City buses: Diesel-, CNG-, Battery- and Hydrogen Buses

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Content

1 Introduction

In order to limit the progress of global warming, it must be a top priority to reduce or eliminate the man-made causes of global warming. To a large part, land, air and water transport are considered to be climate-damaging. Public transport is often mentioned as a game changer to make the transport sector more climate-friendly. If more and more people use public transport, the CO2 footprint could be reduced. Especially in urban areas, public transport is widely accepted. Of course, it is also necessary to analyses public transport in terms of Greenhouse gases. To date, there is still little experience with electric buses or hydrogen buses in urban transport. It is interesting to see how other drive systems affect the costs and emissions. This is the aim of this work, to take up the available data and to give an estimation in which direction these two factors move. Furthermore, it should also be shown how it is in our home countries, what political goals there are, what drives are currently being used.

2 Abstract

The aim of this work is to find out what influence public transport has on the climate. Specifically, buses that are used in urban areas are examined. The objective is to research which fuel releases how much Emissions and how does the drive have effect on the costs. For this the conventional diesel drive is examined and compared with CNG (Compressed Natural Gas), battery and hydrogen. Furthermore, we will show which fuel is used for buses currently and what the trend is for the future. In detail, we will examine and compare the countries Czech Republic and Austria.

By means of literature research we will find out which fuels are used to power city buses today and how it might change in the coming years. As it is interesting to compare the Czech Republic and Austria, we will also look at country-specific literature.

To give a little bit of the results, introducing electric buses or hydrogen buses into our transport will solve the emission problem locally, but they will not disappear. For this, a global approach has to be taken and an attempt has to be made to produce the electricity needed for these drives in an environmentally friendly way, better said with renewable power plants.

3 Available drive types

The way buses are powered must also be analysed in terms of costs and sustainability with regard to the environment. Especially with a view to the expansion of public transport, the question of the "best" fuel should play a central role. This can also seem very complex today, as the conventional types of drive such as diesel or petrol could be replaced by many alternative drives. This chapter will show which types of drive are available for city buses. Furthermore, the Co2 emissions and their costs will be compared.

In this paper, the following energy sources are analysed for driving buses:

In the following, the differences in emissions and costs of the different types of drive will be discussed in more detail. According to the Emissions, in this paper we look at those that drive climate change, the Greenhouse gases. These include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). (World Meteorological Organization, 2019) In order to be able to compare the emissions of the different types of drive, the results of the study "Bewertung von Gasbussen für den öffentlichen Personennahverkehr und Vergleich mit Alternativkonzeten" are used. This study examines the emissions of diesel, CNG, battery and hydrogen drive systems. It should be mentioned that this is a study from Germany. The results cannot therefore be directly transferred to the Czech Republic and Austria, as the electricity mix is different. The electricity mix is a key factor, especially for the battery and hydrogen drive systems. For Germany, the study examined the following 3 different electricity mixes. The first one is based on the values of electricity production in Germany in 2018 (share of renewables: 39,8%), called in the following “2018”. The second one was a prediction for the year 2030 for Germany (share of renewables: 50,2%), called in the following “2030”. The third assumption was with electricity only out of renewable sources, in the following called “100%”. Furthermore, a factor (CO_2-eq) is used in the study to be able to compare the greenhouse gases with only one value.

3.1 Diesel

The majority of buses are powered by this type of drive in the EU. The authors of the report "clean buses – Experiences with Fuel and Technology Options" mentioned that in the EU 95 percent of the buses are operated with this fuel. (Evans, Clement, Wimmer, & Chesterton, 2014)

Diesel is conventionally burned in a diesel engine. With the help of government regulations, such as the EURO 6 exhaust emission standard, permissible exhaust emission values are defined.

Emission

The emissions of the diesel driven bus can be seen in Table 1. The electricity mix hasn´t a significant impact to the emissions.

Table 1: Emissions for the diesel driven bus (Heneka, Gerstein, Köppel, & Kröger, 2019)

scenario	CO_2 [g/MJ]	CH_4 [g/MJ]	N_2O [g/MJ]	CO_2-eq [g/MJ]
2018	11,59	0,04	0,01	14,38
2030	11,51	0,04	0,01	14,30

Costs

The costs of diesel buses are mainly made up of the cost of producing diesel and the cost of transporting them. We need oil to make diesel. Oil extraction, transportation and processing is very expensive. Also transporting gasoline to stores costs something. At this time, diesel prices are astronomical.

3.2 CNG

Compressed Natural Gas, is the most used alternative fuel to drive buses in Europe. In Figure 1 is an overview of alternative fuels to diesel for buses and the distribution of it in Europe.

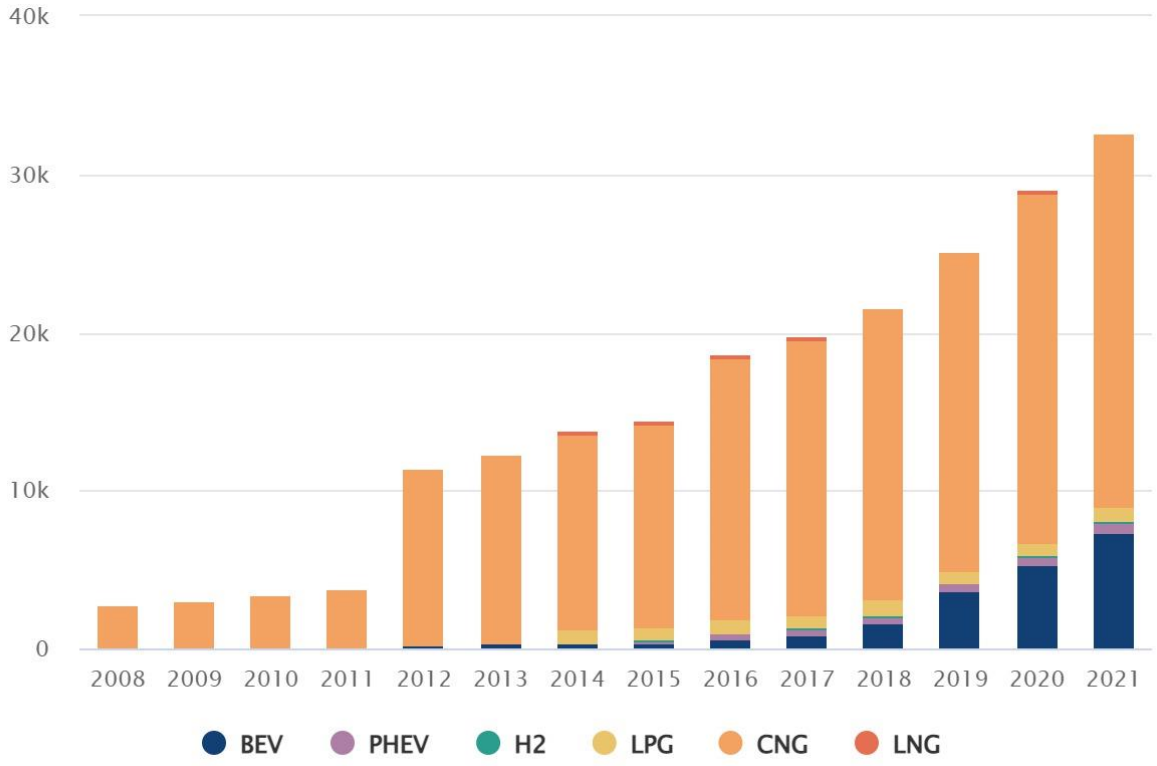


Figure 1: Total Number of buses with alternative fuels to diesel in Europe (Directorate-General for Mobility and Transport) BEV…Battery Electric Vehicle; PHEV…Plug-in Electric Vehicle; H2…Hydrogen; LPG…Liquefied Petroleum Gas; CNG…Compressed Natural Gas; LNG…Liquefied Natural Gas

General the CNG also get burned in an engine which can be imagined like a petrol engine.

Emission

The emissions of the CNG driven bus can be seen in Table 2. Similar to the diesel bus, the electricity mix does not play a decisive role, but the difference between the two scenarios is higher than with the diesel bus.

Table 2: Emissions for the CNG driven bus (Heneka, Gerstein, Köppel, & Kröger, 2019)

scenario	CO_2 [g/MJ]	CH_4 [g/MJ]	N_2O [g/MJ]	CO_2-eq [g/MJ]
2018	6,62	0,18	0	12,16
2030	6,25	0,18	0	11,78

3.3 Battery

Electric vehicles do not burn fuel, they store electrical energy in a battery and use an electric motor to drive the vehicle. As it can be seen in Figure 2, this type has the largest increase in newly registered buses with alternative fuel in Europe. There are two different types of battery-powered buses. On the one hand the opportunity chargers and on the other hand the overnight chargers. In this paper the opportunity chargers get neglected. One reason for this is that in exchange for a diesel-powered bus, for example, you often need two opportunity chargers to be able to bridge charging times. Another reason is that the variable costs and emissions differ only slightly and are not considered in this paper.

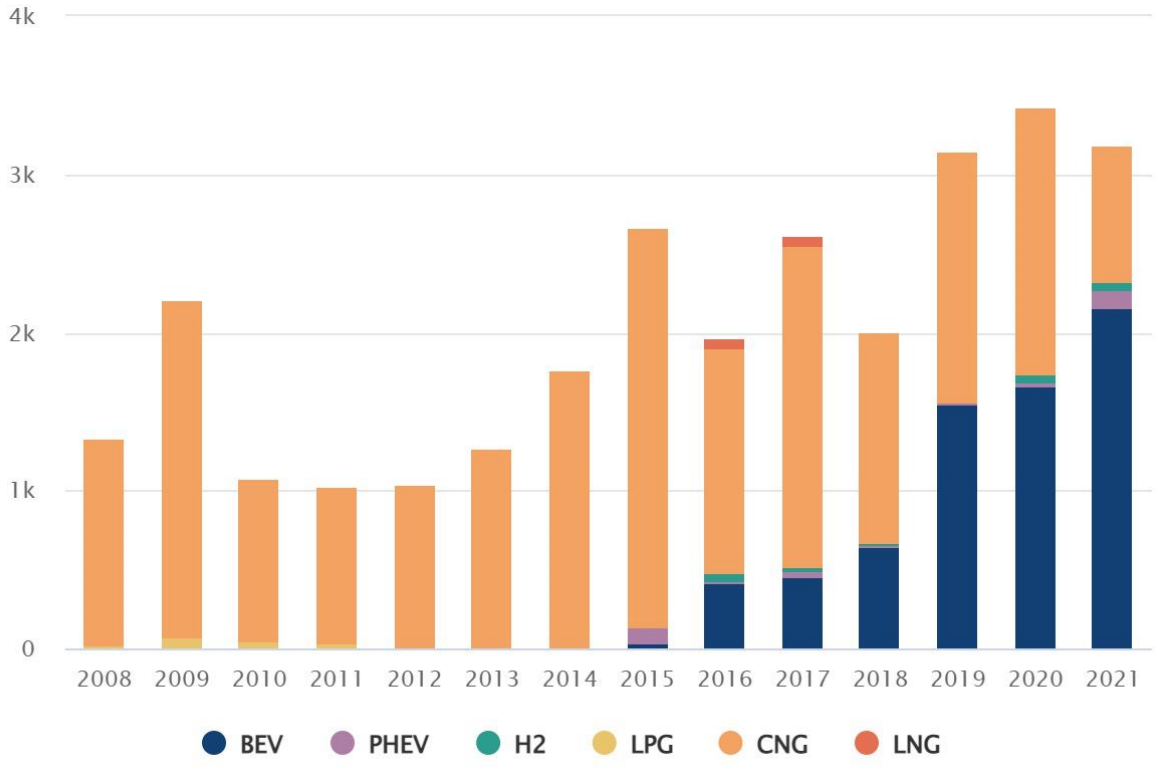


Figure 2: Number of newly registered buses with alternative fuel in Europe (Directorate-General for Mobility and Transport) BEV…Battery Electric Vehicle; PHEV…Plug-in Electric Vehicle; H2…Hydrogen; LPG…Liquefied Petroleum Gas; CNG…Compressed Natural Gas; LNG…Liquefied Natural Gas

Emission

The emissions of the Battery driven bus can be seen in Table 3. Like the diesel bus, the electricity mix does not play a decisive role, but the difference between the two scenarios is higher than with the diesel bus. The numbers shows that the influence of the electricity mix is very important. In the case of buses, emissions from production are often neglected because they are small compared to emissions from use. For this reason, the emissions from the pure use of renewable energy sources were calculated as 0 in this study. (Heneka, Gerstein, Köppel, & Kröger, 2019)

Table 3: Emissions for the Battery driven bus (Heneka, Gerstein, Köppel, & Kröger, 2019)

scenario	CO_2 [g/MJ]	CH_4 [g/MJ]	N_2O [g/MJ]	CO_2-eq [g/MJ]
2018	128,1	0,13	0,01	134,59
2030	101,11	0,11	0,01	106,76
100%	0	0	0	0

Costs

The costs of electricity production and distribution are much lower compared to diesel. If we produce clean electricity from renewable sources, emissions will be very slow. In contrast, the cost of disposing of a battery is very high.

3.4 Hydrogen

Emission

The emissions of the hydrogen driven bus can be seen in Table 4. Most of the energy for hydrogen production today does not come from renewable sources. Furthermore, the losses to produce hydrogen and for reconversion are around 70%. These factors are reflected in the increased emission values. However, the use of renewable energies can make a major positive difference, as can be seen from the scenario with 100%.

Table 4: Emissions for the hydrogen driven bus (Heneka, Gerstein, Köppel, & Kröger, 2019)

scenario	CO_2 [g/MJ]	CH_4 [g/MJ]	N_2O [g/MJ]	CO_2-eq [g/MJ]
2018	69	0,22	0	75,68
2030	67,53	0,21	0	74,17
100%	3,77	0	0	3,96

3.5 Conclusion

Emissions

All in all, the following conclusions can be drawn from the figures taken from the study:

- Today, at least the use of CNG-powered buses in Germany would make sense in terms of emissions.
- If the energy required for electric buses could be obtained from 100% renewable energy sources, this would be the most environmentally friendly solution.
- At present, the emissions of electric buses depend very much on the energy mix of the respective country and can be even higher than the conventional diesel drive.

The respective shares in respect to the EU-countries of renewable energies in electricity generation are shown in Figure 3. A significantly higher share of renewable energies in electricity production (78.2%) can be seen in Austria, as compared to Germany (45%) or the Czech Republic (15%). With this consideration, it can be said that the use of electric buses in Austria would cause fewer emissions than in Germany or the Czech Republic. However, it is not possible to draw any conclusions as to whether the emissions produced by an electric bus in Austria would already be lower than those of a diesel or CNG bus.

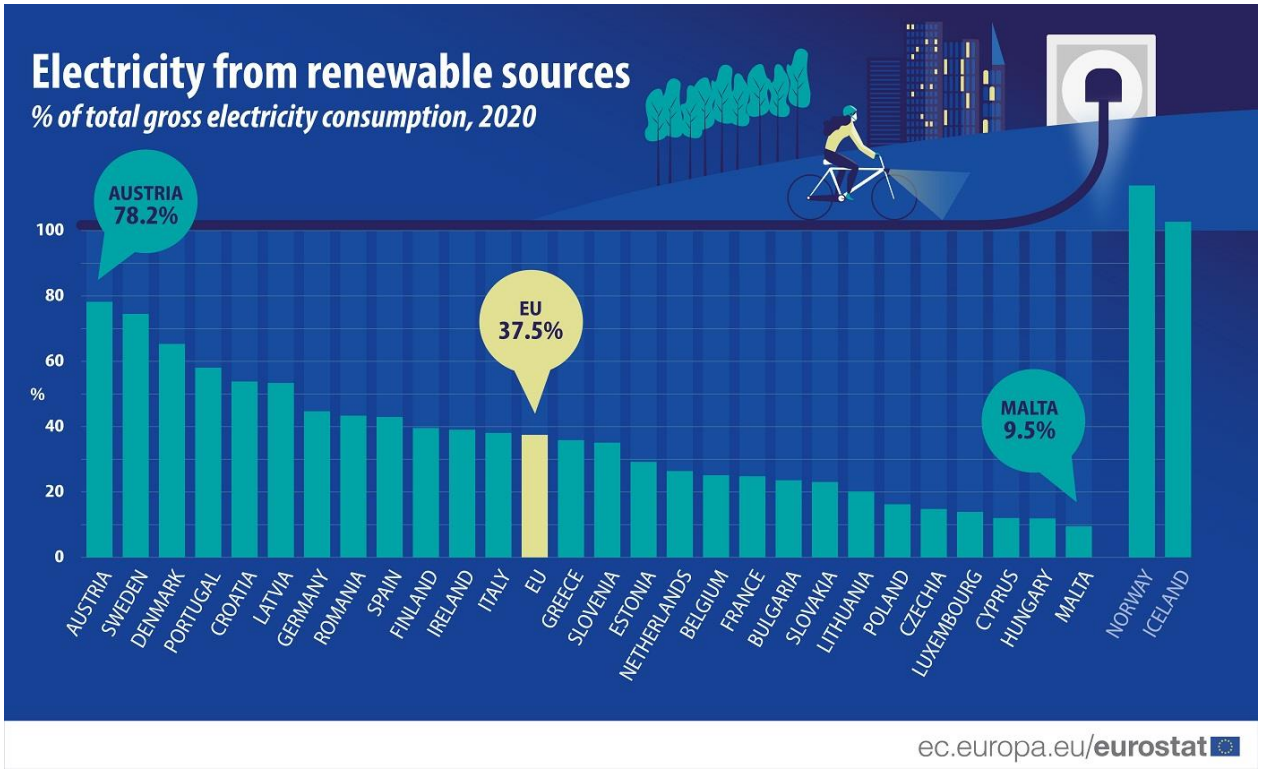
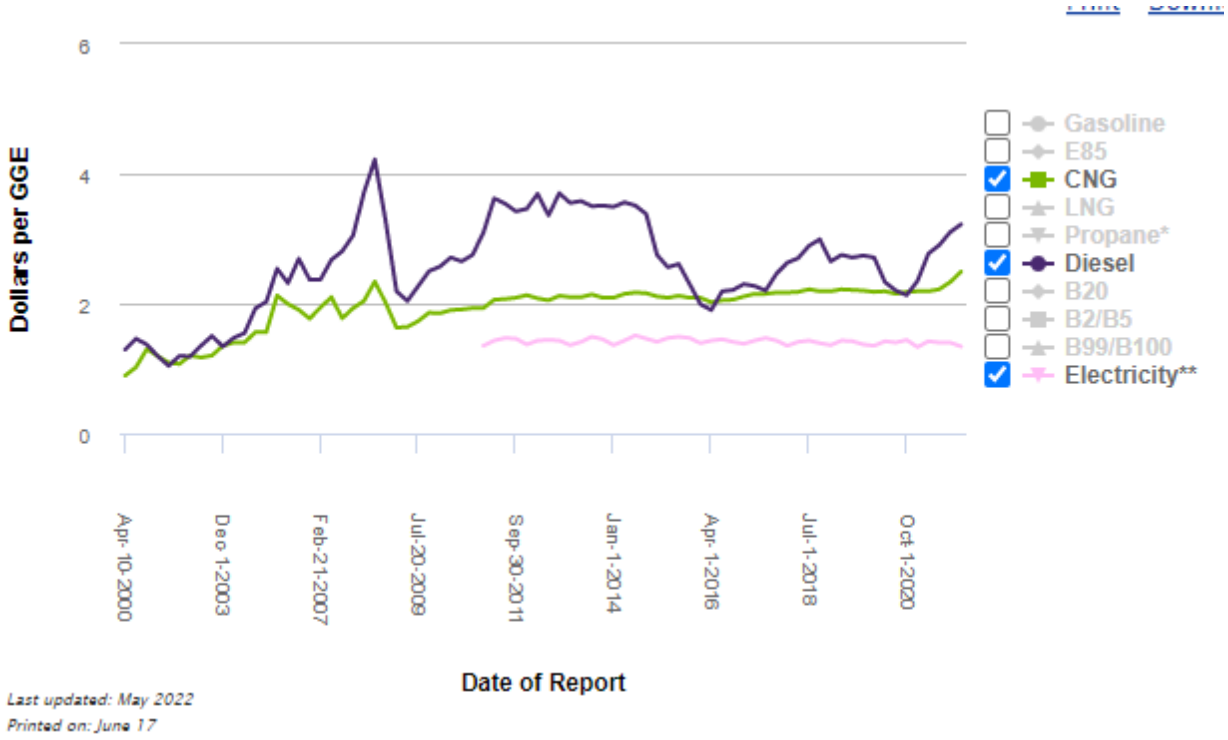


Figure 3: Comparison of the share of renewable sources in the production of Electricity (Eurostat, 2022)

Costs

We can see that in terms of fuel costs, the best part is the battery. We have to compare the costs of production (mining) and distribution. Diesel is the worst. Oil extraction and subsequent processing is very expensive. The transport itself is also very expensive. CNG is on the border somewhere between diesel and electricity.



4 Policies

4.1 Czech Republic

The transport company of the capital city of Prague owns 1,100 buses, which consume over 30 million liters of diesel per year. Among the current alternative drives include mainly low-emission electric drives. Of course, CNG buses, hydrogen powered are included.

As part of the Green deal, the Czech Republic has committed itself to reducing its emissions by 55% by 2030. By this year, at least 75% of the bus fleet should be replaced by emission-free electric buses, battery trolleybuses and low-emission buses.

Otherwise, no more specific emission measures apply to urban transport.

4.2 Austria

Austria wants to be climate neutral by 2040, which is why the transport sector must be decarbonised by 2040. (Schuster & Steinacher, 2021)

To this purpose, transport is to be shifted to environmentally friendly means of transport, such as the bus. New express bus lines will complement and relieve rail transport. Another goal is for all new bus registrations to be emission-free by 2032. This is to be achieved through the electrification of buses, but with the support of hydrogen-powered buses. (Mobilitätsmasterplan 2030 - Neuausrichtung des Mobilitätssektors, 2021)

Separate support programmes have also been set up for more sustainable transport. One of them is called "Zero Emission Mobilitiy". One project funded under this programme is called "move2zero" and aims to completely decarbonise urban bus operations. The project takes place in Graz and starts with the use of 7 battery-powered buses and 7 fuel cell buses. (Graz Holding, k.A)

Furthermore, Austria subsidises the purchase of e-buses with a capacity of 39 to 120 passengers with 60,000 euros per vehicle and buses with more than 120 passengers with 100,000 euros per vehicle. (Weiner, 2019)

5 Used drive types

5.1 Czech Republic

There are approximately 1200 buses running in Prague.

So far, all diesel buses are in Prague with the exception of one electric bus. By 2022, Prague had purchased 14 new electric buses, which it would like to put into operation by the end of the year. The transport company does not support CNG buses, they do not think that they would be as advantageous as other alternative fuels. In the second half of this year, Prague wants to put a hydrogen bus into operation. This is an annual test of this alternative drive. We can say that exchange of emission drives for alternative and emission-free ones is in infancy.

In the rest of the republic, the situation is very similar. We will see how fast there is a transition from diesel buses to buses with alternative drives.

5.2 Austria

Around 5400 buses were in use in Austria in 2017 (Weiner, 2019)

In Figure 4 it can be seen that in the year 2007-2010 the share of newly registered buses with alternative drive systems was very high. From 2011 to 2018, the share of alternatively powered buses flattened out. However, the last two years show that more and more alternative drive systems are being purchased again.Figure 4: New registration of buses in Austria (Statista Research Department , 2022)

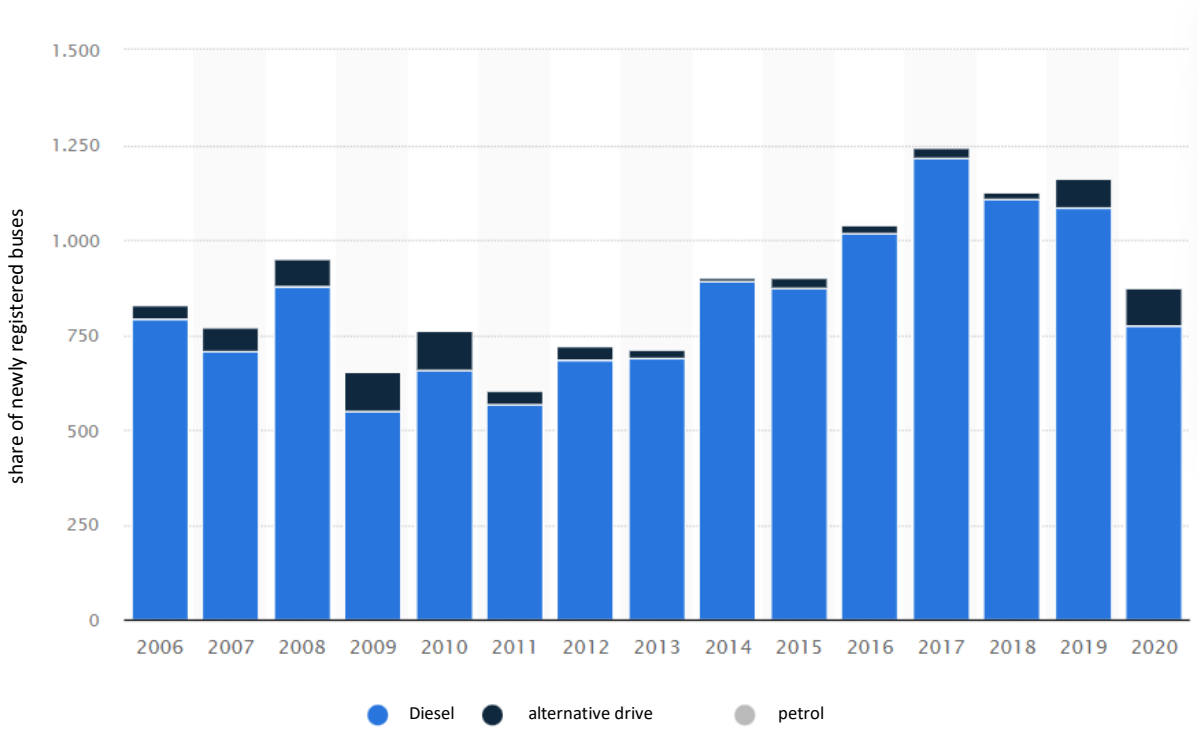


Figure 4: New registration of buses in Austria (Statista Research Department , 2022)

In general, it can be said that the majority of buses in Austria are equipped with EURO VI diesel engines. Some lines are testing the use of electric buses or even hydrogen buses. The best known of these are the 57A, 2A and 3A lines in Vienna and the 50 and 34E lines in Graz. Furthermore, as already described, some projects such as "move2zero" or invitations to tender for buses with alternative drive systems are being carried out.

6 Conclusion

In conclusion, we would like to compare the differences between Austria and the Czech Republic. According to our information and written information Austria is much better off. Their plan to reduce emissions in the future is more specific. They run more alternative drive buses. They are not only going for a test, but they are already in normal operation. We think that the inclusion of other buses with alternative drive will be much easier for them. Therefore, reducing emissions in transport will be faster and easier.

But the Czech Republic is also trying to meet the conditions and they slowly putting alternative drive buses in the transport.

There is a table which describes the percentage of buses by fuel type. We see the Czech Republic and Austria here. This table includes all types of buses in the country. There are long-distance buses, not just city buses.

VEHICLES IN USE, BY FUEL TYPE % SHARE / 2019

Buses

	Petrol	Diesel	Battery electric	Plug-in hybrid	Hybrid electric	Natural gas	LPG	Other	Unknown
Austria	0.0 %	96.2 %	1.6 %	–	0.4 %	1.6 %	0.0 %	0.2 %	0.0 %
Belgium	0.7 %	92.8 %	0.3 %	0.0 %	5.5 %	0.1 %	0.0 %	0.0 %	0.5 %
Croatia	0.0 %	100.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
Czech Republic	0.0 %	89.2 %	0.3 %	0.0 %	0.1 %	6.7 %	0.0 %	0.6 %	3.2 %
Denmark	0.4 %	96.7 %	1.0 %	0.3 %	0.0 %	1.7 %	–	0.0 %	0.0 %
Estonia	4.2 %	91.6 %	0.0 %	–	0.8 %	3.4 %	0.0 %	0.0 %	0.0 %
Finland	0.2 %	98.8 %	0.5 %	0.0 %	0.0 %	0.3 %	0.0 %	0.1 %	0.0 %
France	0.0 %	97.1 %	0.3 %	0.0 %	0.9 %	1.4 %	0.2 %	0.0 %	0.0 %
Germany	0.1 %	96.8 %	0.5 %	0.0 %	1.2 %	1.3 %	0.0 %	0.0 %	0.0 %
Greece	0.0 %	96.1 %	0.0 %	0.0 %	0.0 %	3.9 %	0.0 %	0.0 %	0.0 %
Hungary	0.3 %	97.5 %	0.1 %	–	0.5 %	1.3 %	0.2 %	0.0 %	–
Ireland	0.0 %	100.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
Italy	0.4 %	93.8 %	0.5 %	–	0.1 %	4.7 %	0.3 %	0.0 %	0.0 %
Latvia	0.2 %	99.3 %	0.2 %	0.0 %	–	0.2 %	0.1 %	0.0 %	0.0 %
Lithuania	0.1 %	83.2 %	10.2 %	0.0 %	0.0 %	0.3 %	0.0 %	0.0 %	6.3 %
Luxembourg	0.1 %	86.8 %	5.0 %	0.0 %	5.3 %	2.8 %	0.0 %	0.0 %	0.0 %
Netherlands	0.1 %	84.7 %	7.6 %	0.0 %	1.3 %	6.0 %	0.0 %	0.1 %	0.2 %
Poland	3.4 %	79.7 %	0.3 %	0.0 %	0.3 %	0.7 %	0.6 %	0.1 %	14.9%*
Portugal	0.0 %	97.5 %	0.2 %	0.0 %	0.0 %	2.0 %	0.0 %	0.0 %	0.3 %
Romania	0.0 %	98.9 %	0.1 %	0.0 %	0.0 %	0.5 %	0.0 %	0.0 %	0.5 %
Slovakia	0.4 %	94.5 %	0.5 %	0.0 %	0.0 %	2.5 %	0.0 %	0.0 %	2.1 %
Slovenia	0.1 %	95.7 %	0.0 %	0.0 %	0.0 %	4.0 %	0.0 %	0.0 %	0.3 %
Spain	0.2 %	93.0 %	0.2 %	0.1 %	1.8 %	4.5 %	0.0 %	0.0 %	0.0 %
Sweden	0.2 %	78.5 %	1.8 %	0.0 %	1.0 %	17.6 %	0.0 %	0.8 %	0.0 %
EUROPEAN UNION	**0.8 %**	**94.5 %**	**0.6 %**	**0.0 %**	**0.7 %**	**2.7 %**	**0.2 %**	**0.1 %**	**0.3 %**
Norway	1.3 %	92.2 %	1.3 %	0.0 %	0.0 %	5.1 %	0.0 %	0.2 %	0.0 %
Switzerland	0.5 %	93.6 %	0.7 %	0.0 %	3.1 %	1.6 %	0.0 %	0.2 %	0.2 %
United Kingdom	0.4 %	98.8 %	0.5 %	0.0 %	0.0 %	0.0 %	0.0 %	0.3 %	0.0 %

* Given the large amount of incomplete data ('Unknown') for Poland, the country was excluded from calculating the EU averages to avoid any distortion.

17 ACEA VEHICLES IN USE REPORT – JANUARY 2021

Figure 5: Vehicle in use, by fuel type (Acea vehicles in use report)

6.1% of new buses are electrically-chargeable vehicles today, 9.5% are hybrid electric, 11.4% run on alternative fuels, while diesel still fuels 72.9% of all buses sold in the European Union. This chart shows the trend in the fuel types of new buses in the EU for the 2019-2020 period. So we can see that there is a certain shift away from diesel engines.

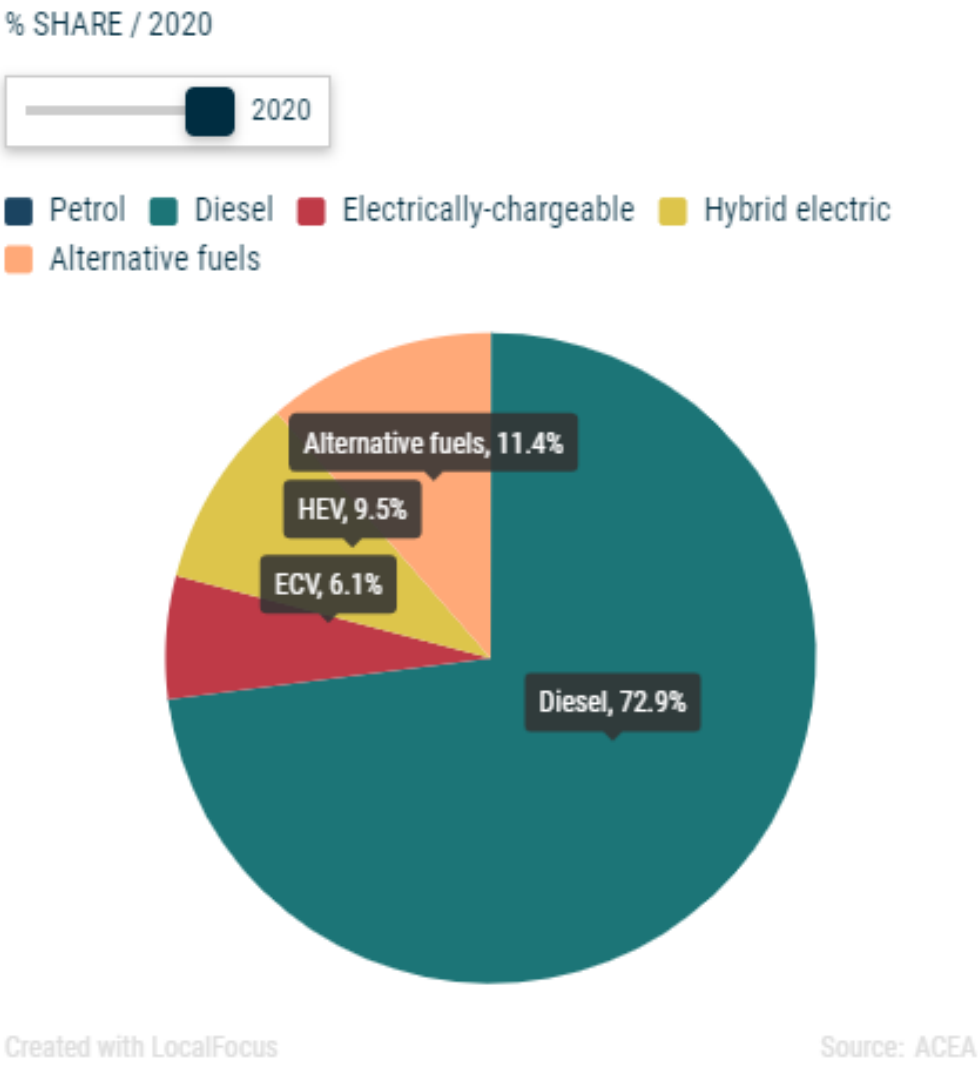


Figure 6: New buses in the EU by fuel type (New buses in the EU by fuel type 2020)

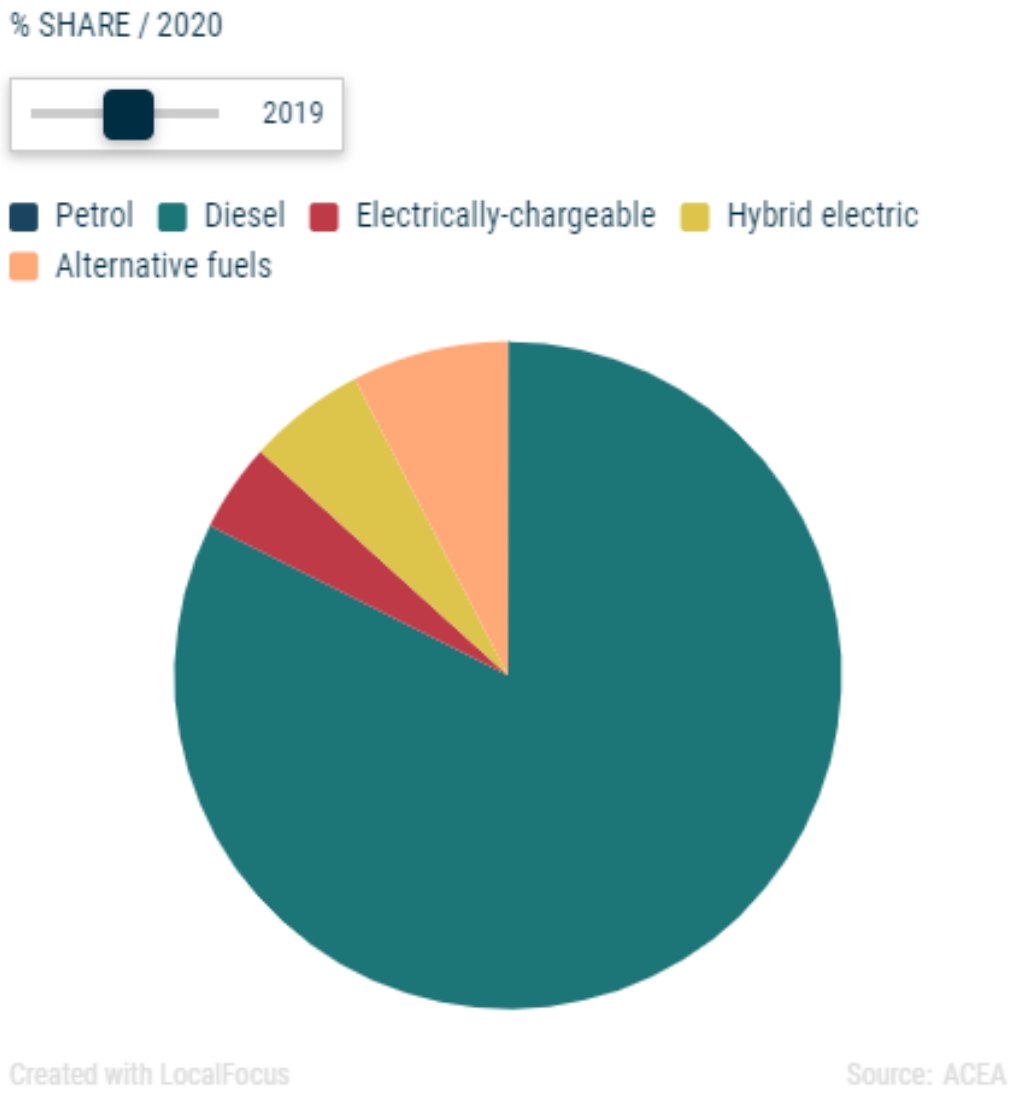


Figure 7: New buses in the EU by fuel type (New buses in the EU by fuel type 2019)

Here we see a table that shows us the ratio of the number of buses according to emissions. Unfortunately, only Austra is marked. Austria is trying to replace diesel buses mainly with hybrid buses. But already has electric and CNG buses.

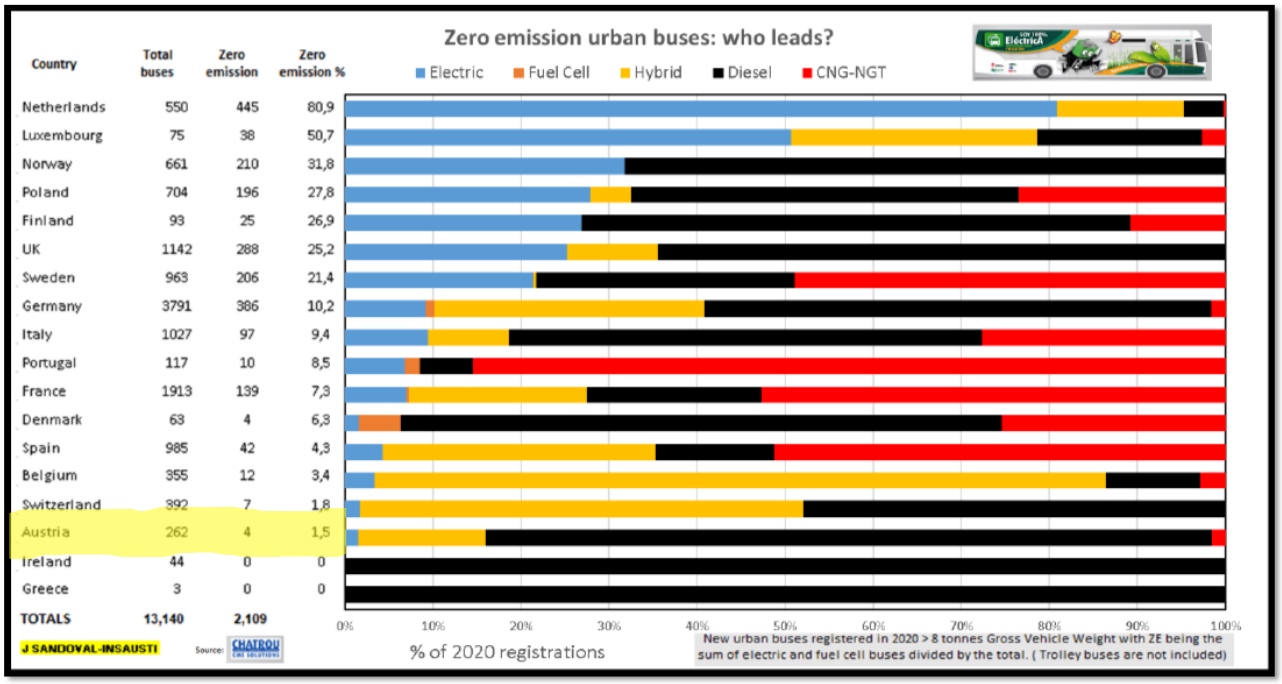


Figure 8: Zero emission urban buses: who leads? (Sustainable bus)

7 References

Directorate-General for Mobility and Transport. (kein Datum). *European Alternative Fuels Observatory*. Abgerufen am 14. Juni 2022 von https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/european-union-eu27/vehicles-and-fleet

Eurostat. (26. Januar 2022). *Renewable energy on the rise: 37% of EU's electricity.* Abgerufen am 15. June 2022 von https://ec.europa.eu/eurostat/de/web/products-eurostat-news/-/ddn-20220126-1

Evans, N., Clement, S., Wimmer, F., & Chesterton, V. (October 2014). *Clean Fleets.* Von clean-fleets.eu/fileadmin/files/Clean_Buses_-_Experiences_with_Fuel_and_Technology_Options_2.1.pdf abgerufen

Graz Holding. (k.A). *move2zero.* Abgerufen am 13. June 2022 von https://www.holding-graz.at/de/mobilitaet/move2zero/#auszeichnungen-des-projekts

Heneka, M., Gerstein, D., Köppel, W., & Kröger, K. (August 2019). *DVGW Deutsche Verein des Gas- und Wasserfaches.* Abgerufen am 15. June 2022 von https://www.dvgw.de/themen/forschung-und-innovation/forschungsprojekte/dvgw-forschungsprojekt-busstudie/

Mobilitätsmasterplan 2030 - Neuausrichtung des Mobilitätssektors. (2021). *Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie.* Abgerufen am 13. June 2022 von https://www.bmk.gv.at/themen/mobilitaet/mobilitaetsmasterplan/mmp2030.html

Schuster, M., & Steinacher, I. (Januar 2021). *Klimaaktiv.* Abgerufen am 15. June 2022 von https://www.klimaaktiv.at/mobilitaet/elektromobilitaet/e-bus.html

Statista Research Department . (26. April 2022). Von https://de.statista.com/statistik/daten/studie/958945/umfrage/neuzulassungen-von-autobussen-in-oesterreich-nach-antriebsart/ abgerufen

Tong, F., Hendrickson, C., Biehler, A., Jaramillo , P., & Seki, S. (Jänner 2017). Which Alternative Fuel Technology is Best for Transit Buses. (C. M. University, Hrsg.) Von https://www.cmu.edu/traffic21/pdfs/alternative-fuels-policy-brief-buses_web.pdf abgerufen

Weiner. (19. August 2019). *Bericht "Alternative Antriebe im ÖV".* Abgerufen am 14. June 2022 von https://gsv.co.at/wp-content/uploads/Bericht%20Alternative%20Antriebe%20%c3%96V%2026%2006%202019.pdf

WIener Linien. (24. November 2020). *Smart City*. Abgerufen am Juni 2022 von https://smartcity.wien.gv.at/wiener-linien-setzen-auf-oeko-busse/

World Meteorological Organization. (25. November 2019). *Greenhouse gas concentrations in atmosphere reach yet another high*. Abgerufen am Juni 2022 von https://public.wmo.int/en/media/press-release/greenhouse-gas-concentrations-atmosphere-reach-yet-another-high

Bus portál (15. March 2022). *Registrace autobusů v roce 2021 podle typu pohonu. [14.06.2022]* *https://www.busportal.cz/clanek/registrace-autobusu-v-roce-2021-podle-typu-pohonu-18154*

Hybrid.cz (27. April 2020). *Praha: až polovina autobusů na elektrický pohon do roku 2030. [14.06.2022]* *https://www.hybrid.cz/praha-az-polovina-autobusu-na-elektricky-pohon-do-roku-2030/*

Acea.auto (January 2021). *Report vehicles in use europe january 2021. [15.06.2022]* https://www.acea.auto/files/report-vehicles-in-use-europe-january-2021-1.pdf#page=15

Acea.auto (24. May 2021) *New buses in the EU by fuel type [14.06.2022]* *https://www.acea.auto/figure/buses-eu-fuel-type/*

Sustainablebus (15. September 2021) *The six European countries where zero emission buses are over 25% of city bus registration [15.06.2022]* https://www.sustainable-bus.com/news/european-countries-electric-buses-city-bus-registrations/

Afdc.energy.gov (May 2022) *Alternative fuel price report [17.06.2022]* *https://afdc.energy.gov/fuels/prices.html*

Petr Spáčil (4. September 2021) *Města nakupují ekologické autobusy. Ty na zemní plyn se ale nevyplatí, tvrdí experti. [14.06.2022]* *https://zpravy.aktualne.cz/domaci/mesta-nakupuji-ekologicke-autobusy-ty-na-zemni-plyn-se-ale-n/r~892cfc180bff11ecb91a0cc47ab5f122/*

Iva Brejlová (19. February 2022) *Veřejná jízda na vodík. Praha otestujes autobus na alternativní pohon, zkoušet ho bude minimálně rok [15.06.2022]* *https://cc.cz/verejna-jizda-na-vodik-praha-otestuje-autobus-na-alternativni-pohon-zkouset-ho-bude-minimalne-rok/*