Electric buses arrive on time

Marketplace, economic, technology, environmental and policy perspectives for fully electric buses in the EU

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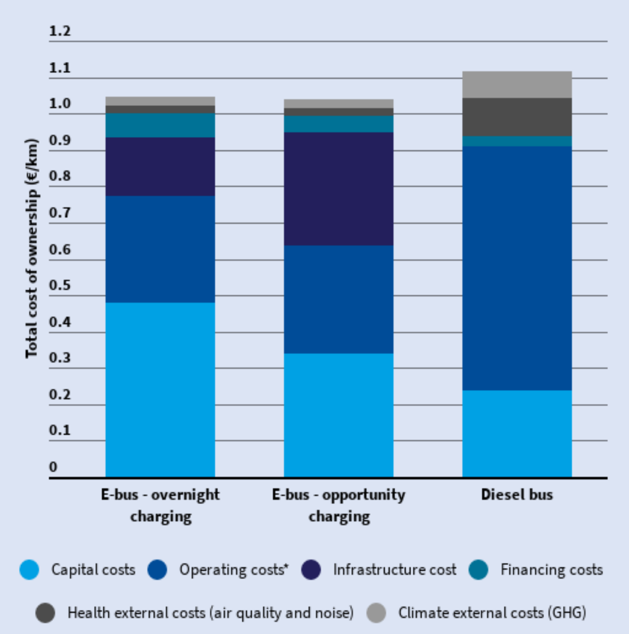
Executive Summary

Urban buses are the first transport mode where electrification is having a significant impact today. This trend is driven primarily by the rising awareness of toxic air pollution in our cities from internal combustion engines and supported by the compelling economic, comfort, and noise advantages. We expect urban buses to be the first transport mode to reach zero emission thanks to electrification.

The impressive deployment of electric buses in China has been the center of much attention, but what is the situation in Europe? Are electric buses ready for mass deployment or will the Old Continent by lagging behind? This paper examines the trend, the economics and challenges to conclude that electric bus market is on the verge of a tipping point in Europe.

The European market is quickly ramping up. In 2017, the number of electric bus orders more than doubled (from 400 in 2016 to more than 1,000); the next years are projected to follow the same tendency as manufacturers scale up production and their offerings. In 2018, the market share is estimated to be around 9%, marking the transition from niche to mainstream and the beginning of a steep and necessary uptake curve.



8-year TCO calculation, daily distance travelled of 250km, excluding driver costs, in 2018, in Europe (€/km)

Source: Transport & Environment calculation including inputs from CE Delft

*operating costs of charging infrastructure are included in the 'infrastructure cost'

Incumbent bus manufacturers are now seriously stepping up their game. Daimler, Scania, MAN, Volvo, and Iveco are actively promoting their full electric buses which are either already in series production or will be in 2019/20. This timely engagement by the traditional European manufacturers and their announced commitments to the electrical drivetrain are proof of this radical market change.

Diesel buses are a heavy cost on society and the climate through air pollution, noise and greenhouse gas (GHG) emissions. Electric buses already offer a better total cost of ownership (TCO) than diesel buses when these external costs are included. When only health costs are considered (air quality and noise), electric buses are roughly on parity with diesel buses.

Electric buses offer many additional benefits compared to their fossil counterparts. They have superior image and comfort, avoid stranded assets from investing in gas infrastructure, use locally produced (renewable) energy and ensure energy sovereignty by displacing oil consumption. The bottom line is clear, the earlier cities transition to a zero emission bus fleet, the better. To expedite this transition, cities, procurement authority and public transport operators need to:

- Embrace the future and start to procure electric buses en masse to replace their aging and polluting fleets and to live up to some of the century's biggest challenges.

- Communicate to manufacturers urging them to ramp up scale of production which in turn would reduce prices.
- Have a TCO-focused approach by shifting from upfront payments to lease or loan payments aligned with the durability of the asset to cover full lifetime over a long period of time.
- Include external costs in the tendering process when comparing different options.
- Seek and encourage new financing mechanisms from traditional funding institutions. In particular, investigate EU grant options (CEF, ERDF and Cohesion Fund) and low-interest loan options from EIB.

The EU also has a role to play to reach its climate targets, initiate a pathway towards decarbonisation and preserve the health of its citizens. To drive this change, we recommend that EU policymakers:

- Incentivise and deploy financial instruments to fund the deployment of zero-emission buses though CEF, ERDF or Cohesion Fund grants and low-interest, long-term EIB loans. In particular a grant ranging from €30,000 to €50,000 (depending on Member State's GDP) should be made easily accessible directly to cities.
- Set a zero-emission bus mandate as part of the HDV CO2 emissions standards for both 2025 and 2030.
- Exclude gas vehicles from the scope of the Clean Vehicle Directive as gas buses offer no real gains compared to diesel buses and can't be considered "clean". From 2030 all newly procured vehicles should be zero emission.
- Consider a temporary additional weight allowance for zero-emission buses to limit the passenger restrictions due to the additional weight from the batteries.

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1. Introduction

"Cities all over Europe will only buy electric buses from 2025 onwards – and I am very sure of this. Urban transport will be electric - we are on the brink of radical change". Joachim Drees in 2018, CEO of MAN Truck & Bus[i]

Joachim Drees is completely right. However, his claim is little surprise to anybody that has been looking at cities around the world introducing electric buses, driven by growing concerns over urban air quality, carbon emissions and operational costs of diesel buses. The most salient example comes from China which has about 99% of the 385,000 electric buses on the roads worldwide in 2017 (accounting for 17% of the country's entire fleet). Every five weeks, China's cities add the equivalent of London's entire working bus fleet (9,500 electric buses)[ii] which is about three times the existing European fleet of electric buses. The size of the Chinese electric bus fleet is roughly equivalent to the number of city buses in circulation today in Europe[1].

The "best practice" case of Shenzhen

A decade ago, Shenzhen was a typical example of a booming Chinese city that had given little thought to the environment. Its smog became so notorious that the government picked it for a pilot program for energy conservation and zero emissions vehicles in 2009. Two years later, the first electric buses rolled off BYD's production line there, and in December 2017, all of Shenzhen's 16,359 buses were electric.

This paper examines the situation of the European electric bus market from different angles: the situation of the market, the economics of electric buses, the role of European manufacturers, and other benefits and challenges emerging from the transition to an electric bus system. The timing is now right for cities to shift to electrified transport and this report is also intended to take procurement authorities and other key stakeholders through some of the main issues.

1.1. European cities want clean air and are committed to zero emission buses

A growing number of city governments are working to combat poor urban air quality. The Dieselgate scandal has exposed many of the problems with diesel and is leading cities to make pledges to clean up their public transport fleets. Some countries are planning to ban diesel vehicles or combustion engines, while many cities are also committing to low/zero emission zones within the city[iii]: e.g. Amsterdam, Athens, Barcelona, Brussels, Copenhagen, Hamburg, Heidelberg, Liverpool, London, Madrid, Milan, Oslo, Oxford, Paris and Rome. Some of these cities are part of the C40 Fossil Fuel Free Street Declaration that pledge to procure only zero emission buses from 2025 (and to ensure that a majority of the city runs emissions-free by 2030)[iv]. Recently, a German court upheld a ban on diesel vehicles[v], emphasising the need for electric vehicles, and zero-emission public transport. Finally, all Dutch provinces committed to procuring only 100% emission free buses from 2025[vi]. There is a clear commitment from European cities to switch to zero emission buses, which will only be strengthened in the future. In recent years, some cities have bought small

[1] Number of buses and coaches in circulation: 892,861 units (ACEA, 2017). 38% of buses and coaches are urban buses (TRACCS, 2010). About 340,000 city bus units.

number of electric buses for demonstration or test purposes or decided not to buy electric buses at all partly due to the lack of supply from their usual suppliers.

Back to the future! The story of the London Electrobus Company
London Electrobus Company was founded in 1906 and operated clean and quiet e-buses which were popular with the travelling public. The company was the first to introduce a double decker bus with a roof on the upper deck and operated up to 20 operating e-buses. In 1910, the company went into liquidation amid accusations of fraud and some of the buses were sold off. The last electro-bus likely ran until 1917 where the lack of spare parts allegedly forced the company to stop running e-buses.

1.2. The overall policy background: decarbonization by mid-century

The European Commission has been asked by the European Member States to draft a long-term 2050 low carbon economy strategy (due first quarter of 2019) which will present a decarbonization strategy in line with the Paris Agreement and with a transition to zero emission societies. Every single transport mode should be fully decarbonised by 2050, including urban buses. This report explains how urban buses can fully decarbonised by 2050 by selling the last diesel bus in 2030.

2. European electric bus market on the rise

Data for this section has been kindly provided by Stefan Baguette, ADL Market Analyst and Product Manager.

2.1. The number of electric bus orders surged in 2017

The number of battery full electric buses ordered[2] in Europe more than doubled in 2017 compared to 2016 reaching 1,031 vehicles. This is estimated to be equivalent to around 9% market share of new registrations in 2018[vii]. Today about 1,600 electric buses are on the roads and another 1,600 are on order (as of mid-2018). Since the lag between orders and deliveries is usually 9-12 months, we expect all these electric buses to be on the road by mid-2019. Clearly, electric buses are no longer a niche and 2017 marks the beginning of the steep uptake curve of the electric bus market that is bound to continue in the next years.

[2] Order date is used as the metric because it is the only with delivery date that can be established without access to business parties' own information or official registration data. Order date is more accurate than that for delivery as the latter can be spread over several months in multiple years. The lag between order and delivery is around 9-12 months on most electric bus projects in Europe. Only buses above 8t GVW (which excludes minibuses).

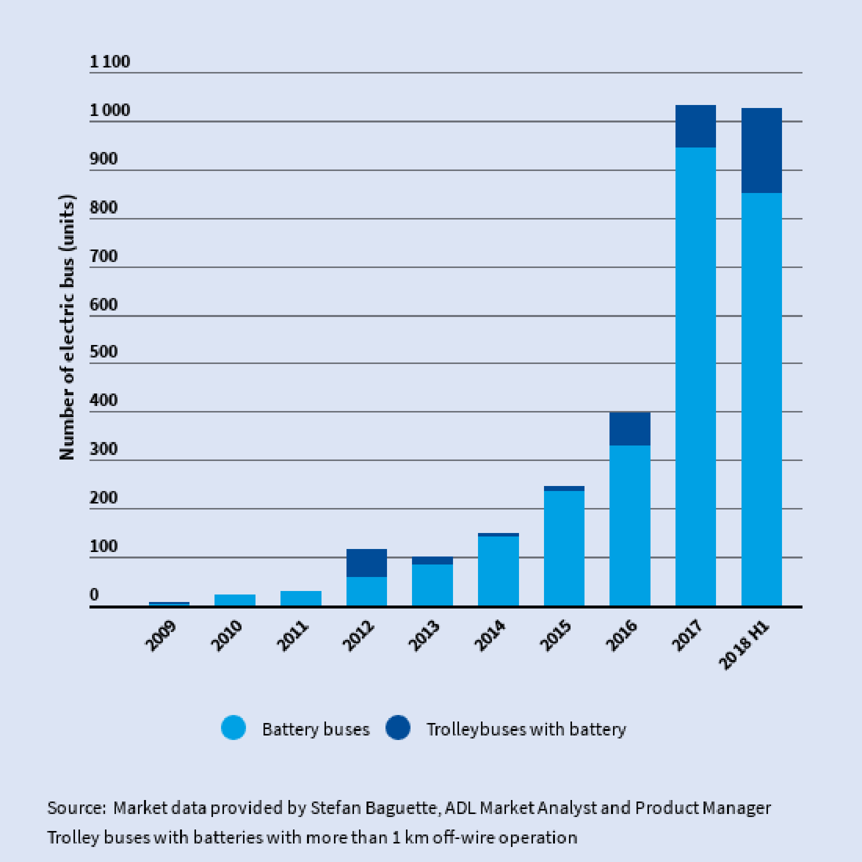


Figure 1: Yearly electric bus orders in Europe from 2009 to H12018

2.2. A clear trend towards battery electric buses

In this paper e-buses or electric buses refer to battery fully electric buses and trolleybuses with batteries. However, both plug-in hybrid buses and fuel cell buses are also classified as electric buses. These buses were excluded from the market analysis here because they do not fit in the "fully battery electric vehicle" category but also because the market trend is not as favourable as for the battery electric buses. The Figure 2 illustrates that, within electric bus sales, about 1% of the bus orders in 2017 were fuel cell buses while 8% were from trolleybuses with batteries[3] and another 8% from plug-in hybrids. However cumulatively trolley-buses with batteries have represented more than two times more orders than plug-in hybrid buses. Battery electric buses are clearly taking over other forms of electric vehicles.

[3] > 1 km off-wire stand-alone operation with full traction and auxiliary performance (also known as dual mode trolley bus). Battery electric buses and trolley buses with batteries are the same with the exception that one is equipped for on-route charging while the other charges statically.

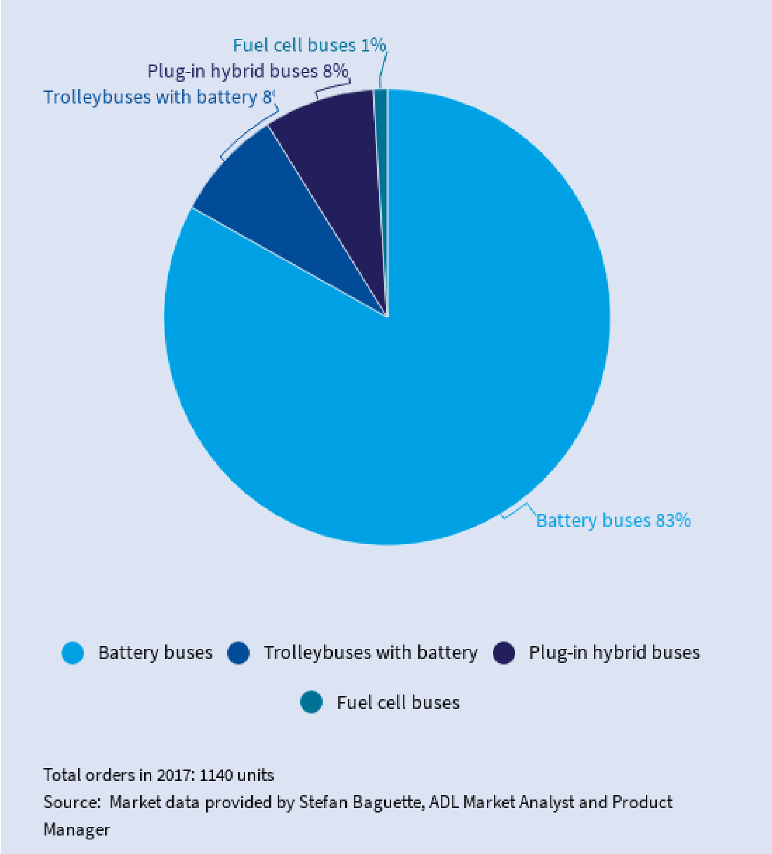


Figure 2: Orders of electric buses in 2017 per technology

Plug-in hybrids, are not likely to play any significant role in the future urban bus market. Mainly because of the manufacturing complexity (thus cost) and tailpipe emissions, but also because trolley buses with batteries or fast charging e-buses are the preferred solution to address range limitations. Interestingly, trolley buses with batteries are more common, in cities that have kept "old" overhead charging wires and are re-using this existing infrastructure. This is also the case in former Soviet Union countries where trolleybuses never disappeared (e.g. Russia, Belarus, Ukraine, Moldova and Kyrgyzstan)[4], although these are not included in the scope of data in this chapter.

2.3. Five countries account for more than half of the electric buses

Electric buses are not equally distributed over European countries, with the Netherlands, UK, France, Poland and Germany accounting for more than half the total number of electric buses in Europe (including orders).

[4] Most European countries removed trolley buses in the 1960s and 1970s to the advantage of private cars and diesel buses
http://www.lowtechmagazine.com/2009/07/trolleytrucks-trolleybuses-cargotrams.html

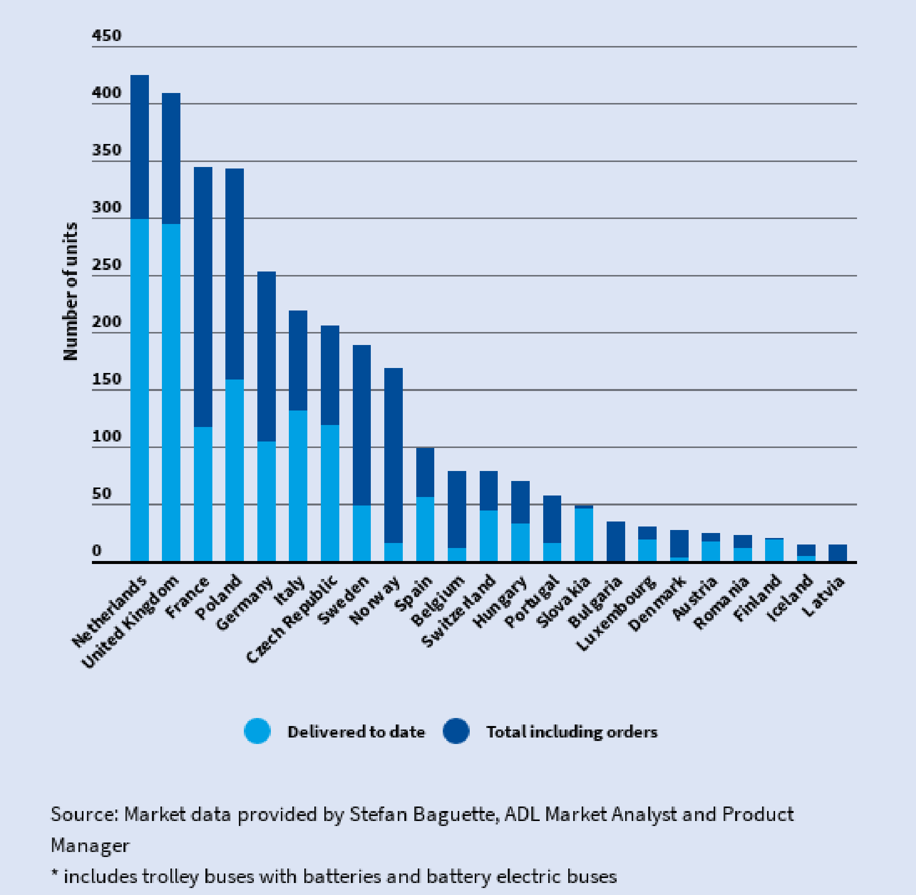


Figure 3: Total electric bus fleet including orders in Europe (up to H1 2018)

Interestingly, three countries have a significantly higher share of trolley buses with batteries. Poland, Italy and Czech Republic have a between 38% and 50% of their buses (including orders) from trolley buses with batteries.

2.4. BYD, VDL and Solaris: from new comers to market leaders

By analyzing manufacturers' statements made in autumn 2018, it is apparent that nearly half of delivered and ordered electric buses come from three manufacturers who appear to lead the market. BYD reported over 600 battery electric buses sold and a 20% market share[viii] , while VDL reported 500 sold[ix]. Solaris claimed 330 battery buses delivered and ordered and also asserted itself as the leader of the European trolleybus market.[x] According to industry sources, Volvo has been selling the lion's share of Europe's plug-in hybrids buses. This enabled the manufacturer to gain the required preliminary experience on the charging infrastructure and the support for route evaluation in order to offer full electric buses today.

3. Different battery electric bus systems for different applications

Before going into more details about electric buses it is important to understand that they are classified in two categories depending on selected charging option while still using electrical energy stored in rechargeable battery packs:

- Overnight charging: Battery electric buses are charged statically from the grid at the depot using mechanical and electrical equipment, mainly overnight. They have large battery capacities (typically >200 kWh) enabling an extended range from 100 to 250 km and recharge at the depot with slow chargers (typically 40-120kW). No products in the market reliably manage over 250 km yet.
- Opportunity charging: Battery electric buses can minimize the weight of the battery by recharging at passenger stopping points or at the bus terminal. They have medium battery capacity (typically 50 - 150 kWh) and need high-power charging usually through over-head pantographs. This can be done either at bus stops (on-route charging, up to 600 kW) in about 30 seconds while passengers board or disembark, or at the bus terminal (usually between 150 to 500 kW) during the longer operational stop at the end station. 60% of electric buses ordered in 2017 will be charged with roof-mounted or gantry-mounted pantographs making it the solution of choice for many operators.[xi]

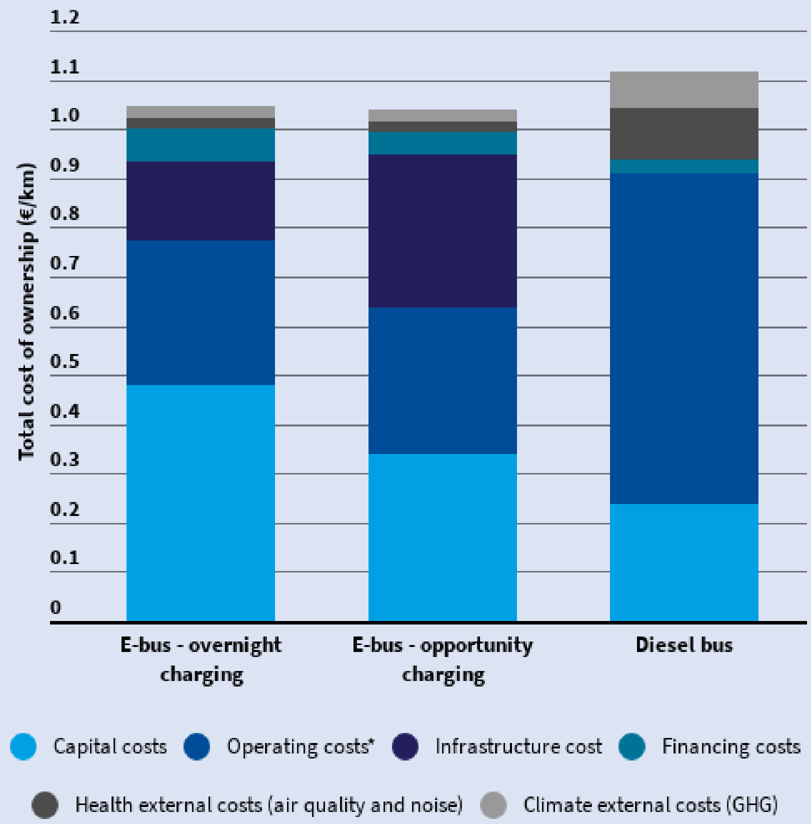
Both systems should not be compared against each other to “pick a winner”. They serve different applications and both should be considered by cities looking to procure clean buses. Depending on the conditions and the context of the procurement, the bus charging system can be implemented in a way that charging time and limited range doesn’t impact operations. For example, in Paris, installing overhead charging systems is not permitted to protect the historical or cultural heritage; thus the city uses only overnight charging buses. On the other hand, opportunity charging buses can run a several hundred kilometers and fast charge at bus terminal during the operational pause and bus driver shift. In Amsterdam at Schiphol Airport[xii], the fleet of 100 electric buses charge with 23 fast chargers at 450 kW via pantographs over a 12 minute process[xiii] enabling a 24/7 operation with buses travelling up to 500 km daily. Opportunity charging enables automatic connection to the overhead electricity source but obtaining construction permits can delay the tendering process.
In 2017, 60% of the orders of electric buses and plug-in buses were buses with pantographs. The other 40% will only be charged with a plug[xiv]. In the future we expect overnight charging buses to take over an increasing share of the market as battery costs continue dropping (see Annex for future cost analysis).

Future possible development: The Autonomous Rail Transit[xv]
“Trackless trams” using rail technologies on buses are being tested in China and Australia. Propelled with energy stored in batteries, these “buses” could carry up to 500 passengers, recharge for a 3 to 5 km trip in 30 seconds. It has the speed (70 km/h), capacity and ride quality of light rail without the high infrastructure costs and disruption to local economies and urban development.

4. Electric buses offer better TCO when external costs are included

4.1. Results

T&E has undertaken a total cost of ownership calculation that includes external costs on health and climate and is based on inputs from CE Delft. These externalities are not reflected in the typical TCO calculation and translate how much noise, air pollution and GHG emissions costs to society. The results presented in the graph below show that after including external costs, electric buses are cheaper than diesel buses.



8-year TCO calculation, daily distance travelled of 250km, excluding driver costs, in 2018, in Europe (€/km)

Source: Transport & Environment calculation including inputs from CE Delft

*operating costs of charging infrastructure are included in the 'infrastructure cost'

Figure 4: TCO comparison of electric and diesel buses

The purchase costs of battery electric buses remains higher, with a purchase price that can typically reach twice the cost of a regular diesel bus. These higher capital costs are mitigated by much lower operational costs as one of the biggest advantages of electric buses is that they rely on electricity to run, which is both much cheaper than imported fuel and more efficient than ICE's. As battery prices drop even further thanks to economies of scale and investment in R&D, purchase price of electric buses are expected to drop. According to BNEF (see Table 1, Section 5.6), battery prices for e-buses will decrease by 9% to 12% annually on average over 2016-2030 depending on the level of demand in the European market. That is a 75%-83% drop in the cost per kWh.

A TCO calculation excluding external costs would indicate that diesel buses are cheaper than electric buses. However, the picture significantly changes when external costs are included and electric buses prove to be a cheaper option. External costs include health costs from air pollution and noise which are directly passed on in the form of premature death, respiratory diseases, loss of productivity and other negative impacts. On top of these health costs, the climate cost of greenhouse gases (GHG) are also considered. The latter costs are not directly passed on to cities but European cities are nonetheless committed to GHG emissions mitigation through the Paris Climate Agreement and other commitments or targets (e.g. EU non-ETS sector targets or the C40 Cities Climate Leadership Group).

Figure 4 shows the TCO comparison of a diesel bus with two different types of electric buses. The assumptions for this calculation and a sensitivity analysis (daily distance travelled, cost of electricity, 2020 outlook) are included in an annex to this paper. The key findings are the following:

- When external costs are excluded, electric buses are still slightly more expensive than their diesel counterparts (0.94€/km for a diesel bus and about 1€/km for both types of electric buses)
- Including health costs shows that the electric buses are cheaper than their diesel equivalent: a diesel bus costs 1.04 €/km versus 1.01 €/km for an opportunity charging e-bus and 1.02€/km for an overnight charging e-bus.
- After including climate external costs, the difference gets more notable and electric buses are clearly a cheaper option at 1.05 €/km for an overnight charging bus, and 1.04€/km for an opportunity charging bus, compared to 1.12€/km for a diesel bus. The gap between the two technologies will only grow bigger as the grid decarbonises.

4.2. Discussion

Calculation of TCO is a multi-faceted exercise, first of all TCO can vary a lot from one country or city to another since it depends on many factors such as fuel / electricity prices, annual driving distances, charging configuration, financing costs, battery specifications and lifetime, and vehicle taxes (i.e. ownership or registration taxes), road charges (e.g. congestion charging) or subsidies (see the Annex for more details).

- When taxes and charges are differentiated to the fuel type of the bus, this may significantly affect the results of the comparative TCO analysis. The same holds for specific subsidy schemes that differentiate between diesel and electric buses. An annual tax or charge of €5,000 for diesel buses would be sufficient to bring the TCO (excluding external costs) of diesel buses to parity with overnight charging buses. This revenue stream could be further used to finance the installation of infrastructure or potential grid upgrade or connection investments. This financing gap could also be addressed with grants on the purchase of e-buses. A grant of €40,000 on the purchase of an overnight charging e-bus would be sufficient for the TCO to reach parity, without including any external costs. This idea is taken up later in this report.
- Electricity costs can vary a lot between countries with costs ranging from 0,06€/kWh in Sweden to 0,15€/kWh in Germany. For example in Sweden, electric buses are at parity without taking external costs into consideration while in Germany parity is only reached when health and climate external costs are included. In addition, Sweden has the lowest grid carbon intensity (10 gCO_2/kWh) which furthermore strengthens the case for e-buses.
- Daily distance travelled is an important factor in the TCO calculation. At 250 km daily, overnight charging electric buses and diesel buses reach cost parity at 1.02€/km when external costs are included (including GHG emissions). Without GHG emissions externalities, overnight-charging electric buses would cost 1€/km whereas its diesel counterpart would be at 0.95€/km (4,500€ difference per year).

The battery capacity influences very much the calculation as battery price can account up to half of the vehicle's capital cost. Hence, it is essential to optimize the battery size and charging infrastructure in line with route needs. Over-sizing the battery or the charging infrastructure could be an unfortunate financial waste (see Section 7: A holistic approach).

To be on the safe side, some assumptions have been chosen rather conservative. For example, the battery was assumed to have no residual value after 8 years (no second use considered), even though it is now clear that these large bus batteries will very probably serve as secondary stationary storage batteries to balance the grid as is done in Amsterdam[xvi] or Hamburg[xvii]. When a replacement for the battery is considered, electric buses are assumed to have a longer lifetime thanks to the relative simplicity and reliance of the electric motor and equipment. In addition, the cost for the bus body is $40,000 higher for an electric bus rather than a diesel bus (+16%, according to IEA); this is a conservative assumption which is probably the consequence of lower production volumes. We expect the cost of the bus body to reach parity in a few years.

This calculation assumes that no additional drivers or buses are needed when shifting from diesel to electric buses. While this will not hold true in all situations, it does apply once the most suitable routes for e-buses are electrified first, together with the use of the most appropriate bus models, and followed by EU reforms regarding bus weight (see recommendations for Weights and Dimensions).

Our findings are corroborated by Scania[xviii]which claims that cost-parity has currently been reached for buses in Germany and Sweden[5] and by Volvo which show-cased a tool comparing TCO including external costs at the IAA 2018 Hannover fair (demonstrating electric buses are cheaper).

Battery chemistries

Lithium-Iron-Phosphate (LiFePo or LFP) batteries used to be the lithium battery of choice but in the marketplace but they are being overshadowed by Nickel-Cobalt-Aluminium (NCA) and Nickel-Cobalt-Manganese (NCM or NMC) batteries that are lighter (higher energy density) and are quickly reducing in price. LFP batteries are safe, have a high cycle life but a low volumetric energy density. On the other hand, the amount of cycles NMC and NCA can be used is coming closer to the amount of cycles provided by LFP. AS a result, NCA and NCM batteries will be the focus for e-buses in the future. This has been corroborated by most of the e-buses presented at the IAA fair in Hannover which are based on NMC chemistry. However when short range suffices, or when weight is not a problem, there would still be a place for LFP because of its higher number of cycles. Later, the focus will likely be on lithium-sulphur, silicon and solid state technologies.

Although TCO is important for cities, costs are not the only forces driving changes to electric buses. There are many more issues to consider other than cost, which can also lead to disinformation and slow down adoption. These challenges will be tackled in later in the paper.

5. Beyond cost considerations, e-buses offer many advantages

Before we investigate some of the challenges linked to transitioning to electric buses, it is worth pointing out several of the other advantages that electric buses offer beyond the cost consideration.

5.1. Air quality

Air pollution resulted in the premature death of around 400,000 people in the European Union in 2015 and approximately 74% to 85 % of EU's urban population was exposed to concentrations exceeding the WHO

[5] Sweden has very low electricity prices of 0.06€/kWh (see above) while Germany benefits from a grant of 80% on the incremental cost of zero-emissions buses when compared to diesel counterparts.

air quality guideline for particle matter, the European Environment Agency reports[xix]. Health benefits should be a key consideration in the decision to switch to new technologies. The TCO calculation in this report can help assess this impact. However it is worth noting that over its lifetime a diesel bus will cost society €19,000 for air pollution alone[6]. The Electro-mobility Platform has conducted an analysis[xx] comparing EU NOx emissions in different scenarios. In this comparison, we see that combustion engines can only reduce emissions to a certain extent, and will always emit toxic fumes.

5.2. Electric buses offer better customer experience.

There is a benefit from e-buses beyond technology change itself; if cities renew their bus fleets with new, electric vehicles, bus systems will get a better image. Electric buses improve the customer experience, with less noise and fewer vibrations, all creating a more comfortable journey. This attracts more customers, which has a positive environmental impact in itself by increasing modal shift from private cars to buses. Cities and transport operators can seize this opportunity to become incentivize behavioral change and evolving from a bus company to a mobility company.

5.3. No stranded assets from investment in gas vehicles

Some cities believe that they have found an efficient way to decarbonize their bus fleet with fossil natural gas and biomethane. In reality this is a very poor choice[xxi]. First, the use of methane will not have a large impact overall (well to wheel) GHG emissions, in the range of -2%/+5% compared to best in class diesel trucks, we can expect similar results for buses.

Second, gas trucks offer no meaningful benefit on air quality as measured by NOx compared to vehicles complying with the Euro VI standard. Most research gives mixed results regarding NOx[xxii] while particle number emissions are also higher in gas/methane powered transport, compared to diesel.

There are no good grounds to move to gas buses. The city of Madrid - which has signed the Clean Bus Declaration - is an astonishing example of how a city can get it wrong when renewing their fleet: the city recently committed to buying 460 gas buses over the next two years[xxiii] (24% of the total bus fleet[xxiv]), where there are cleaner options on the market.

Biomethane can provide significant CO_2 reductions over the whole life cycle; however, future supply availability and scalability beyond the local scale is an issue requiring case-by-case consideration. The sustainability of the source is also a concern as fully sustainable sources are limited. Solid waste streams are partly composed of fossil origin (e.g. plastic), which doesn't make it a sustainable source. Energy crops can lead to undesirable environmental impacts such as increases in indirect land use change and putting pressure on the amount of land available for growing food crops. The current biomethane produced in cities is in most cases already used: it is either injected to the gas grid or used to generate electricity. The limited amount of advanced biomethane not currently used should be used for the sectors which have existing infrastructure such as the heating or electricity sector, not the transport modes that are the easiest to electrify. Mixed fossil gas/biomethane investments are also a concern as today only 4% of the gas in the grid is from renewable sources[xxv]. The European Biogas Association aims at a 5% contribution of biogas in EU's total natural gas consumption in 2020 and 10% in 2030.[xxvi]

[6] 12 year average lifetime (source: ACEA, average vehicle age of heavy duty vehicles)

As emission restrictions for all vehicles get more stringent in cities, gas buses are bound to become stranded assets, together with the high investment costs for refuelling infrastructure while electric bus systems are a future-proof option.

5.4. Load balancing and renewable energy

Relying on electricity as the main source of energy enables greater load balancing of the energy system and higher energy sovereignty through deployment of local renewables.(For example, bus operators can themselves install solar panels on their premises, delivering energy to the grid during the day and taking energy during the night).

5.5. Oil displacement and energy security

Already today, electric buses are starting to dent oil consumption in a significant way. For every 1,000 battery-powered buses on the road, about 500 barrels a day of diesel fuel will be displaced from the market, according to BNEF calculations[xxvii]. Globally, in 2018, BNEF estimates that about 233,000 barrels of oil will be displaced every day thanks to electric buses alone, 84% of total fuel displacement from electro-mobility as a whole. In the EU, the estimated 3,200 electric buses on the road next year would displace close to 600,000 barrels per year, saving more than €40 million annually. The oil displaced also contributes to the EU's energy security as the electricity is produced within Europe.

5.6. Increasing demand for e-buses will bring prices down more rapidly

According to Bloomberg, increasing demand for e-buses in the European market can bring e-bus battery prices down much faster, bringing them closer to the high-volume prices that automakers are able to get for passenger EVs. In this scenario, electric buses with the bigger battery packs would reach upfront cost parity with diesel buses sooner, around 2025-27 instead of 2030. The table below shows the impact of the high-volume demand of European e-bus on the battery price evolution:

Battery price for buses (€/kWh)	2016	2018	2020	2022	2024	2026	2028	2030
Low demand in European e-bus	510	333	269	224	194	167	146	129
High demand in European e-bus	510	333	262	204	160	122	102	85
Variation low vs. high demand			-3%	-9%	-18%	-27%	-30%	-34%

Table 1: BNEF Forecast of battery prices depending on European demand for e-buses

By 2030, batteries could be less expensive by a third in the scenario of high demand. For this reason it is crucial to stimulate domestic demand for electric buses so prices for e-bus batteries can decline rapidly, match passenger EVs battery prices and forge a competitive European electric bus-making industry.

5.7. Stimulating European industry

High procurement levels of electric buses would encourage local industrial players to manufacture clean buses, which in turn would be a benefit to their competitiveness with foreign electric bus manufacturers. The electro-mobility Platform has mapped out the various European actors of the e-bus manufacturing[xxviii], the potential for the European industry and job creation is important with many infrastructure and component suppliers in addition to numerous e-bus manufacturers.

In California, the Zero-Emission Bus (ZBus) regulation from January 2000 mandated a 15% procurement requirement for transit agencies with fleets larger than 200 urban buses[xxix]. As a result the zero-emission bus industry is flourishing and today there are more zero-emission bus manufacturers than conventional buses manufacturers[xxx] with 14 zero emission bus manufacturers (3 fuel cell electric bus manufacturers and 11 battery electric bus manufacturers).

In Europe, the best example of the benefits from European zero emission bus industry doesn't come from any of the traditional manufacturers but from Eastern Europe. Poland has become a leader in electric buses thanks to the company Solaris which has been supplying electric buses to several dozen European cities since 2011. Their flagship electric bus, the Solaris Urbino 12 electric, was named "Bus of the Year 2017" and it was the first time in the history of the competition that the award went to a battery-driven vehicle.

5.8. Long-term Paris agreement compliant

About 7,750 local European authorities, totaling more than 250 million inhabitants (about three quarters of the CO2 emissions produced in the EU) have committed to mitigating climate by signing the Covenant of Mayors. It is their responsibility to provide an action plan which should set a clear trajectory for decarbonization of urban buses, which are just one percent of all vehicles on the road but 25 percent of emissions in the transport sector according to ICCT[xxxi]. Figure 5 compares a reference scenario relying on diesel buses only and a second scenario based on the proposition of the electro-mobility platform[xxxii] which sets a target of 100% zero emission buses sales in 2030 (together with an intermediate target between 45% and 66% in 2025, depending on the Member States). The difference in emission from these scenarios is significant; failing to decarbonize urban buses would contribute to an additional 18 Mt of CO2 eq. emitted annually in 2050 - which is approximately the annual CO2 eq. emissions from passengers' cars in the Netherlands.

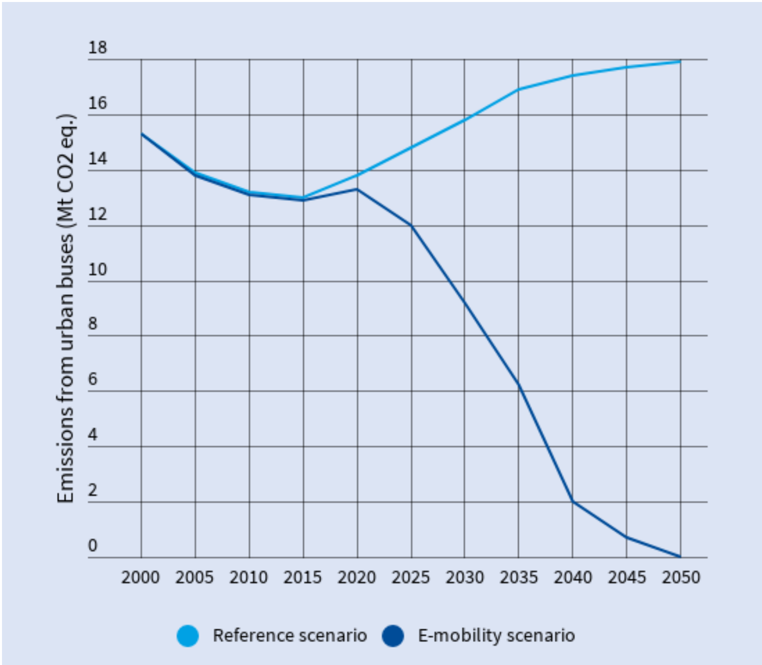


Figure 5: Modelling of greenhouse gas emissions from urban buses

6. European manufacturers are getting serious

Mid-September 2018 saw the IAA in Hannover -the largest European fair for heavy duty vehicles- and manufacturers were keen on unveiling their new electric buses entering or ready for series production. This timely and serious display of the traditional European manufacturers is proof that the challenges that face electric buses, such as adapting operations and financing the upfront costs (see next section) are now mostly solved. The table below shows an overview of the fully electric 12 meter buses offered by the top 5 manufacturers of buses in Europe (all presented at the IAA 2018).

OEM	Name	Battery capacity/Range	Series production
Daimler	eCitaro	240 kWh	end 2018
Scania	CityWide Electric	150 kWh	now[xxxiii]
MAN	Lion's City 12 E	480 kWh/200-270 km	2019[xxxiv]
Volvo	Volvo 7900 Electric	150/200/250 kWh	now
Iveco / Heuliez	GX 337 ELEC	349 kWh/200-250 km	now

Table 2: Selection of electric buses offer by the main European manufacturers

Figure 6: (from left to right, top to bottom): MAN, Heuliez (Iveco), Daimler and Scania fully electric buses presented at the IAA 2018 in Hannover

And some more announcements:

- *"Cities all over Europe will only buy electric buses from 2025 onwards – and I am very sure of this. Urban transport will be electric - we are on the brink of radical change".* Joachim Drees, CEO of MAN Truck & Bus[xxxv]
- *"The future of inner-city transport will be electric—no doubt about it."* Rodrigo Chaves, Traton (formerly Volkswagen Truck & Bus)[xxxvi]
- "*Electric drive is no longer a niche, it's a major player*", said Gustav Tuschen the Head of Development at Daimler Buses[xxxvii].
- Ulf Magnusson, senior vice president of Volvo's Bus Corporation believes "*electric bus systems are the future of urban public transport, as environmentally clean and comfortable as a tram or light rail, but at a fraction of the overall cost.*"[xxxviii]

From private exchanges, many OEMs believe the doubling the sales of electric buses every year seems like a reasonable objective. If this pace is sustained, about 5-6 years could be sufficient to overtake all diesel sales.

Together, Daimler, Scania, MAN, IVECO and Volvo sell 73% of the buses and coaches in the European market[xxxix]. On top of this, in the framework of the ZeEUS project, about 30 additional manufacturers also offer electric buses to the European market.

In recent years, some cities have bought small number of electric buses or decided not to buy electric buses at all partly due to the lack of supply. European OEMs are facing strong competition from Chinese bus makers which benefit from generous national subsidies with the notable example of BYD which already has a production capacity of around 400 electric buses per year in Europe[7]. According to the World Resource Institute, the city of Shenzhen -hometown of BYD- received a $150,000 in subsidy per bus prior to 2016 to electrify its entire bus fleet with BYD e-buses[xl]. The introduction of a wide range of new electric buses from European manufacturers is timely and welcome.

7. A holistic approach

When procuring clean buses, cities are not simply buying new buses but are switching to a whole new system. Many elements need to be reconsidered and revised and a holistic approach is essential.
Because of a range limitations, electric buses are less flexible which can make it difficult to replace a diesel bus with an electric bus on a 1:1 basis. This is particularly the case for the longest routes and for buses with long operational days. For example a bus route that operates 24h/7 would be impossible to incorporate in a fully electric fleet composed only of night charging buses; however, an opportunity charging system could eliminate this complication.

7.1. Modularity of e-buses and charging system

Every city has specific needs and municipalities should carefully choose the products and adapt the operations in order to avoid over-sizing the size of the fleet or the battery. The different possibilities should be compared with a systemic approach involving a trade-off between numerous performance and price categories. Choosing and configuring the products carefully allows e-buses to operate on almost all routes. When procuring, operators and municipal authorities should consider that electric buses are modular systems with many different options and possibilities. These systems are mainly adaptable through the battery size and technology, the charging system and power supply to find the right configuration. For example, all the buses presented in the previous section are offered with a pantograph as an option for opportunity charging (which usually costs an additional €10,000) and most of them offer different options for the battery size. According to Daimler, *"the right configuration of Citaro E-CELLs and supporting infrastructure can be found for every route. (…) thanks to the customization options, the model series covers every conceivable angle. The Citaro E-CELL will be a customized urban bus built on the basis of largely standardized components."*[xli]. Early in the procuring process an analysis of the objectives and needs of the transport operators and authorities should be carried out. This will be essential to decide jointly on the best technological offer. Finally the procurement should be based on optimized worse condition specifications to take into account factors such as battery degradation, heating and cooling, (lack of) eco-driving, traffic, and topography, to avoid over-sizing the fleet.

7.2. Optimized charging and operations

Once the products have been adapted to the specific needs of the city, the operator needs to optimize operations, routes and timetables by taking into account the charging needs of each of the buses and energy network. Carefully optimised charging and operational regimes combined with real-time energy management will eliminate range anxiety and can also help maximise battery life (thus making electric buses cheaper). Some manufacturers (e.g. Volvo, Solaris, VDL) provide instruments and tools which can

[7] BYD recently opened a factory in Beauvais, north of Paris, with a potential of 200 electric buses per year. Another factory un Hungary opened late 2017 has comparable annual production volume

help assess the feasibility of deploying electric vehicles on new routes by providing solutions regarding charging, positioning, battery charge status and energy usage. The usage and driving data collected by the manufacturers will also benefit them by building on additional real performance information.

7.3. Financing the high upfront cost: lease or loan payments

Zero emission buses require intensive initial capital costs for the vehicle but also for the charging system and the re-arrangement of the depot. This can prove to be a market barrier to their adoption. Because concessions typically run for less than the time needed for the electric bus to start returning on its investment, the investment is usually considered risky and unattractive for investors typically focused on shorter term returns. Electric bus concessions should be longer in order to be more in line with the return on investment requirements.

Today, the majority of e-buses on the road were purchased using a combination of national and local grants and self-funding and thus didn't involve loans and financial costs. Additional public funding in the form of grants for the upfront financing is in many cases a condition to enable cities to procure clean buses. National governments and EU funds dedicated to cities (see annex, EU policy recommendations) should provide support to cities that have poor air quality and good ambition but little means to achieve them. As the e-bus sector matures, we will see more loan financing involved. This change is a good opportunity for municipalities to focus more on TCO by shifting from upfront payments to lease or loan payments enabled by lower operating costs and aligned with the durability of the asset to cover full lifetime over a long period of time. Some financing mechanisms are for example municipal capital or operating lease where the local authority can lease the bus with the option to own the bus at the end of the lease term or battery lease where the bus is bought for roughly the same price as a diesel bus and the battery is leased (option offered by Proterra). This enables lower operating risks as the performance of the battery has to be preserved through its life and is therefore the responsibility of the OEM. Other reported financing barriers are banks and other lenders not familiar with incentives, or traditional leasing companies that typically don't value any residual in electric vehicles. Traditional financing mechanisms (and associated traditional financing institutions) are not usually in line with new needs and cities should seek and encourage new practices.
The residual value of the infrastructure should also be considered in the contract and transferred to the next operator.
Member States can also act at national level to help finance the transition to e-buses with a similar grant. For example, Germany introduced a fund to cover 80% of the incremental cost of electric buses through grants, which is expected to fuel a sharp market uptake.[xlii] As a consequence, the five biggest cities in Germany are now planning to order at least 3,000 electric buses by 2030[xliii].

Other elements to be considered in the holistic approach:

- The charging space and location at both depot and bus stops/terminals which are spaces not usually designed to incorporate vehicle chargers
- Finding the location and obtaining the permit for opportunity charging can be burdensome during the tendering phase and providing additional risks. To remedy this challenge, authorities should standardize tender specifications and appoint a location and supply the grid connection, saving time and effort to the tendering organisations.

- Quality guarantees and performance monitoring: It is the role of manufacturers to provide a clear form of guarantee that ties quality and cost on the basis of verifiable performance and to include these features in negotiation and contract
- Infrastructure charging standard: The European Standardization Organisations CEN and CENELUX have been mandated (M/533) by the EU Commission to make a recommendation for standardization of electric vehicle and bus charging by the end of 2019. The deadline is not in line with the current uptake of the market but many consortiums have agreed to ensure interoperability of their e-buses and charging systems.
- Power and grid connection: The distance to the power source can be the issue, not the level of power required for the grid connection[8] since grid costs depend largely on the distance of the bus depot/station to the power source required (usually a 11kV grid connection). Luckily many cities that operate metros and trams already have such a grid connection close to their bus depots.
- Specialised personnel: Offering training to drivers (eco-driving, energy monitoring), to the technical workforce (high-voltage technology, electrical equipment, maintenance procedures) and to the firemen (security, safety) is necessary. The shift from an engine/diesel-centric workforce to an electric one should be carefully addressed and the existing expertise form electrical equipment and power electronics from the existing trams or metros can be very beneficial.
- Heat management: Both A/C and heating can significantly affect the energy consumption of the bus. In summer this is usually offset by reduced operations in July and August while in winter a small heat pump can be used or the coldest days of the year in addition to heating the bus while it is still connected to the grid before starting operations
- and many others: second life batteries, smart energy management, more attractive e-ticketing options, optimized passenger flows, etc...

8. Conclusion: the time is right to engage in the transition

8.1. The turning point for zero emission urban public transport

The European electric bus market is now mature and ready for high-volume production. 2018 is set to be a breakthrough year for the European bus market with many significant signs of full maturity. Paris is a very good illustration of the full maturity level of the technology. The city tendered for 1,000 electric buses worth up to €400 million to start service in 2020[xliv]. Thanks to high volumes, it aims to get prices no higher than €400,000 per bus. Poland has also set a target of 1,000 electric buses, which it hopes to procure by 2020.[xlv]

Even though the challenge to finance the initial capital costs of e-buses is real and might slow down the uptake, tailored financial instruments (e.g. battery leasing) and support (from the EU and national government) are bound to adapt rapidly to the transition and provide tangible and reliable solutions. Electric buses can already offer lower TCO when environmental costs are included and will in the next years be the most cost-effective solution for urban transport authorities and operators. While municipalities may wait a few years hoping the purchase price will drop further, this is not the right approach. The time is right for cities to engage this transition for multiple reasons:

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[8] MW grid connections can be found in many places in metropolitan areas (i.e. metro, trams, industrial or commercial facilities, etc..)

1. Transitioning entirely to zero emission will be a timely process which can't be undertaken with a single tender for most medium and large cities. Starting now guarantees a more step-wise and smooth transition which in turn offers the possibility to identify risks and weaknesses early on and enables timely infrastructure deployment and upgrades. Authorities, managers and employees will need to adapt to zero-emission operations. The sooner the various actors can familiarize themselves with e-buses, the better their qualifications and experience will be, positioning themselves to spread operational expertise across their city or region (experience can already be gained from the early-adopter EU cities).
2. Planning e-buses on attractive and busy routes that are more likely to give a positive experience to a large number of different users. This approach should also address in priority areas suffering from poor air quality.
3. Citizens are very concerned about air quality. Governments, regional and local authorities should live up to those expectations and not wait for citizens to use desperate measure to gain political attention in an attempt to preserve their health (for example, in Flanders, citizens have installed 20,000 air quality measuring devices[xlvi]).

8.2. Going out of the comfort zone

Moving from diesel to e-buses implies engaging in a new tendering structure, where the buses and the infrastructure need to be rolled out simultaneously. Tenders may come from new suppliers, and there is a learning process with the new technology and its elements. This would be eased if the usual suppliers would be strongly incentivising these vehicles and educating on their use. Cities that care about their citizens need to be willing to make this step out of the comfort zone even if it implies changing vehicles technology, but also their technical characteristics, operational aspects, maintenance procedures and tendering specifications. Considering their announcements and new products, it now seems that most manufacturers are ready to supply electric buses. But more importantly citizen deserve honest willingness and ambition from their transport operators and political representatives to make the change.

8.3. Towards a zero emission urban bus system

The approach to the transition has to be holistic and should carefully address all the challenges previously identified. However these challenges can already be tackled today; e-buses are on the verge of becoming a no-brainer for any given comparison metric. The biggest challenge might be for the European bus industry, as it will need to change quite radically to retain market share and its leadership position in the face of fierce competition from abroad.

Clearly in 2025, no public authority will want to order buses that are toxic, loud, and that rely on imports of tens of thousands of barrels of fossil fuel in uncertain political and economic conditions - rather than using renewable energy, often available locally. To fully benefit from the clean technology, the expertise and the positive externalities, an early transition will always be more beneficial.

9. EU policy recommendations

9.1. Clean Vehicle Directive

In November 2017, the European Commission proposed a revision of the Clean Vehicle Directive, which aims to promote clean mobility solutions in public procurements by setting targets for the public procurement of “clean” buses (which includes zero emission buses as well as natural gas buses). The recent vote in Parliament sets targets up to 50 % in 2025 and 75 % in 2030 in most western and northern member states with a sub-target for zero emission buses. A 100% procurement of zero emission buses is technically feasible, economically sound and environmentally necessary. Therefore, the Commission’s proposal lacks ambition as it would merely encourage public authorities to follow the market rather than direct it, giving a negative signal to the industry and not responding to growing citizen concerns over bad air quality. Our recommendations are the following:

- Procurement targets should focus on zero emission vehicles only; gas vehicles should not be considered ‘clean’ in this regulation since gas vehicles show little to not air quality and climate benefits.
- From 2030, all newly procured vehicles in the EU should be zero emission.

9.2. Financial instruments: put forward EU funds for zero emission bus deployment

Financing the upfront costs of electric buses and the fear of embracing a new and different technology are the biggest hurdles to the adoption of electric buses. The EU could play a very significant role here and give a strong signal to industry and cities by creating a fund dedicated to the procurement of electric buses. Such a fund could allow for municipalities or regional authorities to apply for EU grants. This grant could go up to several tens of thousands of euros and would reduce, if not eliminate the concern of financing the purchase cost of the electric bus. Allowing for municipalities to apply directly for such financing would remove the procedural bottleneck involved with applying for EU funds via federal transport ministries. If the EU and local mayors were to be seen to actively push for electric buses, transport authorities would be obliged to support this technology. This signal would also be strong for the EU bus industry too as they would be confident in future demand for electric buses. In the past the European Regional Development Fund (ERDF) and Cohesion Fund have been used to grant €41 million to Poland to fund the acquisition of 130 electric buses in Warsaw. The buses should be in service by 2021 and will help to clean the air of the Polish capital.[xlvii] A far larger share of the ERDF should be earmarked for sustainable urban mobility with a large share of such a fund going towards the co-financing of electric bus fleets. Furthermore, the precedent of grants offered for the purchase and retrofitting of rail wagons with low-noise technology[xlviii] could be applied to promote a grant for zero emission buses on a similar logic. We propose that a sliding scale be applied based on Member State GDP ranging from €30,000 to €50,000 per zero emissions bus.

For higher GDP countries, low interest loans with longer repayment periods could be a good alternative to boost the procurement of electric buses. Taking this idea further, the European Investment Bank (EIB) could encourage cities and public transport authorities to coordinate applications for such loans. This could involve working groups for cities and public authorities or, simply, online documents that outline how to apply for such loans. Such investment would help the EIB to achieve its own climate targets. In Spain for example the EIB has financed the purchase of 17 new “environmentally friendly” buses[xlix] with a €50 million loan while the city of Riga has benefited from a blend of CEF grants (€8M) and an EIB loan (€75M) to finance the acquisition of hydrogen buses and their infrastructure[l]. Another financing option is the European Bank for Reconstruction and Development (EBRD) which has funded the acquisition of 15 electric buses in Sofia, due to be deployed in 2019[li].

9.3. Weight allowance for electric buses

For a temporary period the electric bus will be heavier than an equivalent diesel bus due to extra weight from the batteries. Because of weight restriction on vehicles, this will normally limit the number of passengers onboard. Consequently, for a fixed activity, a bus line may require additional buses to transport the passengers. Therefore, we suggest that a temporary weight allowance for zero emission buses should be considered by the European Commission and member States. The city of Paris has allowed electric buses to carry one extra ton which is an important factor in the success of Paris' transition to overnight charging electric buses since it enables their electric buses to carry as many passengers as a diesel bus.

9.4. Zero-emission bus mandate as part of the HDV CO2 emission standards.

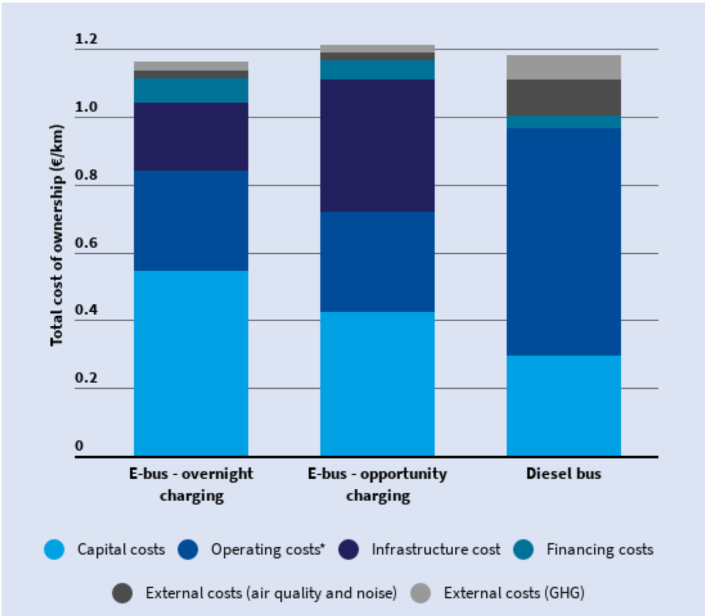
The inclusion of a zero and low emission bus incentive mechanism is in discussion in the current discussion on HDV CO2 emission standards. This is a good opportunity to set a mandate on zero emissions bus sales for manufacturers. We believe that a 2030 mandatory sales target for city buses should be set at 100%. Such commitment would set a clear decarbonization medium-term pathway for both cities and industry. It would provide market certainty to the industry and thus lower prices for cities that would otherwise procure cheaper zero emissions buses for foreign OEMs. On the other hand, the current Commission's proposal includes a supercredit incentive mechanism for zero and low emission vehicles that would include both buses and trucks. This would unjustifiably undermine that CO2 target by granting two credits to every zero emission bus sold and is not a good policy choice since both bus and truck markets are radically different. In order to implement a incentive mechanism for zero-emissions city buses, the Commission should be asked to come up with a technical definition of urban buses (most likely based on floor level).

10. Annex

10.1. Sensitivity analysis of TCO calculation

10.1.1. Influence of daily mileage

Today, electric buses can be slightly more expensive on shorter routes



8-year TCO calculation, daily distance travelled of 200 km, excluding driver costs, in 2018 (€/km)

Source: Transport & Environment calculation including inputs from CE Delft

Figure 7: TCO comparison with 200 km travelled per day (sensitivity analysis)

10.1.2. Future trends (2020)

TCO in 2020: Overnight charging electric buses will become increasingly competitive as battery prices decrease.

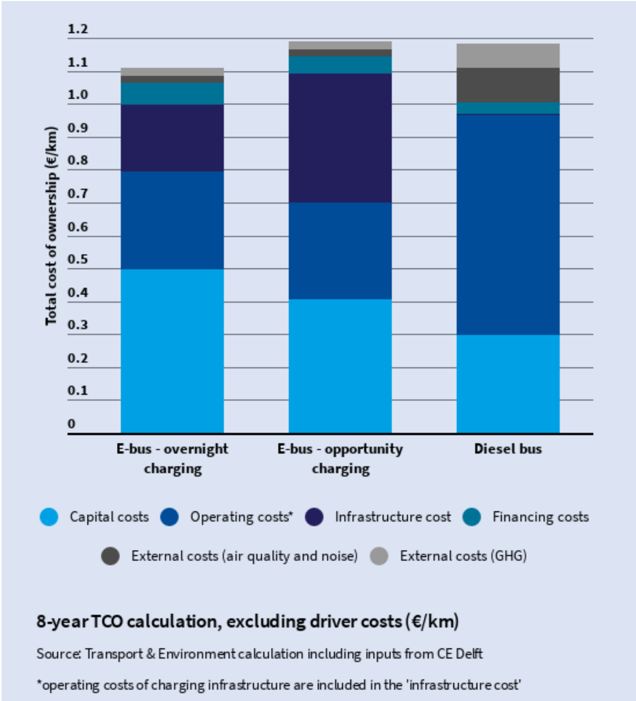


Figure 8: TCO comparison in 2020 with 200 km travelled per day (sensitivity analysis)

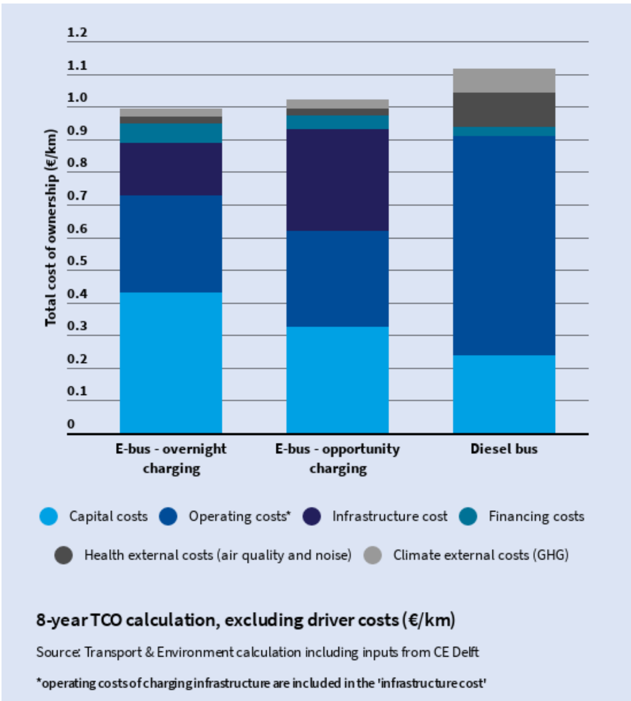


Figure 9: TCO comparison in 2020 with 250 km travelled per day (sensitivity analysis)

Battery prices make up a larger share of the cost of an overnight charging bus compared to an opportunity charging bus where the battery is smaller. We expect overnight charging buses to be increasingly common as battery prices decrease and gradually take over opportunity charging buses.

With a 200 km daily mileage the overnight electric bus is cheaper than the diesel bus when health externalities are included while they are at parity without external costs with a daily mileage of 250 km (0.95€/km for overnight e-bus and 0.94€/km for diesel bus).

As battery technology progresses, so will the number of cycles it can perform during its lifetime (i.e. before the state-of-health of the battery reaches 80%) which will further improve the business case of electric buses as the battery will last longer and the necessary over-sizing of the battery capacity to account for the degradation shrinks.

10.1.3. Influence of electricity cost (and carbon grid-intensity)

High cost: example of Germany[9] and low cost: example of Sweden[10] (left)

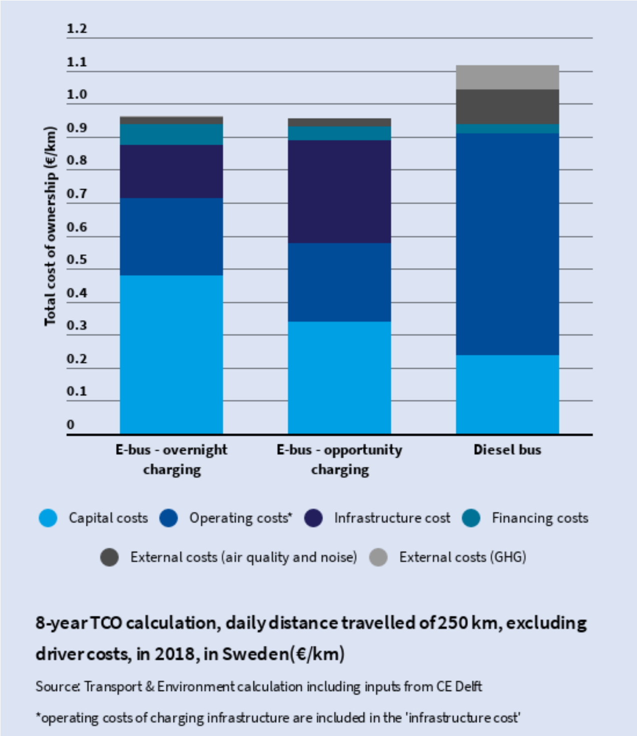


Figure 10: TCO comparison in Sweden with 250 km travelled per day (sensitivity analysis)

[9] Electricity cost: 0.151€/kWh, CO2 intensity of the grid: 424.9 g/kWh
[10] Electricity cost: 0.065 €/kWh, CO2 intensity of the grid: 10.5 g/kWh

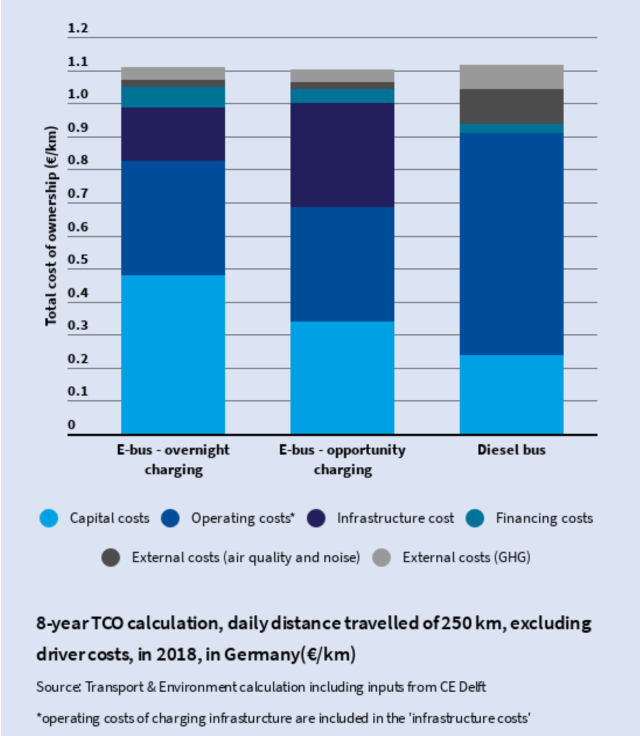


Figure 11: TCO comparison in Germany with 250 km travelled per day (sensitivity analysis)

In a country with a high electricity cost (and a high carbon intensity grid) like Germany, electric buses are at parity with diesel counterpart when all health and climate external costs are included. On the other hand in a country with low electricity costs parity is reached when external costs are excluded. To prevent this barrier to adoption, national governments are advised to implement tax break for electricity when used for electric buses, in particular in countries like Germany or Italy where the electricity prices are high.

10.2. Assumptions for TCO calculation

Category	Assumption	Value	Unit	Source
General	Daily distance	250	km	Typical electric bus with a long range
	Number of days driven per year	350	days	Choice
Financing costs	Learning rate	4%		in line with the recommended discount rate of the EC
	€/$ exchange rate	1,17		Sep-18
Energy	Diesel price	1,175	€/L	EEA (December 2017) Transport fuel and tax, average
	Electricity price	0,112	€/kWh	Eurostat (2017), Electricity prices for non-household consumers, second half of 2017, Europe average

Vehicle	Capital cost of vehicle body - electric (the vehicle excluding equipment and batteries)	247.86 3	€	IEA EV Outlook (2018)
	Capital cost of vehicle body - diesel	213.67 5	€	IEA EV Outlook (2018)
	Depreciation time of battery	8	years	Choice
	Depreciation period of bus	10	years	Choice
	Residual value of bus after 10 years	10%		CE Delft
E-bus	Battery price 2018	335	€/kWh	BNEF (2018) Electric Buses in Cities
	Mark-up for opportunity charging batteries	10,0%		Choice
	E-bus efficiency	1,3	kWh/km	NREL (2017), IEA (2018), CE Delft recommendation Accounts for conservative scenario with utilisation of heat management systems. According to ZeEUS project (ZeEUS final report #2, 2018) values are around 1 kWh/km.
	Cost of other EV equipment	€ 5,860 + €26/k W		Assessment with respect to the EU HDV CO2 legislation, TNO (2018)
	Motor power electric bus	150	kW	selection of buses, ZeEUS report #2
	Max usable battery capacity in worse-case scenario	72%		Based on worst case scenario: 20% for degradation and 10% for operational safety margin
Charger	Operational cost 50kW charger	0,14	€/kWh	Assessment with respect to the EU HDV CO2 legislation, TNO 2018 (with 8 hours of occupancy per day) Include capital expenditures, maintenance expenditures and operational expenditures
	associated occupancy per day	8	hours	-
	Operational cost 300 kW charger	0,21	€/kWh	CE Delft (on-going study) for 130,000 kWh annually Include capital expenditures, maintenance expenditures and operational expenditures

	associated amount of energy delivered	130000	kWh	-
	Charger maintenance cost	2%	per year	Method to analyze cost effectiveness of different electric bus systems, Oscar Olsson et al., 2016
ICE	Cost of replaced ICE components	€50 + 65€/kW		Assessment with respect to the EU HDV CO2 legislation, TNO (2018)
	Engine power	260	kW	Choice based on most sold urban bus Daimler Mercedes Citaro
	Fuel consumption	0,4	L/km	confirmed by CE Delft, TNO (2016), TNO (2015)
	Cost of refuelling infrastructure (dispenser + tank)	78.291	€	BNEF (2018) Electric Buses in Cities
	Depreciation time of refuelling infrastructure	15	years	Choice
	Number of bus per refuelling infrastructure	50		Choice
Maintenance	E-bus maintenance cost	0,183	€/km/year	Olsson, O., Grauers, A., Pettersson, S. (2016), Methods to analyse cost effectiveness of different electric bus systems, paper for EVS29 Symposium, Montreal, June 19-22, 2016 Conservative when compared to IEA (2018) Global EV Outlook 2018 which assumes maintenance cost of e-buses half of those from diesel bus
	ICE bus maintenance cost	0,292	€/km/year	Olsson, O., Grauers, A., Pettersson, S. (2016), Methods to analyse cost effectiveness of different electric bus systems, paper for EVS29 Symposium, Montreal, June 19-22, 2016
Externalities	Air pollution	0,018	€/vkm	Ricardo-AEA, DIW econ, CAU (2014), Update of the Handbook on external costs of transport, London
	Noise	0,087	€/vkm	Ricardo-AEA, DIW econ, CAU (2014), Update of the Handbook on external costs of transport, London Assuming 90% day operation (half dense half thin traffic) and 10% thin night traffic
	Cost of noise reduction ICE vs. Ev	-75%		Turcany, J. (2016), Electric buses and noise, presentation from 02-01-2016, Volvo Buses We apply a more conservative factor to the Volvo value (-87%)
	GHG	0,074	€/vkm	Ricardo-AEA, DIW econ, CAU (2014), Update of the Handbook on external costs of transport, London Assumed Euro VI same as Euro V (data N./A.)

	carbon intensity of EU grid	275,9	gCO2/kWh	EEA(2017) Overview of electricity production and use in Europe
	carbon price	90	€/ton	Ricardo-AEA, DIW econ, CAU (2014), Update of the Handbook on external costs of transport, London
	GHG cost of a kWh	0,025	€/kWh	Calculated

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