Reducing public transport emissions

May, 2023

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We would like to express our gratitude to the consortium members for their review and guidance in shaping this document.

CITATION AND ACKNOWLEDGMENTS

This document may be cited as:
Climate Analytics (2023). Reducing public transport emissions

Cover image: Andre Moura

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

European Climate Initiative EUKI

This project is part of the European Climate Initiative (EUKI) of the German Federal Ministry for Economic Affairs and Climate Action (BMWK). It is the overarching goal of the EUKI to foster climate cooperation within the European Union (EU) in order to mitigate greenhouse gas emissions. The opinions put forward in this publication are the sole responsibility of the author(s) and do not necessarily reflect the views of the Federal Ministry for Economic Affairs and Climate Action (BMWK).

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CLIMATE ANALYTICS

Supporting science based policy to prevent dangerous climate change enabling sustainable development

Contents

Public transportation

Electrification

Fleet-wide bus electrification has been growing worldwide as municipalities seek to reduce their carbon footprint and dependence on fossil fuels. Different kinds of e-buses, such as battery electric buses, plug-in hybrids, fuel cell buses and trolley buses, have seen significant growth recently. Since 2012, around 8,500 e-buses have been registered in Europe. Germany, the UK, and France have registered over 500 e-buses each. European governments registered over 3,200 electric buses in 2021 alone (Sustainable Bus, 2020a). E-buses are expected to grow to over 65% of overall fleets by 2040 (Sustainable Bus, 2020b). Additional studies expect two-thirds of all new registrations to be zero-emissions buses by 2030 (Sustainable Bus, 2021).

All major vehicle manufacturers are pivoting towards e-bus production and produce a variety of sizes and technologies. Chinese automakers BYD and Yutong Bus continue to drive the massive adoption of e-buses in China, delivering thousands of e-buses per year. VDL, Mercedes-Benz, Volvo, Solaris, and Scania all have significant delivery contracts with municipalities and other European groups, driving the European market (Sustainable Bus, 2020a).

Studies accounting for battery life and replacement, infrastructure needs and maintenance requirements, found that e-buses can be very competitive in total cost per passenger mile compared to conventional diesel-powered buses (Meishner & Uwe Sauer, 2020). World Bank studies of bus fleets in Latin America found that cost-competitiveness often depended on existing infrastructure and fleet requirements. At the same time, Bloomberg NEF estimates that e-buses will reach TCO parity within the next two to three years (Graham, 2020). Higher up-front costs associated with e-buses will be on par with conventional buses by 2030 at the latest (Ibid.).

With upfront costs ranging anywhere between 570,000 and 1.2 million USD (520,000 - 1.09 million EUR), the purchase of electric buses can be prohibitively expensive, even for the most affluent municipalities (Johnson et al., 2020). However, before electric buses' upfront costs reach parity with conventional buses, municipalities can convert and refurbish older diesel buses to make savings and facilitate the transition without the sometimes-prohibitive upfront costs. MTB Transit Solutions, a bus repair company based in Canada, proposes changing over municipal buses when scheduled for their engine refurbishments. This refurbishment usually happens every seven to nine years. MTB argues that replacing the standard diesel drive train with an electric battery system when these buses were already scheduled for refurbishment closely aligns with municipal budgets. This alignment facilitates the transition. Diesel engine refurbishment typically adds four years to the lifespan of a bus, but MTB finds that switching to electric adds six to eight years of use. The transition compounds savings and cuts emissions.

MTB currently charges around 500,000 CAD (about 350,000 EUR) for a refurbishment, roughly half the cost of a brand new electric bus (Sarabia, 2020). The refurbishment annually saves an estimated 40000-50000 CAD (28000-35000 EUR) in maintenance and fuel cost (Ibid.).

Electrification examples

Berlin is one of the European leaders in transitioning to e-buses. PricewaterhouseCoopers (PwC) found that, in 2020, Berlin had 137 e-buses in its fleet, leading both municipalities and federal states in Germany. Berlin began adopting e-buses in 2015 and aims to transition the fleet to zero-emission buses by 2030. BVG (Berlin's transit authority) ordered 90 additional e-buses for delivery in 2022, bringing the total number of e-buses in the fleet to over 200 (Donath, 2021; UTM Editorial, 2021).

Shenzhen, China is the first city to have an entirely electric public bus fleet with more than 16000 such buses supported by government incentives to close the cost gap between ICE and electric buses. The '*National Electric Vehicle Industry Base*' (in 2011–15 five year plan), mandates the city of Shenzhen to invest USD 7.9–9.4 billion (7.6-9.0 billion EUR) in the EV industry, as well as construct and integrate more than 100 large-scale public bus charging stations with bus interchange stations (Ralston, 2020).

Hydrogen

Although hydrogen passenger cars do not seem to be the most viable option, hydrogen offers a promising opportunity to reduce emissions for long-distance transport, buses and heavy-duty freight (van Renssen, 2020).

Transit buses are among the best early adoptions of hydrogen fuel-cell technology. Hydrogen-powered buses provide a viable alternative to electric buses for some municipalities. Since hydrogen-powered buses are more energy-dense than conventional batteries, they offer the advantages of longer ranges and shorter refuelling times than traditional buses. For cities with lower temperatures or more hills, hydrogen could be a good alternative, as low temperatures and challenging terrain often saps electric batteries of power quickly (Timperley, n.d.). Hydrogen does not face these challenges (Ibid.).

However, hydrogen buses have higher upfront costs even compared to electric buses. Estimates show that for 2020, the total cost of ownership, which includes infrastructure, purchase price, fuel etc., for a hydrogen bus was around 1.9 EUR/km. An electric bus TCO is around 1.3 EUR/km, a significant saving for municipalities looking to transition an entire fleet (Kim et al., 2021). Infrastructure costs for hydrogen buses, particularly hydrogen production, remain high (Element Energy Ltd., 2017). However, broader adoption may decrease prices through economies of scale (Element Energy Ltd., 2017).

A series of programs have already begun introducing hydrogen fuel cell vehicles. The EU funded Joint Initiative for hydrogen Vehicles across Europe programme (JIVE and JIVE2) introduces new fleets of fuel cell buses and associated hydrogen refuelling infrastructure in cities and regions across Europe in partnership with the International Association of Public Transport. The recent UITP knowledge brief analyses best practices, drawing on a fictional case study from the 2020 JIVE best practice report (Stolzenburg et al., 2020). The H2Bus Europe initiative, centred in the UK, Denmark, and Latvia, aims to introduce low zero-emissions hydrogen buses to participating cities, hoping to achieve the scale required to achieve ideal savings (*H2Bus Europe Deployment*, 2022).

Hydrogen bus examples

London introduced the first fleet of double-decker hydrogen buses, operating 20 zero-emissions buses on the no. 7 line. This comes as part of London's goal to run a fully zero-emission bus fleet by 2030 ('England's First Double-Decker Hydrogen Buses to Launch in London', 2021).

France launched the world's first hydrogen-powered bus rapid transit system in Pau in 2019.

Konin, Poland region will be the first in Poland to introduce hydrogen cell-powered buses into its fleet. The Poznań-based company Solaris designed and produced the buses in Poland. Solaris is also exporting its public vehicles throughout Europe. Konin has leased the buses for the next four years, starting in 2022 (Wiewióra, 2022). A Micro-power plant fuels Solaris' buses using electricity from hydrogen, and the buses have an additional energy storage battery. The only by-products are steam and heat.

Heilbronn, Germany, also opted for the Solaris hydrogen buses. The region plans to generate low-emission hydrogen from wind energy and use the hydrogen to power its fleet with a zero-emission fuel. Therefore, the overall environmental balance of the whole value chain is close to zero (Figaszewski, 2021).

Overhead charging

Overhead charging provides an alternative to battery-equipped electric buses. Private firms are building more efficient and powerful pantograph chargers, advancing the field greatly (*Overhead Fast Charging*, 2015). Pantograph chargers allow drivers to dock wirelessly at a passenger stop and charge for a short period (*Overhead Fast Charging*, 2015). By adapting buses for overhead pantographic charging, transport authorities can ensure that service is uninterrupted and meets range requirements (Estrada et al., 2017).

In-motion charging (also called dynamic charging) is a process through which buses charge while in motion. Overhead systems typically facilitate in-motion charging. Systems for buses were adapted from charging systems commonly used to deliver electricity to trains and trams. As opposed to opportunity charging, this requires no extra time during the day (Sawilla, 2021). However, flexibility is restricted as buses must follow the set lines. Studies have shown that 20-40% network coverage can provide enough charge while ensuring functionality and flexibility (Mackinger et al., 2019).

This kind of charging has significant advantages:

- It reduces the downtime needed for charging - instead, the buses can be charged when in motion.
- It reduces the need for powerful electricity connections required at the buses' depot.
- It reduces the costs of the buses for a powerful battery.

At the same time, the main disadvantage is the high upfront costs of developing the overhead charging system. The initial costs often depend on the existing infrastructure and topography of a municipality and may vary significantly. However, cost-saving approaches include using battery power in places where wire installation would be exorbitantly expensive or achieving economies of scale on installation (Wright, 2021). The visual impairment caused by overhead wires may result in acceptance issues. However, since the buses would still be equipped with a small battery, the charging does not have to take place constantly (Mackinger et al., 2020). Depending on fleet needs, policymakers may reduce wire installations up to 50% (Mackinger et al., 2020).

Overhead charging examples

Berlin has the largest e-bus fleet in Germany, with 137 buses currently in service and a tender for delivery of 90 more in 2022. Berlin is increasing non-depot charging options for its fleet and placing inverted pantograph charging systems at different stops and terminuses around the city (UTM Editorial, 2021). Additionally, BVG plans to bring back trolleybuses in the city, reversing their initial phaseout in the 1970s. BVG plans to install hybrid battery-trolley line buses on lines between Berlin and Spandau. The lines will have 65% overhead wiring to expand the range and connectivity of buses along those routes. BVG is partnering with the Technical University of Berlin to continue researching energy efficiency and wireless charging potential throughout the city ('BVG Berlin Plans Implementation of Hybrid Trolleybuses', 2020).

Mexico City is expanding its trolleybus fleet. Mexico City received 63 hybrid battery-overhead line trolleybuses in 2020 and plans to procure at least 50 more articulated trolleybuses in the coming years. The procurement specifications included that the buses must be zero emissions, have a capacity of at least 140 passengers, and have the battery capacity to run off-network for at least 25 to 35 km (Sustainable Bus, 2020c).

Electrification of railway tracks

Completely electrifying rail networks offer several advantages, especially for reducing emissions. Electric railways rely significantly less on non-renewable fossil fuels and generate fewer emissions over time (García-Álvarez, 2014). Electric railways are also quieter and more efficient. Electrified trains can brake to recharge, improving the train's energy efficiency.

A European Commission study estimates rehabilitating and electrifying conventional rail may cost between 0.4 and 0.6 M EUR/km (European Commission, 2018). The environment, line type, and service type introduce high variability (European Commission, 2018).

Rail networks have electrified 75% of global passenger rail uses (IEA, 2022). Diesel rail uses make up the remaining 25% (IEA, 2022). Over 60% of the European rail network is already electrified, and 80% of total rail traffic runs on electric lines. According to data from Statista, Switzerland is the only European country that has electrified its entire railway network (Statista Research Department, 2022). Other countries like Luxembourg, Montenegro, and Belgium have electrified 80-90% of their network.

Railway electrification example

China is undergoing a rapid electrification push (GSEP, n.d.). In 2018, the combined length of electrified railways and double-track rail was 86,600 and 71,800 kilometres, respectively, accounting for 68% and 57% of the country's total railway mileage (People's Daily Online, 2018).

Hydrogen

Hydrogen competes with electrified and conventional diesel trains to decarbonise trains on hard-to-electrify lines. Hydrogen's lower relative energy density prevents the fuel from meeting the energy demands of high-speed trains and freight trains on conventional rail networks. For these trains, electrification is the only available technology (Alstom, 2021; Transport Committee, 2021).

Hydrogen remains a preferred solution for old diesel trains on non-electric tracks. Hydrogen may be more time and cost-effective compared to network electrification. Train producers can build hydrogen fuel cell trains with large hydrogen tanks. These trains would only charge at specific charging points. This system may be suitable for more rural routes.

Hydrogen train examples

Between September 2018 and May 2020, Alstom, the French transport manufacturing company, conducted a 530-day trial of its Coradia iLint hydrogen-powered train on the German Weser-Elbe network (Alstom, 2020). From 2022, 14 Coradia iLint trains began replacing the existing diesel stock in Lower Saxony. Networks in France and Italy have now ordered Coradia iLint trains (Alstom, 2021a, b). Alstom conducted further tests in Austria, the Netherlands and Germany (Ibid). Alstom and British rolling stock company Eversholt Rail have also led a UK pilot project to test converting existing Class 321 trains to hydrogen (Patel, 2021). The project calls these trains "Breeze" trains (Patel, 2021).

The Birmingham (UK) Centre for Railway Research and Education and railway rolling stock company Porterbrook run the UK-based HydroFLEX hydrogen train scheme. HydroFLEX wants to retrofit existing trains to run on hydrogen. HydroFLEX's first successful trial, a return trip from Quinton Rail Technology Centre to Evesham, took place in September 2020. HydroFLEX is now transitioning its technology to carriage undersides (*Centre of Excellence in Rail Decarbonisation*, n.d.). The transition intends to increase space for passengers.

Scottish Enterprise and Transport Scotland support the Emission Train Project to develop hydrogen trains on the Scottish rail network. The Project showcased a hydrogen train on a closed rail network at COP26 ('Angel Trains to Support Scotland's Hydrogen Train Project Development', 2021; University St. Andrews, 2020).

The Swiss rail manufacturer Stadler secured a contract from the San Bernardino County Transportation Authority in California to deliver the first U.S. hydrogen-powered trains ('Stadler to Deliver Hydrogen-Powered Train to SBCTA', 2019).

Increasing energy efficiency

Increasing train energy efficiency can reduce direct or indirect emissions, independent of the train's fuel use. Train operators typically pay electricity costs based on train weight, mileage and average consumption (Johner, 2017). This billing system discourages train operators from saving energy (Johner, 2017).

There are several strategies for increasing efficiency in trains and rail systems:

- Optimise timetable to balance network loads (Kuzior & Staszek, 2021).
- Timetable-based train preparation. For example, trains should only switch on heating or cooling systems just before being used. In Switzerland, this practice reduced energy consumption by four GWh per year (Johner, 2017).
- Applying more efficient cooling. For example, dry-type transformers, which do not use oil as a coolant and whose higher levels of active conductor materials minimise heat-waste, increased efficiency savings by to 7-8% (Johner, 2017)
- Using RCS-Modul Adaptive Lenkung (RCS-ADL) technology. RCS-ADL suggests the optimal train speed. These suggestions reduce stoppages and save energy. RCS-ADL would especially benefit railways tracks utilised by numerous actors. RCS-ADL in 2000 Swiss trains saved 200 MWh per day. RCS-ADL reduces wear to rolling stock, improving efficiency as the system ages (*RCS-ADL*, 2021).

Increasing railway energy efficiency examples

Switzerland is known for having an efficient, annually improving, rail network. In 2015, Swiss Federal Railways AG (SBB) started charging locomotives equipped with individual metres only for actual energy consumption. Additionally, a project which switches off heating to full carriages during peak hours to decrease energy demand recently won the *Watt d'Or* prize for its innovative approach to flexible consumption management (*Swiss Railways among Winners of Energy Prize*, 2022). SBB also uses an adaptive control program to ensure that trains are travelling at optimal speeds to reduce waiting time, increase efficiency, and avoid conflict between trains, increasing energy demand and reducing efficiency.

The East Japan Railway Company (JR East) invested significantly in network energy efficiency. JR East implemented an energy-saving policy that centres around four pillars of increasing regenerative energy utilisation, increasing renewable energy options at stations, managing energy usage at stations, and implementing battery-operated trains (Johner & Büchi, 2018).

This comprehensive plan aims to reduce energy consumption by 25% and reduce carbon emissions by 40% by 2031, relative to 2014 levels (Itadani, 2018).

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