pkm = CO_2 gram/passenger kilometre, WTT = Well-to-wheel, TTW = Tank-to-wheel, BSO = Battery Swap Operation.

Figure 25 - Emission factors for Belgium



	Bicycle (EV)	Private moped (P)	Private moped (EV)	Felyx moped 25 km/h	Felyx moped 45 km/h	Bus (D)	Bus (EV)	Tram Metro (EV)	Train (EV)	Car (D/P)	Car (EV)	Taxi (D)	Taxi (EV)
BSO	0	0	0	1	1	0	0	0	0	0	0	0	0
TTW	0	37	0	0	0	114	0	0	0	172	0	140	0
WTT	3	11	7	4	6	37	49	39	17	52	38	45	35

Figure 26 - Emission factors for Germany



	Bicycle (EV)	Private moped (P)	Private moped (EV)	Felyx moped 25 km/h	Felyx moped 45 km/h	Bus (D)	Bus (EV)	Tram Metro (EV)	Train (EV)	Car (D/P)	Car (EV)	Taxi (D)	Taxi (EV)
BSO	0	0	0	3	3	0	0	0	0	0	0	0	0
TTW	0	37	0	0	0	114	0	0	0	172	0	140	0
WTT	6	11	13	8	12	37	96	77	34	52	75	45	69

A.2 Sensitivity analyses

Table 5 - Changes in parameters in Sensitivity Analyses 1 and 4 - Rotterdam

	Base scenario (Gemeente Rotterdam, 2021)	Sensitivity Analysis 1 (Molgo, 2019)	Sensitivity Analysis 4
Walking	10%	16%	10%
Moped (owned)	5%	2%	5%
Moped (P)	80%	80%	0%
Moped (EV)	20%	20%	100%
Cycling (owned or leased)	23%	30%	23%
Regular bike	85%	85%	85%
Bike (EV)	15%	15%	15%
Taxi (Uber)	7%	8%	7%
Taxi (D/P)	60%	60%	0%
Taxi (EV)	40%	40%	100%
Public transportation	27%	31%	27%
Bus (D)	9%	9%	0%
Bus (EV)	9%	9%	18%
Tram & Metro (EV)	77%	77%	77%
Train (EV)	5%	5%	5%
Car	23%	10%	23%
Car (D/P)	92%	92%	0%
Car (EV)	8%	8%	100%
No ride	3%	3%	3%
Other	2%	0%	2%