Uptake of alternative fuels in the European Union bus sector

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[1]The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

ABSTRACT

After having been deployed with success in China, electric buses seem to be emerging as the preferred option for reducing oil dependency, noise and tailpipe air pollutant and greenhouse gas emissions from public transport. This paper presents a system dynamics model of the European Union bus market, including urban buses and coaches. The study focuses on the future uptake of alternative fuels in this sector, particularly on electric bus sales and stocks. The paper explores the potential impacts of minimum public procurement targets in 2025 and 2030 on annual CO_2 emissions from diesel buses and on battery cost. Further research is needed for a detailed analysis of purchase incentives at the country level.

Keywords: *electric buses, public transport, alternative fuels, system dynamics*

1. INTRODUCTION

According to EEA (2017b), almost 19% of European Union (EU) transport greenhouse gas (GHG) emissions are caused by heavy-duty trucks and buses. To support its goal to drastically reduce emissions from transport (EU, 2017b), the European Commission proposed in 2018 CO_2 emission reduction targets for heavy-duty vehicles for the first time. Initially applicable to large trucks, it is expected that buses and coaches will be included in 2022 (EU, 2019). The DIONE fleet impact model (Harrison *et al*., 2016) reports in its baseline scenario a 7% increase in tank-to-wheel CO_2 emissions from buses in the EU between 2010 and 2050, generating almost 47 megatons of CO_2 emissions by mid-century.

Public transport initiated modern mobility (Bunting, 2004) and continues to meet the need for passenger travel[1]. Depending on vehicle occupancy rates, fuel consumption per passenger can be lower in public transport than in private transport. Furthermore, the shift from car to public transport reduces congestion (Metz, 2012). In the EU, the most common type of public transport is bus travel (ACEA, 2017). With almost three quarters of the EU population living in cities (Eurostat, 2017), urban buses are expected to play an important role in fostering sustainable transport.

In 2013, 79% of the European bus stock was powered by diesel and 10% by biodiesel (ZeEUS, 2016). Faced with air pollutant concentration levels above the EU limit values (EEA, 2017a), cities are announcing the banning of internal combustion engine (ICE) vehicles in the future (for a list, see Table A in WB (2018)). EC (2015) identified biofuels, electricity, hydrogen, and natural gas (including biomethane) as the most promising energy sources to displace diesel in the bus sector. To facilitate an increase in the use of alternative fuels in the EU transport systems, Directive 2014/94/EU requested that Member States adopted national policy frameworks (NPFs) containing "*measures that can promote the deployment of alternative fuels infrastructure in public transport services*" (EU, 2014: 11). An assessment of the NPFs revealed that the level of ambition of these measures varies significantly by country (see the Appendix).

[1] Less influentially in the United States, where it accounts for only 2% of passenger travel (Sperling & Gordon, 2009), than in other regions.

Fig. 1 shows the number of buses and coaches in use in the EU28 in the years 2005, 2010 and 2015 and the demand this stock of vehicle served, measured in passenger-km (PKM). As can be seen, the behaviour over time of both variables was relatively stable. In 2010, urban buses accounted for 39% of buses and coaches in the EU28 (TRACCS, 2017). In terms of trips, UITP (2016) reported that over 32 billion local public transport journeys were made on EU buses (including trolley-buses) in 2014.

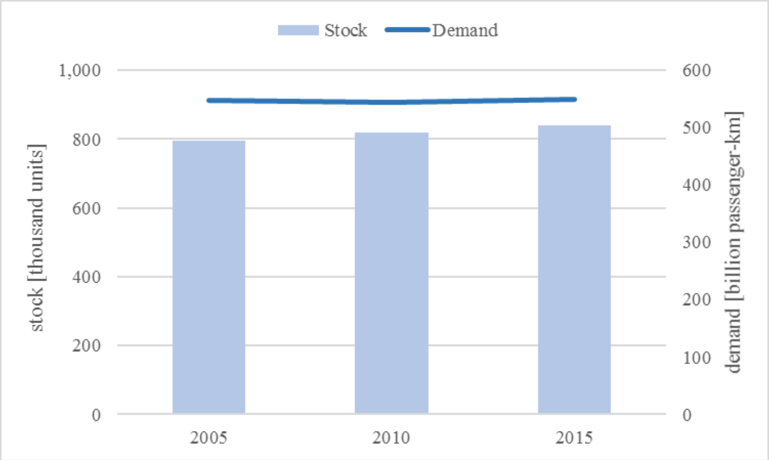

Figure 1. Stock of buses and coaches used to meet demand in the EU
Source: own work based on data from EC (2018b)

The demand for bus and coach travel varies significantly by country, as can be seen in Fig. 2. In 2016, the most extensive use of these vehicles was made in Hungary (21%) while the EU28 average stood at over 9%. In contrast, buses and coaches represented only 3% of the modal split of passenger transport on land in the Netherlands.

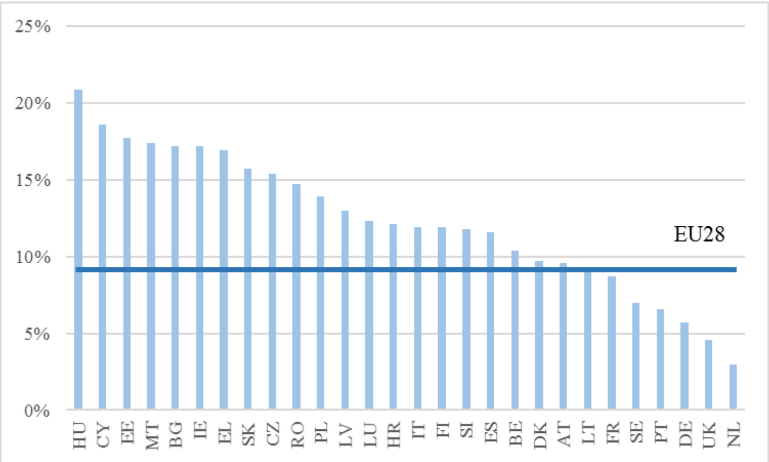

Figure 2. Demand for bus and coach travel as a percentage of land transport passenger demand (excluding two-wheelers) in 2016, by country
Source: own work based on data from EC (2018b)

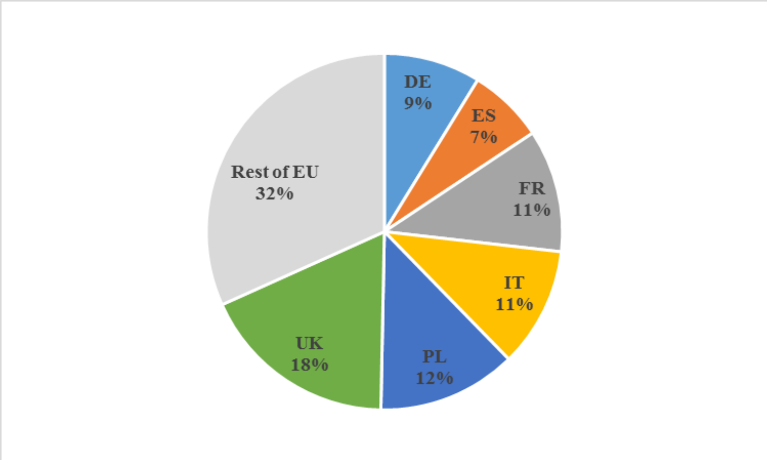

Figure 3. Stock of buses and coaches in 2016, by country[2]
Source: own work based on data from Eurostat (2017)

Fig. 3 shows that 68% of the EU stock of buses and coaches were in use in six of the twenty-eight Member States in 2016. The UK sticks out with a stock of 161,500 buses and coaches[3]. With an estimated fleet of 9,462 buses (TfL, 2018), London stands at a level similar to AT, NL and SK (see Eurostat (2017)).

Previous SD work on alternative fuels use in transport has mainly focused on the passenger car market. This paper focuses on the EU bus sector, particularly on electric buses. Hybrid buses are beyond the scope of this paper. The main reason for this is the large battery an electric bus currently features, which may be relevant in the context of the European Battery Alliance (EC, 2018a) as well as for achieving battery price reductions and improving the value proposition of electric cars vis-à-vis petrol and diesel cars. The objective of the study is to explore the market uptake of electric buses in the EU in the next years as well as to tentatively quantify its potential impact on battery prices. The dynamic problem to be addressed concerns the preservation of public transport services while significantly reducing its adverse emissions impacts.

The structure of this paper is as follows: after the introductory section, section 2 provides further information on electric buses, in section 3 the proposed model is presented, section 4 shows the results and conclusions are drawn in section 5.

[2]See the code list at https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Country_codes.
[3]However, DfT (2018) indicates that about 55% of these are minibuses, as defined for statistical purposes in that country.

2. DATA ON ELECTRIC BUSES

In 2016, over 54,000 buses and coaches were registered in the EU28, adding to a stock of almost 899,000 buses and coaches (Eurostat, 2017)[4]. According to EVI (2018), there were ca. 100,000 electric buses sold and 370,000 electric buses in use worldwide in 2017, most of them in China (see the Appendix). Most of the Chinese electric buses and coaches are battery electric (BEV), rather than plug-in hybrid electric (PHEV), and were sold by BYD and Yutong (GIZ, 2018). The number of manufacturers offering electric versions of buses and coaches is on an upwards trend. Table 1 shows a selection of electric bus models and their relevant characteristics. There are other important manufacturers not shown in that table because they have not fully entered the EU yet. Among them are BAIC Foton, CRRC, Zhongtong Bus active in China as well as New Flyer and Proterra in North America. As can be seen, lithium iron phosphate (LFP), manufactured by several suppliers, emerges as the preferred lithium-ion battery chemistry. Nickel manganese cobalt (NMC) batteries are being deployed in 2019.

Table 1. Main characteristics of electric buses available in the European market

Type	Length	Manufacturer	Model	Battery	Capacity [kWh]	Charging time	Supplied by	Seats / max. PAX	Year
PHEV	12m	Businova / SAFRA	Standard	LFP	132	4-6 h	EVE System	N/A 100	2017
BEV	12m	ADL	Enviro200 EV	LFP	324	4 h	BYD	N/A / 90	2016
		ALSTOM / NTL	Aptis	Sodium nickel	*309*	7-8 h	Fiamm	N/A / 77	2017
		ALSTOM / NTL	Aptis	NMC	N/A	N/A	Foresee Power	N/A / 95	2019
		Bollore	BlueBus	Lithium metal polymer	240	5 h	Blue Solutions	N/A / 97	2016
		Bozankaya	Sileo S12	LFP	*215*	2-8 h	Bozankaya	N/A / 79	2015
		BYD	12m	LFP	330	4-4.5 h	BYD	31 / 90	2013
		Irizar	ie	Sodium nickel	376	6-7 h	Fiamm	N/A / 82	2014
		Daimler	eCitaro	NMC	243	N/A	AKASOL	29 / 93	2019
		Skoda Electric	Perun HE	LFP	230	4-6 h	various	N/A / 82	2013
		Solaris	Urbino 12 electric	LFP/ Lithium titanate	≤ 240	*32 min - 3 h*	Solaris	38 / ≤ 90	2012
		VDL	Citea SLF-120	various	*133*	5 min - 4.5 h	various	N/A / 92	2014
		Volvo	7900 electric	LFP	76	3-6 min	SAFT	35 / ≤ 95	2016
		Yutong	E12	LFP	324	5.5 h	CATL	N/A / 77	2017
	18m	Bozankaya	Sileo S18	LFP	*215*	3-8 h	Bozankaya	N/A / 137	2016
		BYD	18m articulated	LFP	547	2 h	BYD	≤ 60 / ≤ 180	2016
		Irizar	ie tram	various	*150*	5-10 min - 2 h	various	N/A / ≤ 150	2017
		Solaris	Urbino 18 electric	LFP/ Lithium titanate	≤ 240	*32 min - 3 h*	Solaris	48 / ≤ 129	2013

Notes: (i) N/A means 'not available', (ii) PAX means 'passengers', (iii) 'year' refers to the introduction into the European market', (iv) figures in italics reflect estimated average values.
Source: own elaboration based on information from AKASOL (2018), Alstom (2019), BYD (2019), Daimler (2019), EVI (2018), Irizar (2019), Volvo (2019) and ZeEUS (2017)

Fig. 4 shows the market share of the best-selling electric bus manufacturers in Europe in 2018, compared to the previous year.

[4] Both figures include trolley-buses and reflect 2015 values for Romania due to lack of data availability.

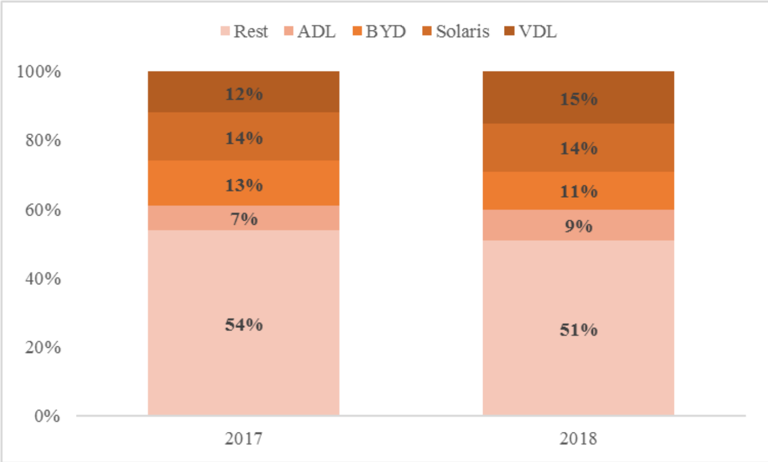

Figure 4. European electric bus sales market shares (2017-2018), by bus manufacturer
Source: own elaboration based on data from Interact Analysis cited by SustainableBUS (2019)

Fig. 5 shows the stock of alternative fuel buses[5] in the EU, which has so far been dominated by CNG (including biogas) buses (in 2016 and 2017, 46 and 44 liquefied natural gas (LNG) buses were sold (EAFO, 2018)). Since 2016, this market is however declining while the electric bus stock is growing. By country, more than 50% of electric bus sales or stock in the EU in 2018 were in NL, UK, FR, PL and DE (EAFO, 2018). In addition, there were 49 hydrogen buses in use in 2018 (EAFO, 2018).

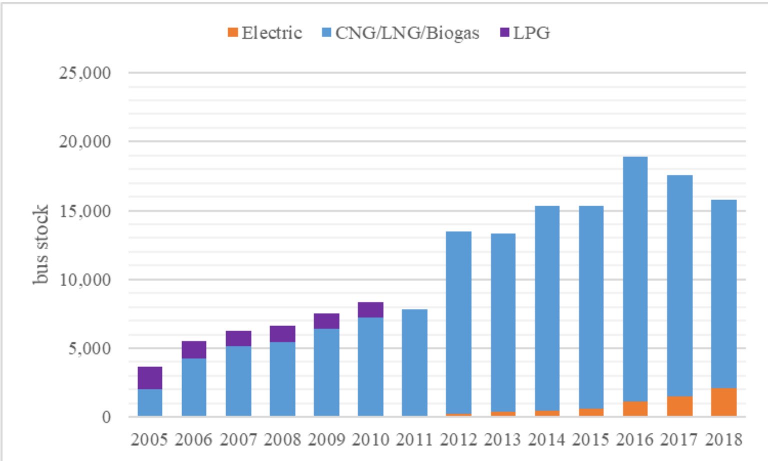

Figure 5. Stock of buses in the EU, by energy source (excluding diesel)
Notes: (i) own estimation in 2011 from CNG sales data, (ii) post-2010 LPG stock N/A (but LPG buses were sold in 2011-2012 and 2016-2017).
Source: own work based on data from TRACCS (2017) and EAFO (2018)

[5] Note that EAFO (2018) follows UNECE (2014) and reports buses as the sum of M2 and M3 categories.

3. THE PROPOSED MODEL

3.1 Key assumptions

The model time horizon runs from 2005 to 2050. For the period 2005-2010, (TRACCS, 2017) is used, which disaggregates buses into urban (buses) and coaches

3.1.1 Sales, stock and scrappage

We disaggregate sales, stock and scrappage by powertrain technology. In line with TRACCS (2017), urban buses and coaches are subscripted and a distinction between new and second-hand sales is made. For simplicity, no ageing chains are used. Fig. 6 shows the stock-and-flow structure at the core of the model.

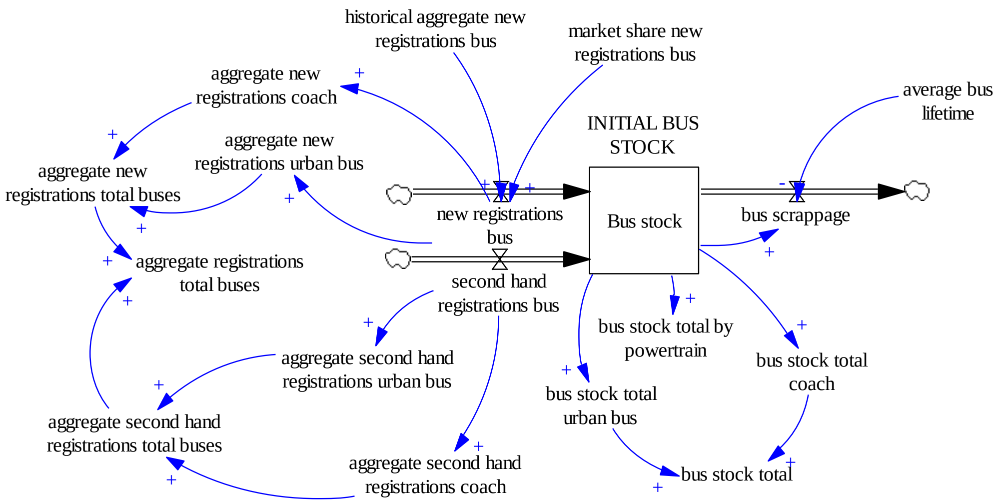

Figure 6. Stock-and-flow structure in the proposed model
Source: own work using Vensim®

The scrappage rate is determined by the stock and the average lifetime. Between 2005 and 2014, the average of the bus fleet in the EU has remained very stable at 9.4 years (EEA, 2016). We assume a constant average bus lifetime of 14 years, shorter than the 20-year lifespan stated by ForeseePower (2018) for the new Alstom's electric bus and slightly longer than the minimum period of service for large buses required by FTA (2008) and the 12-year LFP battery warranty offered by BYD (2019).

3.1.2 Average fuel consumption and annual bus mileage

Based on EU28 average values, the fuel consumption of diesel urban buses and coaches in 2010 was respectively 38.7 litres/100km and 33.9 litres/100km (TRACCS, 2017).

Table 2. EU28 bus fuel consumption [litre/100km]

	Urban		**Coaches**	
	Petrol	Diesel	Petrol	Diesel
2005	46.5	41.0	54.6	35.1
2010	44.0	38.7	50.7	33.9

Source: own work based on data from (TRACCS, 2017)

For the electric bus modes listed in Table 1, fuel economy values range from 0.8-1.5 kWh/km for 12-metre and 1.15-1.30 kWh/km for 18-metre buses (see ZeEUS (2017)). Gao *et al.* (2017) estimated that the energy consumption of an electric bus ranges from 1.24 to 2.48 kWh/km. More recently, ITDP (2018) reported real-world Chinese electric bus data showing energy consumption of 1.063 kWh/km. We assume that an electric bus uses 1.10 kWh/km.

ITDP (2018) also reported a daily average operating mileage equal to 174.4 km. This is above the number reported in the EU28 for the year 2010, when average mileage stood at 44,706 km/year for urban buses and 57,729 km/year for coaches (TRACCS, 2017).

3.1.3 Capital and operating expenditures

For the calculation of capital expenditures (CAPEX), the assumed electric bus battery capacity is crucial. In its report, EVI (2018) assumed electric bus battery capacities equal to 250 kWh (p. 86) and 330 kWh (p. 73). For European buses, we assume an average value equal to 132 kWh for PHEVs (from Table 1) and 250 kWh for BEVs. However, for China a single value (325 kWh) is assumed. The reason for this is due to the evidence that the aforementioned main manufacturers in that country sell 12-metre electric buses with 324-330 kWh battery capacities. Tsiropoulos *et al.* (2018) report the following lithium-ion battery pack costs: 200 €/kWh in 2017, 96-127 €/kWh in 2025 and 75-101 €/kWh in 2030. This would bring the cost, only for the battery, of an electric bus to €50,000-65,000 in 2017 and €22,000-28,600 in 2030 (assuming that average cost is also applicable to LFP batteries and no energy density effects as well as depending on the battery capacity and cost estimate adopted). In addition, the industry mark-up needs to be determined.

Based on information from T&E (2018), we estimate that the purchase price of diesel and electric buses are €182,500 and €350,400 per unit, respectively. According to the same authors, electric buses are nonetheless cheaper on a total cost of ownership (TCO) calculation basis that comprises the internalization of external costs such as noise, air quality and climate. Based on figures from EMT (2018), we estimate that the purchase price of CNG buses in Europe is at present around €300,000 per unit. The current price differential between diesel and electric buses can be reduced through purchase incentives. The UK is supporting electric and hydrogen buses with a £48 million scheme (DfT, 2019). Based on information on the winning bidders, we estimate that the average purchase subsidy is around €207,500 per electric bus and €251,500 per hydrogen bus[6]. With such level of incentives in place, the TCO calculation is even more favourable to electric buses.

For the estimation of operating expenditures daily operating mileage (shown in the previous section) is key. In the aforementioned calculation reported by T&E (2018), electric buses clearly beat diesel buses already today with operating costs (excluding the operating cost of recharging infrastructure) of ca. 0.3€/km, compared to more than 0.6€/km for diesel buses. Given the energy consumption value assumed in section 3.1.2 and an average EU28 electricity price for non-households equal to 0.11€/kWh (Eurostat, 2017), we assume that an electric bus has an operating cost of 0.12€/km (energy only, excluding maintenance).

3.1.4 Deployment of recharging infrastructure

Two recharging options for electric buses are opportunity and overnight recharging. The latter presently dominates (EVI, 2018). Directive 2014/94/EU made a distinction between a normal power and a high power recharging point and defined the latter as "*a recharging point that allows for a transfer of electricity to an electric vehicle with a power of more than 22 kW*" (EU, 2014: 10). EVI (2018) anticipates that electric buses will primarily be recharging using fast (≥ 50 kW) infrastructure. Based on an assessment of publicly accessible recharging points (see EU (2017a)), we implicitly assume in this work that the current and future fast recharging infrastructure is sufficient to meet the electricity demand from electric buses.

[6] Assuming the following exchange rate: £1 = €1.17.

3.2 Policy targets

The policy measure examined in this paper is public procurement, which accounts for 14% of gross domestic product (GDP) in the EU (EP, 2018a) and was regarded in a 2017 public consultation as an important measure to foster low-emission vehicles uptake (EP, 2018b). Among the alternative fuels identified are electric, hydrogen or biogas (EC, 2017). The potential for procurement of public transport vehicles at the local level is particularly high (EU, 2017c). Indeed, European cities such as London, Paris, Copenhagen and Barcelona have pledged to purchase only electric buses after 2025. Amsterdam's municipal public transport operator is even more ambitious and aims at operating only electric buses by 2025 (WB, 2018).

Specifically, we examine bus procurement 2025 and 2030 targets. Although minimum procurement targets have been proposed per Member State (see Table 5 in Council (2018)), we construct a 'Targets' scenario by assuming these procurement targets across countries: 50% in 2025 and 75% in 2030 (5% of which are PHEVs and the rest BEVs).

4. RESULTS

4.1 Evolution of the bus stock

Fig. 7 shows the simulated stock of urban buses and coaches in the EU, compared with historical data. By 2030, total bus stock is simulated to exceed 0.8 million vehicles in the EU. Thus the bus market remains relatively stable over the period.

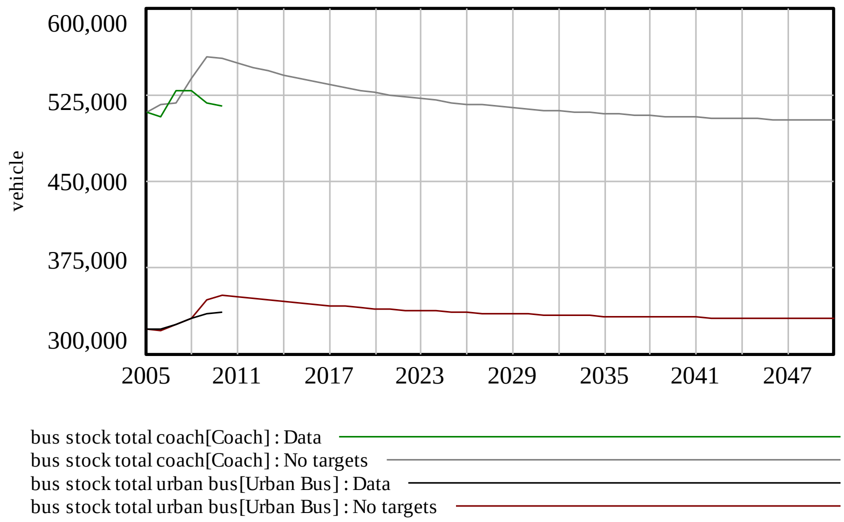

Figure 7. EU28 urban bus and coach stocks, data versus simulation
Source: data from TRACCS (2017) and own simulations using Vensim®

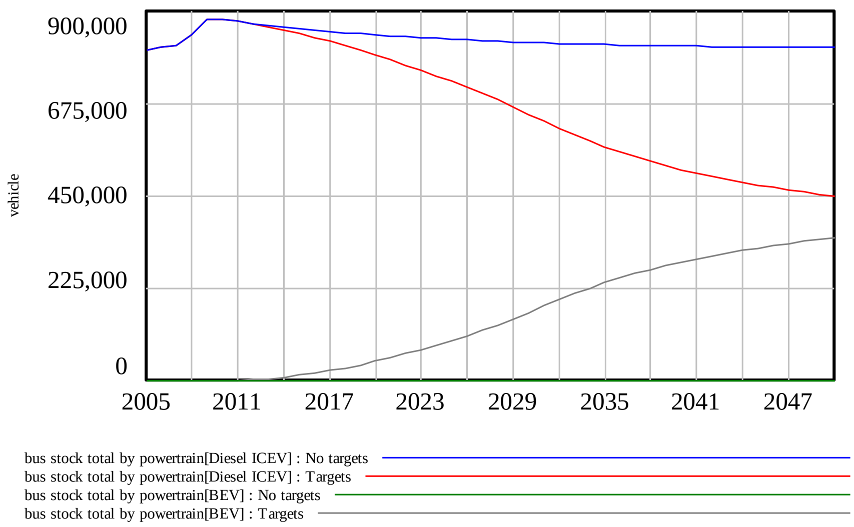

Figure 8. EU28 diesel and BEV bus stocks, by scenario
Source: own simulations using Vensim®

Fig. 8 shows the simulated growth in the number of fully electric buses in use in the EU28 until 2050 under the ‘Targets’ scenario, at the expense of diesel buses. Fig. 9 provides more detailed information on PHEV and BEV stocks by type of bus.

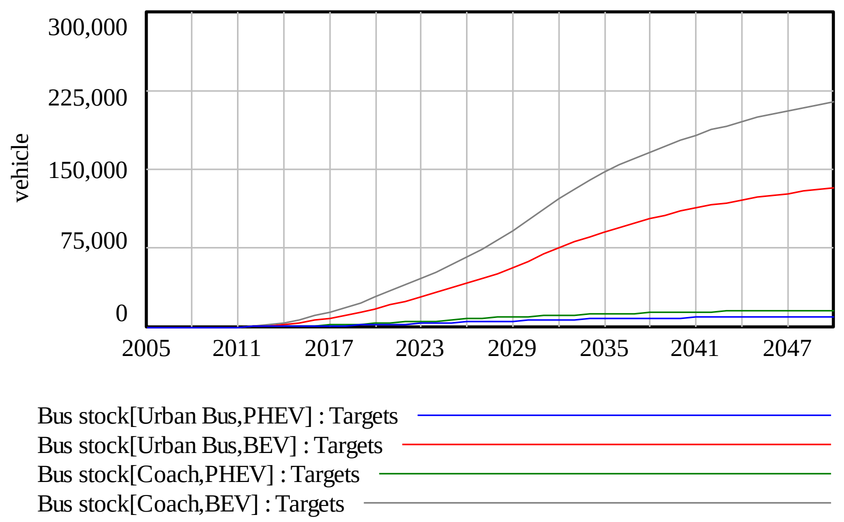

Figure 9. EU28 electric bus stock, by type of bus and powertrain
Source: own simulations using Vensim®

Finally, we use emissions factors for diesel fuel from IPCC (2006) to tentatively estimate the reduction in annual tailpipe CO_2 emissions from diesel buses in the ‘Targets’ scenario with respect to the ‘No targets’ scenario. Our simulations suggest 12%, 21% and 45% emissions reductions in respectively 2025, 2030 and 2050.

4.2 Comparison with similar studies

EVI (2018) presented two scenarios with different electric bus market shares in Europe in 2030: almost 20% under their 'New Policies' scenario and over 40% under their 'EV30@30' scenario. In both cases, fully electric buses dominate over PHEVs.

Further extending the model time horizon, a study by the European Road Transport Research Advisory Council (ERTRAC) reported four scenarios of the EU city bus and coach stock. These are shown in Fig. 10 as follows: 'mixed' scenario (S1), 'moderately electrified' (S2), 'highly electrified' (S3) and 'highly electrified plus H_2' (S4).

Our simulation results would roughly match the 'New Policies' scenario in 2030. For 2050, they would be closer to S1 for city buses and point to a more optimistic view on the future deployment of BEV technology for coaches.

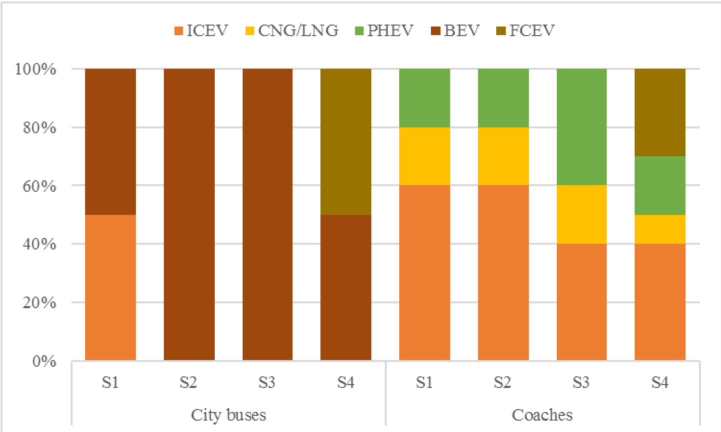

Figure 10. EU28 city bus and coach stock in 2050, by scenario
Source: Krause *et al.* (2019) [*under review*]

4.3 Impact on battery demand and resulting price

In 2016, there was more demand for lithium-ion batteries from electric buses than from electric cars globally (BNEF, 2017). The same authors forecast that the electrification of the bus sector will be quicker than for light duty vehicles (BNEF, 2018). Avicenne (2018) projects that battery demand from electric buses will grow from 21 GWh in 2017 to almost 50 GWh in 2025. Restricting ourselves to the EU context, we simulate battery demand from electric buses to reach 4.9 GWh/year in 2025 and 7.4 GWh/year in 2030.

Next, we used these results as inputs to a different system dynamics model[7]. The results are shown in Fig. 11, measured in dollars per kWh. As can be seen, taking into account the experience from manufacturing electric bus batteries leads to a lower battery cost curve. Though the simulated cost reduction between simulation runs is not dramatic, it appears to be sufficiently attractive in 2019-2020 once the size of electric bus batteries are considered.

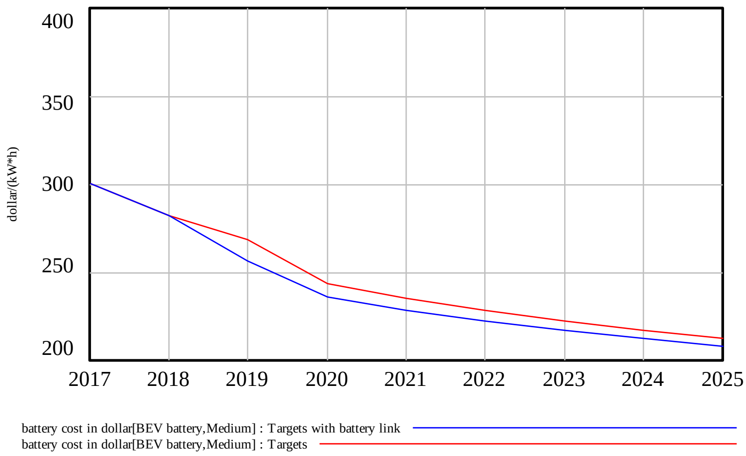

Figure 11. Battery cost, with and without link from electric bus manufacturing
Source: own simulations using Vensim®

5. CONCLUSIONS AND OUTLOOK

In sum, a system dynamics model was developed to represent the EU bus market, with a focus on the future uptake of alternative fuels. In particular, electric bus sales and stocks were analysed. The key feedback process modeled in this paper goes from electric bus sales to battery cost via expected cumulative experience (adding that of buses to the pre-existing manufacturing experience from passenger cars), which can be fed back into the purchase price of electric buses.

In conclusion, electric buses seem to be emerging in recent times as the preferred option for reducing oil dependency, noise and tailpipe air pollutant and GHG emissions from bus and coach travel in the EU, after having been deployed with success in China.

[7] The Powertrain Technology Transition Market Agent Model (PTTMAM). A previous version of this model is available at: https://ec.europa.eu/jrc/en/pttmam.

Whereas the Chinese bus market has played a crucial role to facilitate economies of scale in the lithium-ion battery manufacturing sector, there are signs it is becoming saturated (SustainableBUS, 2019). With annual sales of over 50,000 buses and a stock slowly approaching one million units, the EU bus sector is sufficiently large to supersede China in its role of large-battery consumer.

Among the limitations of this study are the model simplifications needed to analyse the EU bus sector, which is very heterogeneous (see e.g. SDG (2016)) and the insufficient analysis of further alternative fuel options. Two examples for long-range operations are LNG (Scania, 2018) and hydrogen (FCEB, 2019).

Further work will revolve around modeling additional policy measures such as purchase incentives at the country level, allowing for quantification of required budgets. Furthermore, there remains the opportunity to integrate the results of the proposed model into PTTMAM.

Another increasingly interesting research area is the competition between traditional public transport with new mobility-as-a-service businesses and the upcoming wave of autonomous vehicles. These developments are expected to set into motion feedback processes that are likely to lead to a deterioration of public transport (Naumov *et al.*, 2018). This would make the goal of doubling the market share of public transport by 2025 (UITP, 2019) more challenging to attain.

References

ACEA. (2017). *Factsheet Buses.* European Automobile Manufacturers Association (ACEA). Retrieved from https://www.acea.be/uploads/publications/factsheet_buses.pdf

AKASOL. (2018). AKASOL develops second-generation lithium-ion battery systems for Mercedes-Benz' eCitaro. Retrieved from https://www.akasol.com/en/news-akasol-ecitaro-development

Alstom. (2019). Aptis: a new experience of electro-mobility. Retrieved from https://www.alstom.com/aptis-new-experience-electro-mobility

Avicenne. (2018). *Current Status and Future Trends of the Global Li-ion Battery Market.* Avicenne Energy.

BNEF. (2017). *Lithium-ion Battery Costs and Market.* Bloomberg New Energy Finance (BNEF).

BNEF. (2018). *Electric Vehicle Outlook 2018.* Bloomberg New Energy Finance (BNEF).

Bunting, P. M. (2004). *Making Public Transport Work*. McGill-Queen's University Press. Retrieved from https://books.google.it/books?id=S3HIQhc5-bUC

BYD. (2019). BYD Battery-electric buses. BYD Europe. Retrieved from http://bydeurope.com/vehicles/ebus/index.php

Council. (2018). Proposal for a Directive of the European Parliament and of the Council amending Directive 2009/33/EC on the promotion of clean and energy-efficient vehicles. Progress Report. Council of the European Union. Retrieved from http://data.consilium.europa.eu/doc/document/ST-8916-2018-INIT/en/pdf

Daimler. (2019). Der neue eCitaro. Mercedes-Benz. Daimler AG. Retrieved from https://www.mercedes-benz-bus.com/de_DE/models/ecitaro.html

DfT. (2018). *Vehicle Licensing Statistics: Annual 2017 (Revised).* U.K. Department for Transport (DfT). Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/716075/vehicle-licensing-statistics-2017-revised.pdf

DfT. (2019). £48 million funding to drive down bus emissions across the UK. U.K. Department for Transport (DfT). Retrieved from https://www.gov.uk/government/news/48-million-funding-to-drive-down-bus-emissions-across-the-uk

EAFO. (2018). European Alternative Fuels Observatory (EAFO). Retrieved from http://www.eafo.eu/

EC. (2015). *State of the Art on Alternative Fuels Transport Systems in the European Union.* Final report. European Commission (EC). Retrieved from https://ec.europa.eu/transport/sites/transport/files/themes/urban/studies/doc/2015-07-alter-fuels-transport-syst-in-eu.pdf

EC. (2017). Declaration of intent on promoting large-scale deployment of clean, alternatively fuelled buses in Europe. European Clean Bus deployment Initiative.

European Commission (EC). Retrieved from https://ec.europa.eu/transport/sites/transport/files/2017-05-05-european-clean-bus-deployment-initiative-declaration.pdf

EC. (2018a). Speech by Vice-President for Energy Union Maroš Šefčovič at the Industry Days Forum on the Industry-led initiative on batteries / the EU Battery Alliance. Press Release Database. European Commission (EC). Retrieved from http://europa.eu/rapid/press-release_SPEECH-18-1168_en.htm

EC. (2018b). *Statistical pocketbook 2018. EU Transport in figures.* European Commission (EC).

EEA. (2016). *Average age of the vehicle fleet.* European Environment Agency (EEA). Retrieved from https://www.eea.europa.eu/data-and-maps/indicators/average-age-of-the-vehicle-fleet/average-age-of-the-vehicle-8

EEA. (2017a). *Air quality in Europe 2017.* European Environment Agency (EEA). Retrieved from https://www.eea.europa.eu/publications/air-quality-in-europe-2017

EEA. (2017b). *Greenhouse gas emissions from transport.* European Environment Agency. Retrieved from https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-10

EMT. (2018). *EMT invierte 138 millones en la adquisición de 460 nuevos autobuses*. Empresa Municipal de Transportes (EMT) de Madrid. Retrieved from https://www.emtmadrid.es/Noticias/EMT-invierte-138-millones-en-la-adquisicion-de-460.aspx

EP. (2018a). *Clean Vehicles Directive.* Briefing. Initial Appraisal of a European Commission Impact Assessment. European Parliament (EP). Retrieved from http://www.europarl.europa.eu/RegData/etudes/BRIE/2018/615654/EPRS_BRI(2018)615654_EN.pdf

EP. (2018b). *Review of the Clean Vehicles Directive.* Briefing. EU Legislation in Progress. European Parliament (EP). Retrieved from http://www.europarl.europa.eu/RegData/etudes/BRIE/2018/614690/EPRS_BRI(2018)614690_EN.pdf

EU. (2014). Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure. European

Union Law. Retrieved May 22, 2017, from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014L0094

EU. (2017a). COMMISSION STAFF WORKING DOCUMENT Detailed Assessment of the National Policy Frameworks Accompanying the document COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Towards the broadest use of alternative fuels - an Action Plan for Alternative Fuels Infrastructure under Article 10(6) of Directive 201/94/EU, including the assessment of national policy frameworks under Article 10(2) of Directive 2014/94/EU. SWD/2017/0365 final. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1512384850915&uri=CELEX:52017SC0365

EU. (2017b). COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Delivering on low-emission mobility. A European Union that protects the planet, empowers its consumers and defends its industry and workers. COM/2017/0675 final. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52017DC0675

EU. (2017c). COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS EUROPE ON THE MOVE An agenda for a socially fair transition towards clean, competitive and connected mobility for all. COM/2017/0283 final. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52017DC0283

EU. (2019). *Reducing CO2 emissions from heavy-duty vehicles*. European Commission. Retrieved from https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en

Eurostat. (2017). *Your key to European statistics*. European Commission (EC). Retrieved from http://ec.europa.eu/eurostat/web/main/home

EVI. (2016). *Global EV Outlook 2016.* Electric Vehicles Initiative (EVI). OECD/IEA. Retrieved from http://www.iea.org/publications/freepublications/publication/global-ev-outlook-

2016.html

EVI. (2017). *Global EV Outlook 2017.* Electric Vehicles Initiative (EVI). OECD/IEA. Retrieved from https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf

EVI. (2018). *Global EV Outlook 2018.* Electric Vehicles Initiative (EVI). OECD/IEA. Retrieved from https://www.iea.org/gevo2018/

FCEB. (2019). *Towards clean public transport with Hydrogen*. Fuel Cell Electric Buses. Retrieved from https://www.fuelcellbuses.eu/

ForeseePower. (2018). Alstom and Forsee Power announce collaboration to supply batteries for Aptis electric buses. Foresee Power. Retrieved from https://www.forseepower.com/en/news/alstom-and-forsee-power-announce-collaboration-supply-batteries-aptis-electric-buses

FTA. (2008). *Grant Management Requirements. Circular FTA C 5010.1D.* Federal Transit Administration (FTA). U.S. Department of Transportation. Retrieved from https://cms.fta.dot.gov/sites/fta.dot.gov/files/docs/C_5010_1D_Finalpub.pdf

Gao, Z., Lin, Z., LaClair, T. J., Liu, C., Li, J.-M., Birky, A. K., & Ward, J. (2017). Battery capacity and recharging needs for electric buses in city transit service. *Energy*, *122*, 588–600. https://doi.org/https://doi.org/10.1016/j.energy.2017.01.101

GIZ. (2018). *Trends and challenges in electric-bus development in China.* “Sustainable Transport in China” Blog. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). Beijing. Retrieved from http://www.sustainabletransport.org/archives/5770

Harrison, G., Krause, J., & Thiel, C. (2016). Transitions and Impacts of Passenger Car Powertrain Technologies in European Member States. *Transportation Research Procedia*, *14*(Supplement C), 2620–2629. https://doi.org/10.1016/j.trpro.2016.05.418

IPCC. (2006). *Guidelines for National Greenhouse Gas Inventories.* Intergovernmental Panel on Climate Change (IPCC).

Irizar. (2019). Autobuses eléctricos. Irizar. Retrieved from https://www.irizar.com/autobuses-y-autocares/autobuses/autobuses-electricos/

ITDP. (2018). *China Tackles Climate Change with Electric Buses.* Institute for

Transportation & Development Policy (ITDP). Retrieved from https://www.itdp.org/2018/09/11/electric-buses-china/

Metz, D. (2012). *The Limits to Travel: How Far Will You Go?.* Earthscan. Retrieved from https://books.google.it/books?id=kq8-ywsX-y8C

Naumov, S., Keith, D. R., & Fine, C. (2018). The Effect of Autonomous Vehicles on Demand for Driving: Is Pooling the Solution to Avoiding Traffic Gridlock? In *Record of the 36th International Conference of the System Dynamics Society Reykjavík, Iceland -- August 7-9, 2018*.

Scania. (2018). Scania introduces world's first gas-fuelled long-distance coach. Retrieved from https://www.scania.com/group/en/scania-introduces-worlds-first-gas-fuelled-long-distance-coach/

SDG. (2016). *Comprehensive Study on Passenger Transport by Coach in Europe.* Steer Davis Gleave (SDG).

Sperling, D., & Gordon, D. (2009). *Two Billion Cars: Driving Toward Sustainability*. Oxford University Press. Retrieved from https://books.google.it/books?id=IAG1ALI1HGAC

Statista. (2019). *The Statistics Portal.* Statista. Retrieved from https://www.statista.com/

SustainableBUS. (2019). 650 electric buses supplied last year in Europe, according to Interact Analysis. The leader? VDL. Retrieved from https://www.sustainable-bus.com/news/around-650-electric-buses-delivered-in-2018-in-europe-according-to-interact-analysis-the-leader-vdl/

T&E. (2018). *Electric buses arrive on time. Marketplace, economic, technology, environmental and policy perspectives for fully electric buses in the EU.* Transport & Environment (T&E).

TfL. (2018). *Bus Fleet Audit. 31 March 2018.* Transport for London (TfL). Retrieved from http://content.tfl.gov.uk/bus-fleet-audit-31-march-2018.pdf

TRACCS. (2017). *TRACCS*. Final report and datasets. EMISIA. Retrieved from http://traccs.emisia.com/

Tsiropoulos, I., Tarvydas, D., & Lebedeva, N. (2018). *Li-ion batteries for mobility and stationary storage applications - Scenarios for costs and market growth.* EUR - Scientific and Technical Research Reports. Joint Research Centre (JRC). Retrieved from http://publications.jrc.ec.europa.eu/repository/bitstream/JRC113360/kjna29440enn.pdf

UITP. (2016). *Statistics Brief - Local public transport in the European Union*. Union Internationale des Transports Publics (UITP). Retrieved from https://www.uitp.org/sites/default/files/cck-focus-papers-files/UITP_Statistics_PT_in_EU_DEF_0.pdf

UITP. (2019). *Strategy for public transport*. Union Internationale des Transports Publics (UITP). Retrieved from https://www.uitp.org/strategy-public-transport

UNECE. (2014). *Consolidated Resolution on the Construction of Vehicles.* United Nations Economic Commission for Europe (UNECE). Retrieved from https://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29resolutions/ECE-TRANS-WP29-78-r3e.pdf

Volvo. (2019). Volvo 7900 Electric. Busse Deutschland. Volvo. Retrieved from https://www.volvobuses.de/de-de/our-offering/buses/volvo-7900-electric.html

WB. (2018). *Electric Mobility and Development. An Engagement Paper from the World Bank and the International Association of Public Transport.* World Bank (WB). Retrieved from http://documents.worldbank.org/curated/en/193791543856434540/pdf/132636-EMADv4-web.pdf

WRI. (2018). How Did Shenzhen, China Build World's Largest Electric Bus Fleet? World Resources Institute (WRI). Retrieved from https://www.wri.org/blog/2018/04/how-did-shenzhen-china-build-world-s-largest-electric-bus-fleet

ZeEUS. (2016). *ZeEUS eBus Report - An overview of electric buses in Europe.* Zero Emission Urban Bus System (ZeEUS).

ZeEUS. (2017). *ZeEUS eBus Report #2 - An updated overview of electric buses in Europe.* Zero Emission Urban Bus System (ZeEUS).

Appendix

Fig. A1 shows that the level of comprehensiveness of measures supporting the deployment of alternative fuels infrastructure (AFI) ranges from low (four Member States) to high in the case of the UK.

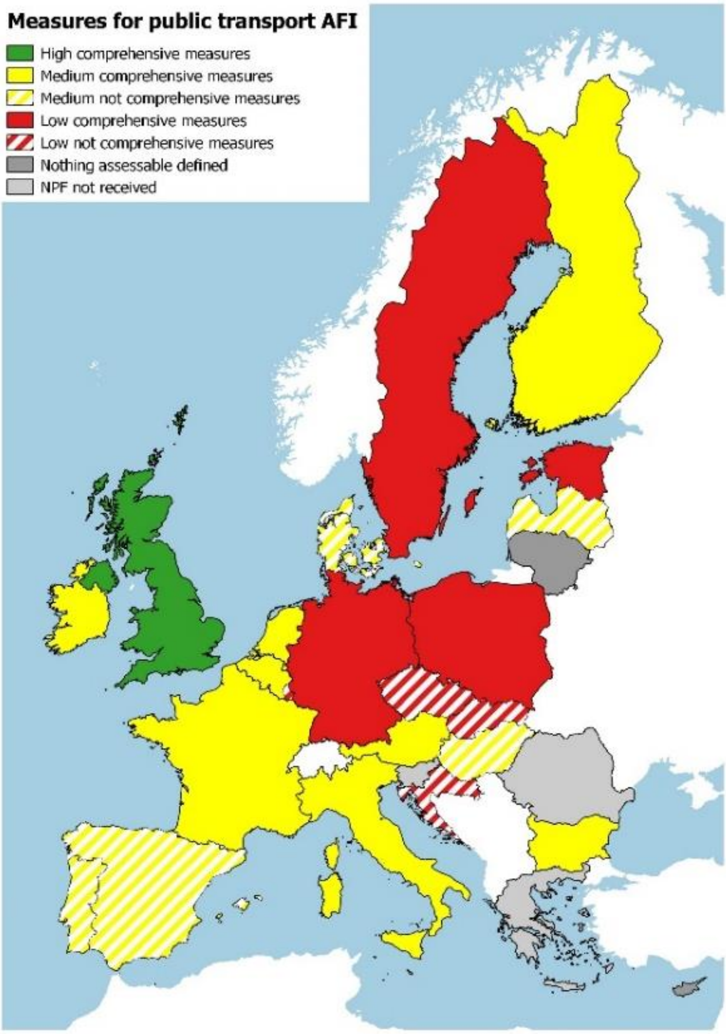

Figure A1. Level of comprehensiveness of measures that promote AFI deployment in public transport services, by country
Source: (EU, 2017a)

Fig. A2 shows the evolution of the total and electric bus stock (including trolley-buses) in urban China between 2010 and 2017. The bus fleet of the Chinese city of Shenzhen, with over 16,359 units in 2017, is reportedly fully electric (WRI, 2018).

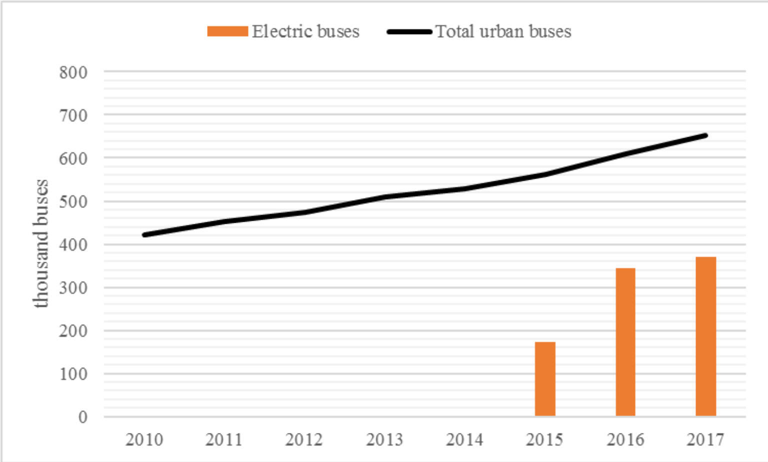

Figure A2. Stock of buses in urban China
Source: own work based on data from (Statista, 2019) (EVI, 2018) (EVI, 2017) (EVI, 2016)