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With the scientific support of Enel Foundation

SCENARIOS AND PERSPECTIVES OF THE ELECTRIFICATION OF LOCAL PUBLIC TRANSPORT

A socio-economical and environmental analysis on electric bus-fleet and its supply chain at a EU27+3 countries level

Final report

This study has been prepared by a joint research team of GREEN - Bocconi University and Enel Foundation coordinated by Oliviero Baccelli and Carlo Papa with the researchers Gabriele Grea, Antonio Sileo, Pietro Morosini, Mirko Armiento and Simone Martinelli. Luca Pelliccia (Enel X) contributed to the study.

Milan, 1st December 2022

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Final report

Section 1

Objectives and approach of the study

This deep dive aims at integrating the analyses and assessments carried out in the previous two phases of the research "Scenarios and perspectives of electrification of public road transport" started in May 2021 with socio-economic considerations, based on three different scenarios of fleet evolution in local public transport in Europe.

A systemic reading of the socio-economic effects meets the needs of understanding the policy tools of an industrial, fiscal and related to innovation and training nature needed to accompany the evolution of the local public transport market to 2030 and 2040. The evaluation are based on Total Cost and Revenues of Ownership (TCRO) differences between 12 meters electric buses vs Euro VI diesel buses.

The goal of the study is to answer to the following three key questions related to the contribution of the fleet electrification at EU27 + 3 (UK, NO, CH) level in three different policy scenarios in 2030 and 2040 :

- **What could be the contribution of fleet electrification in improving economic efficiency of local public transport operators by reducing service production costs?**
- **What could be the contribution to meeting the EU's climate goals and to reducing the cost of environmental externalities of local public transport?**
- **What could be the contribution to meeting circular economy goals and to adding new revenue streams to public transport operators derived from synergies with energy sector due to B2G and 2nd life of the batteries?**

Objectives and approach of the study

The in-depth study includes the following steps:

- Analysis of the literature on the topic of **socio-economic and environmental impacts** of the electrification of the bus in local public transport sector;
- Analysis of **operational impacts** arising from reduced costs for LPT operators resulting from lower operating and maintenance costs;
- Assessment of **environmental impacts** resulting from the reduction of greenhouse gas emissions, local pollutants, and noise;
- Evaluation of the role of the valorization of residual values of batteries and synergies with electricity grid in terms of **new revenue streams** for public transport operators coming from B2G and 2life of the batteries.

For the projections of the electrified bus fleets (national and EU27+3), market scenarios have been based on three different policy options and they are as follows:

1. **Baseline scenario**, related to the one already outlined by policies approved at the European level based in particular on the package of initiatives called "Fit for 55" and the Clean Vehicle Initiative regulations;
2. **Acceleration scenario**, with a 2-year anticipation of European-level targets;
3. **Best practice scenario**, with alignment of the targets of the 27 EU countries to the level of the most virtuous country in terms of speed of BEB bus adoption (the Netherlands).

These scenarios do not attempt to be precise forecasts, but instead they represent "**what if scenarios**" that are designed to achieve long-term climate policy objectives and operational efficiency of local public transport operators.

EU policy impacts on LPT fleets choices

The integration of low and zero environmental impact buses in LPT fleets contributes to two interconnected objectives as highlighted by international and European policy guidelines, namely sectoral efficiency and environmental sustainability.

The importance of having access to sustainable, safe and affordable transport systems, as well as of reducing negative environmental impacts in cities especially concerning air quality, are indicated as specific priorities by the UN 2030 Agenda for Sustainable Development.

At EU level, the general objectives are also expressed through target indicators defined by the Sustainable & Smart Mobility Strategy (COM(2020)789) and the package «Fit for 55%».

European policies of industrial, social and accompanying nature to a greater sensitivity of European investors to the issues of sustainability and circular economy, have a significant impact on the following aspects:

1. The organizational side of the industrial **production supply chain** in the mobility sector;
2. The investment cost components impacting **choices on fleets** of companies or local public transport authoritys or agencies;
3. Supplementary resources to the community budget for mobility policies to support **weaker social groups**.

European policy instruments capable of affecting the socio-economic impacts arising from the evolution of dedicated urban mobility bus fleets

Policy type	Normative tool	Type of expected impact
Industrial policies	EU Directive 1161/2019 - **Clean Vehicle Directive** requiring the purchase of Low Emission Vehicle and Zero Emission Vehicle for public administrations	Acceleration of "Low emission" and "Zero emission" bus purchases from 2021 and even more stringently from 2025
	Proposed Directive COM 564 (2021) – CBAM - **Carbon Border Adjustment Mechanism** that will introduce "environmental duties" for industry supply chain components such as batteries and refined products	From 2024 strengthen European value chains at the expense of more global automotive value chains in general, for example, favouring European suppliers of batteries, hydrogen or bio-fuels
	Proposed Directive COM 563 (2021) - ETD - **Energy Taxation Directive** to internalize external costs.	From 2026 Indication of correct price signals and appropriate incentives for sustainable consumption, eliminating direct and indirect subsidies to fossil fuels, defined as environmentally harmful subsidies
Social policies	Proposed Regulation COM 568 (2021) - SCF -**Social Climate Fund.**	From 2025 Support for measures to facilitate vulnerable users' access to zero- and low-emission mobility and transport solutions, including public transport
Moral suasion and nudging policies	EU Regulation 2020/852, referred to as **Taxonomy Regulation** (TR)- which introduced the taxonomy of eco-friendly economic activities into the European regulatory system	Indicate the local public transport sector eligible for financial instruments defined as sustainable asset classes

Impacts of EU policies on power supply choices (I)

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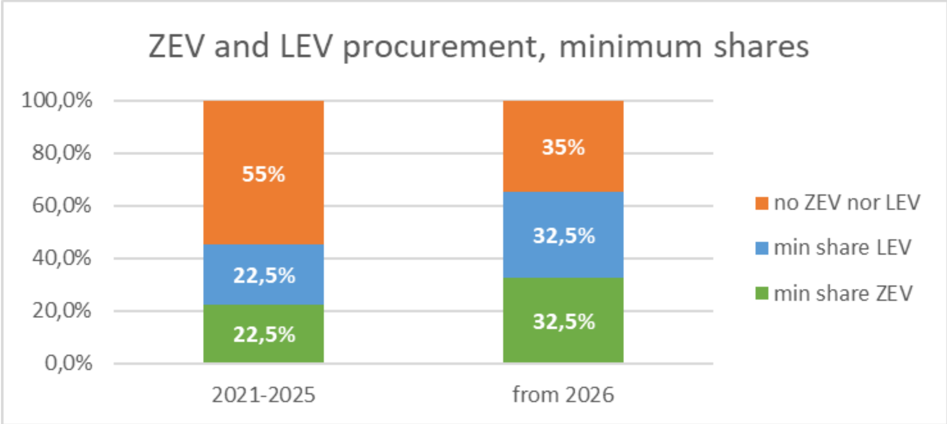
Clean Vehicle Directive (UE 1161/2019): binding purchase quotas for buses

The Directive indications are different among EU countries, but on average for Western countries it specifies 45% in a first phase and 65% in a second phase as the minimum percentages of clean buses (ZEV and LEV) in relation to the total number of buses on the road covered by purchase, lease, rental, or hire-purchase contracts awarded by contracting authorities or contracting entities.
The first phase is between August 2, 2021 and December 31, 2025, and the second phase is between January 1, 2026 and December 31, 2030.



Closely linked to Clean Vehicle Directive is the Alternative Fuel Infrastructure Directive that does not indicate rigid quotas or targets for public transport but contribute to clarify the difference among the “Clean vehicles” and “Zero emission vehicles”

„CLEAN VEHICLES“

- Electricity (incl. plug-in hybrid)
Hydrogen
- Natural gas (incl. biomethane)
- most biofuels
- synthetic and paraffinic fuels
- LPG

„ZERO EMISSION VEHICLES“

Heavy duty vehicles
- without combustion engine

or

- with combustion engine emitting less than 1 g CO_2/kWh

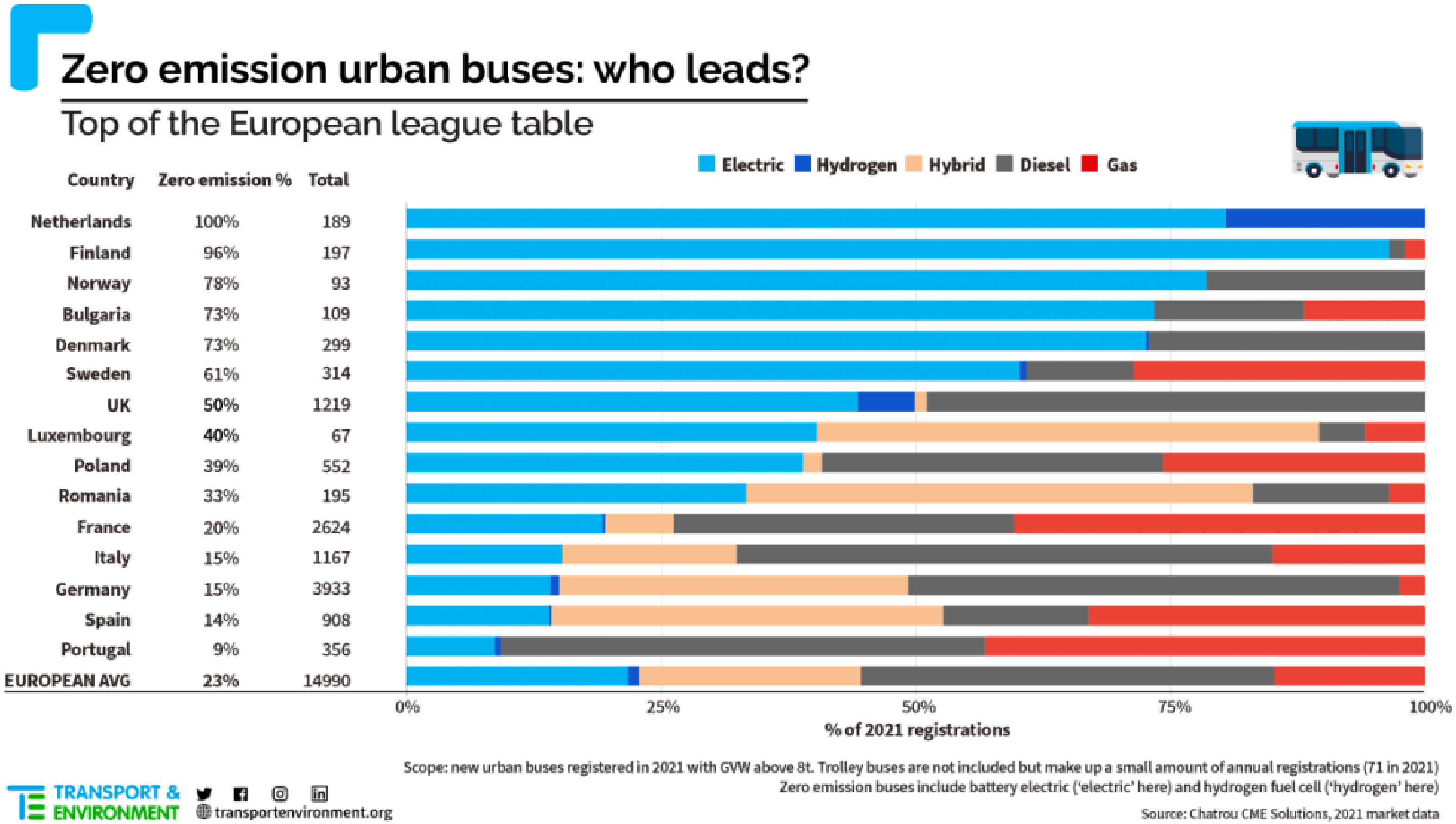
Impacts of EU policies on power supply choices (II)

- **Energy Efficiency Directive**, part of the "Delivering on the European Green Deal" package and a tool to promote energy savings in the transport sector.
- **Renewable Energy Directive,** as a component for achieving the EU's goal of climate neutrality by 2050.
- Proposed Regulation on **Batteries and Battery Waste** (COM 2020)798, which encourages standardization and circular economy approaches in the production and second-life management of batteries, through the introduction of the **Battery Passport** and the requirement to use recycled components. In the medium to long term (starting from 2027), the initiative will be able to significantly affect both the cost of batteries at the procurement stage and the valorisation of components at the second-life stage by changing the battery manufacturing sector through specific support for the localization of gigafactories in Europe. This proposed regulation, which is expected to be finally approved by 2023, is the most significant for **end-of-first-life revenue** parameters for bus batteries, typically above 250kWh capacity and therefore the ideal target for later uses to support stationary renewable depots or complete disassembly and reuse of components. The Regulation will also reinforce the goals of **Critical Raw Materials Act** presented by the European Commission in September 2022 in order to reinforce the European industry trough strategic projects all along the supply chain, from extraction to refining, from processing to recycling of critical raw materials.

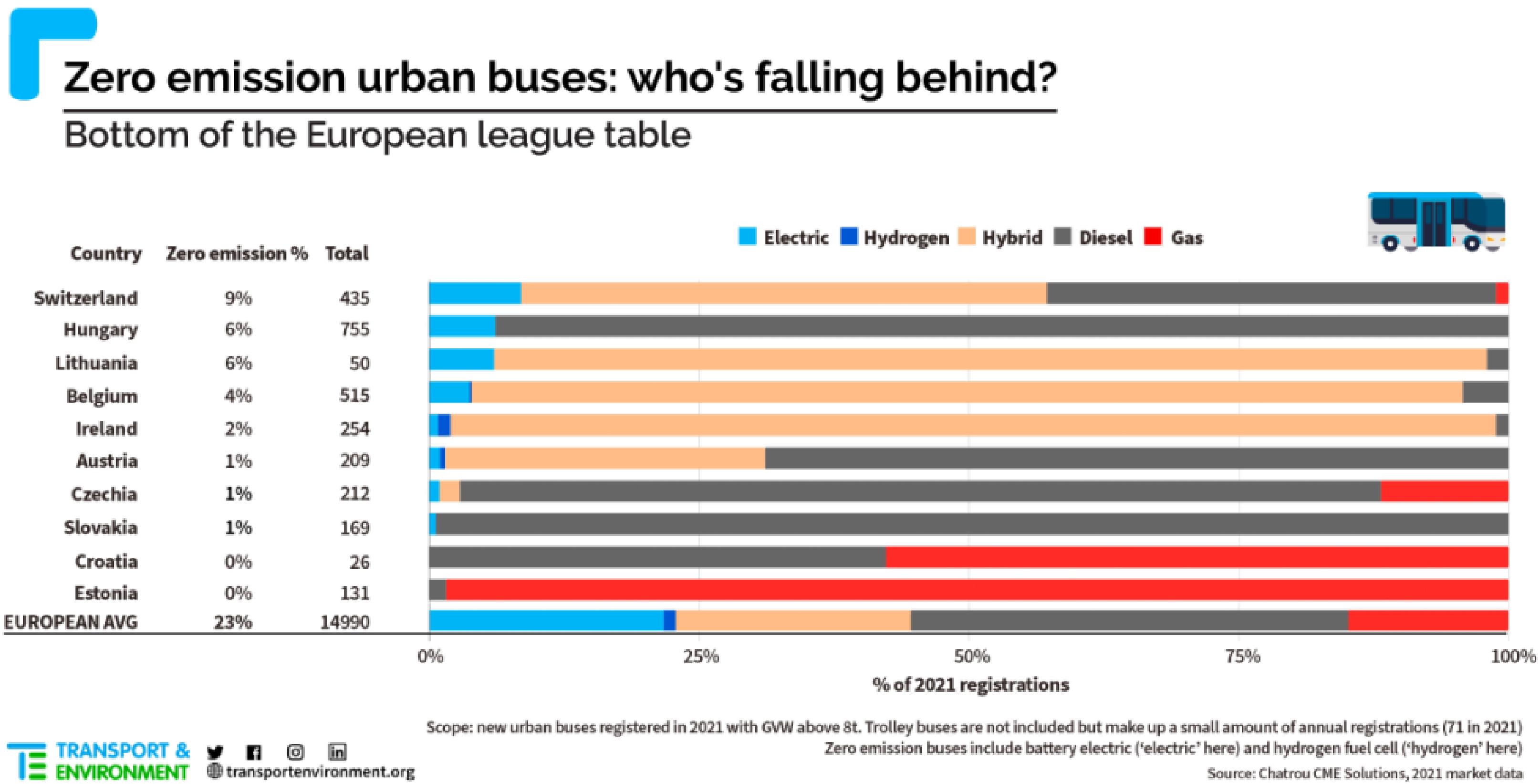
The development of these policies will affect operators' choices on circular economy issues, particularly Bus2Grid and 2nd life of the batteries strategies. These services to the grid will become increasingly important as Europe makes the transition to a renewable-led electricity system. In the study is considered that starting from 2026 LPTO will be able to add these revenues stream in their balance sheets.

Policies at the national level, including, for example, those of the Dutch government, which has planned to purchase only electric buses as early as 2025, or at the **level of large metropolitan realities**, including, for example, those promoted by the C40 association for electrification of fleets by 2030, may also have a major impact in specific contexts, but since the analysis is at the EU level, the context scenario assumptions will be homogenized.

Big differences among European markets in 12M urban bus fleets registrations by propulsion type (2021) (I/II)



Big differences among European markets in 12M urban bus fleets registrations by propulsion type (2021) (II/II)



Big differences among European main metropolitan areas and countries – wide average across the EU 27 (+ UK, Norway, Switzerland) – Impacts on the methodological approach

The deployment of electric buses has increased rapidly, rising from 2.075 in 2018 to 13.135 in the first half of 2022. This trend will accelerate in al scenarios in the coming years, driven by both increased supply from manufacturers and demand, thanks also to EU Clean Vehicle Directive targets.

According to ICCT Briefing «The rapid deployment of zero-emission buses in Europe» dated September 2022, zero-emission buses comprise over 6% of the bus fleet stock across all 31 capital cities considered, significantly higher than the 1,5% country-wide average across the EU-27 at the end of 2021. Capital cities representing 60% of the total bus stock of all 31 capital cities considered in the ICCT analysis have plans to only operate ZEBs in their fleet by 2035. More have targets to convert a sizeable portion of their fleet by the same date.

Moreover, **less noise, better local air quality, fewer greenhouse gas emissions, the increased energy efficiency of electric motors** and the fact that electric buses can provide more attractive public transport for both passengers and drivers are cited as common driving forces behind the introduction of electric buses. **These factors have a major importance in more densely populated areas**.

This statement is coherent with the approach of the study that considers the operational and environmental costs and revenues streams derived from B2G and 2nd life of the batteries of operating bus fleet estimating energy (diesel or electricity) consumptions and emissions in a specific city context (the country average considers 50% of the bus time in a metropolitan area and 50% in an urban area). Environmental parameters are differentiated not only between different densely context, but also among countries as specified in the EC Handbook on the external costs of transport of 2019 and EEA Cost of air pollution from European industrial facilities 2008-2017 del 2021.

Sources and methodological approach for the construction of registrations and stocks scenarios 2030 and 2040 (I) - Sources

Warning: it is not possible to build an accurate picture of the stock of city buses operating in EU based on official sources, due to taxonomy limitations

Original data are available for the following countries: IT, UK, ES, NL, BE, LU, NO, SE, FR, DE, CH, AT, PL

Sources:

- *Chatrou CME Solutions (2022) data on new registrations of city buses 2020-2021 by country and fuel*
- *European Alternative Fuel Observatory (2021), data on stock of alternative fuel buses 2012-2021 by country and fuel*
- *European Statistical System (2021) data on buses by type and by propulsion 2018-2019*
- *Bloomberg New Energy Finance (BNEF) and ING Research (2020) Estimated total number of operated public per buses 2020 (UK, DE, FR, IT, NL, BE, Rest of Europe aggregated)*
- *ICCT Briefing «The rapid deployment of zero-emission buses in Europe» published in Sept. 2022*
- *ING Research (2021) "All aboard Europe's electric bus revolution" on BEBs market forecasts at 2030, as benchmark*
- *UITP Clean Bus Report An overview of clean buses in Europe, June 2022*

Sources and methodological approach for the construction of registrations and stocks scenarios 2030 and 2040 (II) – Assumptions and starting point

Assumptions:

- steady bus fleet substitution rate per country;
- substitution of Battery Electric Buses (BEBs) after 15 years;
- steady number of total city buses per country (all fuels), since the European bus market is considered mature and all the incremental public mobility target will find a new supply by other transport modes (metro, tram or trolleybuses).

The starting point is represented by EAFO data (2021) and Chatrou (2022):

a) estimated stock level of electric city buses in 2021;
b) estimated bus fleet substitution rate per country.

Sources and methodological approach for the construction of registrations and stocks scenarios 2030 and 2040 (III) – Sets of countries

- **3 exemplary Countries (IT, UK and ES) with complete data:**
  - **Italy** has been chosen as original field of the TCRO detailed study, analysing the potential of the addition of revenues to the Total Cost of Ownership;
  - **United Kingdom** represents the country in Europe with the most ambitious city electric bus fleet plans in Europe (London);
  - **Spain** is an exemplary case in EU where TCO of BEBs is already favorable compared to diesel buses;

- **10 countries with almost full and disaggregated data:** for NL, BE, LU, NO, SE, FR, DE, CH, AT, PL data on stock at 2021 and bus fleet substitution rates are available, therefore additional assumptions are not necessary;

- **20 countries with partial data** with limited differences of substitution rate among countries**:** the remaining twenty EU27 countries (for which only partial figures on city buses are available) have been added to the previous set, and average substitution rates have been assumed.

Sources and methodological approach for the construction of scenarios 2030 and 2040 (IV) – Scenarios for projections

The three market scenarios (registrations and stoks):

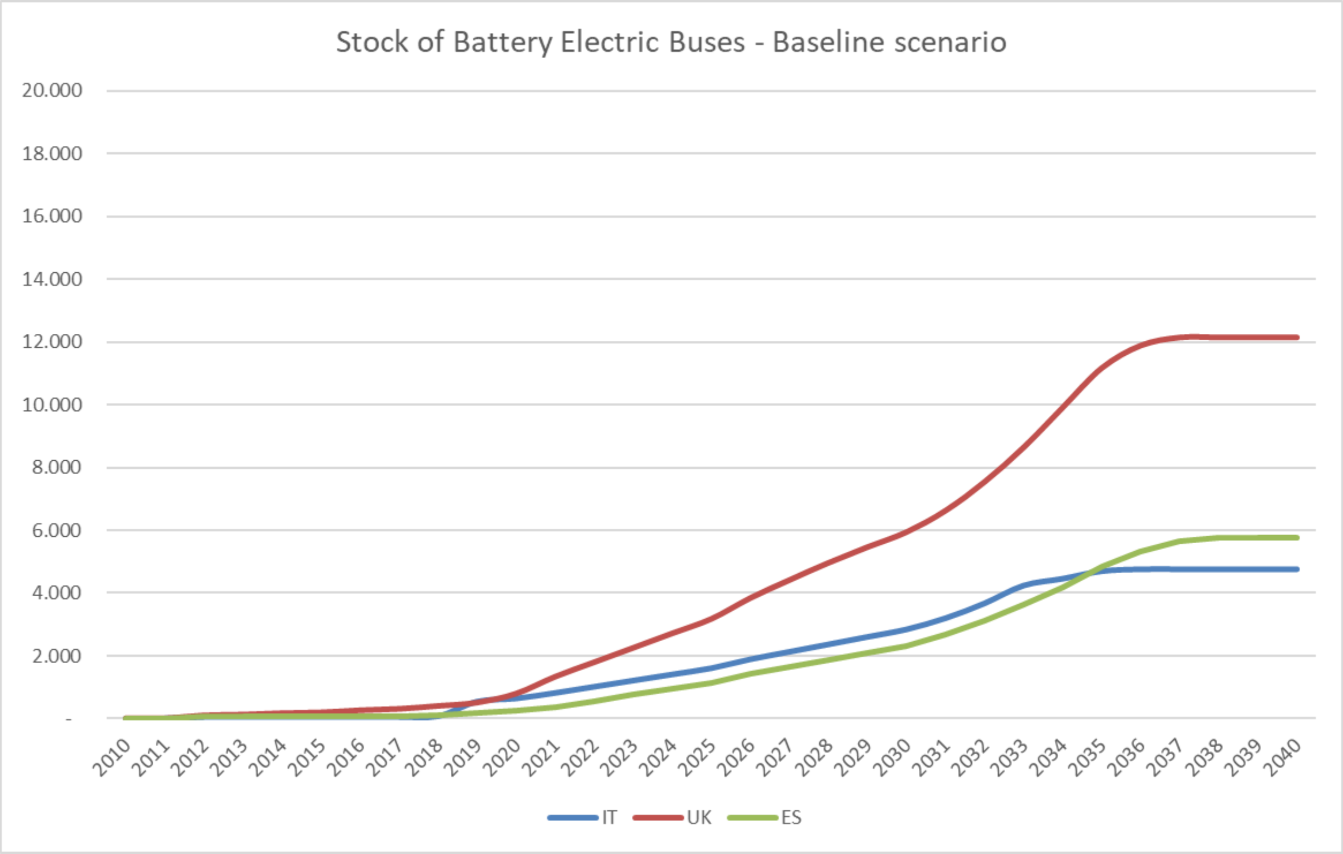
These scenarios do not attempt to be precise forecasts, acknowledging the inherent uncertainties in a market context where both demand and supply are rapidly evolving.
They represent "what if scenarios" that are designed to achieve long-term climate policy objectives and operational efficiency of LPTO.

Projections from 2022 to 2030 and 2040 are elaborated for the different sets of 30 countries on the basis fo the following

- **BASELINE**, assuming target for BEB from Clean Vehicle Directive –CVI (UE 1161/2019) are reached (differentiated among EU 27 countries, with an average of 22,5% BEB in 2022-2025 and 32,5% 2026-2030, between 2031 and 2035 different % among countries and after 2035 100%).
- **ACCELERATION**, anticipating by 2 years all CVI targets (65% starting from 2028 and 100% from 2033 instead of 2035)
- **BEST PRACTICE**, anticipating 100% BEB new registrations by 2028

Bus fleets electrification scenarios 2022-2030-2040 for exemplary countries: IT, UK, ES

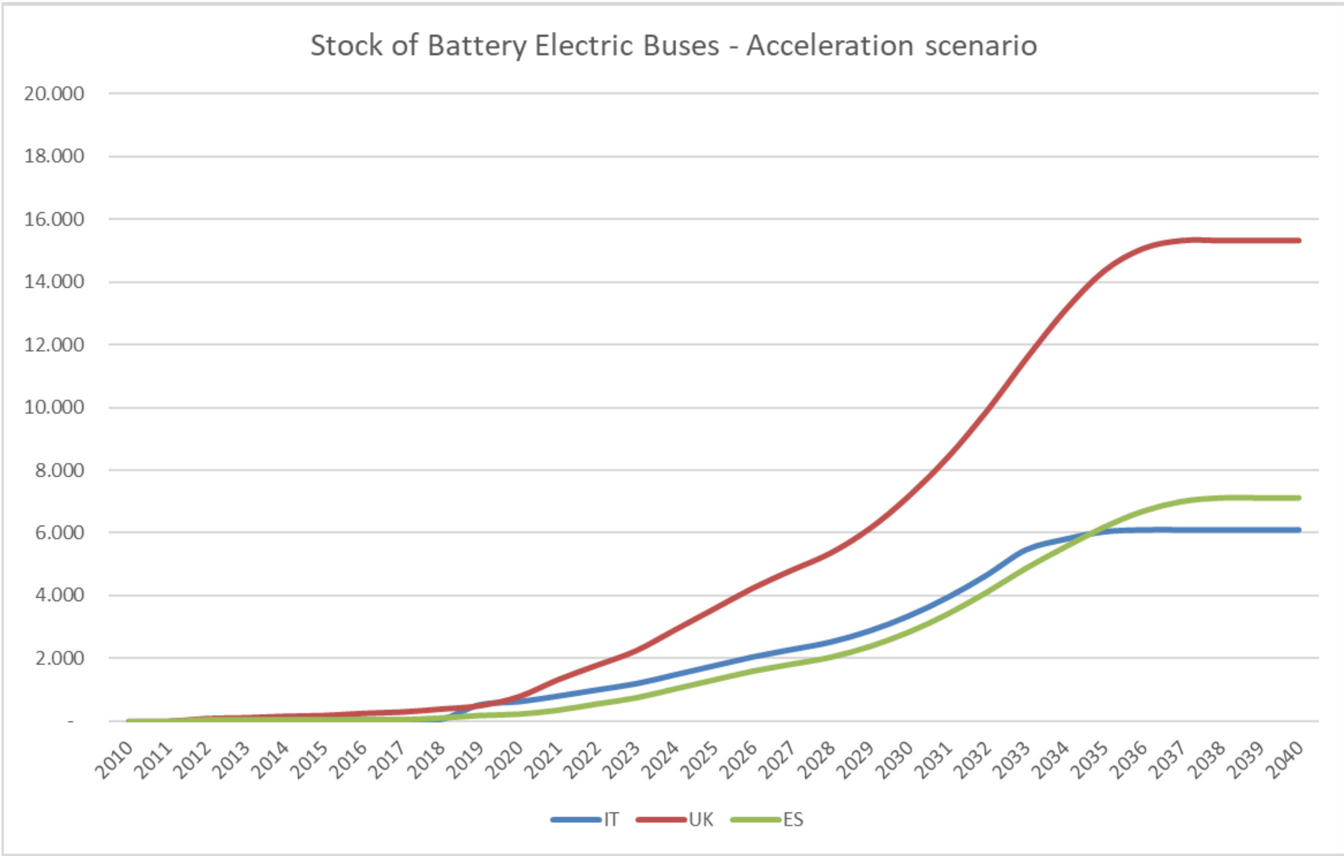
BASELINE SCENARIO



Source: GREEN elaboration on EAFO, 2021 and Chatrou, 2021

Bus fleets electrification scenarios 2022-2030-2040 for exemplary countries: IT, UK, ES

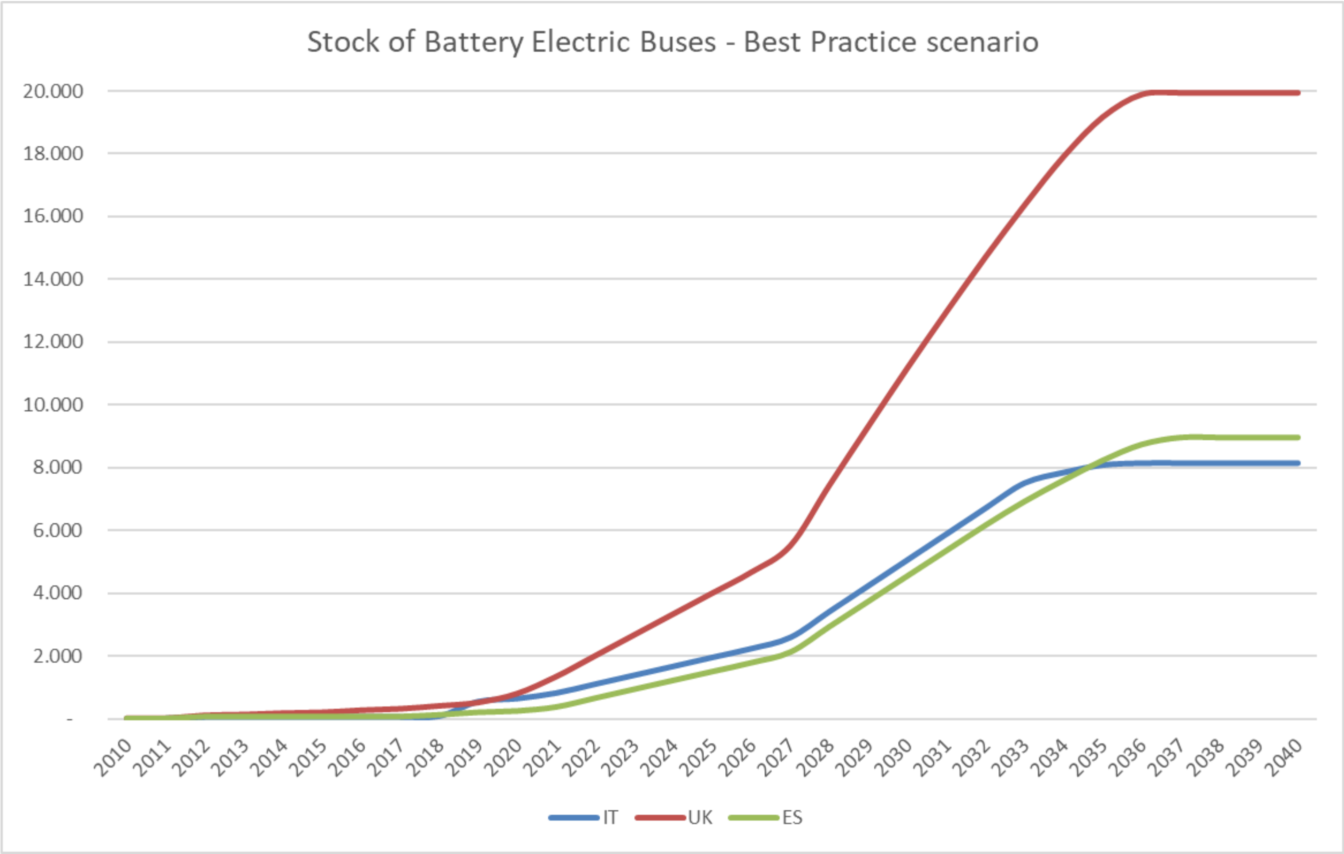
ACCELERATION SCENARIO



Source: GREEN elaboration on EAFO, 2021 and Chatrou, 2021

Bus fleets electrification scenarios 2022-2030-2040 for exemplary countries: IT, UK, ES

BEST PRACTICE SCENARIO



Source: GREEN elaboration on EAFO, 2021 and Chatrou, 2021

Bus fleets electrification scenarios 2022-2030-2040 for IT, UK, ES

The differences between the three country projections are based on their average substitution rates: **in UK, the total number of city buses purchased every year is more than double than in the other two countries considered**.

At some point (2037 for IT, 2038 for UK, 2039 ES in the BASELINE scenario), the number of new BEBs is assumed to replace old ones, therefore the electrified stock stops growing. **New investment strategies or new binding purchase quotas are needed to replace old ICE buses (or to extend BEBs life beyond 15 years)**.

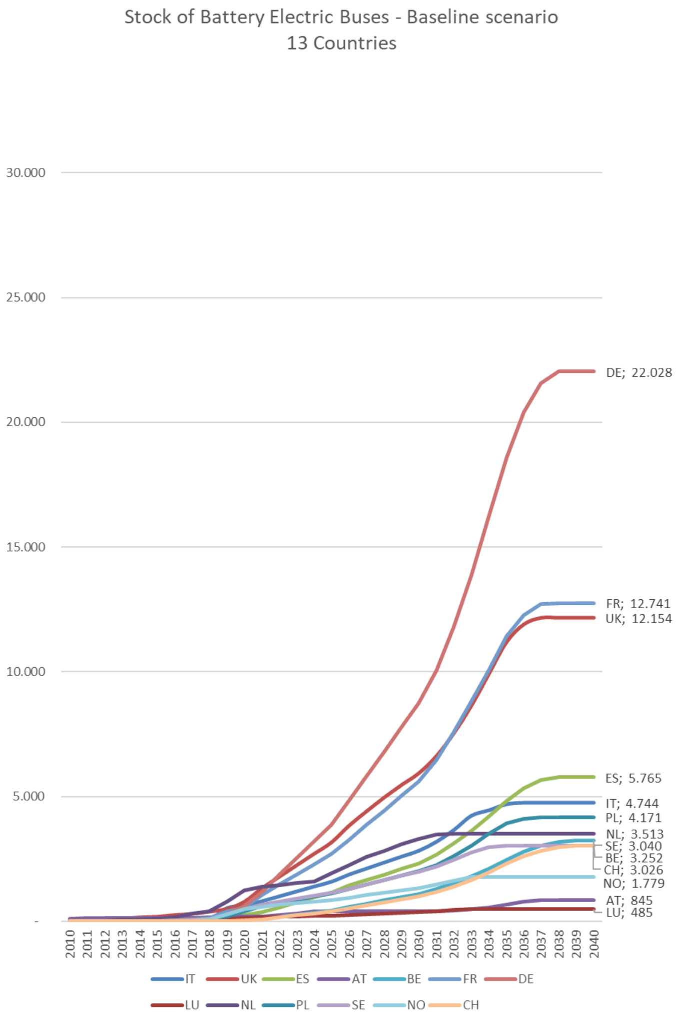
Under the BASELINE scenario the 2040 fleet in IT BEBs will be **4.744** units, **12.154** in UK and **5.765** in ES.
If the ACCELERATION scenario applies, in IT BEBs will be **6.098**, in UK **15.328** and in ES **7.117**.
Lastly, according to the BEST PRACTICE scenarios, in 2040 IT will have **8.160** electric city buses, while UK **19.955** and ES **8.973**.

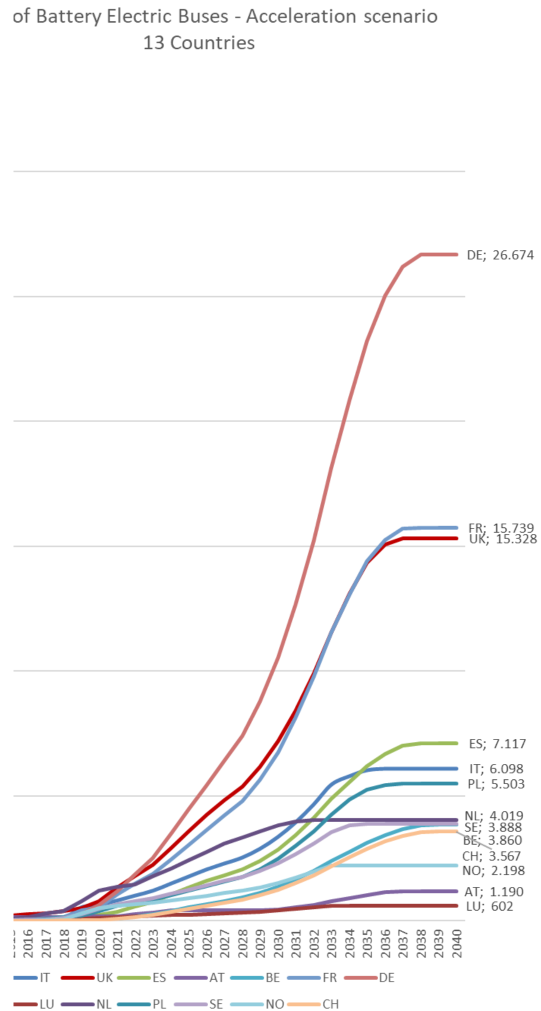
With respect to the BASELINE scenario:

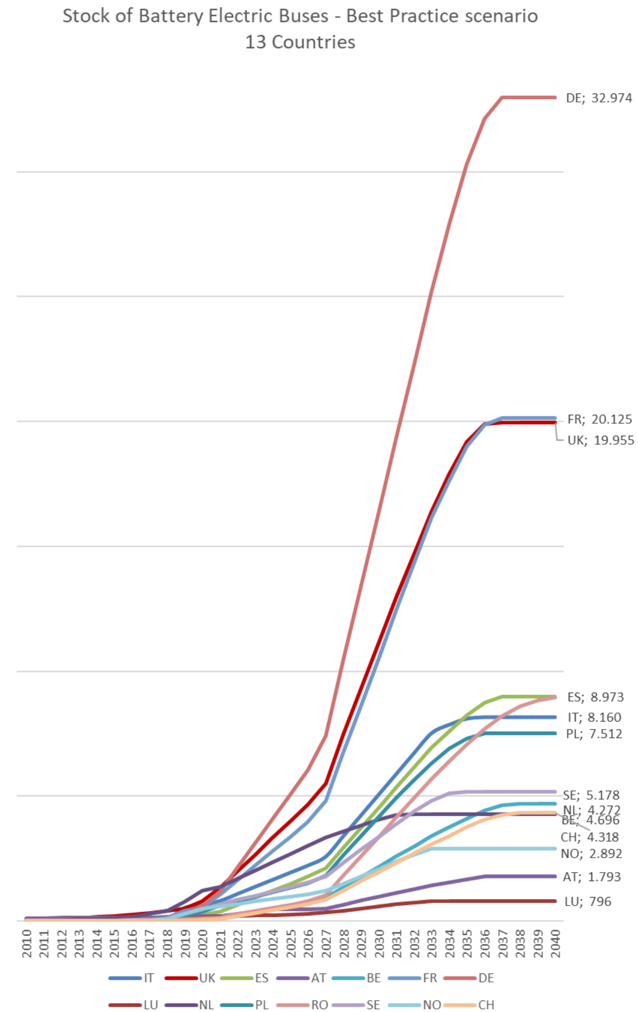
- In Italy, the ACCELERATION scenario would increase the number of total BEBs by **29%**, the BEST PRACTICE by **72%**;
- In UK, respectively by **26%** and **64%**;
- In Spain by **23%** and **56%**.

This is due to the combination of initial BEBs stock and substitution rate.

Bus fleets electrification three scenarios 2022-2030-2040 for 13 countries







Source: GREEN elaboration on EAFO, 2021 and Chatrou, 2021

Bus fleets electrification scenarios 2022-2030-2040 for 13 countries

The absolut number depends on the total stock of city buses, and consequently by the average rate of substitution.

Among the 13 countries, **Germany** is the one that according the projections will achieve the highest number of BEBs in the three scenarios (respectively **22.028** in the BASELINE, **26.674** in the ACCELERATION, **32.974** in the BEST PRACTICE) corresponding to the **19%** of total BEBs estimated in the EU27+3 in 2040.

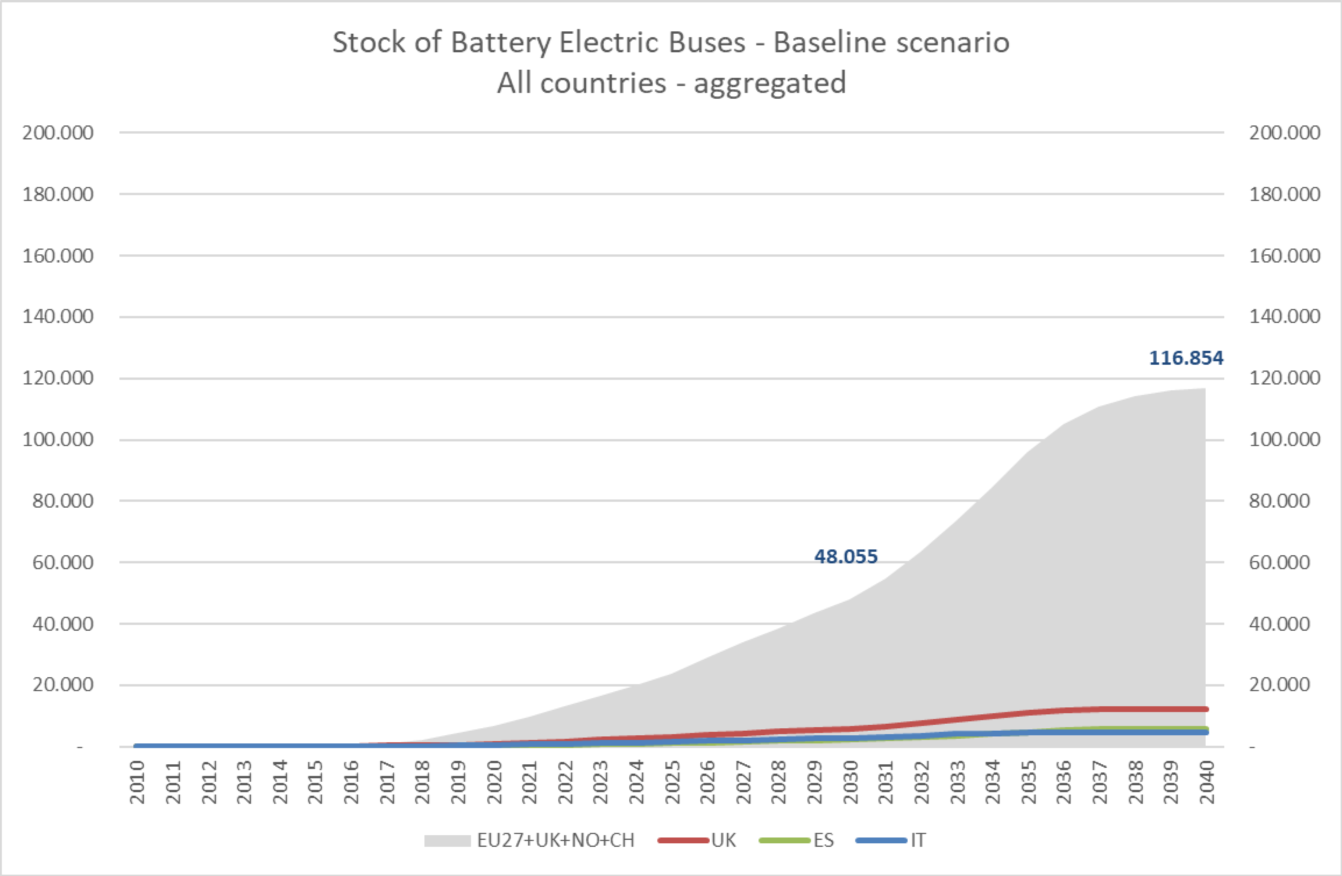
UK and **France** follow with similar figures (**12.154** and **12.741** in the BASELINE, **15.328** and **15.739** in the ACCELERATION, **19.955** and **20.125** in the BEST PRACTICE) equal to around **10%** to **11%** of total BEBs estimated in the EU27+3 in 2040.

Italy and **Spain**, with **Poland**, stand at an intermediate level, each with **4%** to **5%** of total BEBs estimated in the EU27+3 in 2040.

An outlier is represented by **the Netherlands**, where the policies towards full electric foster a high adoption and bring the country to reach its full potential already by 2030.

Bus fleets electrification scenarios 2022-2030-2040 for EU27+UK+NO+CH

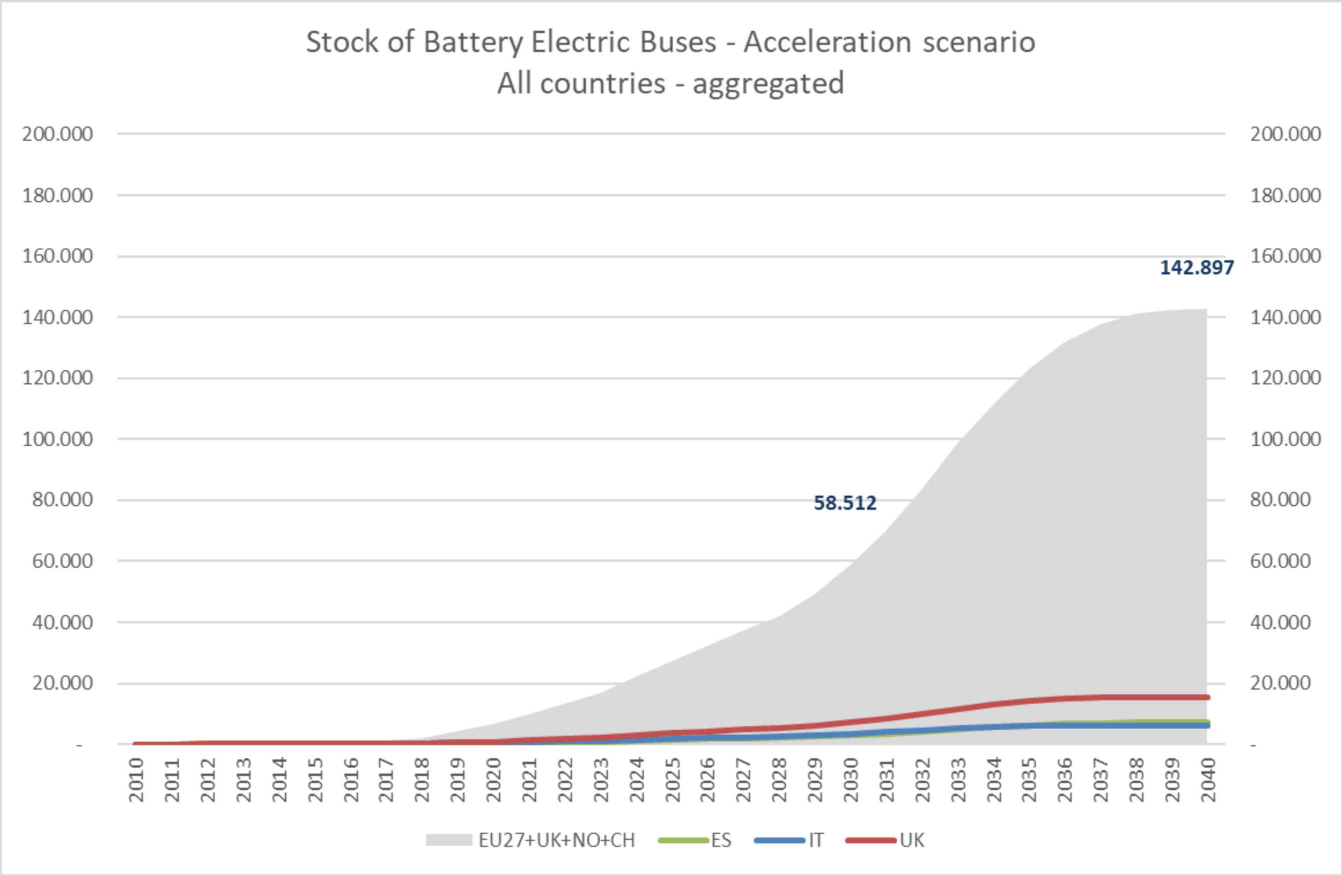
BASELINE SCENARIO



Source: GREEN elaboration on EAFO, 2022 and Chatrou, 2022

Bus fleets electrification scenarios 2022-2030-2040 for EU27+UK+NO+CH

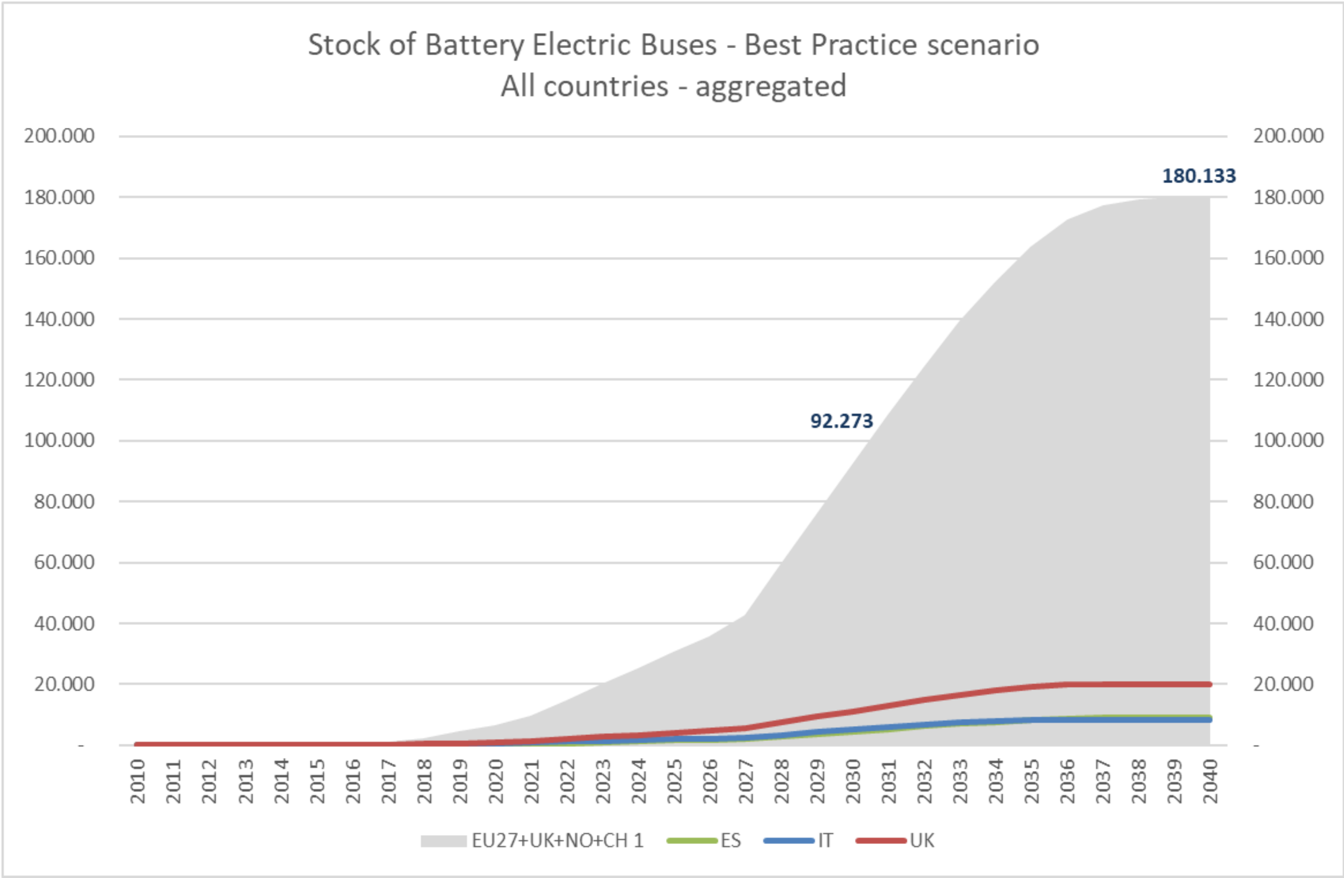
ACCELERATION SCENARIO



Source: GREEN elaboration on EAFO, 2022 and Chatrou, 2022

Bus fleets electrification scenarios 2022-2030-2040 for EU27+UK+NO+CH

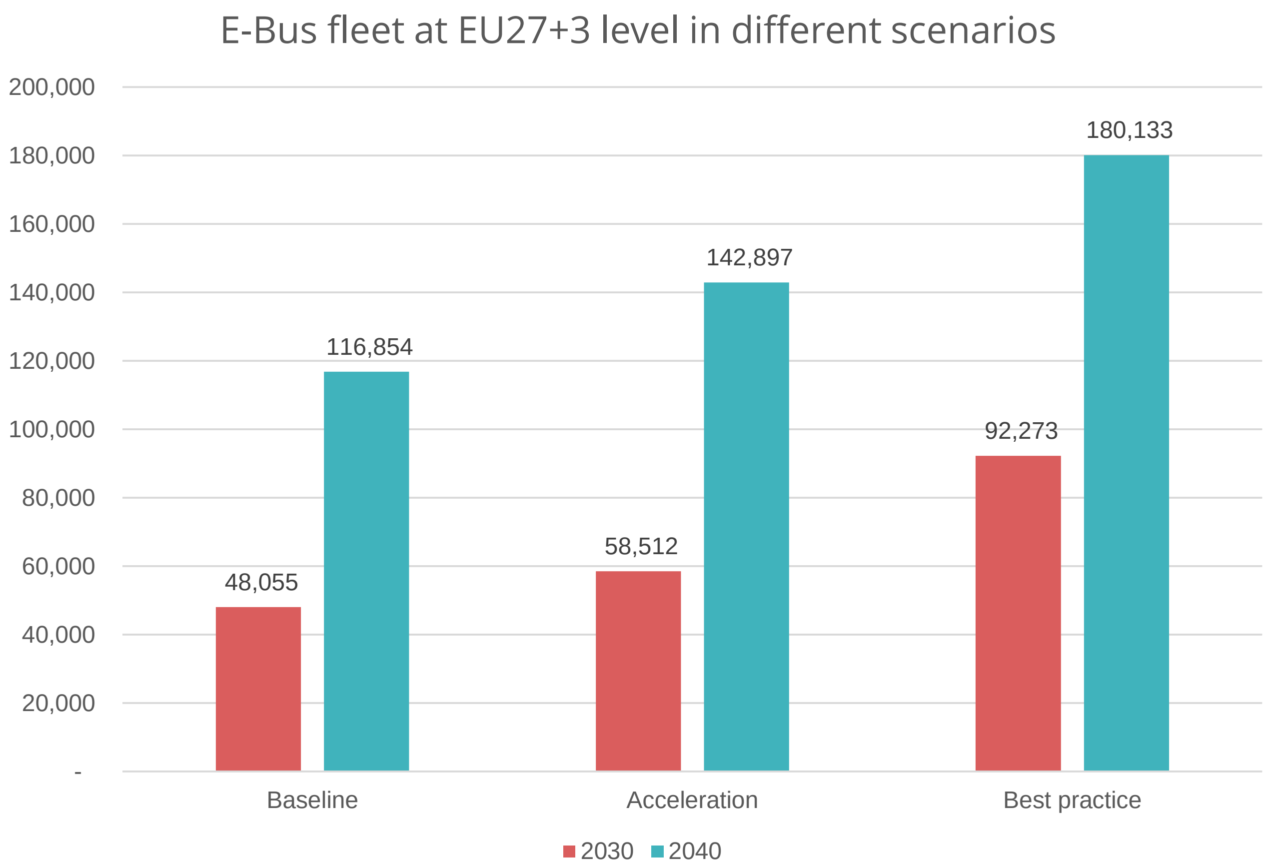
BEST PRACTICE SCENARIO



Source: GREEN elaboration on EAFO, 2022 and Chatrou, 2022

Synthesis of the results of bus fleets electrification scenarios 2022-2030-2040 for EU27+UK+NO+CH

The following projections have been elaborated at aggregated level for the three scenarios.



Source: GREEN elaboration on EAFO, 2022 and Chatrou, 2022

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Section 2

The TCO and TCRO methodological approach

COMPANY COST COMPONENTS
Bus and infrastructure costs including the cost of charging/fueling infrastructure necessary to operate the buses (overnight and opportunity chargers, electrolyzes, fuel tanks, etc.)
Energy costs for traction
Bus maintenance (ordinary) including the ordinary costs of replacing tyres, lubricants, components subject to wear
Bus maintenance (extra-ordinary) including the replacement of components such as batteries or transmission components and allows the extension of the useful life of the bus (includes both opex and capex elements)
Infrastructure maintenance
COMPANY REVENUE COMPONENTS
Bus2Grid (Buses equipped with batteries can generate revenues by participating in the dispatching services market, which requires infrastructure investments typically made by the electricity distribution network operator)
End-of-life batteries valorization (the sale of batteries for other purposes (for example stationary applications in grids, buildings etc.), can be a source of revenue)
SOCIAL COST COMPONENTS
Environmental externalities (CO2 emissions, local pollutants, noise, PTW emissions)

“Total costs of ownership” (TCO) and “Total costs and revenues of ownership” (TCRO) approaches were adopted, including the monetization of environmental externalities (C02, pollution and noise), focusing on standard 12-meter buses dedicated to urban transport

TCO and TCRO values per km are the result of the sum of discounted variables. Since the TCO and TCRO values per km processed by the model are the result of the sum of discounted variables, the monetary value of the operating components of TCO and TCRO will be lower than the starting value indicated in the data sources used for the calculation.

Approach and assumptions for the estimation of operational and environmental benefits and revenues streams deriving from B2G and 2nd life of the batteries in the three scenarios

Field of observation: comparison between TCRO differences between 12 meter e-buses and Euro VI diesel buses, two sets of countries (IT, UK and ES and the rest of EU27+UK+NO+CH).
Objective: identify and quantify operational and environmental benefits under different scenarios.

Operational benefits:

- are calculated as difference between diesel and battery electric buses on the basis of the **TCO** methodology and include the following cost parameters: **bus and infrastructure, energy, maintenance.**
- **Bus and infrastructure costs** are expected to converge at EU level in the long run (after 2030)
- **Energy costs** vary across countries.
- **Maintenance costs** vary across countries according to the labour costs.
- **TCO** is calculated for IT, UK and ES, and derived for the other countries on the basis of specific parameters for energy and maintenance in 2021-2030, in 2030-2040 BEB will have an efficiency gain of 1% per year compared to diesel buses in terms of TCO reduction.

Environmental benefits:

- include Greenhouse emissions, local pollution and noise.
- are considered at country level for IT, UK and ES, at EU level for the rest of EU27+UK+NO+CH.

Revenues streams for local public transport operators (LPTO) deriving from B2G and 2nd life of the batteries:

- are considered at country level for IT, UK and ES, at EU level for the rest of EU27+UK+NO+CH.

TCO and TCRO in Italy, United Kingdom and Spain in 2030 – differences between e-buses and diesel buses

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The different level of market readiness for zero emission buses in the European market underlines slightly different results in terms of TCO and TCRO among three main European markets.

Higher upfront capital costs associated with technologies and infrastructure for the zero emission bus transition are mitigated by the **lower operational** (-56%, IT) and **maintenance costs** (-46% IT) for e-buses in 2030.

Differences among markets could be due to:

1) Labour cost, energy cost, presence of PT operators or PT agencies able to quickly generate **economies of scale in procurement process** and **depots construction** with **specific operational knowledge** in ZEB;

2) presence of **bus and battery factories** that could contribute to reduce maintenance costs and increase the residual value of the batteries;

3) Low-cost or discounted **energy tariffs for PT**;

4) presence of new players proposing **innovative asset ownership and sources for scalable financing**.

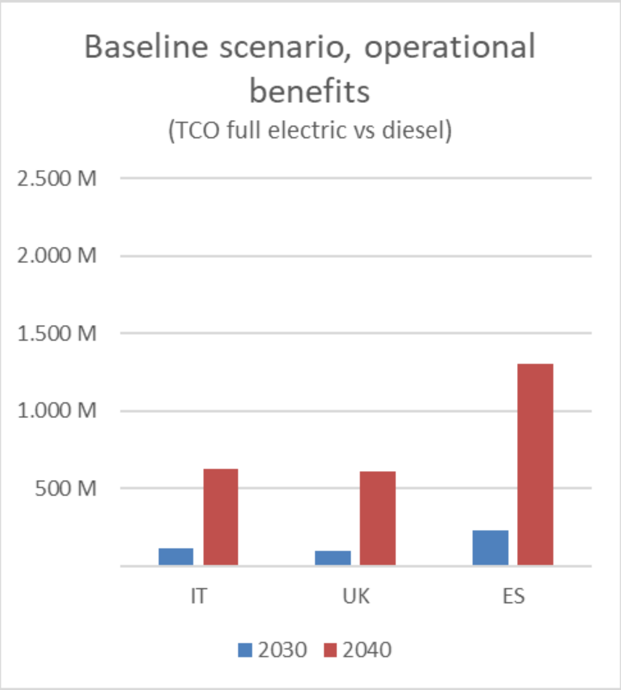
The combination of **synergies with the electric market** (B2G), **valorization of the residual value of batteries** (2nd life) could accelerate the transition to zero emission buses thanks to additional revenue (0,050 Euro*km in Italy, 0,082 in UK and 0,050 in Spain in 2030)

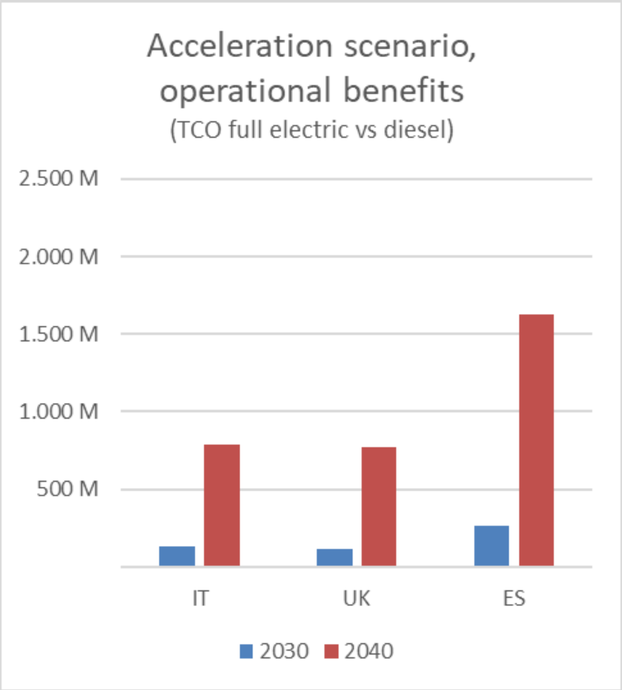
Elaborations by GREEN

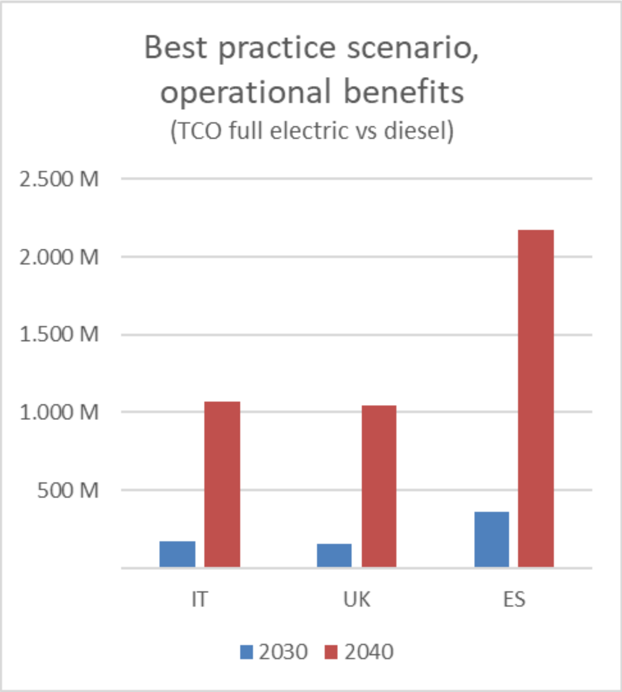
Differences of TCO and TCRO - Full electric vs diesel (12 meters, 2030 in Euro*km)

	Italy		United Kingdom		Spain	
Total TCO	-0,200	-22%	-0,084	-11%	-0,394	-37%
Total TCRO	-0,251	-27%	-0,166	-22%	-0,444	-42%

Bus fleets electrification scenarios, operational benefits (cumulated TCO differences) in IT, UK, ES – years 2022-2030 and 2022-2040







Source: GREEN elaboration

The methodological approach for the environmental benefits evaluation at IT, ES and UK level

The goal of this part of the study is to answer to the following key question: **What could be the contribution of the fleet electrification at EU27+3 level in the different scenarios to meeting the EU's climate goals and to reduce the cost of environmental externalities of local public transport**?

On average, in Europe, switching from a Euro VI bus to a 100% renewable Full Electric Bus saves 22.500 liters of diesel and 58,5 tons of CO_2 per year.

The comparison among the three markets (Italy, Spain and the United Kingdom) through index numbers shows a substantial consistency of assessments, taking into account that the monetary parameters of local pollutants in absolute terms are different among nations (e.g., the average value of PM 10 per ton is 246.111 Euro in Italy, 130.955 Euro in Spain and 115.281 Euro in the United Kingdom, with the differences depending on local impact factors in terms of population density, per capita GDP value at equal purchasing capacity and cumulative effects with other local pollutants).

The result on an annual basis, with an estimated 55.000 km per year, is also different among the three countries analyzed, with a monetary value borne by the community from the environmental externalities generated by a Diesel Euro VI bus of 11.204 Euro in Italy, 9.508 in Spain and 9.840 Euro in Great Britain.

The same value for an electric bus powered by 100% renewable energy is 850 Euro in all three countries because noise emissions have very similar parameters at the European level.

The choice of comparing EuroVI diesel buses with 100% renewable e-buses is justified by the fact that many LPT companies only use certified renewable source (like Transdev in Amsterdam, ATM in Milan, GTT in Turin, AMT in Genoa), further expanding the emission differential with endothermic engines.

Environmental benefits in Italy, United Kingdom and Spain

In order to fully understand the potential of electrification of bus fleets, externalities (CO_2, PM10, NOx, SO_2, NMVOC, Noise) have been added to the TCO and TCRO calculations. The comparison of the cost of externalities among different motorization clearly highlights the economic and social benefits deriving from the electrification choice.

Social Cost Factors for Transport Emissions are based on country and context (50% metropolitan area and 50% urban area) specific parameters

Differences of externalitites Full electric vs diesel (12 meters, 2021 in Euro*km, national electricity grid mix)						
	Italy		United Kingdom		Spain	
CO2	-0,061	-66%	-0,067	-73%	-0,070	-76%
POLLUTION	-0,050	-100%	-0,025	-100%	-0,019	-100%
NOISE	-0,046	-75%	-0,046	-75%	-0,046	-75%

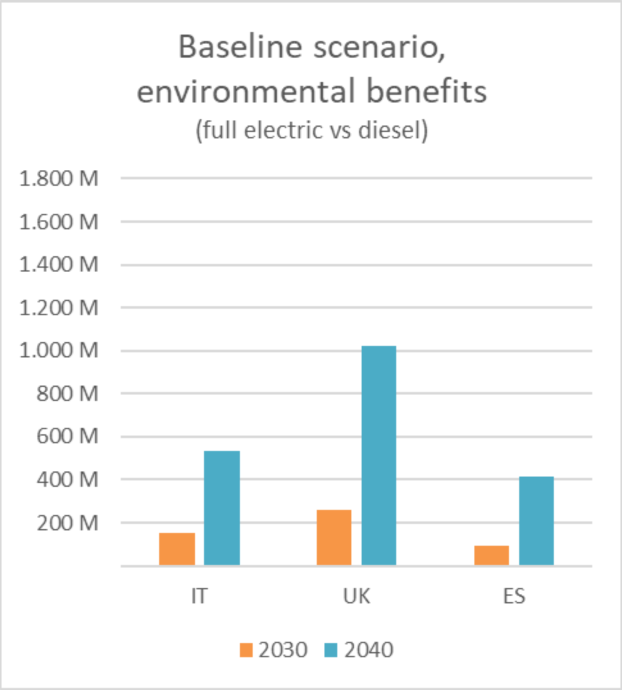
Elaborations by GREEN, Aggregate marginal damage costs over EEA38 + UK (*) for major air pollutants including impacts on health, crops & forests, ecosystems and material damage, in €2019/tonne of pollutant, based on Handbook on the external costs of transport del 2019 e EEA, Cost of air pollution from European Industrial Facilities 2008-2017 del 2021

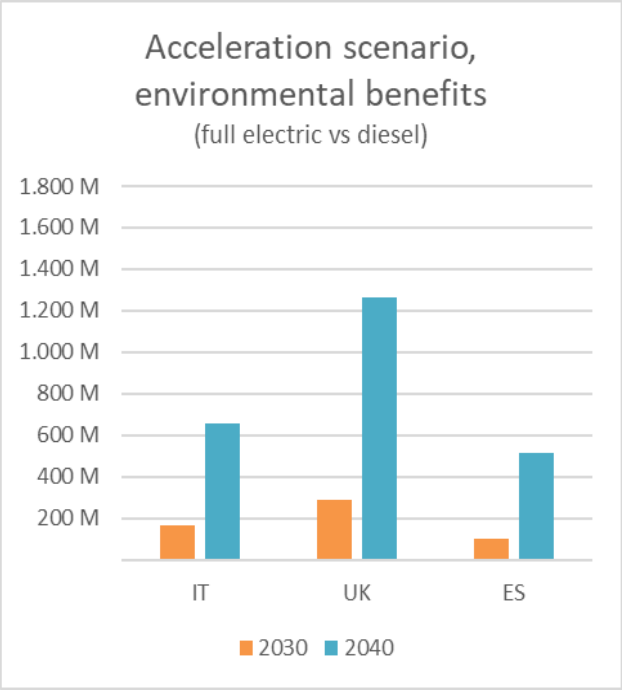
Monetary values (in Euro*km), Italian case specific for a 12 meter bus (based on 2021 data)

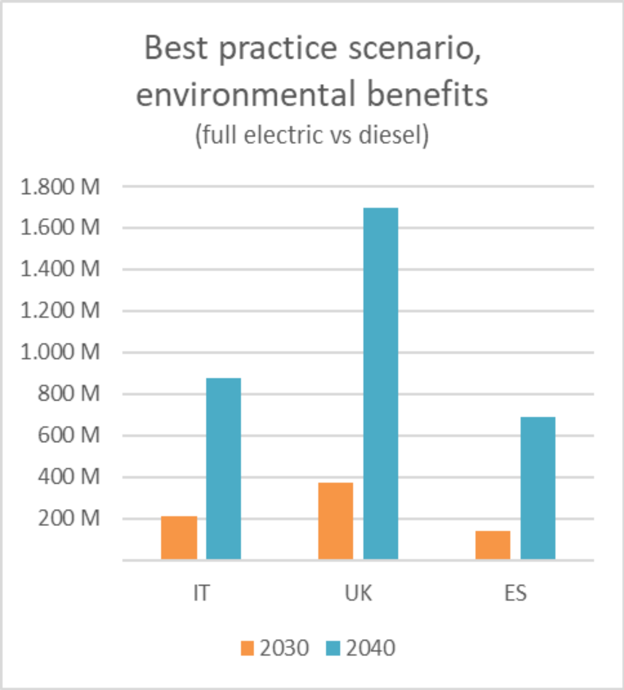
Annual value	Full electric (national electricity mix)	Full electric (100% renewables)	Diesel EuroVI	CNG e LNG (fossil)
Annual value of externalities (Euro, 2021)	4.119	850	11.204	11.032
Index, Diesel EuroVI= 100	37	8	100	98

The analysis showed that BEB could reduce by 92% the costs of externalities if sourced with 100% renewables in comparison with EuroVI diesel buses, thanks to 100% reduction of GHG emissions and local pollution and by a ¼ of the costs of noise

Bus fleets electrification scenarios, environmental benefits IT, UK, ES – years 2022-2030 and 2022-2040 - 100% renewables case for electricity generation (cumulated results)







Source: GREEN elaboration

Bus fleets electrification scenarios, operational+environmental benefits IT, UK, ES – years 2022-2030 and 2022-2040 - 100% renewables case for electricity generation (cumulated results)

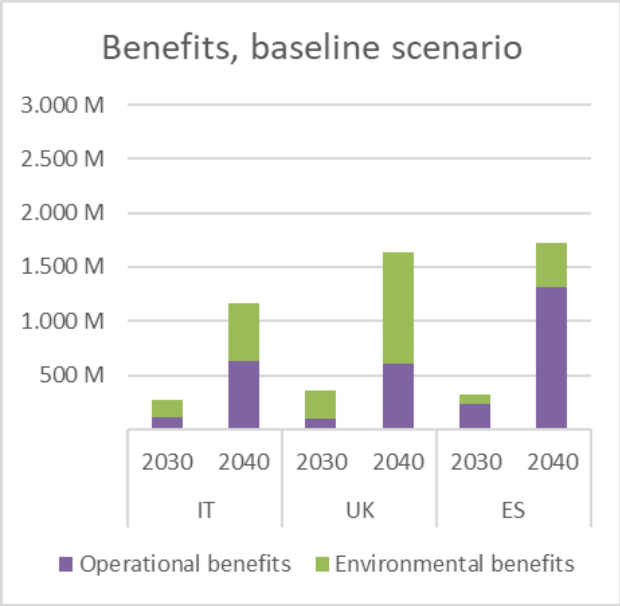
Scenario	Baseline					
Country	IT		UK		ES	
Year	2030	2040	2030	2040	2030	2040
Operational benefits	115 Mio €	628 Mio €	96 Mio €	611 Mio €	230 Mio €	1.307 Mio €
Environmental benefits	154 Mio €	535 Mio €	262 Mio €	1.023 Mio €	92 Mio €	417 Mio €
Total	269 Mio €	1.163 Mio €	358 Mio €	1.634 Mio €	322 Mio €	1.724 Mio €

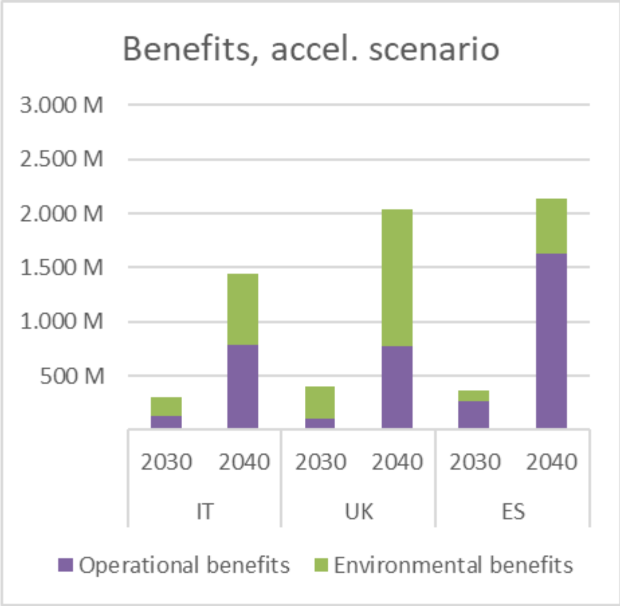
Scenario	Acceleration					
Country	IT		UK		ES	
Year	2030	2040	2030	2040	2030	2040
Operational benefits	129 Mio €	788 Mio €	111 Mio €	769 Mio €	261 Mio €	1.625 Mio €
Environmental benefits	168 Mio €	657 Mio €	289 Mio €	1.264 Mio €	103 Mio €	515 Mio €
Total	297 Mio €	1.445 Mio €	400 Mio €	2.033 Mio €	364 Mio €	2.139 Mio €

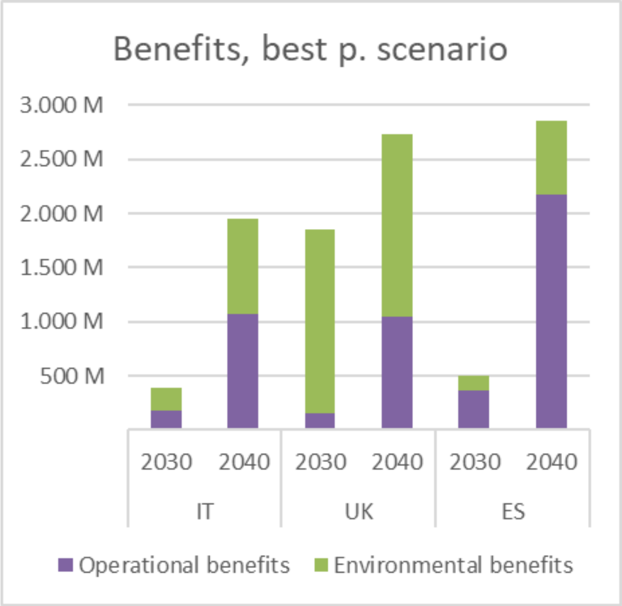
Scenario	Best practice					
Country	IT		UK		ES	
Year	2030	2040	2030	2040	2030	2040
Operational benefits	174 Mio €	1.072 Mio €	155 Mio €	1.045 Mio €	359 Mio €	2.175 Mio €
Environmental benefits	212 Mio €	878 Mio €	1.694 Mio €	1.694 Mio €	138 Mio €	687 Mio €
Total	386 Mio €	1.950 Mio €	1.849 Mio €	2.739 Mio €	497 Mio €	2.862 Mio €

Source: GREEN elaboration

Bus fleets electrification scenarios, operational+environmental benefits IT, UK, ES – years 2022-2030 and 2022-2040 - 100% renewables case for electricity generation (cumulated results)







Source: GREEN elaboration

Bus fleets electrification scenarios, operational+environmental benefits IT, UK, ES – years 2022-2030 and 2022-2040 - 100% renewables case for electricity generation (cumulated results)

Operational benefits are higher in Spain in the three scenarios (BEST PRACTICE 2040, nearly 2,2 billions of euros and 76% of total benefits), since TCO of BEBs is already significantly favorable in 2021.

Italy and **UK** show **not so distant levels of cumulated operational benefits** (BASELINE 2040, IT 628 million euros, UK 611 million) even if the BEBs fleets are very different in consistency; this is due to the fact that **BEBs TCO in UK is significantly higher** (especially because of BEBs' costs).

On the other side, the **UK case reports the highest relevance of environmental benefits** generated by the substitution of diesel buses with BEBs (BEST PRACTICE 2040, nearly 1,7 billions of euros and 62% of total benefits).

In **Italy**, the **ratio between environmental and operational benefits** generated under the three scenarios is more balanced than in the other two considered countries, **in favour of the former in the short run, while the situation changes by 2040** (e.g. BEST PRACTICE 2030, 55% of benefits are environmental, becoming 45% in 2040). This is due to the progressive gains in price competitiveness of BEBs against ICE buses.

An overview of the modelling approach for the operational benefits evaluation at EU27+3 level in the different scenarios

The goal of this part of the study is to answer to the following key question:

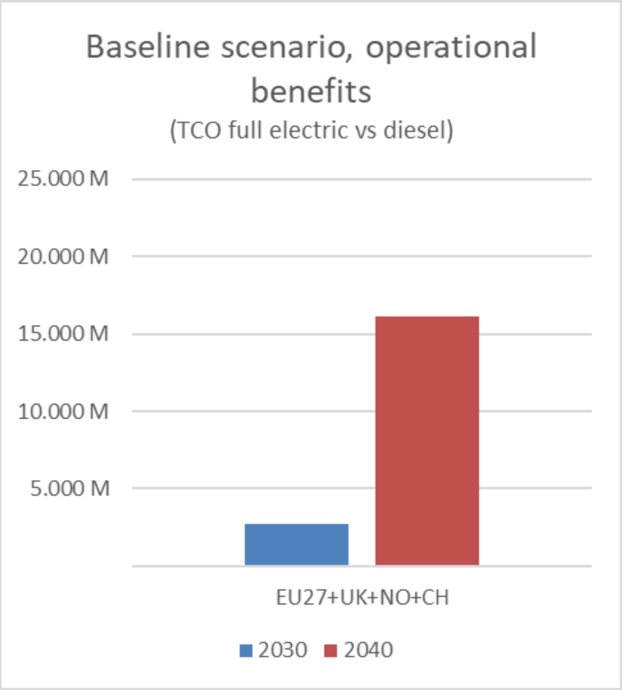
What could be the contribution of the fleet electrification at EU27+3 level in the different scenarios in improving economic efficiency of local public transport operators?

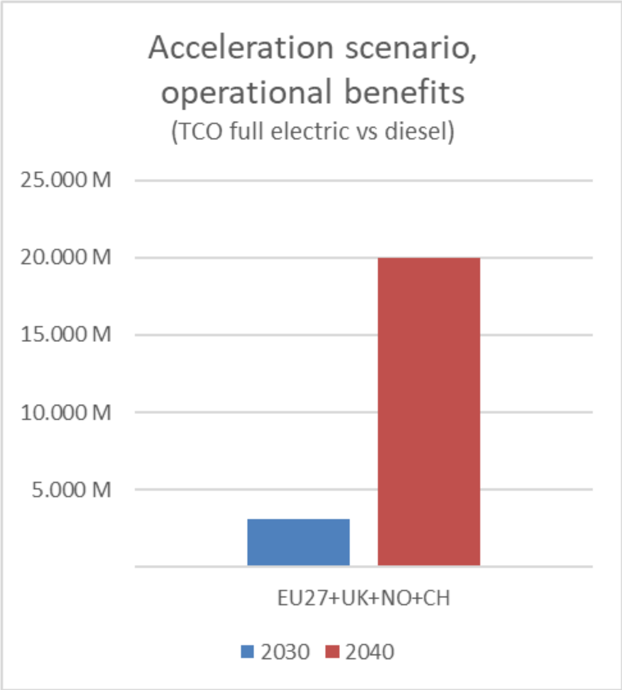
Data inputs and assumptions:

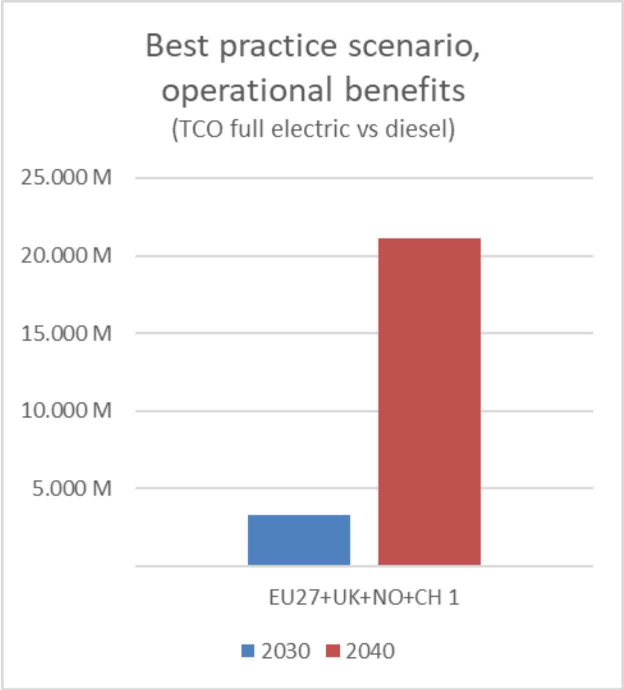
- Detailed analysis of TCO and externalities for electric buses and diesel buses in three important European markets with different level of market readiness for BEB (IT, UK and ES) in 2021-25-30;
- Hypothesis that the difference between TCO of e-buses and diesel buses will follow the same path of the average of the three markets at European level from 2021 to 2030 and from 2030 to 2040 the TCO difference of e-buses compared to diesel buses will increase at 1% per year;
- Hypothesis that in all European market the costs of all investment components (bus, infrastructure for recharging and batteries) will converge towards the average estimated for the three markets in 2030;
- Collection of data on GDP per capita at PPP (Euro, 2021, source Eurostat), and data on electricity prices for non household consumer 1st semester 2021 (Euro* kwh, source Eurostat) in other to differentiate maintenance costs and electricity costs among countries;
- Hypothesis that the different electricity costs among countries will remain the same compared to the average of the three markets in 2030 and 2040 scenario;
- Hypothesis that the different labour costs among countires (estimated through the difference of GDP pro capite based on purchaising power parity using Euro) will remain the same compared to the average of the three markets in 2030 and 2040 scenario.

Model outputs: Efficiency gains for public transport operators at EU27+3 level

Bus fleets electrification scenarios, operational benefits EU 27+3 level – years 2022-2030 and 2022-2040 (cumulated results)







Source: GREEN elaboration

The reduction of maintenance cost and more efficient power engines will reduce the operational costs for local public transport operators at EU 27+3 level up to 21.6 billions Euro in Best Practice scenario in 2040

An overview of the modelling approach for the environmental benefits evaluation at EU level (average electricity generation at Eu level in 2021 and 2030)

The following table shows the monetary values of the environmental externalities generated by 12-meter buses with different motorizations that will be used for the EU-level scenario analyses, expressed in Euro*km and related to the PTT and TTW phases, with index= 100 for the most common motorization being registered in 2021, the Diesel Euro VI.

The average GHG emission intensity of electricity generation at EU level is 231 in 2021 and will be 110 gr Co2 eq*kWh according to European Environment Agency's guidance for scenarios to 2030.

Monetary values (in Euro*km), European case specific for a 12 meter bus (Diesel Euro VI=100, data based on 2021 inputs)

Type of environmental externality	Full electric (European electric mix)	Full electric (100% renewables)	Diesel EuroVI	CNG e LNG (fossil)	CNG (biomethane)	Hydrogen (100% renewables)
CO2	29	0	100	119	0	0
PM10	38*	0	100	1	1	0
NOx	55*	0	100	137	137	0
NMVOC	282*	0	100	4865	4865	0
Noise	25	25	100	50	50	25
Total (Euro*km)	37	9	100	95	29	9

Source: Estimations of GREEN on data from the Handbook on the external costs of transport 2019, European Environment Agency, 2021, 'Greenhouse gas emission intensity of electricity generation in Europe', ISPRA, 2020, 'Fattori di emissione di gas serra nel settore elettrico in Italia e nei principali Paesi europei'. In 2030 the CO2 value for full electric with Eu average GHG emission intensity of electricity generation will be 17.

*detailed figures from Italy (ISPRA 2020) have been considered here

Environmental benefits at EU 27+3 level in 2021 and 2030

enel Foundation

The comparison of the cost of externalities CO2, PM10, NOx, SO2, NMVOC, Noise) among different motorization clearly highlights the economic and social benefits deriving from the electrification choice. The results underline that there is no environemental and health benefits to be gained with CNG and LNG bus relative to a EuroVI diesel bus.

Social Cost Factors for Transport Emissions are based on country specific parameters

Full electric vs diesel (12 meters, 2030 in Euro*km, European electricity grid mix

	Differences of economic value - Europe	
CO2	-0,079	-86%
POLLUTION	-0,018	-100%
NOISE	-0,046	-75%

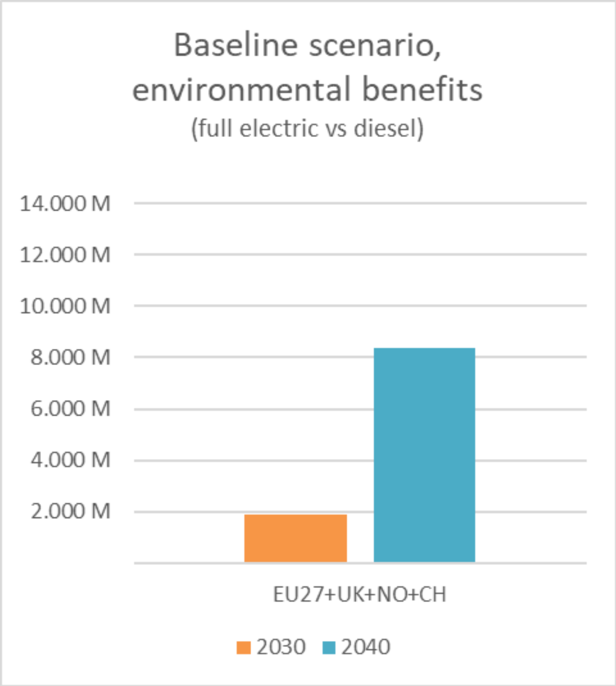
Elaborations by GREEN, based on Handbook on the external costs of transport del 2019 e EEA, Cost of air pollution from European Industrial Facilities 2008-2017 del 2021

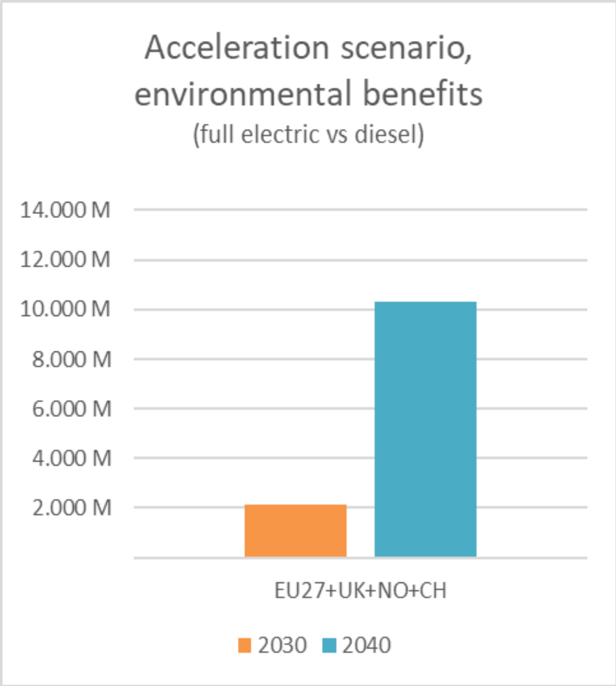
Monetary values (in Euro*km), average European level for a 12 meter bus (dati al 2021)

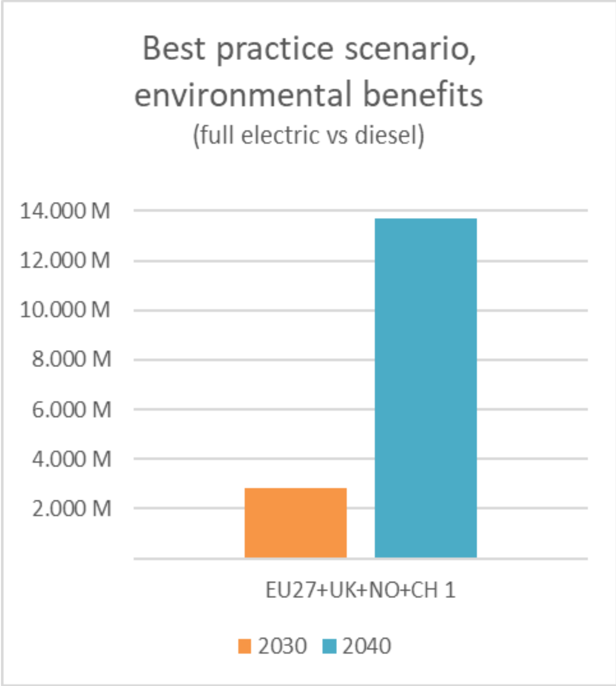
Annual value	Full electric (national electricity mix)	Full electric (100% renewables)	Diesel EuroVI	CNG e LNG (fossil)
Annual value of externalities (Euro, 2021)	3.389	850	9.160	8.697
Index, Diesel EuroVI= 100	37	9	100	95

The analysis showed that BEB could reduce by 91% the costs of externalities if sourced with 100% renewables in comparison with EuroVI diesel buses, thanks to 100% reduction of GHG emissions and local pollution and by a ¼ of the costs of noise

Bus fleets electrification scenarios, environmental benefits EU 27+3 level – years 2022-2030 and 2022-2040 - 100% renewables case for electricity generation (cumulated results)





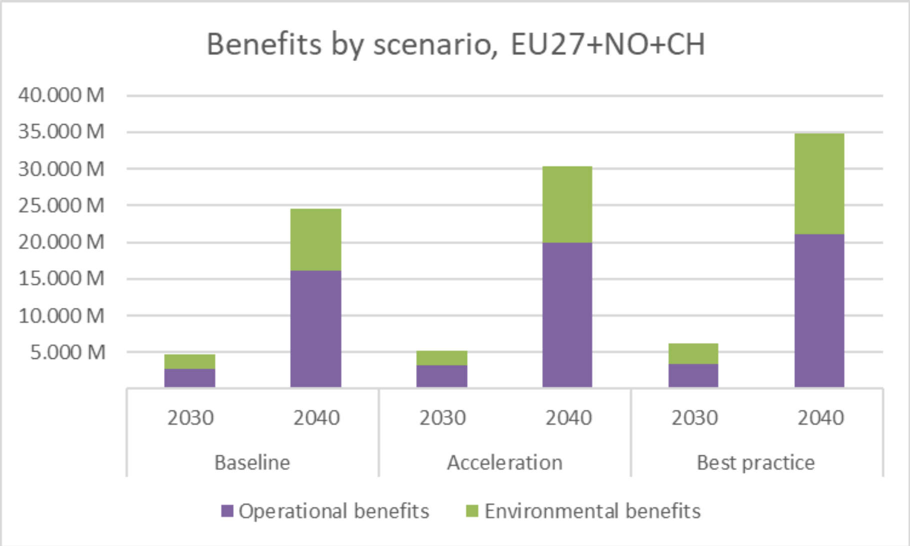


Source: GREEN elaboration

Electrifying European city buses has the potential of reducing externalities (greenhouse gas emissions, local pollutants, noise, well to tank emissions) and the analysis highlights the potential indirect cost savings for the health system and in terms of premature deaths avoided and of reduction of climate change effects: up to 13,6 billion Euros in Best practice scenario in 2040

Bus fleets electrification scenarios, operational+environmental benefits EU 27+3 level – years 2022-2030 and 2022-2040 - 100% renewables case for electricity generation (cumulated results)

Source: GREEN elaboration



The contribution of swapping from diesel to electric buses to meet the economic efficiency goals of local public transport operators and to reduce the cost of environmental externalities for the society as a whole is relevant: up to 6,13 billion Euro in 2030 and 34,78 billion Euro in 2040 in Best practice scenario (anticipating 100% BEB new registrations by 2028).

Anticipating 100% BEB new registrations by 2028 compared to the indication of Clean Vehicle Directive (100% BEB new registrations by 2035) will generate incremental 10,3 billion Euro in 2040
In this scenario the project results underline that in 2040 the operational and environmental cumulative benefits of each of the 180.133 e-bus part of the EU 27+3 stock market will be around 193.095 Euro.

Approach and assumptions for the estimation of potential revenues stream for LPT operators in the three scenarios

The goal of this part of the study is to answer to the following question:

- What could be the contribution of the fleet electrification at EU27 + 3 (UK, NO, CH) level in different scenarios to meeting **circular economy goals** and to adding **new revenue streams to public transport operators** derived from synergies with energy sector due to B2G and 2nd life of the batteries?

Definitions:

2nd life batteries valorization: revenues coming from the sale of batteries for other purposes (for example stationary applications in grids, buildings, bus depots, etc.)
Bus2Grid services: Buses equipped with batteries can generate revenues by participating in the dispatching services market, which requires infrastructure investments typically made by the electricity distribution network operator (savings for infrastructure in depots).

The important new regulatory framework for 2nd life of batteries and B2G at EU level starting from 2026

In 2022 European market is still not mature, but the regulatory framework will change starting from 2026 after the approval of **Battery and Battery waste Eu regulation** foreseen at the end of 2022, that is designed to modernise the EU's regulatory framework for batteries in order to secure the sustainability and competitiveness of battery value chains. This important regulation will contribute to the **valorization of residual values of batteries and generate important synergies with electricity grid** and it will contribute to reduce the investment risks for public transport operators and accelerate the transition.

Evaluation of B2G and 2nd life of the batteries revenues streams starting from 2026

The role of 2nd life batteries valorization

Monetary evaluation of 2nd life of the batteries is based on the willingness to pay battery manufacturers that are able to regenerate the single battery pack and update the software of the battery management system, or for the direct re-use of the battery for stationary storage purposes. It could be estimated in 50% of the foreseen value of the new batteries in 2030 and 2040 and it is differentiated among countries according to specific market trends in battery sectors and electricity costs (e.g. for IT 60 Euro * kwh in 2030 and 40 Euro in 2040).

The role of B2G

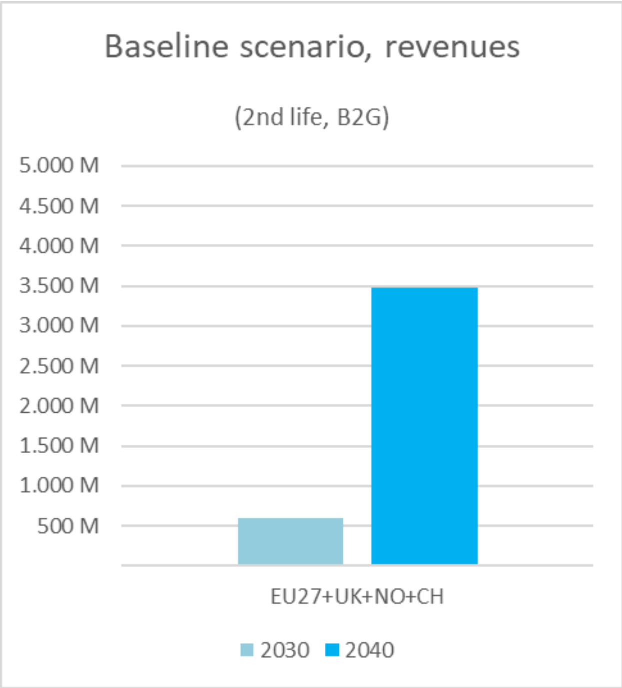
The evolution of the regulations that support the opening of the market for network services to the aggregates of e-buses in a B2G logic will lead to a reduction of the Capex and the Opex for e-buses.

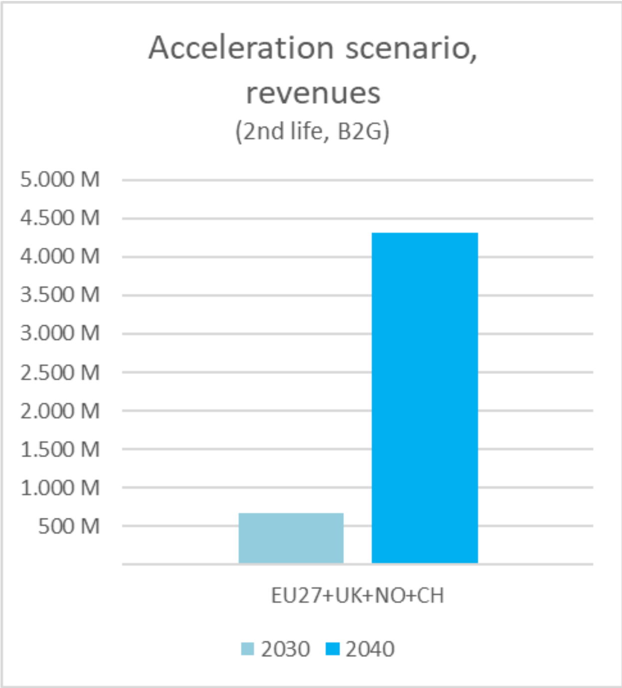
The hypotheses foresee the participation to Mixed Enabled Virtual Units to offer to the net in the time slot between the 3 p.m. and the 24 p.m. (expecting TSOs will extend the V2G activities to this timeframe) the following dispatching services:

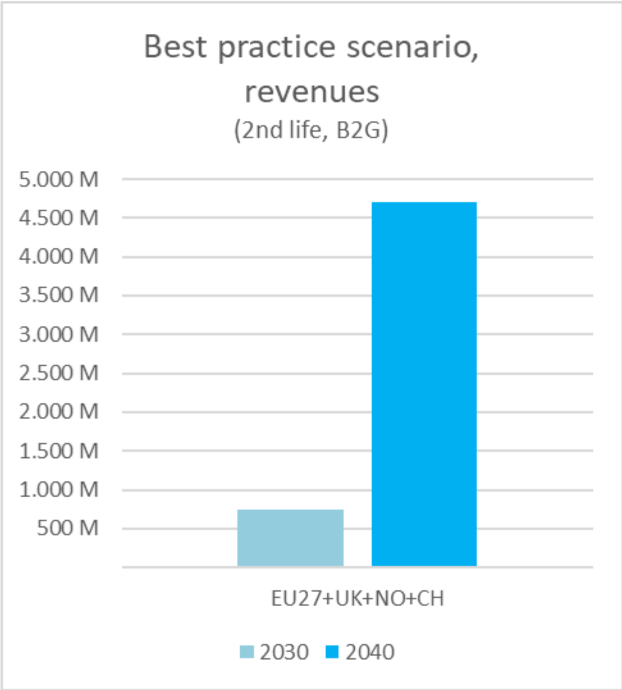
a. Congestion resolution;
b. Tertiary rotating reserve, in "up" and/or "down" mode;
c. Tertiary replacement reserve, in "up" and/or "down" mode;
d. Balancing, in the "up" and/or "down" mode

It is expected that B2G could lead to zero infrastructure costs in storage and generate additional annual revenues (e.g. for IT equal to 1.212 €/bus per year based on 50 KW charging infrastructure and 240 kwh batteries used). In the hypotheses of the study, starting from 2026, the revenue streams at Eu27+3 level are estimated as an average of IT, UK and ES detailed cases considering the different electricity costs among countries as a proxy of the different value of B2G services and 2nd life (the higher the cost of electricity, the higher is the value of B2G services and 2ndlife of the batteries).

Bus fleets electrification scenarios, benefits coming from sinergies with energy system EU 27+3 level – years 2026-2030 and 2026-2040 (cumulated results)







Source: GREEN elaboration

The creation of market conditions enhancing the competitiveness of the electric bus industry at national and international level is a key for amplifying the social and economic impacts of the electrification process, generating positive spillovers on different tiers of the value chains and industries, up to 4,7 billions Euro in Best Practice scenario in 2026 – 2040 period.

Final comparison of the benefits components

1. What could be the contribution to meeting the EU's climate goals and to reduce the cost of environmental externalities of local public transport?

Scenario	Baseline		Acceleration		Best practice	
Year	2030	2040	2030	2040	2030	2040
Cumulative environm. benefits	1.906 Mio €	8.368 Mio €	2.130 Mio €	10.293 Mio €	2.807 Mio €	13.697 Mio €
Index, Scenario Best practice 2040=100	14	61	16	75	20	100

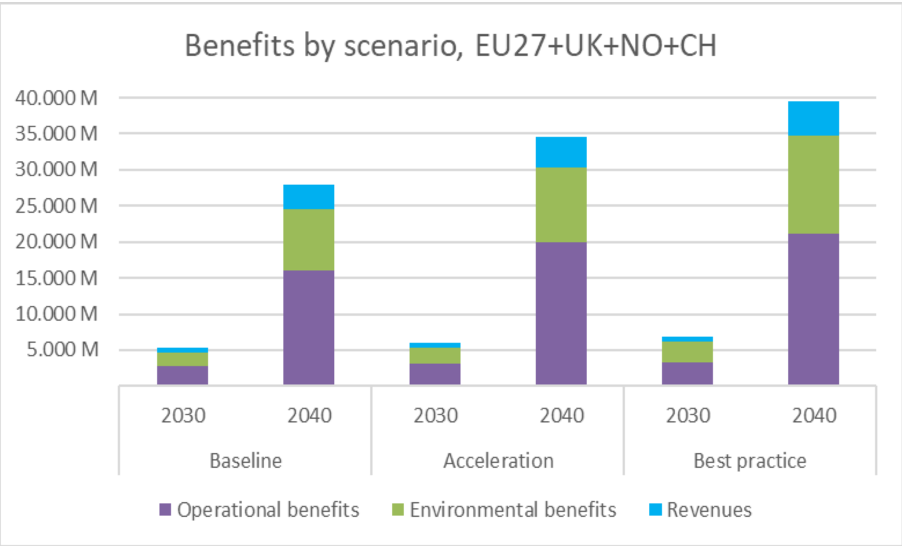
2. What could be the contribution to meeting efficiency goals of local public transport operators?

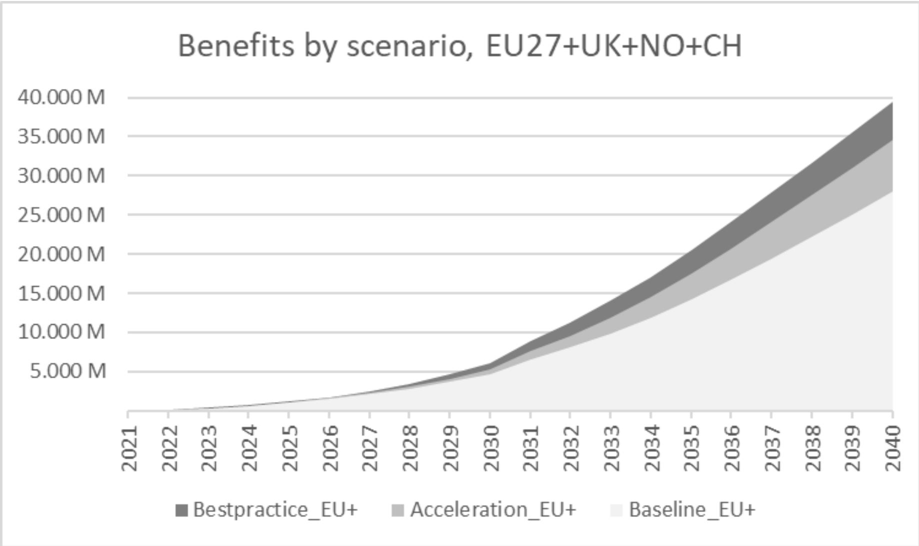
Scenario	Baseline		Acceleration		Best practice	
Year	2030	2040	2030	2040	2030	2040
Cumulative operational benefits	2.761 Mio €	16.112 Mio €	3.142 Mio €	19.976 Mio €	3.329 Mio €	21.086 Mio €
Index, Scenario Best practice 2040=100	13	76	15	95	16	100

3. What could be the contribution to meeting circular economy goals and to adding new revenue streams to public transport operators derived from synergies with energy sector due to B2G and 2nd life of the batteries?

Scenario	Baseline		Acceleration		Best practice	
Year	2030	2040	2030	2040	2030	2040
Cumulative revenues	590 Mio €	3.473 Mio €	672 Mio €	4.314 Mio €	743 Mio €	4.710 Mio €
Index, Scenario Best practice 2040=100	13	74	14	92	99	100

Bus fleets electrification scenarios, operational+environmental+ revenues stream benefits EU 27+3 level – years 2022-2040 - 100% renewables case for electricity generation (cumulated results)





Source: GREEN elaboration

The contribution of swapping from diesel to electric buses to meet the efficiency goals of local public transport operators and to reduce the cost of environmental externalities for the society as a whole is relevant: up to 6,88 billion Euro in 2030 and 39,49 billion Euro in 2040 in Best practice scenario (anticipating 100% BEB new registrations by 2028).

In this scenario the project results underline that in 2040 the total benefits of each of the 180.133 e-bus part of the EU 27+3 stock market will be on average around 219.242 Euro.

Bus fleets electrification scenarios, benefits EU27+ 3 level – years 2022-2040 - 100% renewables case for electricity generation (cumulated results)

Country	EU27+UK+NO+CH					
Scenario	Baseline		Acceleration		Best practice	
Year	2030	2040	2030	2040	2030	2040
Operational benefits	2.761 Mio €	16.112 Mio €	3.142 Mio €	19.976 Mio €	3.329 Mio €	21.086 Mio €
Environmental benefits	1.906 Mio €	8.368 Mio €	2.130 Mio €	10.293 Mio €	2.807 Mio €	13.697 Mio €
Revenues	590 Mio €	3.473 Mio €	672 Mio €	4.314 Mio €	743 Mio €	4.710 Mio €
Total	5.257 Mio €	27.953 Mio €	5.944 Mio €	34.582 Mio €	6.880 Mio €	39.493 Mio €

Source: GREEN elaboration

At EU 27+3 level, operational benefits show a higher value than the environmental ones, representing between 53% (BASELINE scenario 2030) and 58% (ACCELERATION scenario 2040) of total benefits. As an example, in the BEST PRACTICE 2040 scenario, **2nd life, B2G revenues contribute for 12% of total benefits in Italy, 8% in Spain and 27% in UK**, where the market for 2nd life batteries is at an advanced stage and the relevance of the London metropolitan area increases the average value for batteries for stationary storage.

The cumulated benefit generated by the increase of BEBs in city fleets goes from **27,9 billion Euros** under the BASELINE scenario up to **39,5 billion Euros** in the BEST PRACTICE in 2040.
Anticipating 100% BEB new registrations by 2028 compared to the indication of Clean Vehicle Directive (100% BEB new registrations by 2035) will generate incremental 11,5 billion Euro in 2040. Considering that the purchasing cost differential between BEBs and ICE buses is decreasing significanty between 2021 and 2030, and expected to be zero by 2035, the benefit/cost ratio of the fleet renewal in EU is expected to be over 1 in all scenarios.

The outlook of the transition to e-buses in EU 27+3

The results of the study underline the socio-economic importance of the acceleration of the transition to zero emission buses in all three scenarios, while using a mid-range costs assumption differentiated among countries and acknowledging the inherent uncertainties in a market context where all the major bus manufacturers have committed to increasing their production of BEB and important investment are occurring in battery field.

It is also worth noting three further positive impacts not quantitatively tackled by the study:

- the **impact on the competitiveness** of local public transport, in terms of attractiveness for passengers compared to private mobility in city areas, thanks to a better quality of service (less noise, less vibration, less pollution);
- A **potential increase of the number of buses or of additional and more capillary services**, that might be delivered thanks to the expected savings in operational costs for local public transport operators;
- While the study calculates the net impact on the operational costs as a whole, it does not provide a detailed analysis of the **changes within the public transport sector** itself (e.g. on maintenance department, energy suppliers, depot management, etc.)

Moreover, the study do not evaluate the strategic importance of the **shift from mainly imported fossil fuels to domestically produced 100% renewable electricity**.

Policy recommendations

The analysis has shown that the scenario defined “Best practice” of electric buses deployment will guarantee the highest benefits both for public transport operators and for society has a whole.

The potential enablers of the acceleration identified in the study are the following:

1. Reinforce e-buses business by potentially **enforcing new skills and abilities** for reducing the purchase cost through a greater standardization and joint procurement **and supporting synergies among local public transport operators and energy utilities** in order to accelerate investments in depots and electricity grid upgrades and facilitate the goal of 100% renewables public transport services;
2. **Streamline regulatory framework and industrial policies to support innovative business models** designed around the characteristics and opportunities presented by BEB providers and associated charging or refueling infrastructure managers. (Example: early approval of EU Batteries regulation or fast track permits in order to be able to increase the % of self-produced renewables);
3. In EU context, the renewable energy sources production will rapidly increase leading to the reduction of thermal plant operation and enhancing the role of storage and other flexibility resources, therefore **the role of circular policies supporting 2nd life and B2G services will increase, and local public transport operators could have new revenues streams**. Example could come from a regulatory framework that could facilitate the use of batteries inside bus depots that can enhance their potential as central elements of urban electricity networks both as a producer (thanks to photovoltaic panels on roofs) and as a stabilizer of the network, in B2G logic, or being part of an energy community that could protect the residual value of batteries.

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