KpVV CROW

Status of zero emission buses 2022

CROW-KpVV

CROW-KpVV develops, disseminates and safeguards collective knowledge in the field of mobility for local and regional authorities. This knowledge provides fundamental support for policy development and implementation.

About CROW

CROW devises smart and practical solutions for issues relating to infrastructure, public space, traffic and transport in the Netherlands. We do this together with external professionals who share knowledge with each other and make it applicable in practice.
CROW is an independent, non-profit knowledge organisation that invests in knowledge for today and tomorrow. We strive for the best solutions for issues ranging from policy to management, in infrastructure, public space, traffic and transport, and work and safety. Furthermore, we are experts in the field of tendering and contracting.

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1 Introduction

In 2015, it was still customary to see the droning diesel bus on the streets of the Netherlands. But 'cleaner' versions were already on their way: CNG buses, or natural gas buses, represented an initial improvement in terms of air quality in comparison to Euro III and IV buses.
In addition, various regions introduced hybrid vehicles that were more environmentally friendly than the old standard diesel buses. Although the first battery-electric buses appeared on the road back in 2013, they had a very limited range. Manufacturers, transport companies and public transport authorities then started experimenting with fully electric vehicles in order to further decrease harmful emissions.
When the Administrative Agreement on Zero Emission Buses (BAZEB) was established in 2016, the final goal suddenly appeared on the horizon: all buses used for urban and regional transport had to be emission-free by 2030. This agreement clearly defined the timeframe, and once again emphasised the importance of sustainable public transport. As a result, public transport by bus takes a lead over other modes of transportation.
For example, the rule that applies to passenger cars is that all new passenger cars are only required to be electric starting in 2035.

In this brochure, CROW-KpVV shows how much progress has been made on the journey to the final goal, while also explaining some of the stops along the way.
In addition, we also take a look at the other road users around us. How far have they progressed in the development to sustainable transport?

1.1 Zero emission vehicle developments

The first public transport companies started using zero emission vehicles in 2013. Arriva put eight BYD battery buses into service on Schiermonnikoog to make transportation on the island more sustainable. Furthermore, GVU introduced three induction-based midi-buses made by Optare for Utrecht's city line 2, between Utrecht's central station and its city centre. The buses on Schiermonnikoog are charged via the mains, while the buses in Utrecht were charged by means of induction. The latter turned out to be more difficult in actual practice than originally thought. After many malfunctions, the induction buses were withdrawn in 2019. Nine years later, the BYD buses are still going strong on Schiermonnikoog.
New zero emission buses were not added until 2016: Eindhoven received 43 articulated VDL buses for its citywide service. In between trips, Hermes rapidly charges them via the pantograph on the roof at the bus depot, which is close to the station. In certain parts of Brabant and Limburg, such as the towns of 's-Hertogenbosch and Venlo, smaller VDL buses (10 and 12 metres) were also introduced. They are charged en route, on the street, using a pantograph.
In 2018, major advances in public transport were made with the introduction of electric buses in various regions.

Zero emission bus of the Connexxion public transport company for Schiphol's public transport network.

In Amstelland-Meerlanden, 100 articulated VDL buses were deployed for transport around Schiphol Airport, while in Noord-Holland Noord, over 20 BYD midi-buses were put into service in and around Alkmaar. The Hague was the first of the three large cities to introduce electric buses. HTM deployed eight VDL buses on a single bus line, which are charged via a pantograph at the end point. Difficulties were initially encountered in the charging process due to the proximity of salty seawater. However, after making a few modifications, the charging stations started working effectively.

In December 2020, the first virtually fully zero emission bus fleet was introduced in the IJssel-Vecht concession, where over 250 BYD buses were put into service. Surprisingly, a decision was made to charge all the buses using a pantograph attached to the charging station, except for the buses in Zwolle where the pantograph is located on the bus roof. In 2022, the concession was transferred to a new operator, whereby part of the concession was split off and 25 electric buses remained with the former concession operator. These buses are currently not being deployed in another concession. The new concession operator also took over the charging infrastructure at the various locations in the region.

The introduction of larger numbers of zero emission buses is increasingly becoming the norm. In 2021, the Region Utrecht (38 buses) and Amstelland-Meerlanden (107 buses) concessions followed suit with battery-electric buses. In addition, another 20 hydrogen buses were introduced in Groningen-Drenthe. In 2021 and 2022, public transport companies GVB (+27) and RET (+40) took steps in making their bus fleet sustainable. The plan called for the Gooi en Vechtstreek concessions to be fully equipped with zero emission buses by the end of 2022. Due to delivery problems, the planned introduction has since been deferred to the spring of 2023.
The covid pandemic caused increased uncertainty about the introduction of new zero emission vehicles. Due to a decrease in passenger numbers, and thus revenues, it became more difficult to obtain financing for the new buses. Furthermore, the tenders for various expiring concessions were deferred. In response, the government took steps to facilitate the financing of buses. At the start of 2022, the Ministry of Infrastructure and Water Management launched a subsidy scheme to stimulate the introduction of (extra) zero emission buses. Under the 'Specifieke Uitkering Zero Emissie-bussen 2022-2024 [Specific Grant for Zero emission Buses]' scheme, public transport authorities can receive a subsidy of €25,000 per battery-electric bus and €75,000 for an articulated battery-electric bus, zero emission coach or hydrogen bus.

Interior of an electric BYD bus at the IJssel-Vecht concession.

Reading guide
This report consists of an introduction and four sections. These sections highlight the developments and results over 2022.
The complete reports of various studies are available on the website www.zeroemissiebus.nl. Statistics about various topics, such as inflow, CO_2 emissions and energy consumption by concession are available at staatvanhetov.nl.

En route with zero emission
This section contains statistics about inflow into the vehicle fleet, the environmental performance by concession, the emissions per passenger kilometre and timetable kilometre, and the visibility of zero emission buses in the Public Transport Customer Satisfaction Barometer.

Zero emission in actual practice
This section contains practical examples and describes developments in public transport in Europe, in target group transport and in other modalities in the Netherlands.

Zero emission costs and financing
This section deals with the financing of zero emission transport. This includes financing the acquisition cost, the total cost of ownership and any additional costs in comparison to diesel. This section also covers the zero emission systems takeover regulation that applies when there is a concession changeover.

Parking and charging/refuelling zero emission buses
The last section is about parking zero emission buses and challenges relating to charging battery-electric buses or refuelling hydrogen-electric buses.
In addition, we review the energy's origin and battery capacity. Finally, there is a separate section about hydrogen buses.

2 En route with zero emission

2.1 Inflow into the vehicle fleet

The inflow of Zero emission Buses Monitor was introduced a few years ago and reports quarterly on the progress of sustainable bus transport. Introducing a virtually fully zero emission vehicle fleet has more or less become the norm when a new concession is started up. The ultimate goal of the Administrative Agreement on Zero Emission Buses (BAZEB) is to have a fully zero emission bus fleet by 2030. CROW publishes a new Monitor on zeroemissiebus.nl every quarter. The statistics in this section come from the last quarter of 2022.

In 2022, 96 zero emission buses entered the public transport domain. This resulted in a net gain of only 71 zero emission buses, because at the end of 2022, 25 buses were taken out of service. This concerns a series of buses from the IJssel-Vecht concession that were not taken over by the new concession operator.
In the first quarter of 2023, almost 40 Ebusco buses will be added to the Gooi en Vechtstreek concession, as a result of which this concession will fully consist of zero emission buses.
In the Achterhoek-Rivierenland region 10 Solaris hydrogen buses will be introduced in the first quarter of 2023. Following the fire in a bus depot in Doetinchem at the end of 2021, this series was delayed by over a year. Furthermore, there are a number of other regions that are expecting new buses. However, the delivery date of these buses is uncertain.

Currently, the Amsterdam Transport Region has the most zero emission buses within its boundaries. The bus fleet of the Amstelland-Meerlanden concession largely consists of zero emission buses and the number of electric buses in the Amsterdam concession is also increasing. The transport region has negotiated an agreement with public transport company GVB to replace the vehicle fleet in batches until the fleet is fully zero emission. The new Zaanstreek-Waterland concession will start operations at the end of 2023 with a fully zero emission vehicle fleet. There are but a few electric buses in the current Zaanstreek and Waterland concessions.

The Province of North Holland was the first public transport authority with more than 50% zero emission buses. In the Noord-Holland Noord and Haarlem-IJmond concessions, approximately two thirds of the vehicle fleet consists of electric buses. Public transport company Connexxion (Transdev) introduced midi, 10-metre and 12-metre electric buses. Half of the buses in the Gooi en Vechtstreek concession is now electric. Part of these buses are from the Noord-Holland Noord concession. The remaining buses will be replaced in the first quarter of 2023. This will make Gooi en Vechtstreek the first concession in which the time-table is entirely driven with a fully electric bus fleet.

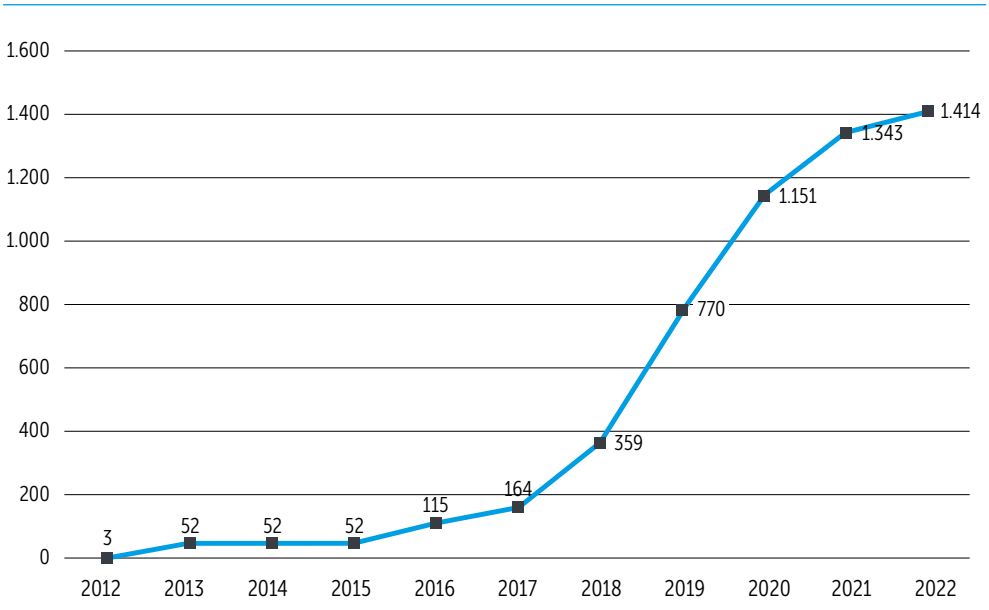

Figure 1. Number of zero emission buses in the Netherlands between 2012 and 2022.

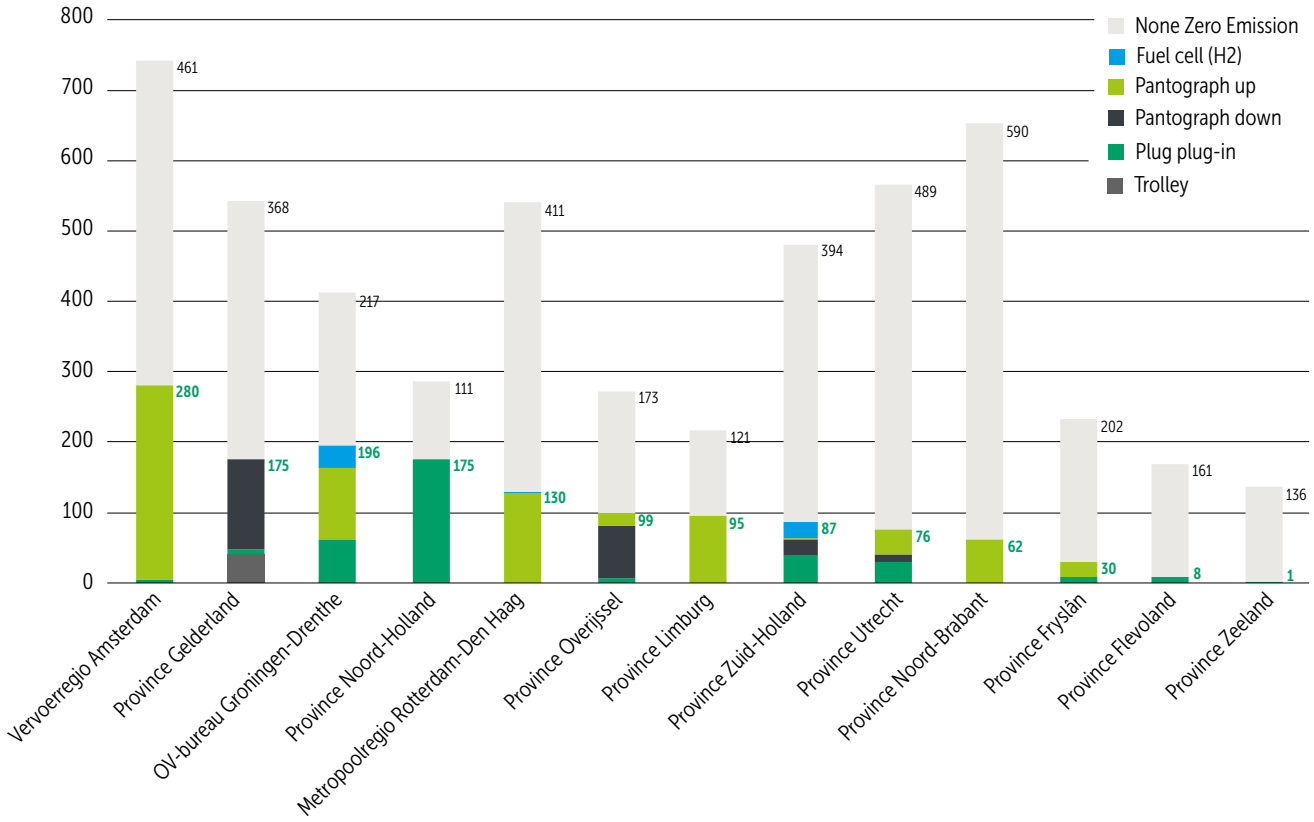

Figure 2. Composition of vehicle fleet by public transport authority.

Currently there are three concessions in which more than 50% of the bus fleet consists of zero emission buses. More than 95% of the bus fleet in the IJssel-Vecht concession consists of electric buses. The number of leased buses, for example for school bus lines, for this concession is unknown and is therefore not included here. This concerns subcontractors that use coaches or (old) public transport buses to make a few trips each day. In the Amstelland-Meerlanden, Haarlem-IJmond and Noord-Holland Noord concessions the proportion of electric buses is around 70%. Any leased buses in these concessions are included in the figures.

The number of zero emission buses by concession operator, concession and public transport authority are available at staatvanhetov.nl under the header sustainability.

2.2 Deployment of zero emission in the vehicle fleet

In 2009, CROW-KpVV first published the environmental performance poster that displays the sustainability of the vehicle fleet. The key reference points here are the Euro standards established for buses. A Euro III classification or lower only yields 1 point, while Euro IV (the highest classification for combustion engines) yields 5 points. Depending on the type of fuel and the presence of a hybrid engine, the maximum score for a vehicle with a combustion engine is 8.8 points. A zero emission bus scores at least 9.5 points. The block heater, whose use is generally limited, in these buses runs on diesel. A fully zero emission bus, including electric block heater, yields a full 10 points.

In the spring of 2022, the Province of Limburg achieved first place with a score of 9.1. Within the Limburg concession there are 95 electric buses with an HVO-powered block heater, while the remaining 121 buses run entirely on HVO. This reduces CO_2 emissions by approximately 95%.

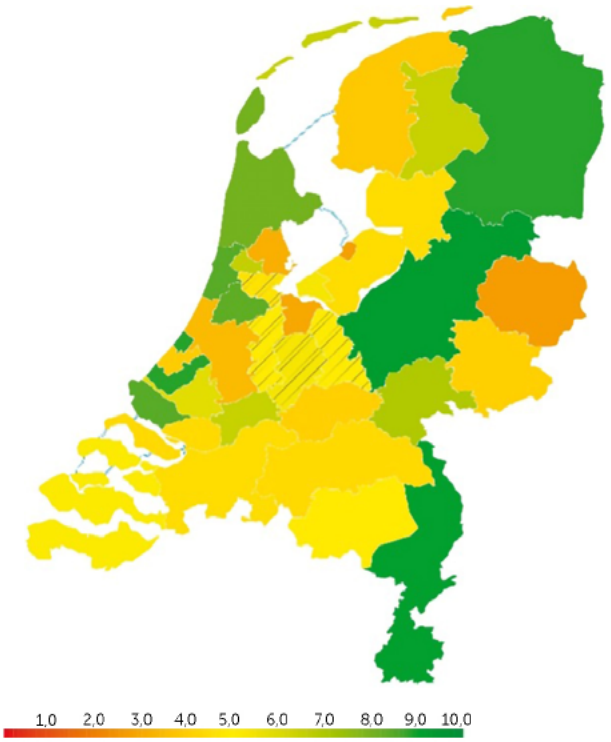

Figure 3. Environmental score of public transport buses by concession on 1 March 2022.

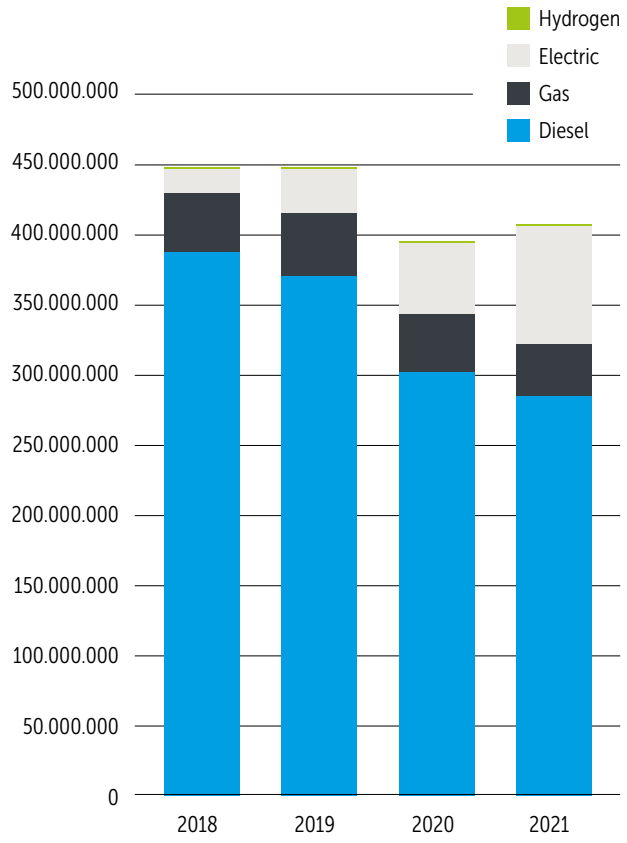

Figure 4. Number of timetable kilometres by powertrain.

The Groningen-Drenthe Public Transport Office took second place with a score of 8.8. 164 electric buses (largely with an HVO-powered block heater), 32 hydrogen buses and over 200 buses entirely running on HVO are now driving here. Groningen-Drenthe has more hydrogen buses on the road than anywhere else in the Netherlands.

The Monitor also tracks the use of the type of vehicle. The presence of an electric bus alone does not tell us anything about its actual use. The circuit to which a bus is assigned also plays a role in the distance covered each day. Due to the more limited range of a battery-electric or hydrogen bus, its reach, without recharging, is much less than a traditional diesel bus. During charging the bus cannot be put into operation, and as a result its maximum achievable distance is lower than that of a diesel bus.
In 2018, only 4% of the trips in urban and regional transport was driven by an electric bus. A year later, this had almost doubled to 7%. In 2020, the number of kilometres driven dropped considerably, but the number of electric kilometres driven once again almost doubled to 13%. In 2021, over 20% of the kilometres driven was electric. This percentage is expected to further increase in 2022.
In 2020, the share of all kilometres driven by hydrogen buses was only 0.05%. In 2021, this increased to 0.2% due to the inflow of new hydrogen buses. This percentage is expected to increase somewhat with the arrival of additional hydrogen buses in the Hoeksche Waard-Goeree-Overflakkee and Achterhoek-Rivierenland regions.
Yet this share will remain limited due to the low number of 68 hydrogen buses (including 10 new buses for Achterhoek-Rivierenland) out of a total of over 5,200 buses.

2.3 Clean on the road

The Monitor calculates the emissions of the entire regional public transport sector. The DUINN research firm performs the calculations under contract to CROW.
The timetable kilometres driven are registered in NDOV-loket – a dataset of Automatic Vehicle Location data, including bus movements – and are linked to a specific vehicle on the basis of its large vehicle fleet number. The average emission per kilometre for that specific vehicle is also linked to this, which produces a fairly accurate result. Flex and shuttle services are excluded from consideration in the calculations because they do not drive in accordance with a fixed route and/or timetable.

This section addresses three indicators: energy consumption, CO_2 emissions and NO_x emissions (nitrogen). These indicators are often also used to compare transport modes.

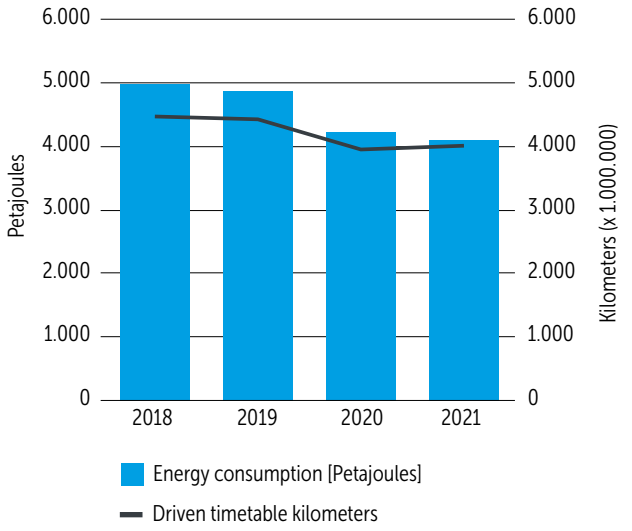

Figure 5. Trend of total energy consumption and timetable kilometres driven over the period 2018-2021.

In 2018, the energy consumed for the entire regional bus transport sector was approximately 5 petajoules. In 2020, energy consumption declined because timetables were scaled down due to the covid pandemic. This is clearly evident from the number of timetable kilometres driven. The number of kilometres decreased by 11%, while energy consumption dropped by 14%. In 2021, there is an increase in kilometres, while, by contrast, energy consumption decreased. Energy consumption per kilometre has dropped due to the use of more efficient (zero emission) vehicles.

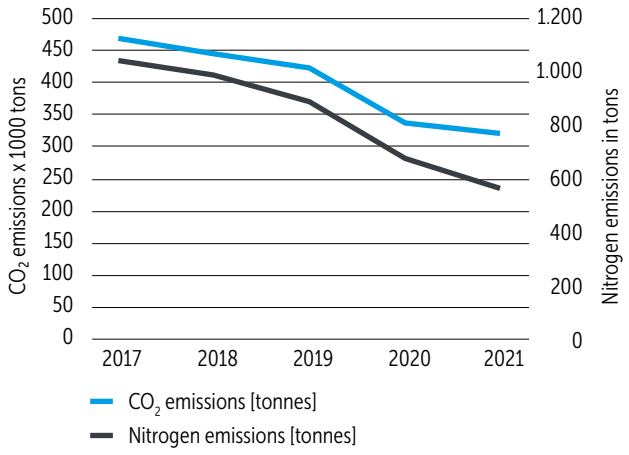

Figure 6. CO_2 and nitrogen emissions of public transport buses in the Netherlands.

The total CO_2 emissions of regional buses in the Netherlands has declined in recent years. In 2021, emissions were more than 30% lower than they were in 2018. Emissions at the exhaust are decreasing due to the inflow of battery-electric and hydrogen buses. Nitrogen emissions also are steadily decreasing and in fact are decreasing even faster than CO_2 emissions. This is due to a reduction in the deployment of Euro III and IV buses. This trend is expected to persevere over the coming years due to the inflow of additional zero emission vehicles.

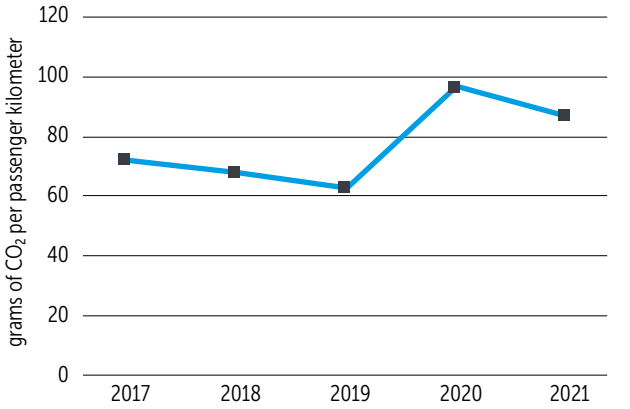

Figure 7. CO_2 emissions per passenger kilometre.

Aside from total emissions, the emissions per passenger kilometre is also of importance. The more passengers there are in a vehicle, the lower the emissions per passenger. In 2020, the number of passengers dropped significantly due to the covid pandemic, while the number of timetable kilometres driven did not drop as fast. This caused the emissions per passenger kilometre to increase. By deploying more zero emission buses and a modest increase in the number of passengers, emissions in 2021 were somewhat lower in comparison to 2020. However, it was higher than in the busiest year, 2019. By comparison: the emissions of a car passenger kilometre was on average 154 grams of CO_2 in 2020.

Passengers rate the zero emission bus somewhat higher than the fossil bus.

2.4 Customer evaluation of zero emission buses

The electric bus is increasingly gaining ground in the Netherlands. Electric transport is considered to be a cleaner and quieter alternative to combustion engines and furthermore has less vibrations. Bus passengers should perceive this as positive. A quieter bus with reduced vibrations makes the trip more comfortable. Furthermore, travelling in an electric bus generates a positive feeling due to its sustainable character. In this section we review the results of the Public Transport Customer Satisfaction Barometer 2021, an annual passenger survey in which passengers evaluate their public transport or Friese Waddenveren ferry service trip in/on the vehicle itself. In this section we only focus on the bus. The question is whether there is a perceptible difference in customer satisfaction between passengers in electric buses and passengers in fossil fuel buses. Here we not only review the overall score, but the sub-scores of individual aspects as well.

To be able to illustrate the trend in the passenger evaluation of electric buses, we need to refer back to the Public Transport Customer Satisfaction Barometer 2018. Today, there are 3.5 times as many lines with zero emission buses. The questionnaire about lines with primarily zero emission buses (more than 75% electric) were compared with the results of lines with primarily fossil fuel buses (more than 75% fossil).

Results

Looking at the overall score for a trip in a zero emission bus, we see that it is slightly higher (8.1) than the overall score for a trip in a bus with a combustion engine (7.95). However, the difference on a number of individual aspects is much higher.

- *Noise* (+0.52)
  The level of noise in a zero emission bus indeed is actually much lower.
- *Interior* (+0.44)
  With the inflow of new vehicles, passengers score the interior higher than before.
- *Punctuality* (+0.38) and *Frequency* (+0.37)
  Zero emission buses mostly drive through urban areas, where a next bus is generally more quickly available.
- *Climate* (+0.35), *Clean and tidy* (+0.32) and *Travel information* (+0.29)
  The higher ratings probably relate to the inflow of new vehicles.
- *Crowding* (+0.26) and *Transfer time* (+0.24)
  Wait times are low in urban areas, which is where the zero emission buses primarily drive.
- *Boarding stop information* (+0.22)
  Dynamic (travel) information is more often used in urban areas.

A comprehensive overview of the individual aspects is available in the appendix on page 24.

Conclusion

As a result of the covid pandemic, 2021 was a special year for the Public Transport Customer Satisfaction Barometer. Due to a year without a survey (2021), a changed population and a different measuring method, due care is required to identify any annual trends. In reviewing the overall scores and sub-scores of the zero emission buses, it would appear that the higher zero emission ratings can probably be explained by the availability of new vehicles and the higher frequencies in urban areas. Noise is an individual factor that scored a half point higher in 2018, as well as in the current survey, probably due to the quieter engine. The overall zero emission score is only a fraction higher in comparison to the overall fossil score.

The deployment of zero emission vehicles on a route often is incomplete. Buses rotate across various lines during a service or there are too few buses to fully make a line zero emission. For this reason a subdivision has been introduced, whereby it was decided to select lines with more than 75% zero emission (ZE) buses from the survey results. This produces a sample of more than 3,000 questionnaires. Furthermore, it is possible for the same lines to occur within concessions, particularly in urban bus services. This increases the probability of erroneously allocating a trip to with or without ZE. The appendix contains an overview of the lines used in each concession.

3 Zero emission in practice

In this section we review five examples of the introduction of zero emission vehicles into a concession. We review the role of the public transport authority, the concession operator, as well as the passenger, in the sustainability process. In addition, we consider the sustainability of other forms of mobility. Target group transport, which is tendered by municipalities, is closely related to public transport. Lastly, we provide insight into the overall vehicle fleet in the Netherlands, including scooters, passenger cars and trucks.

3.1 Case studies in public transport

In Europe, the Netherlands is seen to be leading in sustainable regional public transport, with over 25% electric buses. This section contains five examples of larger sustainability projects within the public transport sector in the Netherlands.

Hydrogen buses in Hoeksche Waard-Goeree-Overflakkee

Solaris hydrogen bus in HWGO at the Connexxion public transport company.

As of the end of 2021, twenty new Solaris hydrogen buses entered service in Hoeksche Waard-Goeree-Overflakkee (HWGO). These buses are in addition to the previous four VDL hydrogen buses in this concession. The VDL buses are 12-metre buses with a small trailer for the hydrogen, while the Solaris buses are standard 12-metre buses.

Drivers require an extra driving license for the four hydrogen buses with trailer, which makes these buses more challenging to operate. This is not required for the twenty standard hydrogen buses, which makes them easier to fit in. The range of these buses is around 300 kilometres, depending on the routes driven and on weather conditions. In March 2022, a new hydrogen refuelling station was opened in Heinenoord, close to the hydrogen bus depot. It is one of the largest hydrogen refuelling stations in Europe, and is able to supply over 50 buses with hydrogen. The refuelling station is located on public property, as a result of which other parties can also make use of it in the future. Everfuel, a supplier of hydrogen, will supply green hydrogen – the most sustainable form of hydrogen available – to this station for at least 12 years. The fuelling pressure provided by the hydrogen station makes it suitable for servicing heavy vehicles, so that trucks will also be able to fill up here in the future. The 20 hydrogen buses and the hydrogen refuelling station are subsidised by the Province of South Holland, the Ministry of Infrastructure and Water Management and by the European JIVE2 and Mehrlin projects. The project is the result of excellent cooperation between the province, the hydrogen supplier, the municipality and the concession operator.

Fully zero emission in Gooi en Vechtstreek

Electric VDL bus of public transport company Transdev at the bus station in Bussum.

The Gooi en Vechtstreek concession was supposed to start operating at the end of 2020. However, due to the covid pandemic the world had changed a great deal between the concession's award and start-up. The number of passengers dropped by half, resulting in lower passenger revenues, which in turn made it impossible for the public transport company, Transdev, to develop a viable business case. Transdev therefore started looking for a solution together with the customer, the Province of North Holland. A tripartite agreement was ultimately negotiated (see Section 4.2) in which the three parties set out the financing arrangements. The goal remained unchanged, namely to fully implement the concession using zero emission buses.

However, unfortunately the electric buses were not yet available at the concession's start-up in July 2021. Due to the aftermath of the covid pandemic, it was difficult for bus manufacturers to acquire the necessary parts. Ultimately, the first electric buses were introduced in the region in May 2022. Some of these buses were entirely new and some were from the Noord-Holland Noord concession. Because of the downscaled timetable at the beginning of 2021, these buses were no longer needed for the Noord-Holland Noord concession. The remaining buses were to be delivered at the beginning of 2023. However, this has been delayed due to the global shortage of electronic chips and delivery problems caused by the war in Ukraine. This involves the delivery of the first series of Ebusco 3.0 buses in the Netherlands. Due to their larger operating range of almost 400 kilometres they can drive on the long R-net line between Hilversum and Amsterdam. This virtually eliminates the need for charging the buses at the end point for their return trip. Once the full series goes into operation, the Gooi en Vechtstreek concession will be the first to be entirely zero emission.

New IJssel-Vecht concession takes over large fleet of electric buses

Electric BYD bus in Hoenderloo.

In December 2022, the public public transport company EBS started operating the new IJssel-Vecht concession for a period of 12 years. The concession is a continuation of the emergency concession IJssel-Vecht (with the exception of the Veluwe-Zuid segment) and is a follow-up to the Veluwe and Midden-Overijssel concession regions. At the end of 2023, the IJsselmond and Lelystad concessions will also be added to this concession. In line with the emergency concession, the new operator, EBS, will also be driving its buses under the RRReis brand name.

Update of the Guide.

EBS took over virtually the entire electric fleet from the previous operator. Electric buses are deployed on all lines, except the community bus lines and a number of school bus lines. The 234 BYD electric buses can recharge their batteries en route at four bus stations. The electric buses (221 BYD K9 and 13 BYD K7) were taken over pursuant to the takeover regulation included in the tender for the IJssel-Vecht 2023-2035 concession. The buses were inspected for this purpose and a valuation was completed for the transfer. This is the first time that this many (electric) buses were taken over in a single batch by a concession operator. In previous concessions the buses were generally written off over the term of the concession. Only in a few cases was it necessary to transfer a (small) series. Because the depreciation period of an electric bus is longer than the duration of the average concession, there will be more frequent (mandatory) vehicle takeovers. In part on the basis of the experience gained by this concession, the Guide for the Takeover of Zero emission Bus Systems was recently updated.

Further work remains to be done to make the vehicle fleet in IJssel-Vecht fully sustainable. At the end of 2023, the concession will be expanded to include the current IJsselmond and Lelystad urban transport concessions. At that time, another 31 new Ebusco 3.0 zero emission buses will be added. These buses will replace the buses in IJsselmond and Lelystad, but will be driving throughout the entire concession region. Thanks to this merger, three customers will be jointly responsible for a single concession for the first time.

Province of Utrecht shares knowledge about zero emission buses within Europe

Sharing experiences with European partners in Utrecht.

Through Interreg Europe, the European Union supports regional projects relating to sustainability. The Province of Utrecht participates in the eBussed project. In this project, various topics are explored to stimulate and support the development of the e-bus. eBussed focuses on the exchange of experiences in the transition to zero emission buses. Turku (Finland), Hamburg (Germany), Gozo (Malta), Livorno (Italy), Dél-Dunántúl (Hungary) and Utrecht (Netherlands) are participating in this project.

Visiting a depot in Hamburg.

The eBussed project contributes to Interreg Europe programme objective 3.1 'Improving low-carbon economy policy'. This is accomplished by supporting and encouraging regions to develop improved policy relating to the deployment of e-buses. (Digital) meetings are held during the term of the project, in which knowledge and experience are shared.

In 2022, meetings were held in Hamburg and Utrecht, where the experience relating to a major bus fire in Hamburg was shared, among other things. In June 2021, a fire raged in a bus depot in Stuttgart in which several electric buses were completely burned out. The experience gained during this fire has been incorporated in a study on fire safety in bus depots in the Netherlands. In addition to this specific presentation, a tour of depots and charging stations was also conducted. Participants also presented the progress of their projects during the meeting.

The Province of Utrecht and Utrecht University of Applied Sciences are the Dutch participants in the eBussed project. Various parties are furthermore involved in presentations and meetings. For example, public public transport company Qbuzz made a presentation about monitoring buses during trips. CROW-KpVV shared statistics about the inflow and deployment of busses. The Province of Utrecht shared its experience with the conversion of a complete bus line to zero emission vehicles.

Electric and HVO-powered buses in the Province of Limburg.

Electric bus with HVO block heater in Maastricht, the Netherlands.

In their journey towards a zero emission fleet by 2026, bus public transport company Arriva and the Province of Limburg took a major extra step forward in making their bus fleet more sustainable at the beginning of 2022. This is when the last buses were converted to run on Hydrotreated Vegetable Oil (HVO). HVO is a biological diesel fuel made from various oils, including plant-based oils. Currently, 95 buses run on electricity, with an HVO-powered block heater, and over 130 buses run on HVO. Regional bus transport in the Province of Limburg is to be entirely emission-free by 2026.

Buses running on HVO in the Province of Limburg at transport company Arriva.

Within its tender and the Zero emission Bus Transport agreement, the Province of Limburg gave tenderers complete freedom in terms of their transition goals and the path to be followed to accomplish them. According to the Province of Limburg this was a bold decision given the (limited) knowledge available at the time.
Looking back, the province suggests that Arriva (within the formulated agreements and with even greater ambition than agreed upon) is serious about making the transition to zero emission in Limburg.

In 2021, Arriva indicated that there were (technical) possibilities and that opportunities had opened up to roll out the transition to HVO for the remaining diesel buses. The public transport company then took up the gauntlet and completed the rollout in actual practice at a fairly rapid pace. The conversion did not affect the quality of service in the interim. With the earlier rollout of the planned zero emission tranches (in 2017, 2018 and 2019) and this interim extra step (remaining fleet from diesel to HVO), the region is well on course towards 2026.

3.2 Zero emission target group transport

In 2018, the Ministry of Infrastructure and Water Management signed an administrative agreement with a number of municipalities.
The agreed upon objective is fully zero emission target group transport by 2025. In addition to an administrative agreement, an agreement was also signed with a number of public transport companies and other parties in the target group transport domain. In contrast to the administrative agreement for zero emission buses, not all parties have as yet signed the target group transport agreement.

Under contract to the Ministry of Infrastructure and Water Management, the consulting firms Mobycon and EVconsult in the spring of 2022 carried out an initial survey of the status of zero emission in target group transport. The primary purpose of the survey is to provide insight into the state of affairs concerning the sustainability of target group transport. This Monitor will be repeated regularly.

In 2021, 9.3% of target group transport was zero emission. Various types of vehicles are used for target group transport. At 11.6%, passenger cars represent the largest share, followed by the taxi minibus.

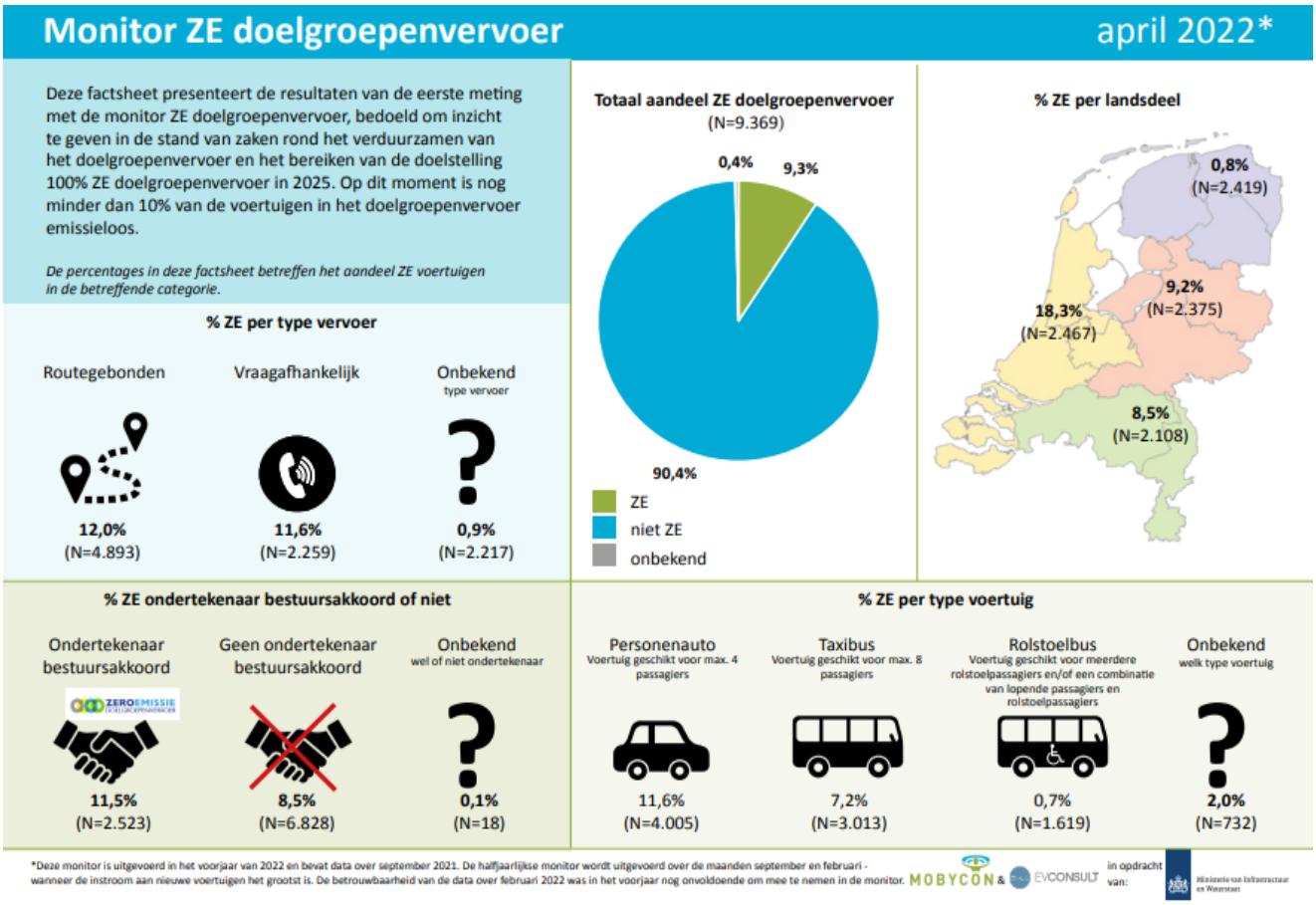

Figure 8. April 2022 Monitor – zero emission target group transport.

3.3 Comparison with other zero emission vehicles

From the statistics published by Statistics Netherlands (CBS) on the basis of the registrations of the National Vehicle and Driving Licence Registration Authority (RDW), the number of electric vehicles is increasing across the full breadth of the mobility sector. Figure 9 displays the results for five vehicle categories. Because RDW does not make a distinction between coaches and public transport buses, these vehicles have been combined. In 2021, most of the new coaches and public transport buses had an electric motor. This inflow is entirely for the account of public transport buses. Zero emission vehicles for longer distances, where coaches generally operate, are still in full development. Among the new moped license plates, almost 40% is electrically driven.

This trend goes back some time and provides a good alternative for transport over medium distances. The shared electric scooters hold a significant share here as well.
The entire vehicle fleet is not as green (Figure 10). But in the bus segment, almost 20% of the bus fleet runs on electricity or hydrogen. In the moped segment, the share of electric vehicles is almost 10%.
Due to the large numbers of passenger cars, the transition to zero emission is moving much slower in this segment, while work on freight traffic has only just begun.

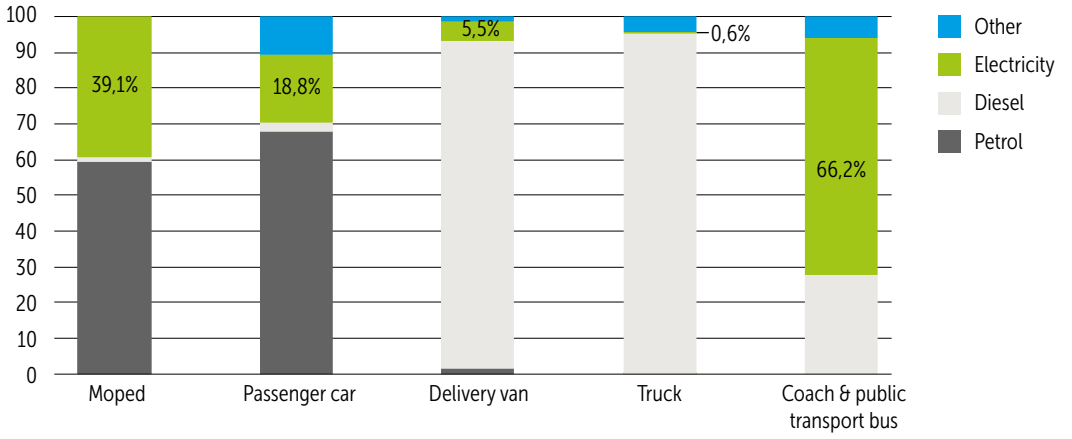

Figure 9. Inflow of new vehicles in 2021 by energy carrier and by vehicle category (source: CBS).

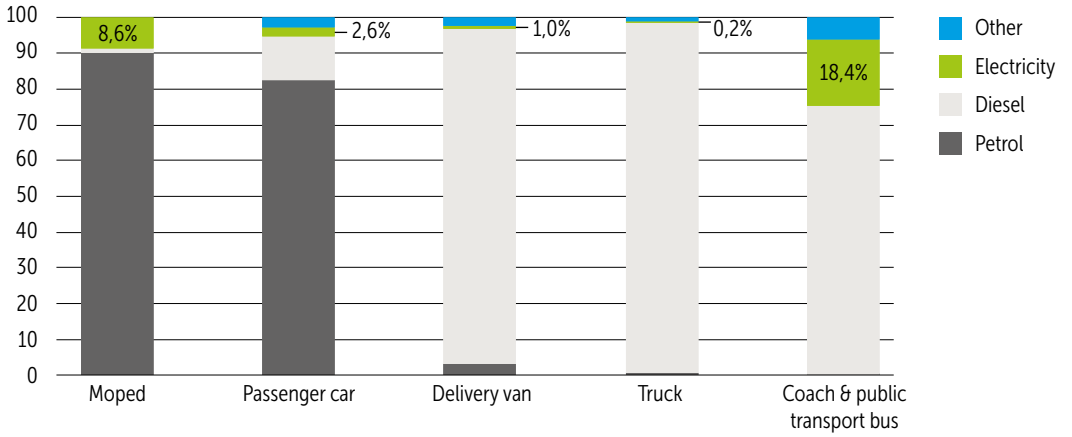

Figure 10. Composition of vehicle fleet on 1 January 2022 by energy carrier and by vehicle category (source: CBS).

3.4 Zero emission in Europe

The Alternative Powertrains for City Buses 2021-2022 Summary published by Chatrou Cme Solutions shows that the number of zero emission buses is increasing at a rapid rate in Europe. In 2022, 4,250 new zero emission buses were introduced. Of this number, only 2% is a hydrogen bus. Implementing facilities for battery-electric buses for the time being is simpler and more economical than hydrogen infrastructure. This may change in the future, for example when trucks also start to make use of hydrogen as an energy carrier.

For many years, the Netherlands was the frontrunner in Europe in terms of absolute numbers of registered zero emission buses. In 2022, the Netherlands was finally surpassed by large countries, such as Germany and France. Both countries have a larger fleet of public transport buses than the Netherlands, and are therefore faced with a greater task in switching over to zero emission.
The summary clearly shows that most countries opt for a battery-electric bus. Only a small number of countries is investing in hydrogen technology. Germany has the largest number of hydrogen buses: 138. Austria, Belgium, Norway, Poland and Sweden each have less than 10 hydrogen buses. There are no hydrogen buses on the road in Luxembourg and Finland.

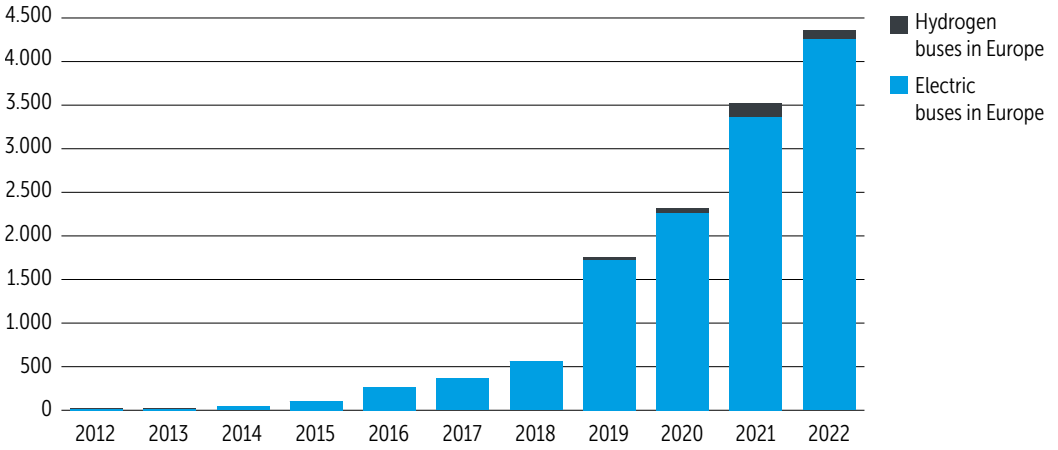

Figure 11. Number of new zero emission buses in Europe 2012-2022.

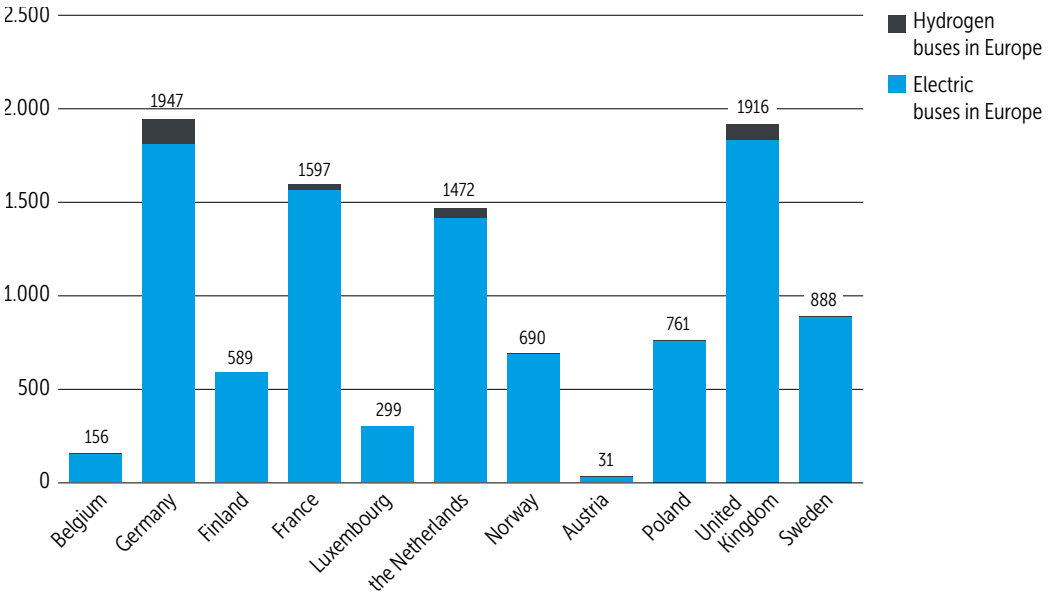

Figure 12. Number of new zero emission buses by country in 2022.

4 Zero emission costs and financing

A zero emission bus is more expensive to acquire than a diesel or CNG bus. The required infrastructure, such as charging facilities, is also more expensive than a diesel or CNG pump. However, a zero emission bus can be cheaper to operate due to lower fuel costs and cheaper maintenance. In this section we review the acquisition as well as operating costs of zero emission buses, forms of financing, and any additional operating costs due to shorter circuits.

4.1 TCO model: total cost of ownership

In 2016, CROW made the total cost of ownership (TCO) model available with the objective of supporting the transition to zero emission bus transport with financial information. This model has now achieved its goal. Battery-electric buses have increasingly become commonplace in public transport concessions and the TCO has since become equal to or lower than that of diesel buses. The cost of acquiring a battery-electric bus is higher than that of a fossil fuel bus. However, the operating costs are lower, as a result of which the higher cost of acquisition can be recovered. Hydrogen-electric buses still are more expensive than fossil fuel buses, in terms of acquisition as well as operating costs.

Public transport authorities and other public transport parties increasingly more often have their own tool for calculating the TCO. The TCO model calculates all bus-related costs, including charging infrastructure, operating costs and social benefits, and displays this information in a well-organised way. Now that zero emission buses have become increasingly commonplace, the zero emission buses Programme Group in the autumn of 2022 decided to stop providing this model.

In the spring of 2023, CROW will update the cost parameters for the last time, after which it will be used to make a calculation of the unprofitable top segment using various scenarios. A report will be produced with an overview of the updated costing parameters and the results of calculating the unprofitable top segment that stakeholders in the public transport sector can use to make their own calculations.
The report will be posted on the zeroemissiebus.nl website.

The previous version dating from 2021 is still available on the website. This publication is now obsolete because the range of available electric buses has since increased considerably. This has reduced the necessity of interim charging at end stops. This reduces installation costs and the cost of extra personnel due to standstill during charging.

Articulated electric VDL bus at the GVB public transport company in Amsterdam.

4.2 Financing

The acquisition cost of a zero emission bus is higher than that of a diesel or CNG bus. A public authority can therefore make financing the buses easier, for example by making bus loans available or by acquiring the vehicles itself and then leasing them out to the concession operator. After the covid pandemic, a new form of financing was introduced for the Gooi en Vechtstreek concession. Under this arrangement, the concession operator, financier and public transport authority negotiate joint agreements about the vehicles. The public transport authority pays the financier, instead of the concession operator, from the operating contribution. This way the financier has greater assurance about his investment and can therefore charge a lower interest rate. Furthermore, the public transport authority, in case of problems with the concession operator, is assured of buses for the concession. The selected form of financing depends on the public transport authority's policy.

Aside from the vehicles, the charging facilities are also important. Together they make up the zero emission bus system. It is important for the public transport authority to make effective agreements about this with the involved parties. MuConsult, under contract to CROW-KpVV, has developed a Guide for the Takeover of Zero emission Bus Systems for this purpose. This publication includes sample texts and detailed options for documenting takeover arrangements. The guide is available at zeroemissiebus.nl.

4.3 Zero emission bus circuits in comparison to fossil fuel buses

A bus drives different trips in a single day. These trips can be on a single line, as well as on various lines within the concession. The sum of these trips is referred to as a circuit. Various factors are involved that determine the circuit of a bus. In case of a battery-electric bus, one of these factors is the (limited) operating range on a single battery charge. A diesel or GCNG bus is generally able to drive all day without interim refuelling. By limiting the layover times between two trips and allowing a driver to take a break without a bus, a bus can drive many kilometres on a single day.
The range of the first battery-electric buses was approximately 70 kilometres. After a few trips, the bus needed to recharge its batteries at the charging station. The concession operator has two options during charging: allow the driver to take another bus for the next trip or allow the driver take a break while the bus is charging. In both cases this takes extra time and this therefore costs extra money; it requires additional drivers and buses to drive the same timetable. Since that time the range of electric buses has improved considerably and can now attain distances of up to 400 kilometres on a single battery charge. The actual range depends on the outdoor temperature, the driver's driving style and the type of route.
In 2021, the average timetable kilometres driven by a zero emission bus was higher than most diesel buses.
Only the small group of Euro III buses drove more kilometres. This is due to their allocation to long-distance lines.
Following the covid pandemic, the deployment of buses was optimised due to rising diesel prices. Because a zero emission bus on average requires less maintenance, an e-bus can be driven more days per year and therefore drive more kilometres.

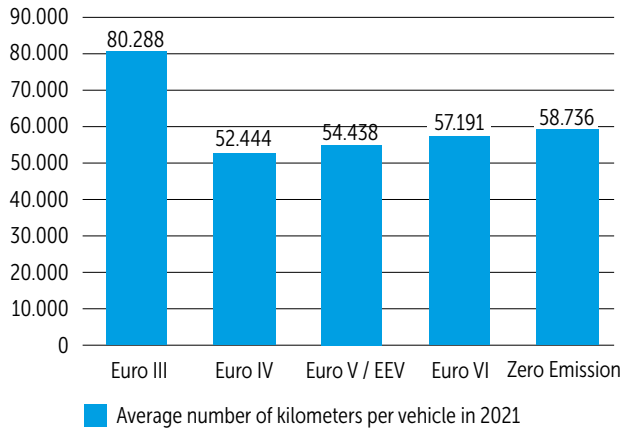

Figure 13. Average number of timetable kilometres per year per vehicle, based on the Euronorm.

The average number of kilometres driven per day by a zero emission bus is just below the distance driven by the largest group of fossil fuel buses. This difference has dropped dramatically in recent years. The maximum number of kilometres driven is also virtually the same as the cleanest series of diesel and CNG buses. Charging the bus or refuelling it with hydrogen in the interim increases the range of a zero emission bus on a single day.

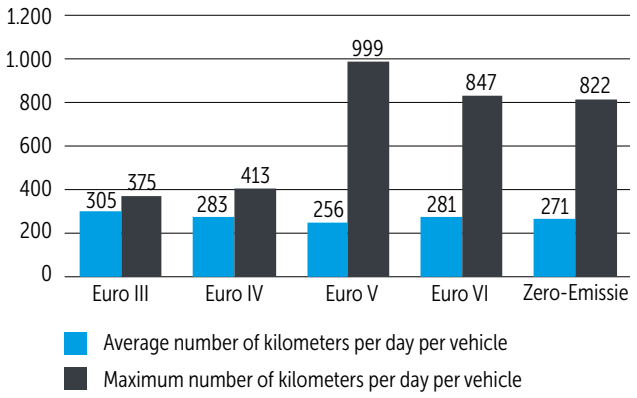

Figure 14. Number of timetable kilometres per vehicle on the busiest day of 2021, average and maximum.

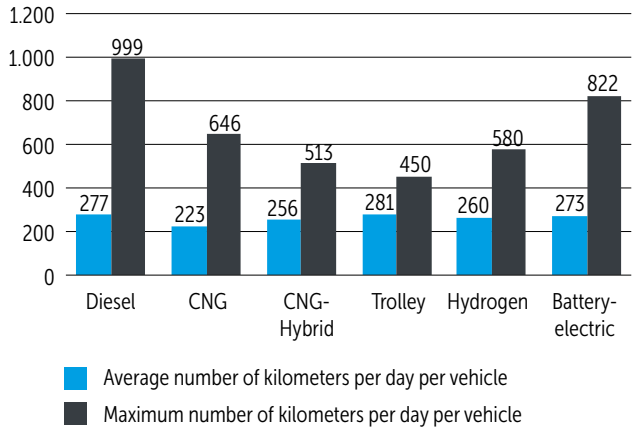

Figure 15. Average number of timetable kilometres per day per vehicle, based on powertrain.

From the perspective of the powertrain, the zero emission buses now also perform well. The average number of kilometres per day for all powertrains is around 260 kilometres. The battery-electric bus places third in the rankings, after a diesel and trolley powertrain. Hydrogen lags somewhat, but still occupies fourth place.
The maximum number of kilometres driven in a circuit by a battery-electric bus is second highest. Only diesel is significantly higher. This is probably due to the use of a number of diesel buses on long-distance lines via motorways.

On the basis of circuit data, it is evident that 60% of the circuits do not surpass 300 kilometres on any given day. Given the average circuit driven by a zero emission bus, it would be easy to convert the above-referenced circuits to zero emission without requiring any additional buses. Another 35% of the buses has a circuit of between 300 and 500 kilometres on a single day. Assuming a large battery pack and interim charging, as necessary, it should also be possible to replace the buses used for these circuits with zero emission buses. The last 5%, 190 circuits, cover more than 500 kilometres on a single day. The maximum daily circuit is more than 800 kilometres. This concerns long lines, such as the Rotterdam-Utrecht via Papendrecht line.

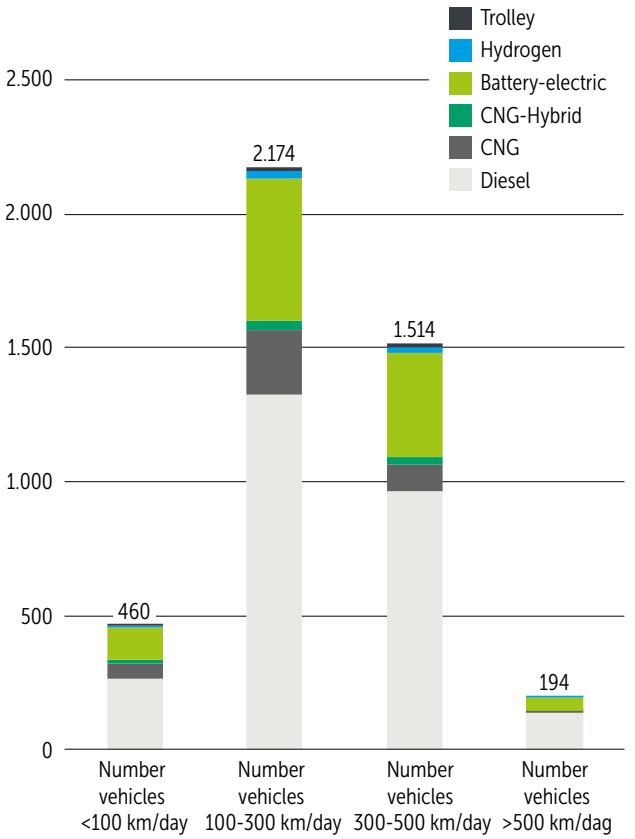

Figure 16. Number of circuits by distance category based on powertrain.

5 Parking, charging and refuelling zero emission buses

A zero emission bus differs from a conventional diesel bus in terms of a number of aspects. This results in new issues and challenges relating to safety while en route, parking, charging and refuelling the buses. In this section we review the safety studies conducted in the context of the Administrative Agreement on Zero Emission Buses (BAZEB). In addition, this section covers the origin of the electricity and the role of hydrogen in sustainability.

Hydrogen buses at the bus depot in Heinenoord.

5.1 Safety

In 2021, CE Delft, under contract to CROW-KpVV, conducted a survey of the safety aspects of zero emission buses. This study identified seven knowledge gaps (see table below).

In 2022, the Netherlands Institute for Public Safety (NIPV), under contract to CROW-KpVV, developed knowledge gap 7 in further detail and conducted research into the identification of potential measures and submitting proposals that can be incorporated into the design guidelines for garages, bus depots and bus stations, so that battery-electric buses and hydrogen buses can be parked safely in these spaces and, if necessary, be recharged or refuelled there. It was not the objective of the study to deliver a fire safety concept for bus depots.

In 2023, NIPV will work out knowledge gap 5 in further detail. For the remaining five knowledge gaps, the BAZEB Programme Group has decided not to tackle these for the time being, because they generally apply to all vehicles or because they are not relevant to BAZEB's objectives. Other organisations could perhaps further define these knowledge gaps instead in the future.

	Knowledge gaps	Explanation
1	The lack of empirical data about the impact of zero emission technologies on the magnitude of an incident in the event of a collision.	A battery-electric or hydrogen bus is heavier than a diesel or CNG bus. The weight plays a role in the impact of a collision (due to the weight) and due to the higher collision speed (longer braking distance due to higher weight). Data about the results of collision tests is lacking in the available literature, as a result of which the impact of a zero emission vehicle in a collision is unclear.
2	The safety criteria set with respect to the design, operation and testing of zero emission buses (including the process concerning the European type approval for the buses).	This turned out to be an issue for the Programme Group. This issue furthermore applies to all bus types: what are the safety criteria set with respect to the European approval process?
3	The exchange of knowledge and experience after incidents involving zero emission buses.	Fortunately, because the zero emission bus is still reasonably new, there have been few incidents. It is important to share the results of investigations of incidents with each other.
4	Sharing information about the causes of incidents involving zero emission buses.	Fortunately, because the zero emission bus is still reasonably new, there have been few incidents. It is important to share the results of investigations of incidents with each other.
5	The interaction with the environment in case of fire with a zero emission bus at a public transport node.	A burning zero emission bus creates a very different situation compared to a burning diesel bus. Many parties are often present in the environment at a public transport node. This includes passengers, other public transport vehicles and shops. A covering structure, possibly with a building on top of it, impacts the effect of the fire.
6	Salvaging zero emission buses after a fire.	Salvaging a zero emission vehicle after a fire requires extra measures. For example, in case of passenger cars, the car is placed in an immersion bath to cool it. In the Netherlands, there is only one immersion bath for buses.
7	Design guidelines for parking zero emission buses in garages and bus depots.	Up to a certain surface area, zero emission buses may simply be parked inside in contrast to, for example, CNG buses. Moreover, these buses may be parked closely together. Pursuant to a number of (small) fires, the question is what guidelines are required for a garage/bus depot with zero emission buses.

5.2 Renewable energy

The third BAZEB objective is that by 2025, zero emission buses will make use of 100% renewable energy that is as much as generated regionally. Moreover, a European guideline for renewable energy has been in effect since 2018: RED II (Renewable Energy Directive). RED II requires fuel suppliers to supply a minimum of 14% of the energy consumed in road and rail transport as renewable energy by 2030. The Netherlands has implemented this provision in the Annual Renewable Transport Energy Commitment. The Dutch annual commitment for the share of renewable energy goes beyond RED II and increases year by year to reach 28% in 2030.
But what exactly is renewable energy? Renewable energy, also known as green or sustainable energy, is energy produced by various means, such as hydropower, sun, biomass, geothermal and soil energy. In the 'Energy for Transport Register', fuel suppliers use Renewable Energy Units (HBEs) to show how much renewable energy they have supplied for road traffic. An HBE is equal to 1 gigajoule of supplied renewable energy.

In 2022, the research firm DUINN carried out an initial survey of the renewable energy used for regional public transport. Public transport authorities were asked to provide the following information:

- The type of energy carrier used in a concession and the consumption of this energy carrier.
- The source of the renewable energy carrier, if applicable.
- What agreements about the renewable energy have been made with the concession operator, how this has been secured and the raw material used to produce the renewable energy carrier.
- Whether any HBEs are generated in the concession, and if so, to which party these HBEs are allocated and how the agreements with concession operators and suppliers are secured and verified.

The survey was carried out as a pilot and was sent to all public transport authorities. Ultimately, the public transport authorities of 10 out of the 33 concessions responded. The findings of the survey are as follows:

- Six concessions make use of a renewable energy source.
- The use of HBEs is diverse and runs from fully under control of the concession operator to fully under control of the concession provider.
  The HBEs generated are often not transferred to the public transport authority.
- The Guarantee of Origin (GoO) is generally used as the sustainability system. In many instances, these GoOs are handed over to the public transport authority.

Renewable energy generation in the Province of Zeeland.

Trade in HBEs

Companies with an HBE obligation must have a sufficient number of HBEs in their account in the Energy for Transport Register (REV) every year prior to 1 May. To meet this commitment, companies can trade HBEs. At the beginning of 2022, one HBE (1 gigajoule) traded at 13 to 16 euros. This amount is doubled when an HBE-G (advanced HBE) is involved. An HBE-G consists of entries of energy carriers based on certain waste flows and residual sources.

This is potentially relevant for zero emission buses that are charged by a metered supply point. Companies and organisations, under certain conditions, are permitted to register the renewable share of electricity supplied to road vehicles/inland waterway transport through company connections to the power grid exclusively destined for this purpose. Assuming an annual consumption of 400 GJ per bus driving on 100% green electricity, 5,000 to 6,000 euros in HBEs is generated per bus based on current prices and regulations.

The survey only portrayed part of the concessions. Mutual differences are large and the situation in each concession is different. This is why it is difficult to draw conclusions from the survey. In 2023, in consultation with the Programme Group, there will be a follow-up to this study.

Hydrogen refuelling station near the Connexxion bus depot in Heinenoord (Zuid-Holland).

5.3 Hydrogen

There have been various pilots involving hydrogen buses in recent years. In addition to the current projects in Groningen-Drenthe, Hoeksche Waard-Goeree-Overflakkee and Rotterdam, there were also pilots in Amsterdam, Eindhoven and in the Veluwe region. The trials are supported by various subsidies, because the hydrogen energy carrier and the installation of fuelling infrastructure is currently considerably more expensive than a charging station.

In a hydrogen bus, a fuel cell converts hydrogen into electricity, which is then used to charge the battery. The hydrogen is generally stored in tanks on top of the bus. The construction of a hydrogen tank is similar to that of a CNG tank. In case of excessive pressure inside the tank, the tank, under controlled conditions, blows off hydrogen in order to avoid an explosion. Should a hydrogen tank detach, for example during a serious collision, the tank immediately shuts itself off so that there is no release of hydrogen.

Electrolysis is used to produce hydrogen. In this process electricity is used to split the water molecule. When there is an excess of green electricity, for instance when there is bright sunshine or strong wind, the electricity can be used to make hydrogen, for example for buses or cars. At the present time, the facilities required to effectively store this excess energy are not always available. Hydrogen can be a solution in this respect and can easily be transported over longer distances. A drawback is that in the conversion from electricity to hydrogen and from hydrogen to electricity there is always a loss of energy.

A second method of producing hydrogen is making use of residual products from the industry. For example, chlorine is produced in Delfzijl. Hydrogen is a residual product in this process and, provided it is not used as a fuel elsewhere in the process, is a waste product. This hydrogen is now used to fuel part of the hydrogen buses in Groningen-Drenthe at a nearby refuelling station in Delfzijl.

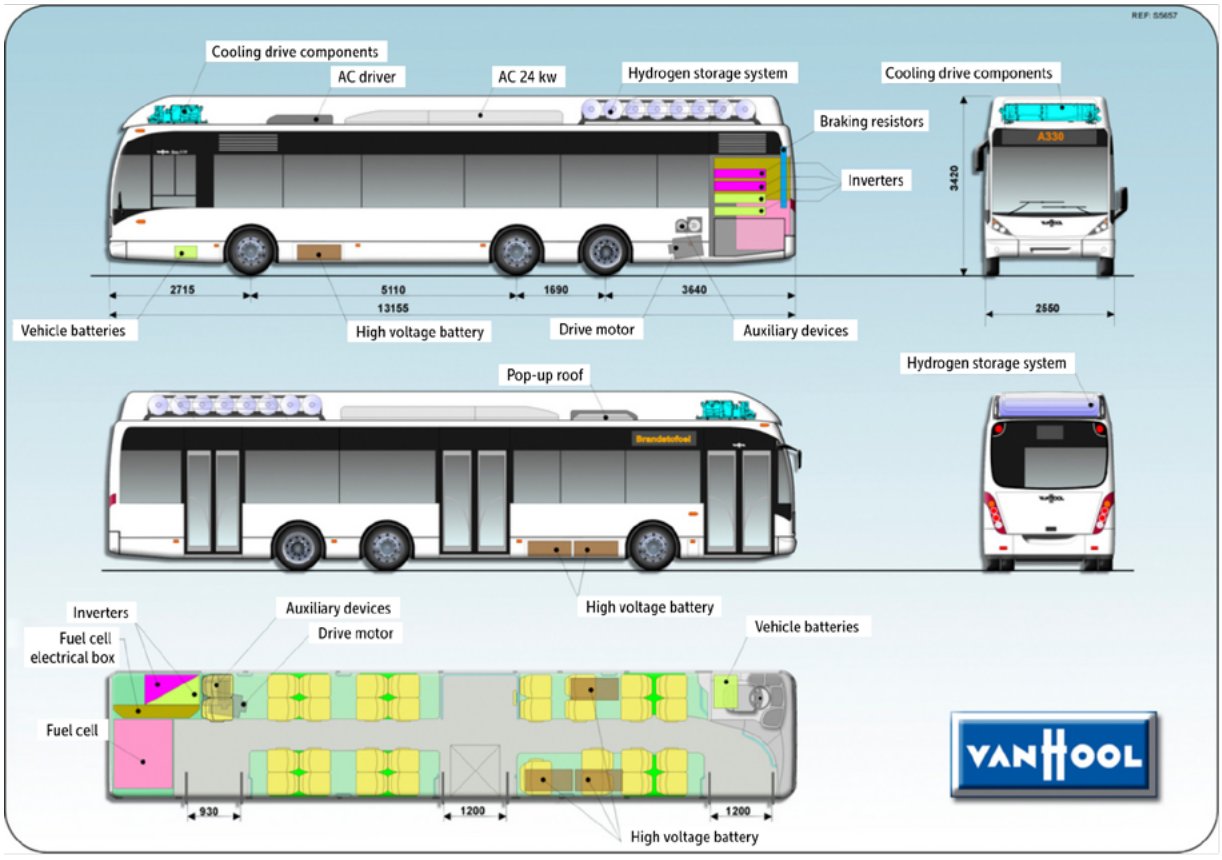

Figure 17. Technical drawing of a Van Hool hydrogen bus.

Appendix – Public Transport Customer Satisfaction Barometer 2021

Variable		Electric	Fossil	Difference	Explanation
V1	Was it difficult or easy for you to find a seat when you boarded the bus	8.83	8.76	0.08	No difference
V2	How would you rate the bus stop and the station where you boarded the bus	8.04	7.92	0.12	Small difference
V3	How would you rate the punctuality of the bus at your bus stop	7.83	7.45	0.38	Large difference
V4	Was it difficult or easy for you to board the bus	8.96	8.96	0.01	No difference
V5	How would you rate the staff's customer friendliness	8.29	8.27	0.02	No difference
V6	How would rate the driver's driving style	8.05	8.01	0.04	No difference
V7	How would you rate the travel time of this trip	8.22	8.16	0.06	No difference
V8	How would you rate the vehicle's tidiness and cleanliness	8.07	7.76	0.32	Large difference
V9	What did you think of the noise inside the bus	7.64	7.11	0.52	Large difference
V10	Do you consider the climate in this bus pleasant	7.84	7.48	0.35	Large difference
V11	How would you rate the interior of this bus	7.84	7.4	0.44	Large difference
V12	How would rate the information available at your bus stop	7.92	7.7	0.22	Medium difference
V13	How would rate the travel information available in the bus	8.08	7.79	0.29	Medium difference
V14	Was it difficult or easy for you to purchase your travel ticket or to top up your travel balance	8.07	8.24	-0.16	Slightly negative
V15	How would you rate the price of this trip	6.28	6.12	0.16	Small difference
V16	Were you inconvenienced by your fellow passengers during this trip	8.3	8.23	0.07	No difference
V17	Did you feel stressed or relaxed during this trip	8.14	8.1	0.04	No difference
V18	How would you rate the frequency on this line	7.26	6.89	0.37	Large difference
V19	What is your overall rating for this trip	8.1	7.95	0.15	Small difference
V20	If you transferred, what did you think of the transfer time	7.14	6.9	0.24	Medium difference
V21	How are you informed of delays or other problems	6.1	5.98	0.11	Small difference
V22	How do you rate the ease of use of this payment method	8.55	8.63	-0.08	Slightly negative
V23	What was your experience with crowding on this bus	7.35	7.08	0.26	Medium difference
V24	How safe do you generally feel on public transport	8.15	8.05	0.1	Small difference
V25	How safe did you feel during this trip	8.56	8.45	0.11	Small difference
V26	How safe do you usually feel at the bus stop where you boarded	8.17	8.02	0.14	Small difference

Concession	Lines with more than 75% zero emission buses included here
GD Concession	2, 3, 4, 7, 8, 9 11 and 16
Haaglanden Streek	60, 61, 62, 63, 64, 70, 71 and 73
Haarlem / IJmond	2, 15, 72, 74, 78, 79 and 385
Limburg (incl train)	16, 18, 19, 30, 31, 32, 33, 34, 37, 56, 80, 87 and 88
Noord and Zuidwest-Fryslân and Schiermonnikoog	612
Noord-Holland Noord	1, 2, 3, 10, 151, 162 and 165
Amstelland-Meerlanden	180, 181, 186, 190, 191, 194, 198, 199, 274, 300, 340, 347, 348, 356 and 357
Stadsvervoer Amsterdam	15, 22, 61, 231 and 369
Tram and Bus Utrecht Region	2, 3 and 8
Waterland	316
Zuidoost-Brabant	400, 401, 402, 403, 405, 406, 407 and 408
Zaanstreek	67
Zuid-Holland Noord	5, 7 and 8
Zuidoost-Fryslân, Vlieland, Terschelling, Ameland	1 and 2
IJssel-Vecht emergency concession	1, C2, 2, 3, 4, 5, 6, 7, 10, 11, 13, 14, 43, 86, 105, 107, 108, 160 and 165
Bus Rotterdam and environs	33, 44, 56 and 156
Drechtsteden, Molenlanden and Gorinchem	1, 2, 3, 5 and 7

Disclaimer Public Transport Customer Satisfaction Barometer survey 2021

Due to the covid pandemic, the composition of the population in 2021 as it pertains to the Public Transport Customer Satisfaction Barometer, in part due to increased working from home and online education, is different from previous years.

Take note of the following points:

- There was no Public Transport Customer Satisfaction Barometer in 2020, and therefore there is no comparison with last year.
- Measurements in 2021 were conducted in the autumn, instead of spread out throughout the entire calendar year.
- In 2021, approximately fifty percent fewer questionnaires were collected in comparison to prior years, because there were fewer passengers and the field work was halted sooner due to tighter measures.
- As a result, the survey does not always meet the quality standards set in each area of study: (general) a sample of at least 380 and (specific) a 95% significant difference for 2019-2021.
- The Public Transport Customer Satisfaction Barometer 2021 provides a picture of customer satisfaction under these changed conditions. The figures are less suitable for interpreting trends and identifying changed performance.

Colophon

Status of zero emission buses 2022

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