Bocconi

With the scientific support of enel Foundation

SCENARIOS AND PERSPECTIVES OF THE ELECTRIFICATION OF PUBLIC ROAD TRANSPORT

A benchmark analysis on 9 countries based on an innovative Total Cost and Revenues of Ownership (TCRO) analysis.

A sensitivity analysis based on three different scenarios depending on the role of externalities and incentives

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 Claudio Brenna, Gabriele Grea, Antonio Sileo and Mirko Armiento. Ignazio Cordella (Enel X) contributed to the study.

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Introduction

The integration of Low and Zero environmental impact buses in LPT fleets contributes to 2 interconnected objectives: **sectoral efficiency** and **environmental sustainability**.

The *UN 2030 Agenda for Sustainable Development* and the *Transport policy programs* released in all the countries analyzed in this study have set among their specific priorities the access to **sustainable**, **safe** and **affordable transport systems** and the **reduction** of **negative environmental impacts** in cities.

Policy initiatives in the fields of **environment**, **industry** and **circular economy** are playing a significant role in fostering and accelerating the transition towards **zero emissions fleets**.

Objectives

The aim of the study is to support the decision-making process of LPT companies and LPT services contracting bodies on **bus fleets renewal** in urban contexts.

The growing complexity of these decisions (due to increasing innovations in policy, organizational and industrial terms) has required a new analysis approach.

The analysis models proposed (TCO & TCRO), based on a **benchmark approach** among different **management models** and **power supply** alternatives, allow to better understand scenarios and perspectives of the electrification of public road transport and provide guidance for an efficient selection of solutions to be deployed in different contexts and time scenarios (2021, 2025, 2030).

The approach of the study

- "**Total costs of ownership" (TCO)** and **"Total costs and revenues of ownership" (TCRO)** provide a systemic view on the cost and revenue components of buses across their lifetime, including circular economy-related elements (e.g., 2nd Life Battery Management and Bus2Grid options) as revenues for electrified options.
- The sensitivity analysis then presented is based on **3** different **scenarios,** depending on the role of **environmental externalities** and specific **public incentives** to reduce initial investments in sustainable public transport fleets.

To adopt a systemic vision, the study highlights even **external elements** expected to influence the choices of public transport operators. In particular:

- **Policies:** procurement obligations stated by EU regulations and other national directives, but also strategic choices by public transport companies' shareholders (e.g. sustainibility-oriented Public bodies)
- **Technological factors:** infrastructure investment costs requiring economies of scale and availability of space (e.g., for dedicated depots, charging facilities or alternative fuel plants)
- **Organizational factors**: specific charachteristics of the lines (e.g., elevation profiles, length or climate conditions).

DETAILS OF THE STUDY

Geographical scope: 9 countries (**Italy, Spain, UK, US, Mexico, Brazil, Colombia, Chile, Peru**).

Object_: standard 12-meter (12m) buses dedicated to urban transport (with annual distances differentiated by country, according to specific national parameters).

Motorizations analyzed: Diesel, CNG-LNG & Biomethane, Electric and Hydrogen.

EU Policy context

EU POLICIES IMPACTING ELECTRIFICATION

Synoptic view of different EU policies and their expected impact on LPT companies' decisions on road fleet renewals (by 2025 & 2030).

EU POLICIES AND STATE OF APPROVAL	SHORT DESCRIPTION	TIMELINE OF IMPACTS
EU Clean Vehicle directive *(Approved)*	Obligation for public administrations to purchase Low Emission and Zero Emission Vehicles	From 2 August 2021 to 21 December 2025 at least 45%, from 1 January 2026 to 31 December 2030 at least 65%
EU Euro VII Directive proposal *(Final proposal expected by November 2022, approval by national parliaments of EU by 2024)*	Reduction of $C0_2$ emissions of internal combustion engine buses by 25% by 2025 and by 30% by 2030	Predictably growing from 2025 (but bus manufacturers will anticipate the evolution of engines)
EU Fuel Quality Directive proposal *(Proposal expected by the end of 2023, approval by national parliaments of EU by 2025)*	Reduce the level of intensity in terms of greenhouse gases in fuels used in the transport sector	Predictably growing from 2026 (but refineries will anticipate the evolution of the types of fossil fuels and biofuels)
Proposal for a Regulation concerning batteries and waste batteries *(Proposal presented in December 2020, approval expected by 2023)*	Encouraging standardization and circular economy approaches in the production and second life management of batteries, through the introduction of the Battery Passport and the obligation to use recycled components	More strictly from 2024, with progressive milestones by 2026, 2027 and 2030.

Source: GREEN Elaborations

Global market perspectives

Global Electric Bus Market: main figures

- Expected to grow from 81k units in 2021 to reach 704k units by 2027, **CAGR 43.1%***
- **Non-homogeneous** growth across the world
- 98% of e-buses were in **China** in 2020
- Circulation of e-buses will be relevant in **LATAM** countries (e.g. Colombia and Chile), and in **Europe** (e.g. United Kingdom and Netherlands) from 2021

Main barriers to public transport electrification

- lack of **operational knowledge**
- **technical** limitations
- **inflexible procurement** process
- non-scalable **financing**
- **institutional** barriers

* Source MarketsandMarkets " Electric Bus Market by Propulsion (BEV, PHEV & FCEV), Application (Intercity & Intra-city), Consumer Segment (Fleet Operators & Government), Range, Length of Bus, Power Output, Battery Capacity, Component, Battery type & Region"

Policy and market readiness

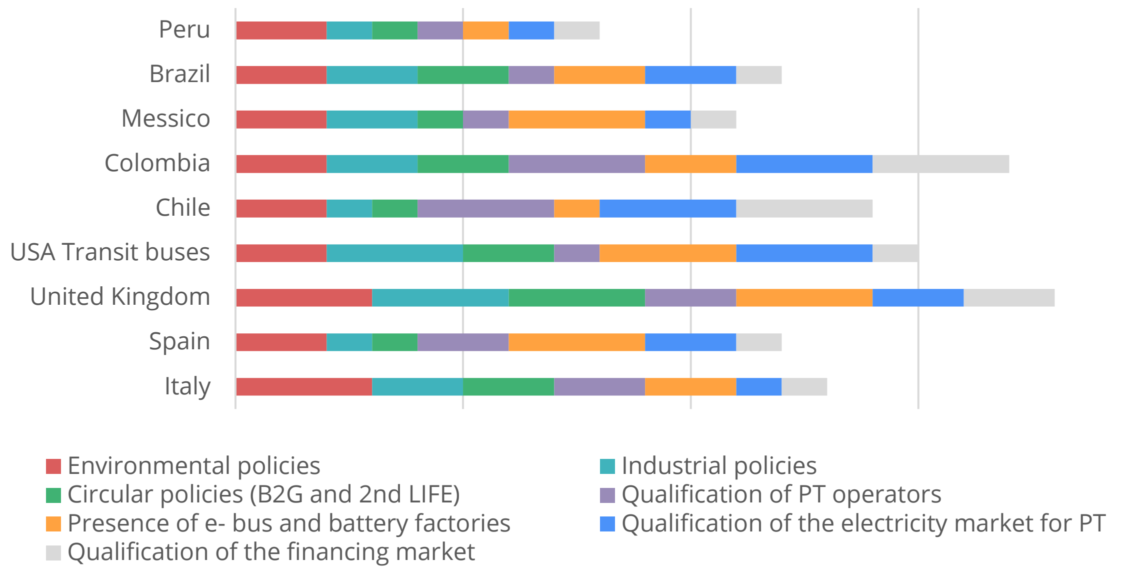
POLICY CONTEXT:

1) **Environmental policies** based on long term commitment to Zero Emission Buses (ZEB) through specific target goals (e.g. bans on the procurement of diesel buses or specific target of investments in ZEB)

2) **Industrial policies** based on local procurement targets or supporting innovative business models designed around the characteristics and opportunities presented by ZEB providers and associated charging or refueling infrastructure managers

3) **Circular policies** supporting 2nd life and B2G services

POLICY AND MARKET READINESS LEVELS FOR ZEB*



Source: GREEN elaboration

MARKET CONTEXT:

1) Presence of PT operators/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**

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

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

*Each factor is evaluated on a scale from 1 to 3, with 3 being the highest value in terms of readiness and pervasiveness.

TCRO: methodological approach and components

Company cost component	Description
Bus and infrastructure costs	This component includes the cost of the bus and the charging/fueling infrastructure necessary to operate the buses (overnight and opportunity chargers, electrolyzes, fuel tanks, etc.), which can receive co-financing from Local Authorities or Ministries, in several cases differentiated according to the type of energy/fuel
Energy costs for traction	Consumption constitutes a significant component of the TCRO, depending on the efficiency of the vehicle's engine, but also on average commercial speeds, altimetric profiles and the need or not for heating/air conditioning
Bus maintenance (ordinary)	It includes the ordinary costs of replacing tires, lubricants, components subject to wear, in addition to insurance costs, and can vary significantly between the first years of purchase and the last few years
Bus maintenance (extra-ordinary)	Extraordinary maintenance includes the replacement of components such as batteries or transmission components and allows the extension of the useful life of the vehicle
Infrastructure maintenance	The infrastructures dedicated to energy supply in depots or along the line or at the terminus are subject to routine maintenance to remain efficient
Company revenue components	**Description**
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	This component depends on many factors and is typically considered to be equal to zero in the TCO analyzes, since the buses with greater age are used until the end of their lifetime; in the case of battery buses, the sale of batteries for other purposes (for example stationary applications in grids, buildings etc.), can be a source of revenue
Social costs	**Description**
Environmental externalities	It is a cost component borne by the community, as the economic quantification of externalities (greenhouse gas emissions, local pollutants, noise, well to thank emissions) highlights the potential indirect cost savings for the health system and in terms of premature death avoided by a greater environmental sustainability of the vehicles

Source: EF and GREEN elaboration on Grauers et al. (2020), World Bank (2019) and TOI - Institute of Transport Economics (2018)

Notes on TCO and TCRO methodological approach

Vehicles

- Full service considered as benchmark for maintenance
- Opex depend on the bus model (8/12/18m) and on average km/year

Infrastructure

- Charging options and/or new fuel depots management
- Benchmark and synthetic values (e.g., number of chargers per bus/line)

From TCO to TCRO

- Hypothesis for the valorization of second life batteries
- Hypothesis for the valorization B2G services

Time horizons

- 2021; 2025; 2030

Scenarios

- Fleet/ fleet + infrastructure (considering also as benefits hp on 2nd life and B2G)
- Evolution of engine technologies in terms of cost and performance

Other features

- Discounting of monetary values (Net Present Value)
- Key variables for sensitivity analysis: average kms/year; temperature
- Possible adaptation to different management models (by country)
- Differentiation of technical and cost elements between different bus models (8/12/18 meters operating in metropolitan cities and on urban roads)

Sensitivity and scenario analysis

The sensitivity analysis complements the TCO and TCRO models taking into account the role of **environmental externalities** and specific **public incentives** to reduce initial investments in sustainable public transport fleets. To compare the effects of potential revenues from 2nd life batteries and B2G (1), available incentives (2) and monetary evaluation of negative externalities (3), 3 scenarios were analysed:

1. "**Current policy**" scenario= combines TCO + available incentives
2. "**Comprehensive**" scenario= includes TCRO, incentives + externalities
3. "**Long term market**" scenario= includes revenues generated on the market (TCRO) and the compensation of externalities applied for all technologies (thus, generating additional costs but also competitive advantage for Full electric, hydrogen and bio LNG).

Environmental externalities

The model includes the estimated economic value* of the main externalities generated by buses with different motorizations. The environmental externalities considered are **acoustic emissions**, **greenhouse gases** and **pollutants** (**CO2** - carbon dioxide, **NOx** - oxides of nitrogen, **PM** - particulates and **NHMC** - non-methane hydrocarbons). 2 approaches were used to measure gas emissions:
Tank to Wheel (TTW): measures direct emissions from the use phase, namely from the fuel consumed directly by the vehicle (indeed, from the tank to the wheel).
Production to tank (PTT): measures the emissions from the production and distribution of the energy source (for BEBs and Fuell Cell Hydrogen buses).
Types of impact considered to assess the monetization of negative externalities are impacts on health (death rate), on climate changes, damage to ecosystems, buildings and monuments, and agricultural losses.

The parameters used are related to the main metropolitan areas of the countries analyzed and using average monetary parameters for that type of context for local pollutants.

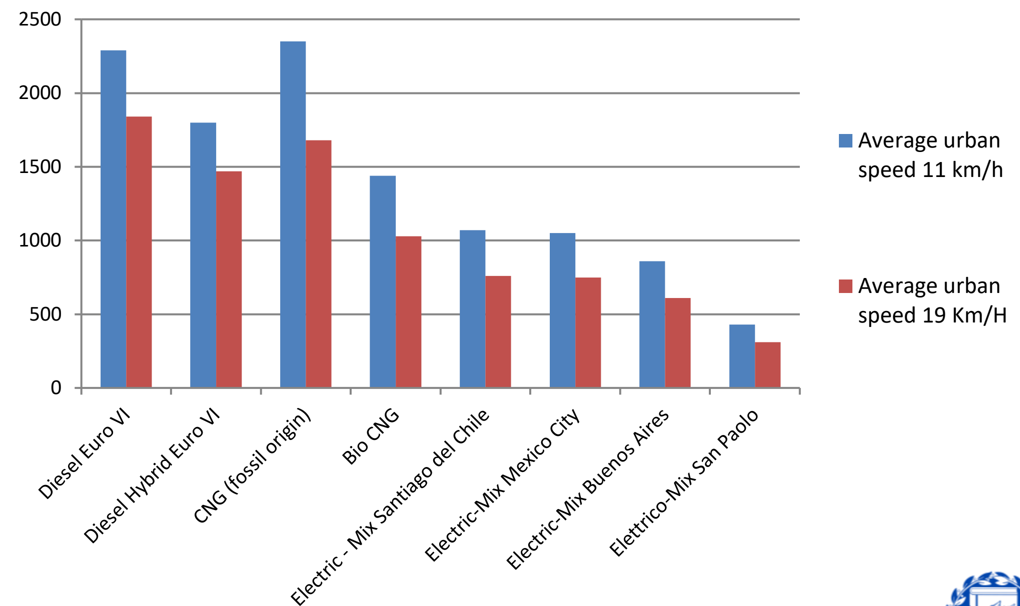
Methodological sources and inputs

Methodological sources are research reports from European (DG MOVE, EBRD) and international bodies (World Bank, ICCT, ITF-OECD, Global Sustainable Electricity Partnership) and articles from the scientific literature.

Exact **input data** for research, relating to full-life cost parameters and key variables influencing their specific values, are be based on the availability of public information from industry analysis (e.g., UITP), scientific research, company accounts, results of public tenders (e.g., CONSIP tenders, GTT, ATAC, TPER, ATM tenders), technical insights with construction companies and, for the Italian market, also through comparison with operators.

The *weel-to-wheel* (*WTW)* approach to measure GHG emissions (*well-to-tank* + *tank-to-wheel* emissions) from buses with different engines depend on several factors, among which average speed and the power mix of the reference power mix.
Ebuses report a level of **CO2 emissions** between **50 and 80 % lower** than hybrid buses and also much lower emission levels of local pollutants and noise.

Many LPT companies only use certified renewable source (like ATM in Milan or GTT in Turin), further expanding the emission differential with endothermic engines.
For instance, switching from a Euro VI bus to a Full Electric Bus saves 22.500 liters of diesel and 58.5 tons of CO2 per year.



Source: ICCT, "Low-carbon technology pathways for soot-free urban bus fleets in 20 megacities" Working Paper 11-2017

Italy

EU and national policies affecting PTOs' decisions on engine type by 2025 and 2030 in Italy

EU policies and time references	Procurement obligations for non endothermic buses (*)	Purchasing cost increase for endothermic buses	Management cost increase for endothermic buses	Cost reduction of battery electric buses
EU Clean Vehicle Directive (progressively from 2021)				
EU Euro VII Directive Proposal (from 2026)				
EU Fuel Quality Directive Proposal (from 2026)				
Proposal of a Regulation on Batteries (from 2023)				
Italian Policies and time references				
National Plan for Sustainable Mobility (from 2019)				
Integrated National Plan for Energy and Climate (from 2020)				
National Recovery and Resilience Plan and Complementary Plan (from 2021)				
Bus2Grid Regulation (from 2022)				

GREEN Elaborations

The green color scale shows the relevance of the expected impact. In particular:

- Very relevant= can modify the choices of operators for a fleet share greater than 20%
- Relevant= can modify the choices of operators for a fleet share between 10 and 20%
- Not very relevant= can modify the choices of operators for a fleet share smaller than 10%.

(*) Autobus Low emission (LEV) o Zero Emission (ZEV)

National policies affecting PTOs' decisions on ebuses market by 2025 and 2030

Investments from PNRR and Complementary Funds for the renewal of bus fleets and infrastructures in Italy

Source of funding	2022	2023	2024	2025	2026	Notes
PNRR	50	125	640	700	900	26% dedicated to infrastructure and 74% to vehicles. Of them, 56% are specifically dedicated to major metropolitan areas. In particular, €1.095 billion are dedicated to full electric TPL and €1.4 billion to innovative zero emission buses
Complementary Plan	62,12	80,74	159,01	173,91	124,22	Only for extra-urban and suburban bus fleets, powered by methane, electricity, hydrogen and a maximum of 15% at LNG. 50% dedicated to the regions of Southern Italy.
Totale	112,12	205,74	799,01	873,91	1.024,22	

GREEN Elaborations

- For the most polluting cities, the Strategic National Plan for Energy and Climate (**PNIEC**) provides for an obligation to purchase **electric or natural gas buses** sooner than as required by Community directives. By 2022, **30%** of purchases for urban bus fleets **renewal** must be of this type. The share rises to 50% in 2025 and 85% in 2030.
- The National Recovery and Resilience Plan (**PNRR**, 2021) provides for the progressive renewal of buses for the LPT *Local Public Transport* (€ 1,788.26 million of which 1/3 destined to the 3 main Italian cities) and the construction of dedicated charging infrastructures (€ 627.7 million) with the purchase of about 3,360 low-emission buses (electric or hydrogen) by 2026. In particular, **€1.095 billion** is dedicated to **LPT full electric** and **€1.4 billion to innovative zero emission buses.**
- The **National Plan for complementary investments** provides additional € 600.67 million of investments for the renewal of the fleet of extra-urban and suburban buses fuelled by methane, electricity, hydrogen and related infrastructure, with the possibility of allocating 15% of the resources allocated to the conversion of Euro 4 and Euro 5 diesel vehicles to natural gas.
- The sum of investments for the fleet (€ 2.4 billion), for infrastructure (€ 627.7 million) and for the development of the industrial chain dedicated to electric buses in Italy (€ 300 million) between 2021 and 2026 provided by the PNRR and the complementary plan is equal to € 3.32 billion.

Market trends on electric engines*

POTENTIAL REVENUES FROM 2ND LIFE BATTERIES

For the residual value to be considered in the TCRO PTOs should consider several elements:

- EU Regulatory trends and the New Circular Economy Action Plan for a Cleaner and More Competitive Europe, 2020;
- Evolution of industrial strategies (based on public-private partnerships) promoted by the **European Batteries alliances** and an EU **investment of € 3,2 mld** on the topic through the **Important Projects of Common European Interest (IPCEI),** that will strongly reduce the price of new batteries;
- The **nominal capacity of packages and individual modules** as the higher these values, the lower the process cost per kWh produced;
- The **cost of new components** (e.g. battery management system software) that typically weighs between 30 and 35% of the total cost of production and the development of automation processes of disassembly and assembly processes, thanks to **strong developments of innovative eco-design** approaches;
- The spread of industrial plants distributed throughout Europe that allows a **reduction in transport costs** and **greater competition and diversification** of initiatives to enhance the 2nd life of batteries. In Italy, an important plant is planned by Seri Industrial which, in addition to Italvolt and Stellantis sites, will make Italy one of the main EU countries in the sector.
- Based on the available market information the residual value from 2025 for Italy can be estimated at €60 per kwh. This value is equal to 50% of the value of new batteries estimated at 2030, because the higher the nominal capacity of packages and individual modules, the lower the process cost per kwh produced, since some process steps (e.g. transport, testing and disassembly) are less affected by the size of the whole package.
- The use of batteries inside bus depots can enhance their potential as central elements of urban electricity networks both as a manufacturers (thanks to photovoltaic panels on the roof) and as a stabilizer of the network, in B2G logic.

Market trends on ebuses are strongly affected by significant changes expected worldwide. Indeed, the report from April 2021 MarketsandMarkets " Electric Bus Market by Propulsion (BEV, PHEV & FCEV), Application (Intercity & Intra-city), Consumer Segment (Fleet Operators & Government), Range, Length of Bus, Power Output, Battery Capacity, Component, Battery type & Region", shows a growth rate of 43,1% per year for next 7 years (CAGR 2021-2027), passing from 81k in 2021 to 704k in 2027.

Market trends on electric engines

POTENTIAL REVENUES AND COST REDUCTIONS FROM THE VALORIZATION OF B2G

The evolution of the regulations that support the opening of the market for network services to the aggregates of electric vehicles in a V2G logic will lead to a reduction of the Capex and the Opex for ebuses.

The hypotheses foresee the participation to Mixed Enabled Virtual Units (**UVAM**) to offer to the net in the time slot between the 2 p.m. and the 8 p.m. (when about 35% of the bus fleet bus of PTO of medium-large size is estimated to be in deposit) 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

In this first estimation phase, it is expected that B2G could lead to **zero infrastructure costs in storage** and generate **additional annual revenues** equal to 1,054 €/bus (Source: CESI-RSE based on 50 KW charging infrastructure and 240 kwh batteries used, at this stage, as parameters for the 12m buses).

Based on RSE estimates, this value could rise significantly leading to possible additional revenues per single bus of 4,215 € (in the case of 240KWh capacity battery), which could rise further to 6,145 € /year (in the case of 350KWh battery).

Main parameters & assumptions

- The **bus life cycle in Italy** is also linked to the regulations of the funding bodies (Ministry and Regions), which typically indicate 12 years, although for some engines (BEV and H2) a useful life of 15 and 14 years is expected respectively.

- Differentiations between the engines for some types of OPEX are not considered as they are minimal and are compensated between the different engines (e.g. insurance costs, road taxes or fuel costs of tyres).

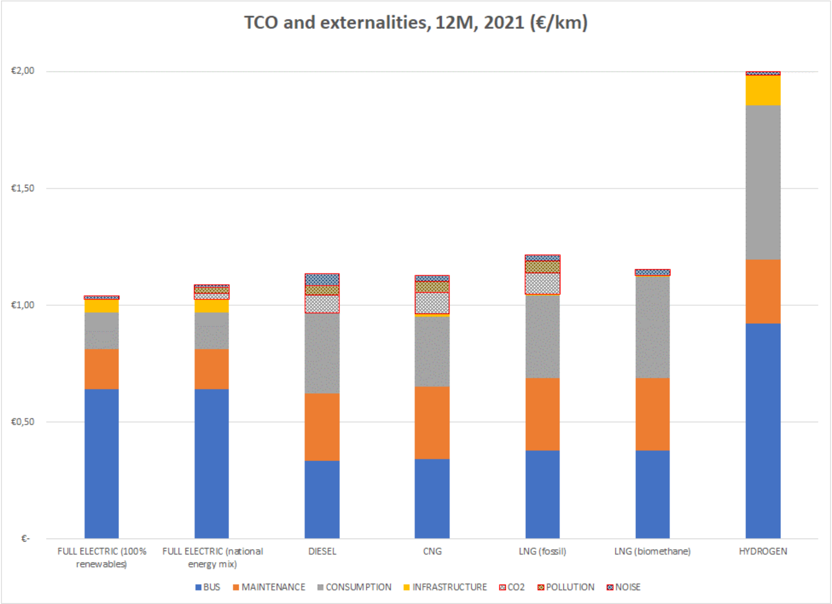
- The **driven kms** per year per bus model, based on the indications of the tenders (Consip, GTT, ATM and others)are:

    - 8 m: 45.000 km/ year (only diesel)
    - 12 m: 55.000 km/year
    - 18 m: 60.000 km/year

- **Battery** replacement for BEV and H2 buses is needed after 8 years.
- The revamping of the vehicle in the case of buses with endothermic engines should be carried out after 10 years, at an average cost of €40.000 for 8 m buses, € 50.000 for 12m and € 70.000 for 18 m buses.

TCO and externalities

The advantages of Full electric are more relevant, considering that the estimated revenues from B2G and 2nd Life would lower the TCO further by 4,8 €cents.
TCO for BEBs doesn't reach the other power supplies by 2021: infrastructure costs are equal to the differential with DIESEL and CNG (about € 6 cents); revenues reduce the gap below € 2 cents.
The role of TCRO should also be highlighted since the impact is not negligible (4.8 cents/km). This suggests, with particular reference to low mileage, the importance of generating revenues through B2G in the future .

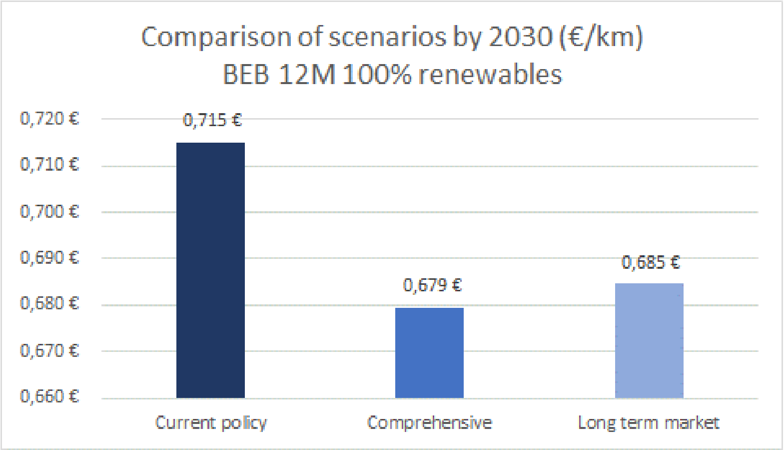


GREEN Elaborations

Scenarios including externalities and incentives (by 2030)

In order to compare the effects of a) potential revenues from B2G and 2nd life battery reuse b) available incentives (limited for **Italy** to **30% of infrastructure costs** and c) monetary valuation of negative externalities, 3 TCO scenarios have been elaborated and compared:

1. "**Current policy**" scenario
2. "**Comprehensive**" scenario
3. "**Long term market**" scenario



The role of externalities: greenhouse gases, local pollutants and noise

The following table underlines the monetary values of the externalities genereted by a 12 meters urban bus with different power supply. Values are expressed in Euro* km and related to tank to wheel (TTW) and production to wheel (PTW) process for electricity.

Monetary values (in €*km), Italian case specific for a 12m bus (2021)

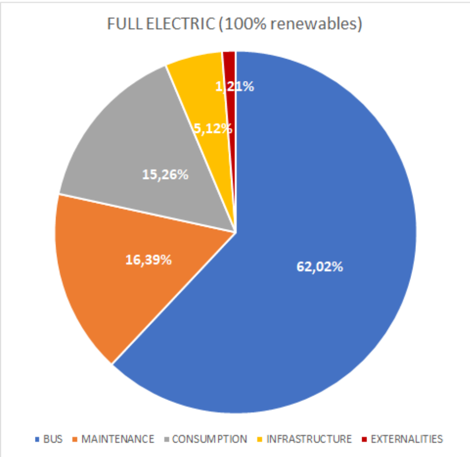
Pollutants	Full electric (national electricity mix)	Full electric (100% renewables)	Diesel EuroVI	CNG e LNG (fossil)	LNG (bhiometan)	H2
CO2	0,030889	0	0,0921	0,11	0	0
PM2.5	0	0	0	0	0	0
PM10	0,00752854	0	0,019442769	0,000123056	0,000123056	0
NOx	0,01662449	0	0,029981041	0,0411639	0,0411639	0
SO2	0,00333688	0	0	0	0	0
NMVOC	0,00106562	0	0,000378214	0,0183996	0,0183996	0
Noise	0,01545	0,01545	0,0618	0,0309	0,0309	0,01545
Total (Euro*km)	0,07489452	0,01545	0,203702024	0,200586556	0,090586556	0,01545

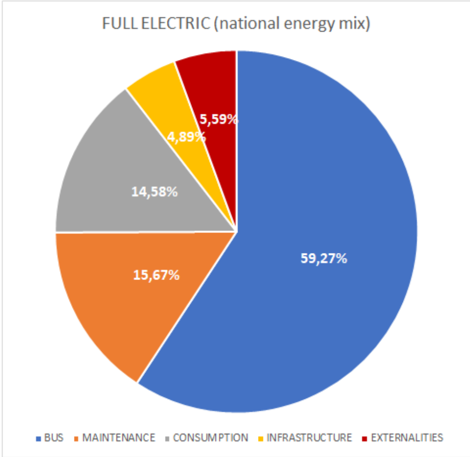
Annual value	Full electric (national electricity mix)	Full electric (100% renewables)	Diesel EuroVI	CNG e LNG (fossil)
Annual value of externalities (Euro, 2021)	4.119	850	11.204	11.032
Index, Diesel EuroVI= 100	37	8	100	98

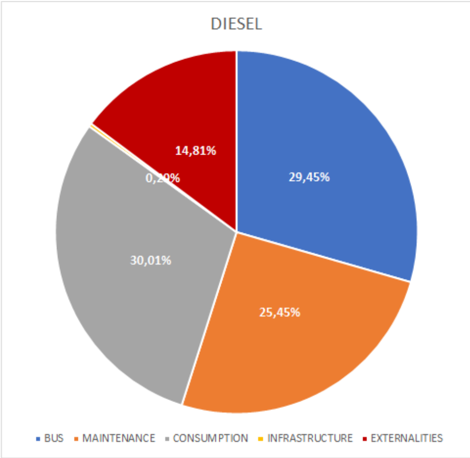
The analysis showed that BEB could reduce by 92% the costs of externalities if sourced with 100% renewables in comparison with EuroVI diesel buses

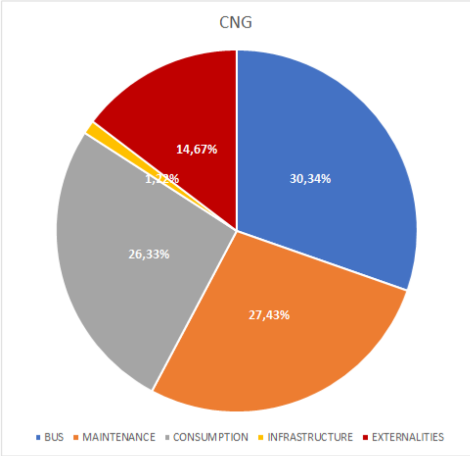
Source: GREEN Elaborations on data from Handbook on the external costs of transport del 2019 e EEA, Cost of air pollution from European Industrial Facilities 2008-2017 (2021), PNSMS from MIMS (2018) and CNR study (2021)

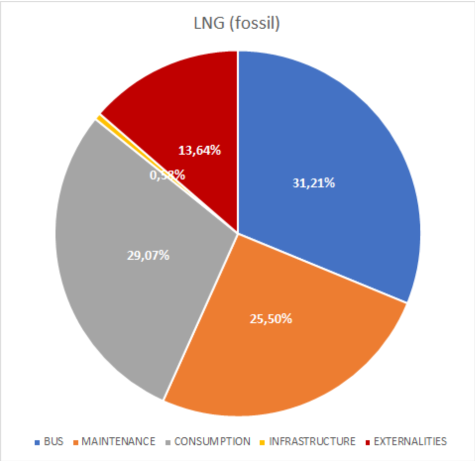
TCO and externalities, contribution in % of cost components for the public transport company and for society

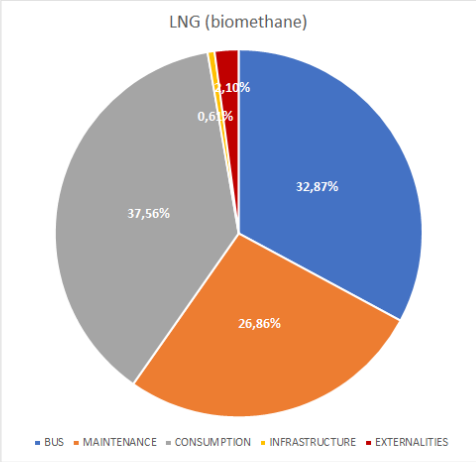


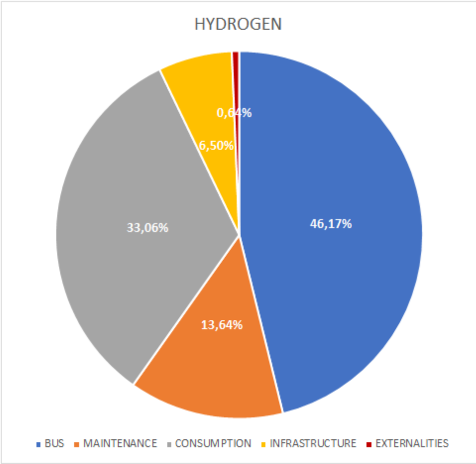






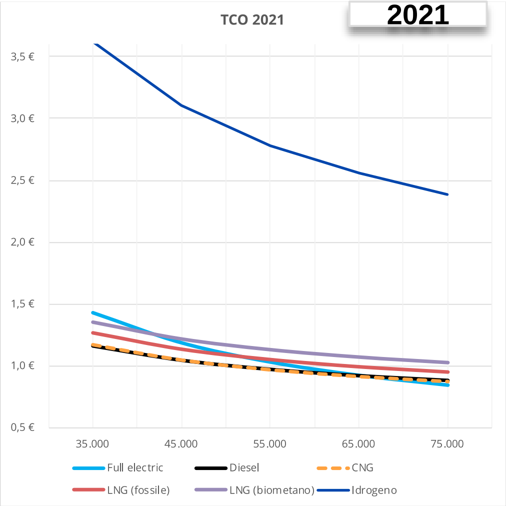


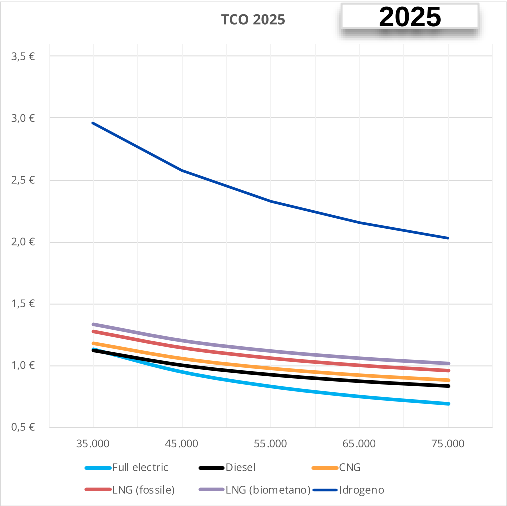


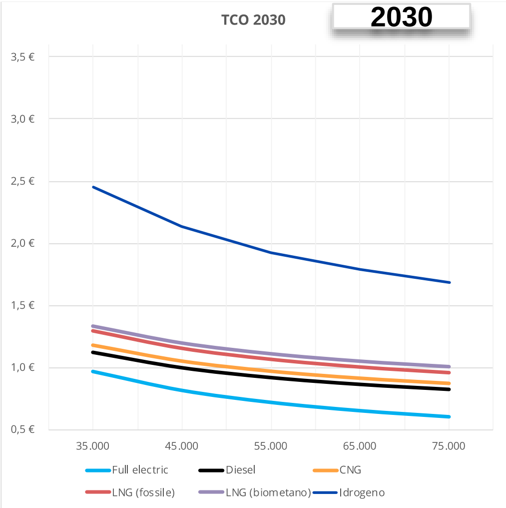


Elaborations by GREEN

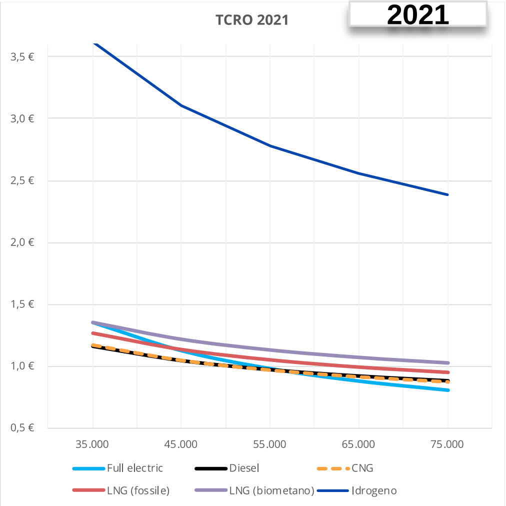
Sensitivity analysis TCO & TCRO (€/km)

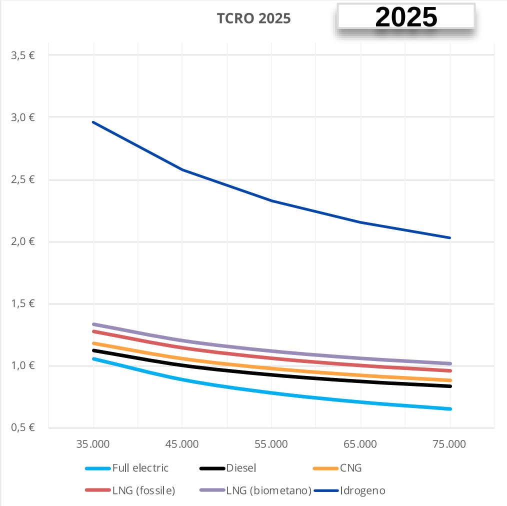


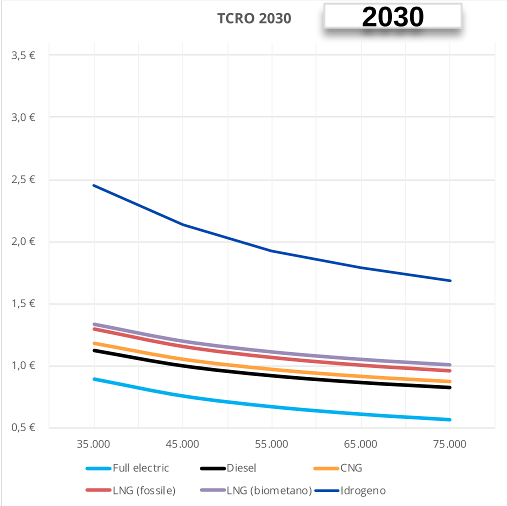




GREEN Elaborations (2021, 2025, 2030)





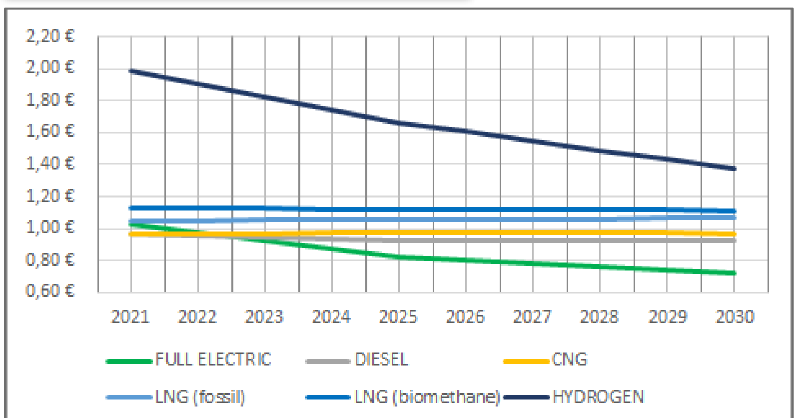


2022: the year of TCO and TCRO break-even in Italy

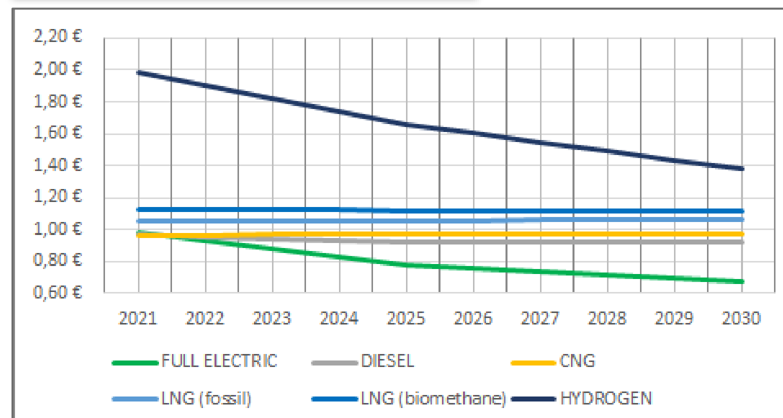
Dynamic comparison of TCO over time for 12 m buses shows the Full Electric option already competitive against diesel at the beginning of 2022. This is even more evident when looking at TCRO.

From 2023 the advantage of BEBs is constantly increasing until 2030 both in terms of TCO and TCRO, enhancing the advantages of the Full electric supply.

Sensitivity TCO/years

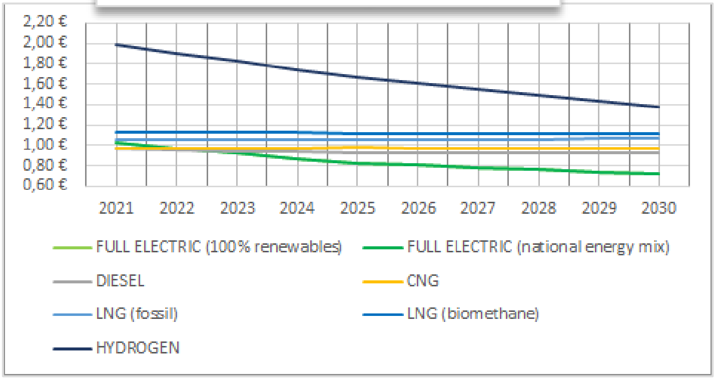


Sensitivity TCRO/years



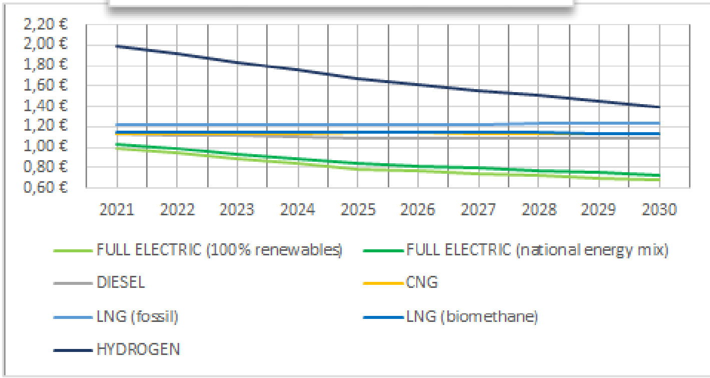
Scenarios

Current Policy (€/km)



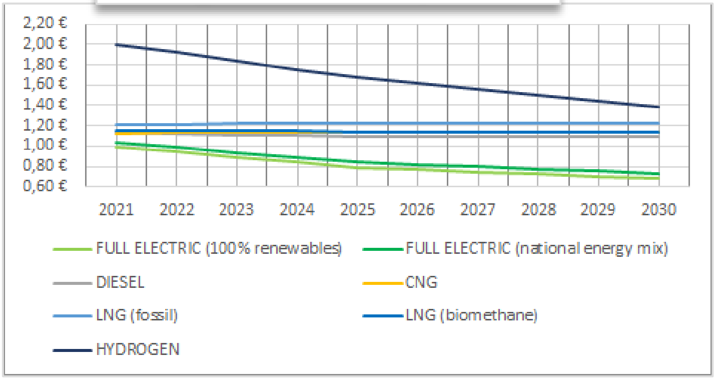
For Italy, the role of incentives is limited to the co-funding available according to Alternative Fuel Initiative (within the CEF), focused on electric charging infrastructure (in storage and online) and to initiatives for energy storage and grid connection (max 30% investment with no-repayable funds). According to the TCO and TCRO models, this results in a decrease of 0,5 €cents per bus*km, thus contributing to a very slight anticipation of the break-even point.

Comprehensive (€/km)



This scenario includes the effects of revenues, externalities and incentives on TCO. Compared to the first scenario, this one shows how the combination of the 3 factors generates a relevant competitive advantage for electrified public transport. Another interesting aspect of this scenario is that, thanks to the integration of externalities, the costs of fossil based options raise significantly (and fossil LNG overcomes bio LNG).

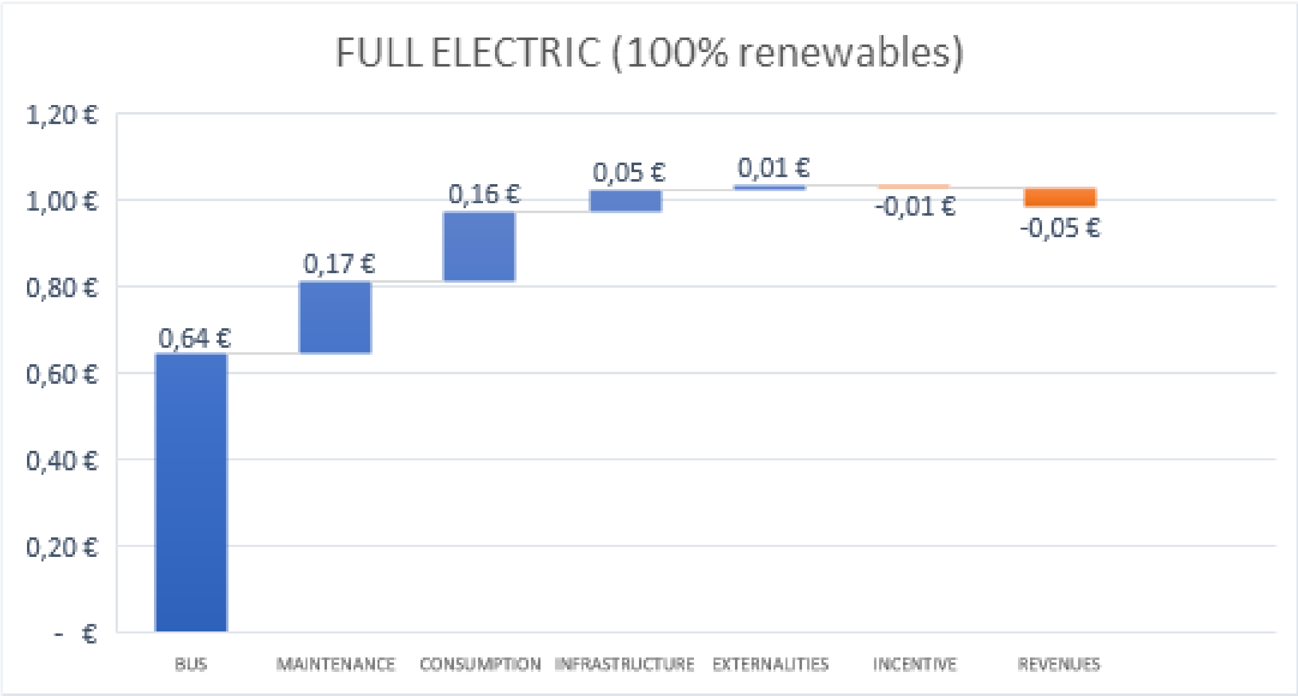
Long-term market (€/km)

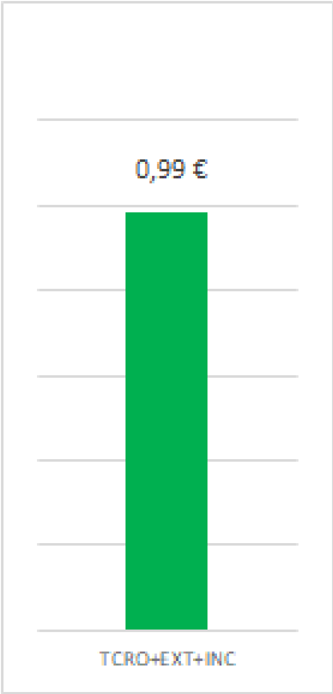


For Italy, this is slightly different than from other countries, and it shows that even without incentives a correct assessment of the comparative benefits combined with the possibility of generating revenues with B2G and 2nd life batteries makes the electrification choice strongly competitive.

GREEN Elaborations

Scenario 2: overview on TCRO composition





GREEN Elaborations

Key themes and tools arising from the TCRO, environmental externalities and incentives analysis

- The higher upfront capital costs associated with technologies and infrastructure for the zero emission bus transition are mitigated by the **lower operational** (-54%) and **maintenance costs** (-41%) for e-buses (not for hydrogen even in the long run).
- According to this analysis, most relevant investment cost reductions will happen in the next years (before 2025) thanks **to economies of scale** generated by the **demand growth** and by the **diversification of the supply**.
- The **protection of residual values of batteries and synergies with electricity grid** could contribute to reduce the risks for PTOs and accellerate the transition, but they require a **clear regulation framework** and a **proactive role by financial and utilities operators**.
- Revenues from B2G and 2ndlife of the batteries will keep the operating costs for PTOs to be as low as possible, with **potential benefits for public finance.**
- Monetization of externalities underlines the **opportunities for the society** coming from **decarbonising the bus sector.** Benefits are absolutely striking (-92% compared to diesel) when considering the option of consuming energy coming from 100% certified renewable sources (as in the case for PTOs in Milan and Turin, for instance), which can lead to **up to €10.000 annual value reduction in the cost of externalities for each bus.**

Spain

Spanish policy context

European policy tools expected to influence the choices of public transport operators in terms of bus engines in 2025 and 2030 in Spain.

EU POLICIES AND TIME REFERENCES	PROCUREMENT OBLIGATIONS FOR NON ENDOTHERMIC BUSES (*)	PURCHASING COST INCREASE FOR ENDOTHERMIC BUSES	MANAGEMENT COST INCREASE FOR ENDOTHERMIC BUSES	COST REDUCTION OF BATTERY ELECTRIC BUSES
EU Clean Vehicle Directive (progressively from 2021 on)				
EU Euro VII Directive proposal (from 2026)				
EU Fuel Quality Directive proposal (from 2026)				
Proposal of a regulation on batteries (from 2023)				

Source: GREEN Elaborations

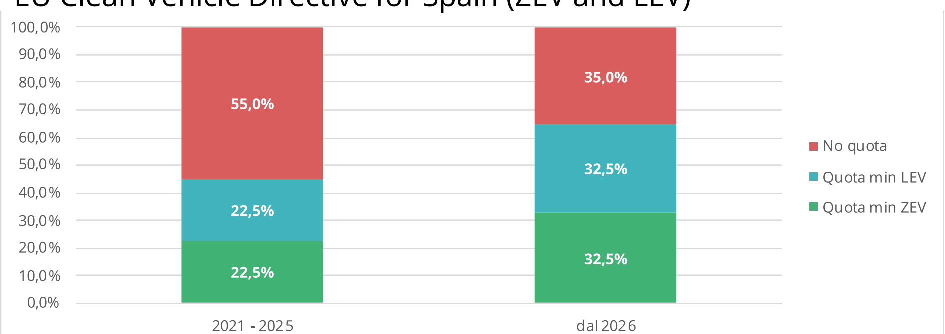
The green color scale shows the relevance of the expected impact. In particular:

- Very relevant= can modify the choices of operators for a fleet share greater than 20%
- Relevant= can modify the choices of operators for a fleet share between 10 and 20%
- Not very relevant= can modify the choices of operators for a fleet share smaller than 10%.

(*) Low emission (LEV) and Zero Emission (ZEV)

Spanish market context

Minimal target for bus procurement according to EU Clean Vehicle Directive for Spain (ZEV and LEV)



Source: *GREEN Elaborations* on Directive 1161/2016/EU parameters

The main public transport operators in Spain have specific policy targets more ambitious compared to the targets indicated in the EU Clean Vehicle Directive for Low and Zero emissions buses.

Spanish market context

TMB - Barcelona has an accelerated business plan for fleet conversion

- In 2021 63% of 1.157 buses were CNG/BEV/Mild Hybrid
- Starting from autumn 2021, Barcelona will receive 8 hydrogen buses that TMB bought with EU funds (JIVE 2 project)
- In 2021-2025 business plan is foreseen the substitution of 410 diesel buses with 210 e-buses, 46 hydrogen buses and 154 CNG hybrid buses.
- In 2030 scenario, more than 50% of the bus fleet will be BEV

TMB business plan at 2024 for bus fleet renewal

Bus type	Propulsion	Bid value (in Euro VAT excluded)	N° of buses
18 m	BEV with opportunity charger	955.900	29
12 m	BEV with night charger only	617.705	25
12 m	BEV with night charger only	617.705	24
12 m	CNG hybrid	393.250	85
18 m	CNG hybrid	517.880	23
12 m double deck	Diesel hybrid	533.005	24

EMT Madrid business plan

- In 2021 EMT started a collaboration with CNH2 for a specific study on green hydrogen buses.
- In April 2021 EMT finalised the procurement tender for 520 CNG buses and for 50 e-buses
- Starting from 2023, all the 2.000 buses (with average age of only 5,7 years) will be only CNG, BEV and Hybrid
- Starting from 2027, the fleet will be ebuses (for 1/3) and CNG buses (for 2/3).

EMT tender results for 570 buses (April 2021)

Bus type	Propolsion and manufacturer	Final price of the tender (Euro, VAT excluded	N° of buses
12 m	BEV - BYD	552.500	20
12 m	BEV-Irizar	498.000	30
12 m	CNG- Solaris	293.000	250
12 m	CNG - Scania N280	278.000	170
12 m	CNG-Mercedes Citaro	310.000	100

Market trends in e-buses sector

Trends that will change TCRO in 2025 and 2030 (European trends)

- Initial investment cost reduction due to the economies of scale in manufacturing process at global level*, EU Battery Directive will support economies of scale and economies of specialisation on all the technological aspects related to CAPEX and OPEX for BEB (proposal COD-2020/0353)
- Cost reduction of power consumption thanks to the use of new and lighter materials, weight reduction of batteries and better efficency in reusing braking energy)

Potential revenues for 2° life batteries and bus to grid (B2G) revenues (European trends)

- 2° Life Batteries. At EU level many projects have been supported by OEMs, for istance Volvo Bus (a stationary use for a residential building in Gothebourg) or Solaris Bus&Coach (in collaboration with Polish National Centre for Research with different use of the batteries) or Irizar (in collaboration with Repsol in Spain for innovative charging station for e-cars) or Daimler Bus (for the reuse of braking energy in the tram sector in Hannover).
- In 2025 the residual value of the bus battery, according to the willingness to pay of battery manufacturers that are able to regenerate the single battery pack and update the software of the battery management system, could be estimate in in **60 Euro per KWh**, that is approximately equal to 50% of the value of the new Nissan Leaf batteries and 50% of the new bus batteries in 2030 estimated by European Commission JRC analystis (Source: European Copper Institute (2019) e Tsiroupoulus (2018).

B2G Potential revenues

- From the analysis of the Sustainability Reports of the main Spanish public transport operators, and from the evaluation of EU funded projects, it seems that in Spain there are no pilot projects for B2G. Estimates of potential revenues are calculated on a parametric and analogic way compared to other European experience in medium-long period.

*According to the April 2021 market research report " Electric Bus Market by Propulsion (BEV, PHEV & FCEV), Application (Intercity & Intra-city), Consumer Segment (Fleet Operators & Government), Range, Length of Bus, Power Output, Battery Capacity, Component, Battery type & Region", published by MarketsandMarkets™, the global Electric Bus Market size is projected to grow from 81 thousand units in 2021 to reach 704 thousand units by 2027, at a CAGR of 43.1%.

Main parameters & assumptions

The **asset life** in Spain is clearly indicated in the procurement tender documents by the Public Transport Operator.

The **business plan** for the **fleet renewal** is a public document, with a 4 years duration, that leverages the economies of scale in the production, with the final adjudication to more than one bidder. Thus, the final bus manufacturing will be assigned to more than one manufacturer in a proportional way, in order to increase competition among applicants and reduce the risks for the operator (e.g., if there are 4 participants to the bid the first 3 will be the winners in a proportional way).

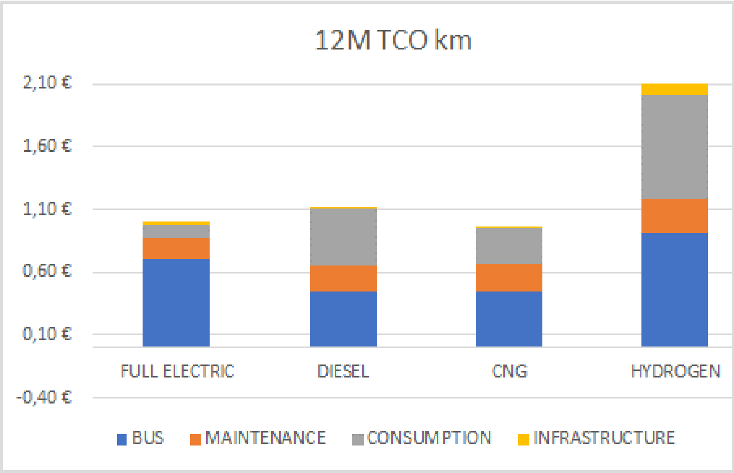
The **driven km** per year are differentiated among operators, while the detailed benchmark analysis is differentiated only for the bus lenght (not for the type of motorization):

- 8 meters: 45.000 km per year (only diesel)
- 12 meters: 55.000 km per year
- 18 metri: 60.000 km per year

Battery replacement for BEV and H2 buses is needed after 7 years.

No specific differentiation of consumption related to air-conditioning or intensive winter heating is considered due to the average temparature of the main Spanish cities in the 10-30° C range.

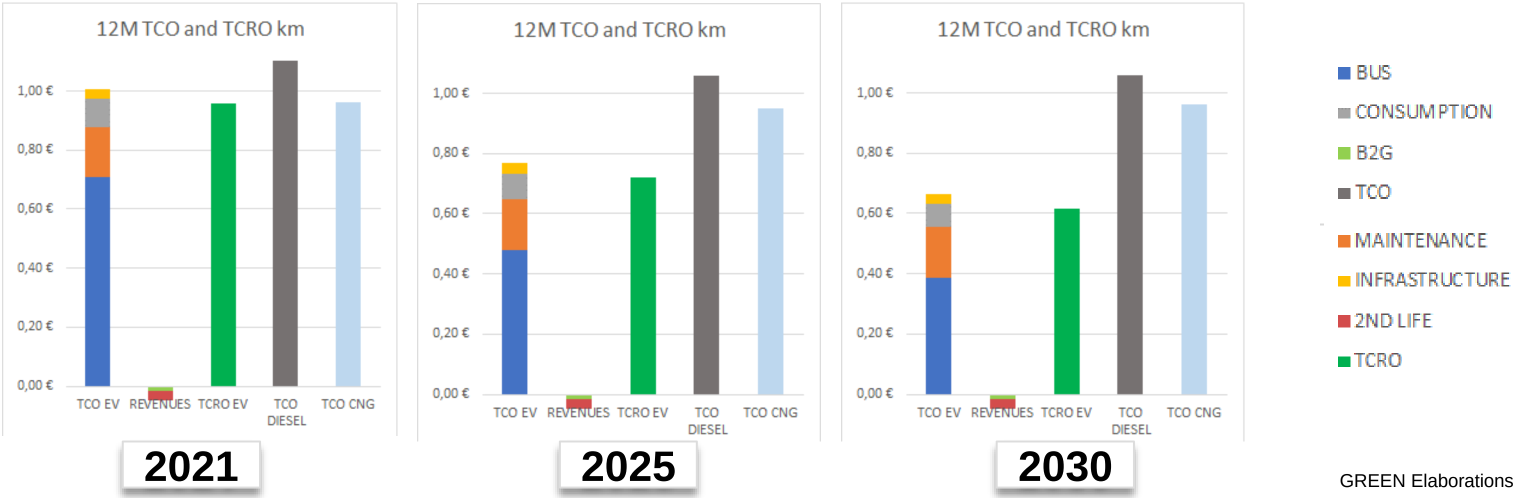
Costs and revenues by component (%) for 12m buses



	FULL ELECTRIC	DIESEL	CNG	HYDROGEN
BUS	0,710 €	0,444 €	0,445 €	0,912 €
MAINTENANCE	0,170 €	0,203 €	0,217 €	0,273 €
CONSUMPTION	0,093 €	0,454 €	0,285 €	0,826 €
INFRASTRUCTURE	0,034 €	0,003 €	0,014 €	0,130 €
B2G	0,0153 €			
2ND LIFE	0,0327 €			
Total TCO	1,006 €	1,105 €	0,961 €	2,140 €
Total TCRO	0,958 €	1,105 €	0,961 €	2,140 €

GREEN Elaborations (2021)

The role of revenues – TCO & TCRO



GREEN Elaborations (2021, 2025, 2030)

Break-even according to TCRO approach

Enel Foundation

TCO and TCRO: break-even price for 12M e-bus compared to Diesel and CNG (2021)

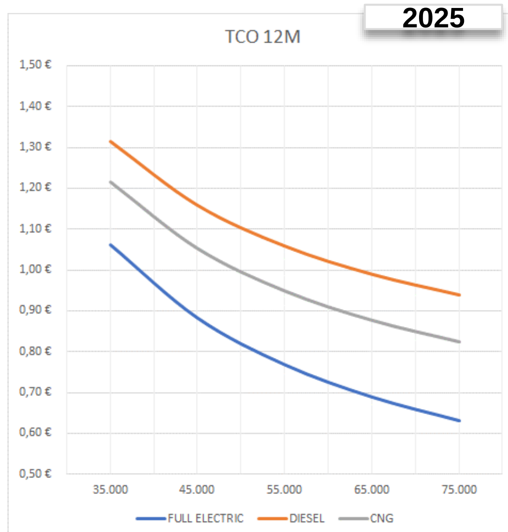
TCO

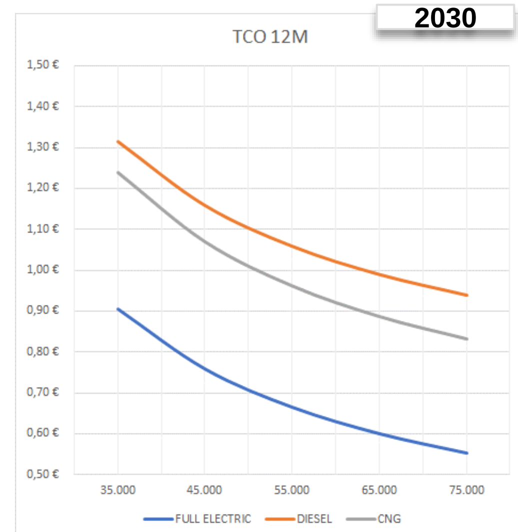
	break even price	diff. current price	diff. %
vs CNG	460.589,85 €	- 37.410,15 €	-7,51%

GREEN elaborations, year 2021

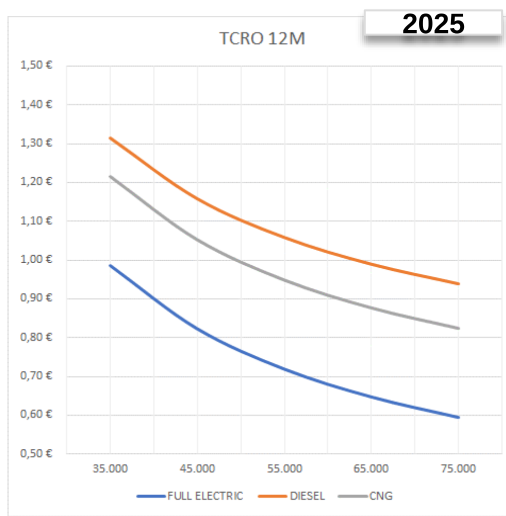
- The table highlights the difference between the current BEB price (2021) and the cost of BEB needed to equal TCO compared to CNG bus.
- At current prices the comparison in terms of both TCO and TCRO is favourable to Full electric vs Diesel, and moreover the former are competitive vs CNG when we consider TCRO.
- The data show that the price of e-buses is fairly close to the one of yet more competitive CNG alternatives, with a reduction of the purchasing cost needed estimated around 7,51% of the current price. As can be seen later, also in the current policy scenario, the break-even for 12m e-bus is expected in 2022.

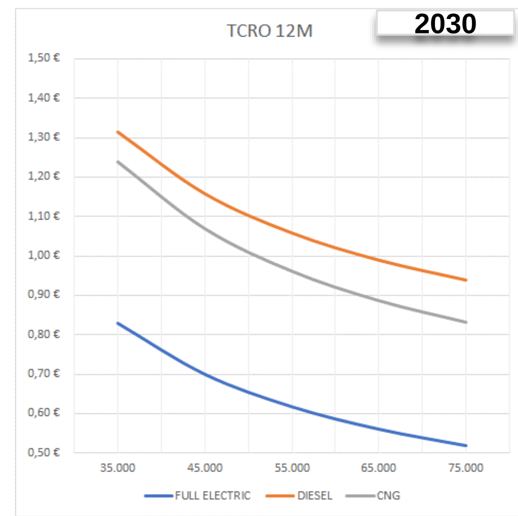
Sensitivity analysis TCO & TCRO





GREEN Eaborations (2021, 2025, 2030)



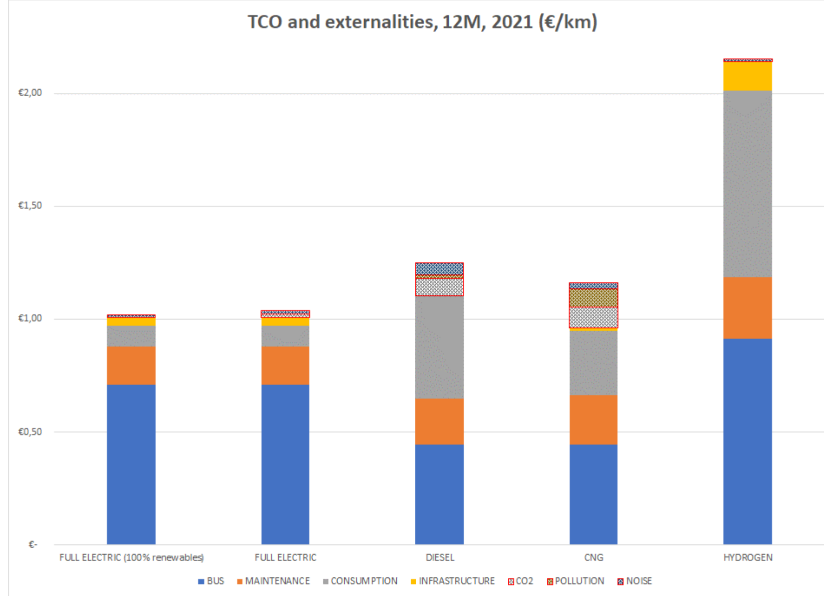


GREEN Elaborations (2021, 2025, 2030)

TCO and externalities

The comparison between TCO, TCRO and TCRO+externalities highlights the economic and social benefits deriving from the electrification choice already in the basis year 2021, also compared to CNG.
The advantages of FULL ELECTRIC are even more relevant considering that the estimated revenues from B2G and Second Life would lower the TCO further by 4,8 €cents.

Sources: European Commission, DG REGIO Handbook on the external costs of transport, (2019) ;REE- Red Electrica de Espana "CO2 emissions of electricity generation", March 2021.

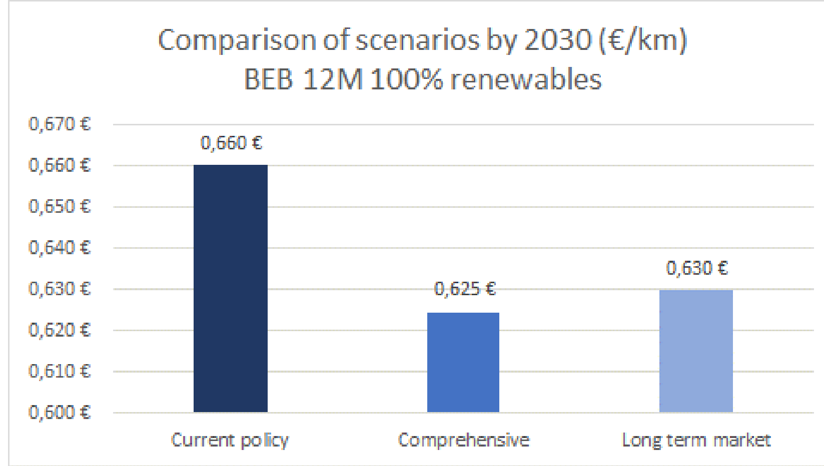


GREEN Elaborations

Scenarios including externalities and incentives (by 2030)

To compare the effects of a) potential revenues from B2G and 2nd life battery reuse b) available **incentives** (limited for Spain to **30% of infrastructure costs**) and c) monetary valuation of negative externalities, 3 TCO scenarios have been elaborated and compared:

1. "**Current policy**" scenario
2. "**Comprehensive**" scenario
3. "**Long term market**" scenario



GREEN Elaborations

Synthesis of the TCO & TCRO analysis

Policy context in Spain is favorable to the introduction of BEB thanks to:

1) Clear European and National environmental policies based on long term commitment to ZEB through specific target goals
2) Presence of industrial policies supporting pilot test of different technologies (E-buses, Hydrogen buses, CNG buses)
3) Specific circular policies supporting 2ndlife of the batteries projects

Also **market context** is very favorable thanks to**:**

1) Presence of large and multinational PT operators and PT agencies able to quickly generate economies of scale in procurement process and depots construction with specific operational knowledge in BEB;
2) Low cost energy tariffs for PT;
3) Spain is a favorable test bed for supporting innovative business models designed around the characteristics and opportunities presented by zero-emission buses manufacturers
4) Presence of new players proposing innovative asset ownership and sources for scalable financing.

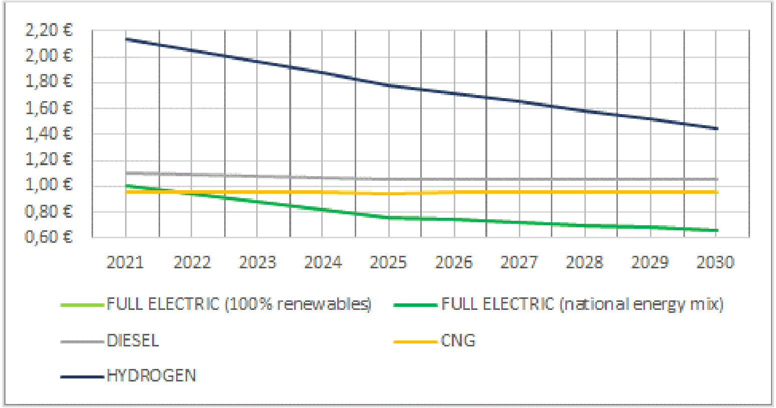
In 2021 TCO of full electric buses (in the 12-meter version) is still not competitive compared to CNG (+0,045 Euro*km), due to high CAPEX, but it is already competitive compared to diesel (- 0,099 Euro*km). In terms of TCRO a BEB is already competitive compared both to CNG and diesel buses.

In 2025 and 2030 the average yearly mileage necessary for reaching the break-even in terms of TCO for BEBs compared to CNG and diesel buses is very low therefore BEB are always more competitive for public transport use.

In all scenarios **BEBs** are estimated to be **always more competitive compared to hydrogen buses** both in terms of TCO and TCRO, due to very high CAPEX (for buses and refueling stations) and OPEX costs of hydrogen buses.

Scenarios

Current Policy (€/km)



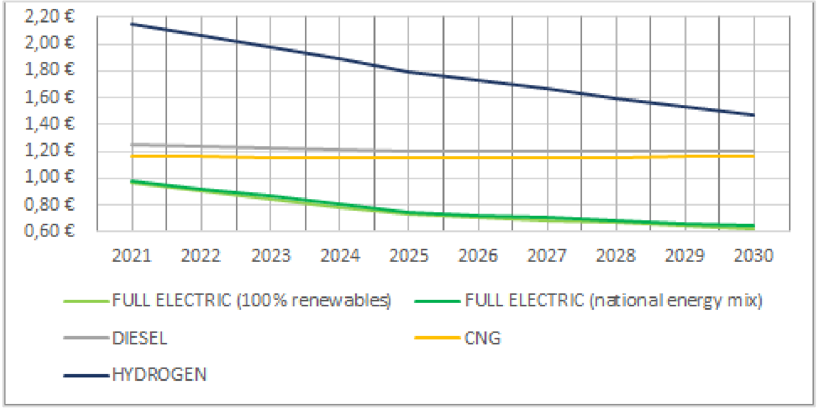
GREEN Elaborations

The role of incentives is limited to the co-funding available according to Alternative Fuel Initiative (Connecting Europe Facility). This results in a decrease of 0,5 €cents per bus*km, thus contributing to a very slight anticipation of the break-even point with CNG.

Long-term market (€/km)

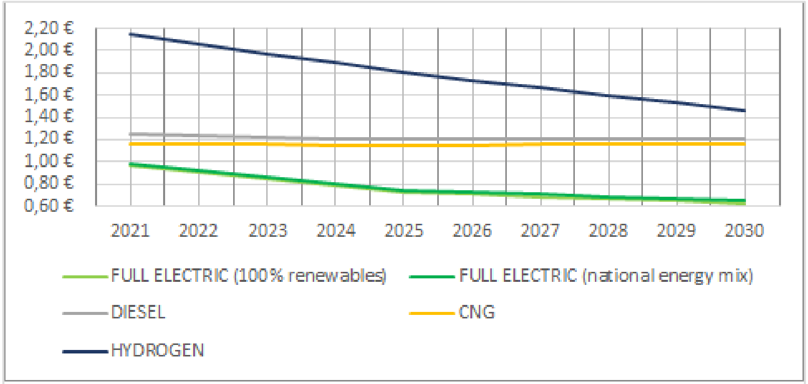
The third scenario is interesting in particular when looking at the long term, when no incentives are in place while externalities shall be valuated and compensated. For Spain, even without incentives, the electrification choice is strongly competitive.

Comprehensive (€/km)



GREEN Elaborations

In this scenario there's an evident competitive advantage for electrified public transport. Also, thanks to the integration of externalities, the costs of fossil-based options raise significantly.



GREEN Elaborations

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le risorse naturali, l'energia,
l'ambiente e le reti

The specific British case. 2021: the year of changes

UK bus operators have invested over £1.3bn in cleaner and greener buses over the 2016-2020 (mostly hybrid or gas-powered buses) , supported by £89m funding through the Government's Low and Ultra-Low Emission bus schemes. Just around 2% of England's bus fleet is fully zero emission today (DfT (2020) Energy and environment: data tables).

- January 2021: the Department for Transport announced **Coventry and Oxford were set to become the UK's first all-electric bus cities**, replacing up to 500 buses across the two cities
- March 2021:The **National bus strategy** *Bus back better* was published containing several pledges to improve the environmental friendliness of the country's bus sector supported by a funding scheme of approximately 3 billion £. To ensure funding from the new zero-emission-bus fund is used quickly to help provide British bus manufacturers with an injection of orders, in 2021 the government called on consortia of local transport authorities, energy companies, bus operators and manufacturers to come together to work up strong cases for funding, according to a specific **Zero Emission Buses Regional Area (ZEBRA) scheme**.
- August 2021: the first 23 projects (all outside London) were presented with the aim to deliver up to 500 zero-emission buses, supporting the Government's wider commitment to introduce 4,000 zero-emission buses.
- September 2021: the Mayor for London announced **that all new TfL buses in London will be zero-emission and the commitment to deliver a 100% zero-emission bus fleet in London has been brought forward to 2034.**
- 10% of London's bus network will be zero-emission by the end of 2022. With Government funding the **entire fleet** could be **zero-emission by 2030.** Making buses zero-emission will **save 4 million tons** of **carbon** by **2037** (and moving the date forward to 2030 will save an additional 1 million tons).
- UK is set to have the **largest electric bus** fleet in Europe **by 2024**, with the number of buses projected to grow by close to 180% from approximately 1.000 to 2.800 vehicles.

The specific London market. Scenario for operators and perspectives for British manufacturers

- The Mayor's Transport Strategy sets a target for 80% of all journeys to be made on foot, by cycle or using public transport by 2041 against a backdrop oriented towards a greener and healthier city.
- March 2021: according to an audit conducted by Transport for London, at that time all the major bus operators had electric buses in their fleet for a total of **495 e-buses** (5,4% of the total fleet of 9.065 buses), 217 of them being double deckers (8,4% of the total fleet of 2.579).
- Go-Ahead is the main public transport operator of e-buses with 206, followed by Metroline (90), RATP (65), Stagecoach (52), Abellio, Town Transit (20), Arriva (13, the 1st mover in e-bus market in London in 2014) and Uno (5).
- BYD UK in partnership with Alexander Dennis Ltd. (ADL) is the leading bus in the market with 386 e-buses delivered (single and double deckers). Optare is the its competitor with 63 e-buses (single and double) delivered for TfL, followed by Caetano (63 single) and Irizar (2 single type).
- The acceleration of **London's shift to zero-emission** is bringing down costs and enhancing products for the entire country, and with committed funding from the DfT, TfL can ensure that the Government's commitment to 4,000 zero-emission buses can be achieved faster.
- With London making up 1/3 to half of all new bus orders in the UK in any given year, increasing the number of these buses in the capital is also supporting 3,000 jobs across the UK (such as at the Alexander Dennis (ADL) factories in Scarborough and Falkirk, Switch Mobility near Leeds and Wrightbus, in Ballymena, Northern Ireland).

The specific Scottish case.

Scottish Ultra-Low Emission Bus Scheme (SULEBS) & Scottish Zero Emission Bus Challenge Fund (ScotZEB)

SULEBS supported the Scottish Government's net zero targets providing fund for the purchase of new ultra low emission buses (up to 75% of the differential costs against diesel buses, depending on their zero emission running capability) and for the infrastructure (up of 75% of the capital cost).

- SULEBS 1st round (August 2020): > £10.1 million of funding supported 4 completed bids, for the introduction of 57 ultra-low emission buses and supporting infrastructure.
- SULEBS 2nd round (January/February 2021): > £40.5 million of funding supported 6 completed bids, introducing a further 215 ultra-low emission buses and supporting infrastructure across Scotland.

Bus operator	Type of bus	Number	Infrastructure included	Manufacturer	Cost	Price per bus
First Glasgow No 1 Ltd	Single and double	35+91	Yes	ADL	£24,301,840	
McGill's Bus Service Ltd	Single	33	Yes	Yutong	£ 6,011,718	£ 182.173
Ember Core Ltd	Single and Arrival bus	6+4	Yes	Yutong + other	£1,302,634	
Stagecoach West	Single	15	yes	ADL	£2,666,359	£ 177.757
Stagecoach East	Single	9	yes	ADL	£2,181,663	£ 242.407
Stagecoach Bluebird	Double	22	yes	ADL	£4,079,134	£ 185.415

Source: SULEBS January/February 2021

- **Scottish Zero Emission Bus Challenge Fund (ScotZEB)** was born to support innovative business models designed around the characteristics and opportunities presented by zero-emission buses and associated charging infrastructure. It opened for bids with £50 million (August 4th 2021) .

The Bus2Grid project (B2G) in London

In January 2018, the Office for Low Emission Vehicles and the Department for Business, Energy and Industrial Strategy awarded almost £30 million, through an **Innovate UK vehicle-to-grid programme**, where electric vehicles can supply electricity to the grid at times of high energy demand.

Bus2Grid is part of this programme and is exploring the commercial value and social benefits to the energy and passenger transportation systems, with an amount of £725.412 of public funds for a total cost of £ 2.405.000**.**
The project will develop services to support National Grid, local Distribution Network Operators (DNOs), bus operators and transport authorities and at the same time will consider bus fleet consumer engagement approaches necessary for its commercial implementation.

B2G claims to be developing the “world’s largest bus to grid site”. The project is a first of a kind large scale, multi-megawatt, demonstration of vehicle-to-grid technology in electric bus depots located in London.
This process is managed by an aggregation platform that enables the 28 e-bus batteries to interact with the energy system by charging or exporting energy to support the grid in times of high energy demand.

The **key objectives** to deliver:

- 11 retrofit and 22 new build V2G enabled e-buses and 2.64 MW of bi-directional charging infrastructure in Northumberland Park London bus depot, with > 1-2 MW of V2G response;
- An aggregation platform integrated with the depot's Charging Management System with interfaces to offer services to National Grid and UKPN (DNO);
- Understand bus operators’ attitudes to V2G technologies at different project stages and to new business models, and create a tailored V2G services proposition;
- Disseminate key findings and recommendations for stakeholders critical to the development of V2G markets.

Market trends in e-buses sector

Trends that will change TCRO in 2025 and 2030 (UK and general trends)

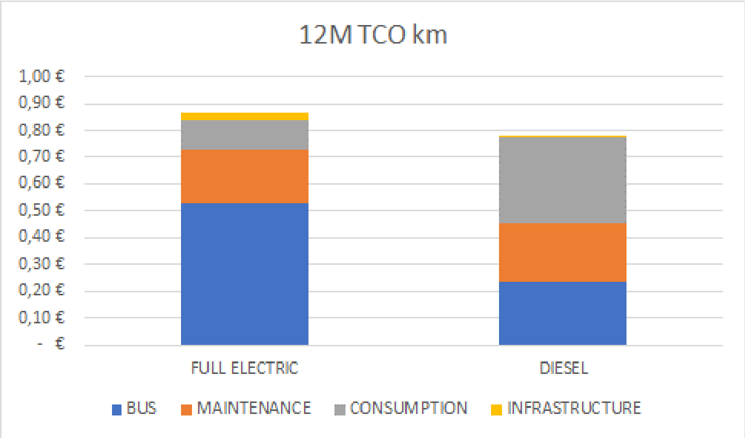
- UK is already one of the biggest market for e-buses in Europe and it set to have the **largest electric bus fleet** in Europe by 2024, generating economies of scale and moreover local manufacturer will contribute to cost reduction of chassis and battery. UK Government considers a priority the sector as strategic for the national economy.
- Initial investment cost reduction due to the economies of scale in manufacturing process at global level*
- EU Battery Directive will support economies of scale and economies of specialisation on all the technological aspects related to CAPEX and OPEX for BEB (proposal COD-2020/0353)
- Cost reduction of power consumption thanks to the use of new and lighter materials, weight reduction of batteries and better efficency in reusing braking energy)
- **Potential revenues for 2° life of the batteries and bus to grid (B2G) revenues**
- The largest B2G project in Europe has been implemented in London, but no public results are available. A proxy of €1.200/year is indicated in the TCRO analysis for 12 meters bus.
- In 2025 the residual value of the bus battery, based on the willingness to pay of battery manufacturers that are able to regenerate the single battery pack and update the software of the battery management system, could be estimated in 50% of the foreseen value of the new batteries in 2025 and 2030 (198 € * kWh in 2025 and 188 €* kWh in 2030 according to Committe on Climate Change)

* According to the April 2021 market research report " Electric Bus Market by Propulsion (BEV, PHEV & FCEV), Application (Intercity & Intra-city), Consumer Segment (Fleet Operators & Government), Range, Length of Bus, Power Output, Battery Capacity, Component, Battery type & Region", published by MarketsandMarkets™, the global Electric Bus Market size is projected to grow from 81 thousand units in 2021 to reach 704 thousand units by 2027, at a CAGR of 43.1%.

The main parameters: buses specifications and cost assumption

- The driven kms per year are differentiated among operators: for 12 m buses are 70.000 km/year
- Battery replacement for BEV and H2 buses after 7 years
- In order to extend body life and to improve body appearance and amenity of ICE buses at 10 years, it is necessary to consider € 49.000 for a diesel transit bus
- No specific differentiation of consumption related to air-conditioning or intensive winter heating is considered due to the average temparature of the main UK cities in the 10-30° C range

Costs and revenues by component for 12m buses (2021)

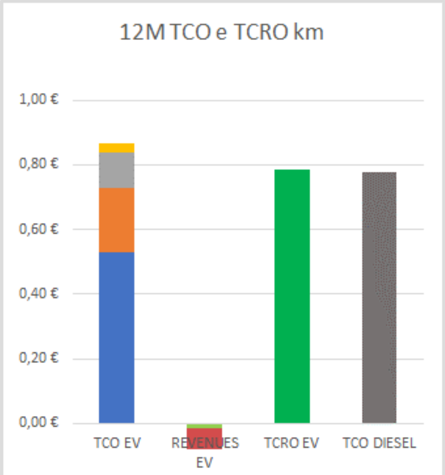


	FULL ELECTRIC	DIESEL
BUS	0,531 €	0,237 €
MAINTENANCE	0,199 €	0,217 €
CONSUMPTION	0,109 €	0,321 €
INFRASTRUCTURE	0,027 €	0,002 €
B2G	0,0145 €	
2ND LIFE	0,0656 €	
Total TCO	0,865 €	0,776 €
Total TCRO	0,784 €	0,776 €

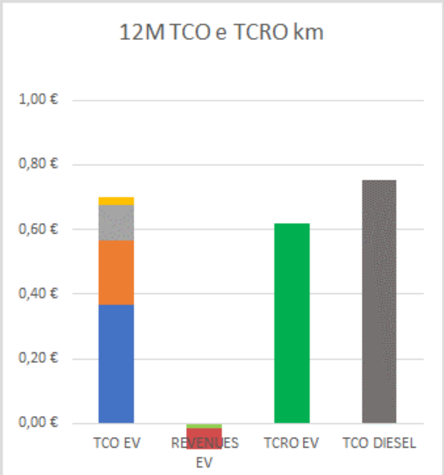
GREEN Elaborations (2021)

TCO break-even of e-buses is expected by 2023

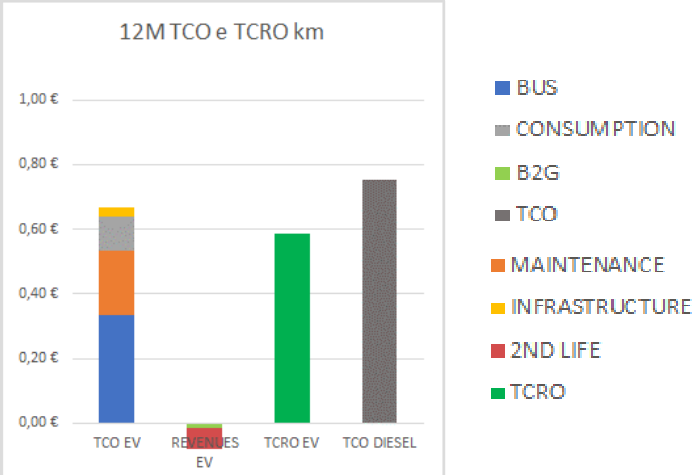
The role of revenues – TCO & TCRO



2021



2025

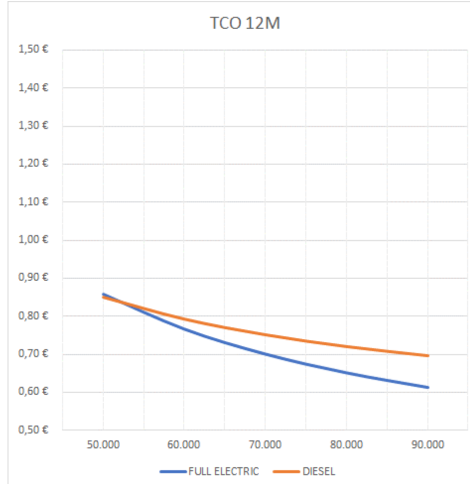


2030

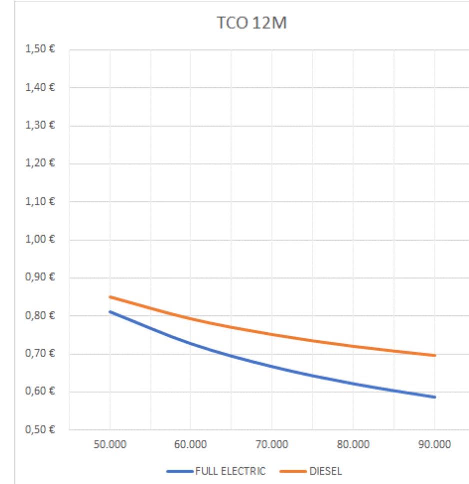
GREEN Elaborations (2021, 2025, 2030)

Sensitivity analysis TCO & TCRO

2021

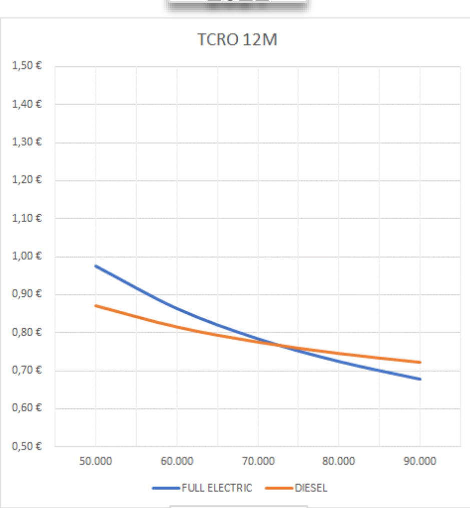


2025

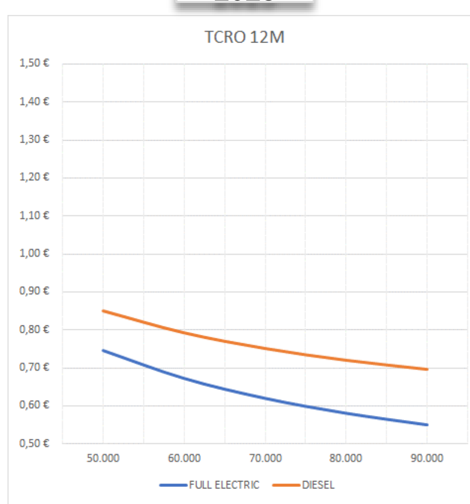


2030

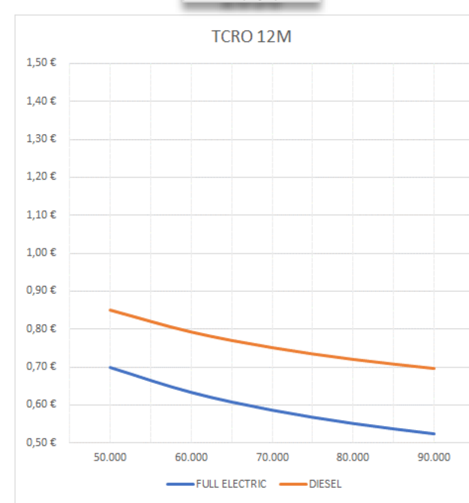
GREEN Elaborations (2021, 2025, 2030)



2021



2025



2030

GREEN Elaborations (2021, 2025, 2030)

TCO & TCRO break-even in Uk

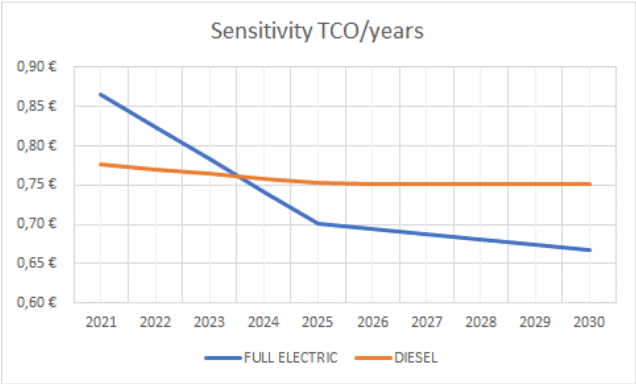
TCO and TCRO: break-even price for 12M ebus compared to Diesel (2021)

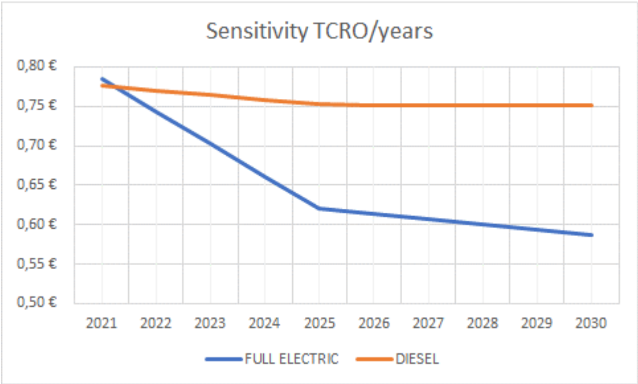
TCO

	break even price	diff. current price	diff. %
vs DIESEL	388.639,55 €	- 92.960,45 €	-19,30%

TCRO

	break even price	diff. current price	diff. %
vs DIESEL	472.748,71 €	- 8.851,29 €	-1,84%





GREEN Elaborations (2021)

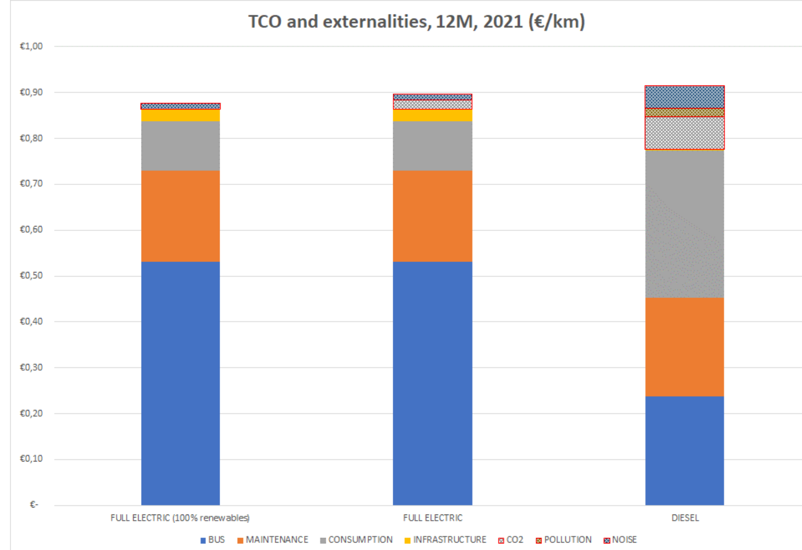
- The tables highlight the differences between the current price (2021) and the one needed to equal TCO and TCRO compared to DIESEL.
- The data show how close the current price of ebuses is to the one needed to reach the break-even in terms of TCRO (1,84% difference). Instead, when considering the TCO, the current price needs to be reduced by 19,30%.
- The analysis of 12m buses TCO over time shows how Full electric parity with diesel is reached in 2023. The dynamic is even faster considering TCRO.
- Since 2024, TCO and TCRO get more and more favourable for BEBs, continuously decreasing up to 2030.

TCO and externalities

The comparison between TCO, TCRO and TCRO+externalities highlights the role of economic and social benefits creating convenience for electrification in the basis year 2021.

The advantages of FULL ELECTRIC are even more relevant considering that the estimated revenues from B2G and Second Life would lower the TCO further by 4,8 €cents.

Source for monetary parameters of externalities: European Commission, DG REGIO Handbook on the external costs of transport, (2019) and for carbon intensity of electricity: Final UK greenhouse gas emissions national statistics 1990-2019 (https://www.gov.uk/government/collections/final-uk-greenhouse-gas-emissions-national-statistics)

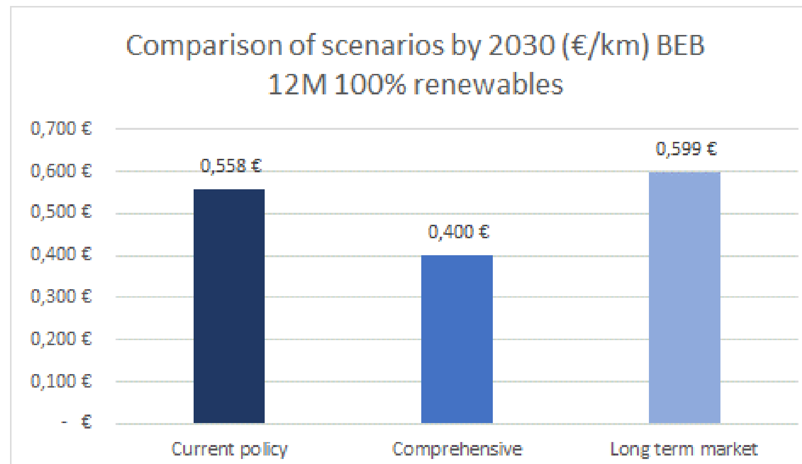


GREEN Elaborations

Scenarios including externalities and incentives (by 2030)

In order to compare the effects of a) potential revenues from B2G and 2nd life battery reuse b) available **incentives** (**22 pence*km for BEBs**) and c) monetary valuation of negative externalities, 3 TCO scenarios have been elaborated and compared:

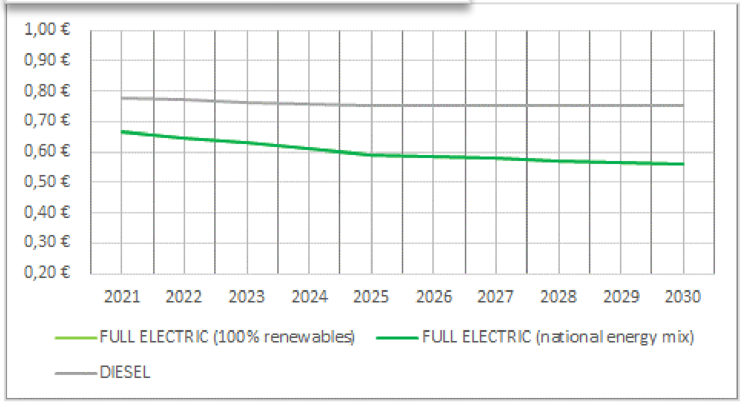
1. "**Current policy**" scenario
2. "**Comprehensive**" scenario
3. "**Long term market**" scenario



GREEN Elaborations

Scenarios

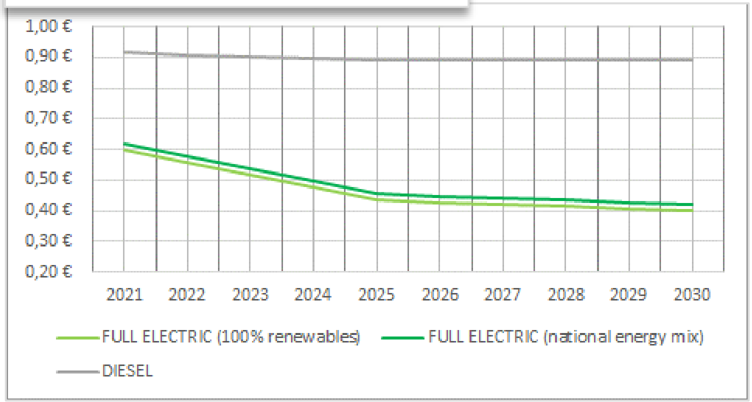
Current Policy (€/km)



GREEN Elaborations

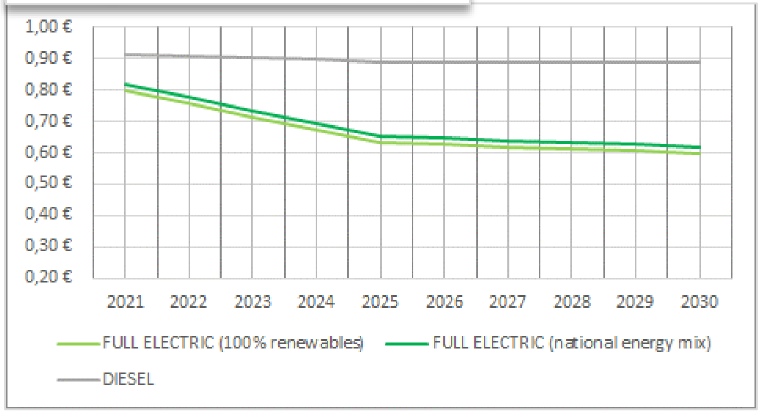
For UK, incentives are framed within the Bus Service Operators Grant (BSOG), consisting in 22p^km for ZEBs on top on the contribution for traditional fuels.This results in a decrease of 25 €cents per bus*km, more than neutralizing the energy costs.

Comprehensive (€/km)



GREEN Elaborations

Long-term market (€/km)



GREEN Elaborations

For UK, the valorisation of externalities, B2G and 2nd life batteries determines a strongly increasing competitive advantage on the medium-long term compared to the current policy scenario. Thus, a combination of incentives in the short-run and market approach (e.g., working on the regulatory framework for B2G, 2nd life battery reuse and market for emissions) in the long-run seems to be the most promising policy mix.

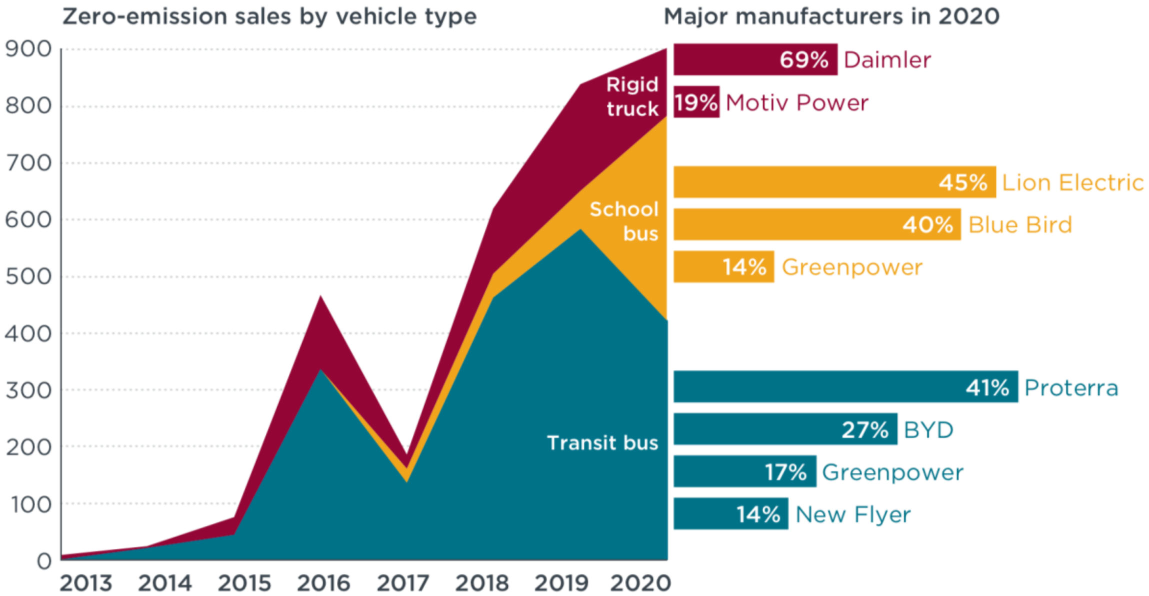
This scenario shows how the combination of the 3 factors generates further competitive advantage for electrified public transport. Another interesting aspect of this scenario is that, thanks to the integration of externalities, the costs of fossil based options raise significantly.

US - Transit

The specific USA bus market

- In 2019 the total bus fleet in USA was composed by 55.236 transit buses, 6.008 articulated buses (FTA, 2019) and 480.000 school buses (Schoolbusfleet.com).
- In 2020 the USA registered 40.714 school buses and only 5.402 transit buses.
- In 2020, the United States and Canada accounted for 1.2% of global zero-emission bus sales (422 transit e-buses and 258 electric school buses) underlining the **early stage context with few players both on demand and supply side**.
- In 2020, buses made up 87% of zero-emission commercial vehicle sales in the United States and Canada, with transit and urban buses representing 54% of these bus sales and school buses making up the remainder.

ZEB and truck sales in the United States and Canada by vehicle type



- Proterra is the early leader in the zero-emission transit bus market, accounting for 41% of 2020 sales in the United States and Canada.
- Including Proterra, **the four largest electric transit bus manufacturers represented 99% of the zero-emission transit bus market in 2020**.

Source: ICCT (2021), "Made in North America: Manufacturers invest in zero-emission buses and trucks"

USA policy context

- Since the creation of the **Clean Air Act** (CAA) in the 1990s, the federal government has been working with public and private organizations to reduce the amount of pollution released into the atmosphere. Transit buses have historically and predominantly operated on diesel fuel.

- The "**Low or No Emission Vehicle Program-** 5339(c)" provides funding to state and local governmental authorities for the purchase/leasing of zero-emission and low-emission transit buses as well as acquisition/construction/leasing of required supporting facilities. As announced on June 25th 2021, this year the program will fund 49 projects in 46 states with a total investment of $182,156,692 in low and no emissions buses and facilities.

- Concerning school buses, the "**Clean School Bus Act**" re-introduced in 2021 as part of a broad electric vehicle (EV) legislative package, envisages **$1.2 billion** funding to replace diesel vehicles with electric buses over a 6 fiscal year period (**2022-2027**). The bill aims at creating a create a program at the Department of Energy (DOE) providing **financial and technical assistance to school districts** for the **replacement of traditional school buses with electric ones**, investments in charging infrastructure and support to workforce development.

- The recently issued "**Infrastructure Investment and Jobs Act**" envisages $174 billion investments in electromobility, with $7.5 billion dedicated to electric bus initiatives. Among the objectives, the act includes the **replacement** of **50,000 diesel transit buses** and the **electrification** of at least **20% of the school buses fleets**.

- As of December 2020, more than 40 cities worldwide, including Los Angeles, Austin, Santa Monica, Seattle, West Hollywood, signed the **C40 Fossil-Fuel-Free Streets declaration**, pledging to purchase **only ZEBs from 2025** onward. Few examples in USA are the city and country of Honolulu,

- Other relevant initiatives have been launched at city and state levels. For instance, MTA NY (planned to transform its 5,800 buses to a zero-emissions fleet by 2040), Massachusetts MBTA (procured 80 BEB expected to enter in service in 2023), Virginia (planned the complete replacement of diesel buses with EV buses by 2031) and Maryland established the Zero-Emission Vehicle School Bus Transition Grant Program and requires newly purchased school buses must be electric).

The specific procurement process in USA

- The public transport sector is highly fragmented and this slows the introduction of new technologies and reduce capacity investment, due to the fact that **approximately 6.800 organizations provide public transportation in the United States**.
- Transit agencies plan around replacing existing buses on a 12-year life cycle, based on the expected useful life of standard diesel buses as determined by Altoona tests (which refer to Federal Transit Administration-required bus certification at the Bus Research and Testing Center).
- In order for a new bus model to be eligible for federal fund assistance in the United States, bus models must pass a series of tests on "maintainability, reliability, safety, performance, structural integrity and durability, fuel/energy economy, noise, and emissions".
- **Joint procurement** via state facilitated request for proposal (RFPs) or regional pairings of transit agencies is becoming more common and helps share the cost of holding RFPs amongst more parties.
- Bus procurements must satisfy the United States Federal Transit Administration (FTA)'s "**Buy America**" requirement, which mandates that **a bus must undergo final assembly in the United States and that 70% of the bus's components, by cost, must be produced in the United States** in order to receive Grants for Nationwide Projects to Expand Advanced, Efficient Bus Technologies. This virtually eliminates foreign bus manufacturers from U.S. bus procurement consideration.

The specific procurement process in USA

- The **Infrastructure Investment and Jobs Act** includes specific goals of electrifying 50 000 public transport buses and 20% of all school buses by 2030 (White House, 2021). Goals also exist at the state level; in particular, California has a goal of 5 million “zero-emission vehicles” on the roads by 2030 (CPUC, 2021).
- The main **customers** of buses are **transit agencies** that operate as **Metropolitan Planning Organizations** (MPOs) and **Regional Transportation Planning Organizations** (RTPOs). These government organizations are responsible for coordinating regional and government efforts in transportation planning, improvements, and policy.
- **Federal Transport Authority** (FTA) is responsible for programs that directly or indirectly provide assistance to municipalities and transit agencies looking to deploy electric buses, including but not limited to the **Low or No-Emission Vehicle Program, Urbanized Area Formula Grants,** and **Formula Grants for Rural Areas**.
- Between 2013 and 2020, the Federal Transit Administration (FTA) has distributed over $485 million for hybrids, battery electric, and hydrogen fuel cell buses via the Low or No-emission Bus Program. State-level grant programs, such as California’s Transit and Intercity Rail Capital Program (TIRCP), have also supported the adoption of ZEBs.
- Since 2016, **Volkswagen Emissions Settlement Funds** increased the National budget with an additional $2.925 billion on nitrous oxide mitigation and $2 billion on clean vehicle infrastructure. These funds are eligible for a wide range of activities, including “replacing or repowering older engines for newer engines at a rail switchyard, or could include replacing older city transit buses with new electric-powered transit city buses”.

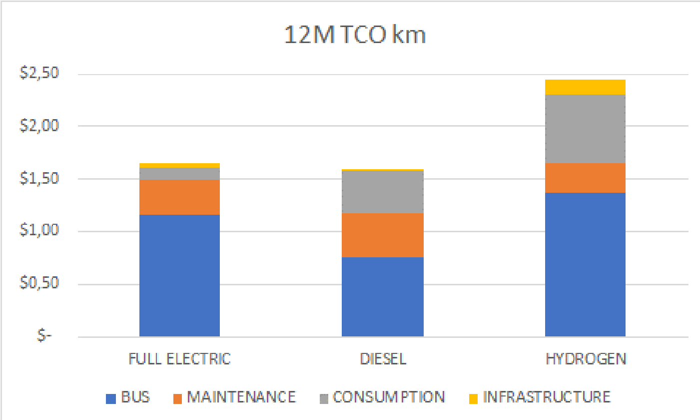
Transit buses: main parameters and main assumptions

- The driven kms per year are differentiated among operators:
  - 8 m: 45.000 km/year
  - 12 m: 55.000 km/year
  - 18 m: 60.000 km/year
- Battery replacement for BEV and H2 buses after 7 years
- In order to extend body life and to improve body appearance and amenity of ICE buses at 10 years is necessary to consider a 115.000 USD for a diesel transit bus while for a CNG 12 meters the cost of revamping is 137.000 USD.
- No specific differentiation of consumption related to air-conditioning or intensive winter heating is considered due to the average temperature of the main USA cities in the 10-30° C range.

Potential revenues for 2° life of the batteries and B2G revenues

- Cost reduction of power consumption thanks to the use of new and lighter materials, weight reduction of batteries and better efficency in regenerative braking energy
- In 2025 the residual value of the bus battery, could be estimated in **67,20 USD per KWh**, that is approximately equal to 70% of the foreseen value of the new batteries in 2025 (BloombergNEF 2020).
- On May 17th 2021, Nuvve announced plans to pursue formation of a joint venture with Stonepeak Infrastructure Partners (“Stonepeak”) to deploy fleet vehicles (including school buses) and charging infrastructure utilizing Nuvve’s proprietary V2G technology. Estimates of potential revenues are calculated on a parametric and analogic way compared to school buses (1/3) and estimated in 1.200 USD per year in 2025 for a 12 meters transit bus.

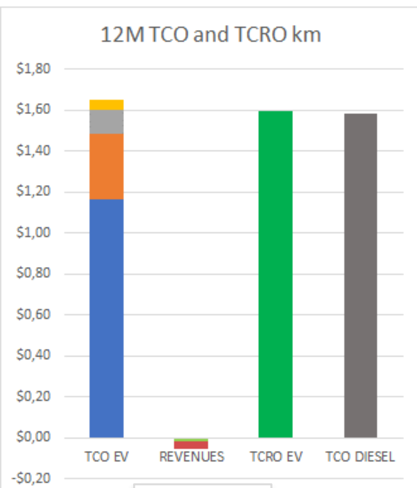
Costs and revenues by component for 12m (2021)



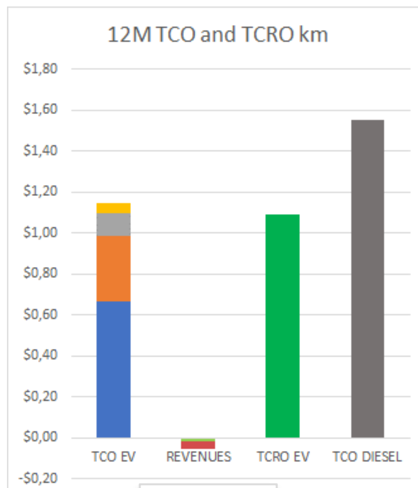
	FULL ELECTRIC	DIESEL	HYDROGEN
BUS	$ 1,166	$ 0,750	$ 1,375
MAINTENANCE	$ 0,322	$ 0,423	$ 0,273
CONSUMPTION	$ 0,116	$ 0,411	$ 0,661
INFRASTRUCTURE	$ 0,047	$ 0,001	$ 0,130
B2G	$ 0,018		
2ND LIFE	$ 0,037		
Total TCO	$ 1,652	$ 1,585	$ 2,438
Total TCRO	$ 1,596	$ 1,585	$ 2,438

GREEN Elaborations (2021)

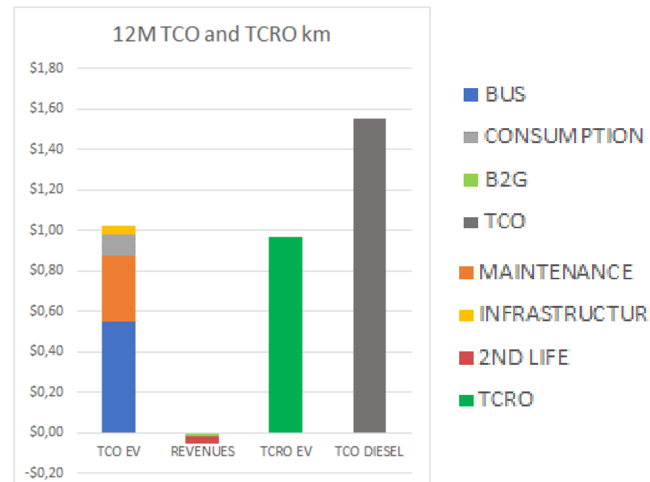
The role of revenues – TCO & TCRO



2021



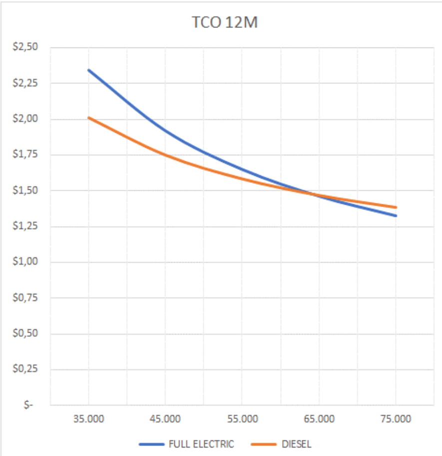
2025



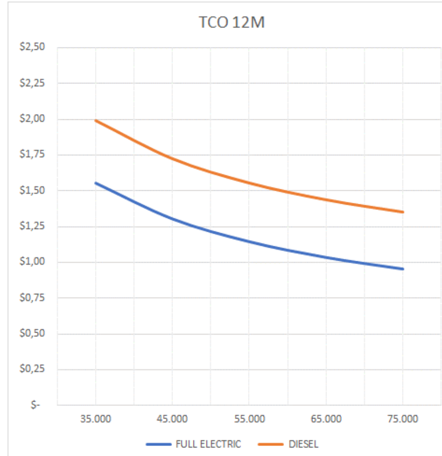
2030

GREEN Elaborations (2021, 2025, 2030)

Sensitivity analysis TCO & TCRO



2021



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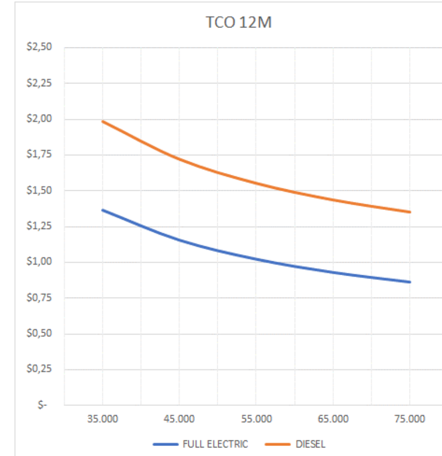
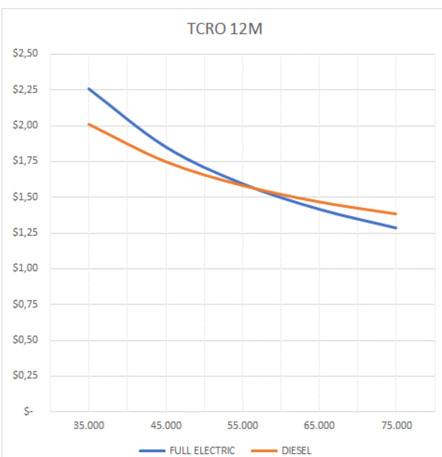
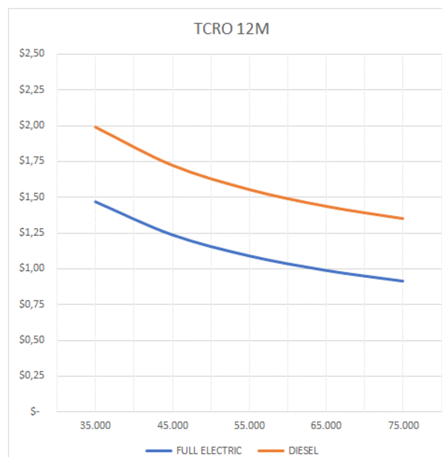


2030

GREEN Elaborations (2021, 2025, 2030)



2021



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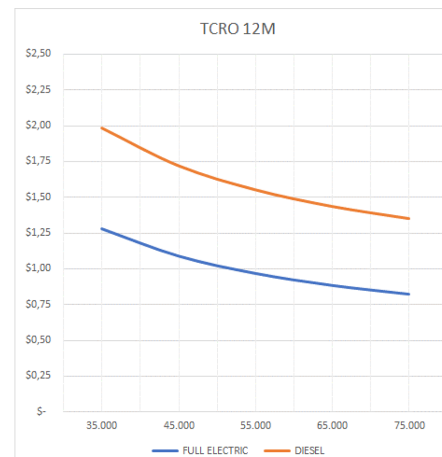


2030

GREEN Elaborations (2021, 2025, 2030)

The TCO & TCRO break-even in USA

TCO and TCRO: break-even price for 12M transit e-bus compared to Diesel and CNG (2021)

TCO

	break even price	diff. current price	diff. %
vs DIESEL	834.370,70 €	- 54.880,30 €	-12,47%

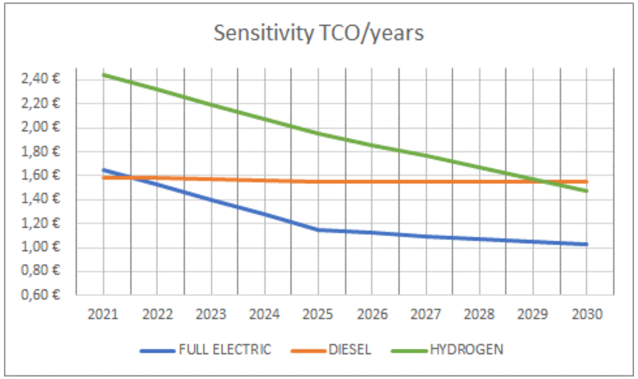
TCRO

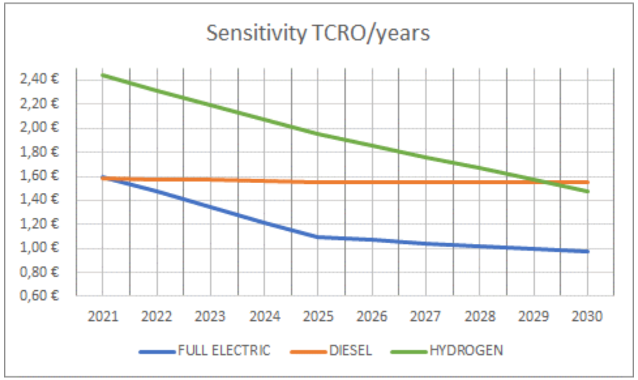
	break even price	diff. current price	diff. %
vs DIESEL	880.358,49 €	- 8.892,51 €	-2,02%

GREEN Elaborations (2021)

- The tables highlight the differences between the current price (2021) and the one needed to equal TCO and TCRO compared to DIESEL.
- The data show how close the current price of e-buses is to the one needed to reach the break-even in terms of TCRO (2,02% difference), while when considering TCO the current price needs to be reduced by nearly 12,5%.

- The TCO of 12m buses over time show that Full electric parity with diesel is reached in mid 2022. The dynamic is faster considering TCRO.
- Since 2022 TCO and TCRO will get more and more favourable for BEBs, continuously decreasing up to 2030.





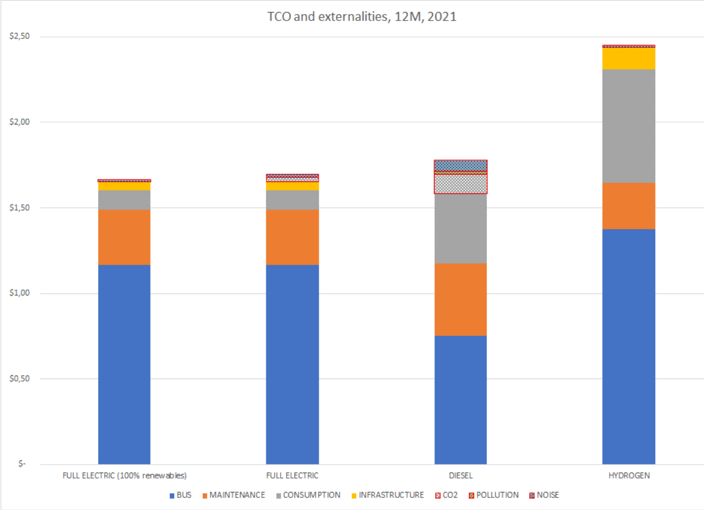
GREEN Elaborations

TCO and externalities

The comparison between TCO, TCRO and TCRO+externalities highlights the role of economic and social benefits creating convenience for electrification in the basis year 2021 compared to diesel.

The advantages of Full electric are more relevant considering that the estimated revenues from B2G and Second Life would lower the TCO further by 6 $cents.

California Regional factors are sourced directly from the United States Environmental Protection Agency's (EPA) eGrid database. https://www.epa.gov/egrid 2020 factors, published January 2022

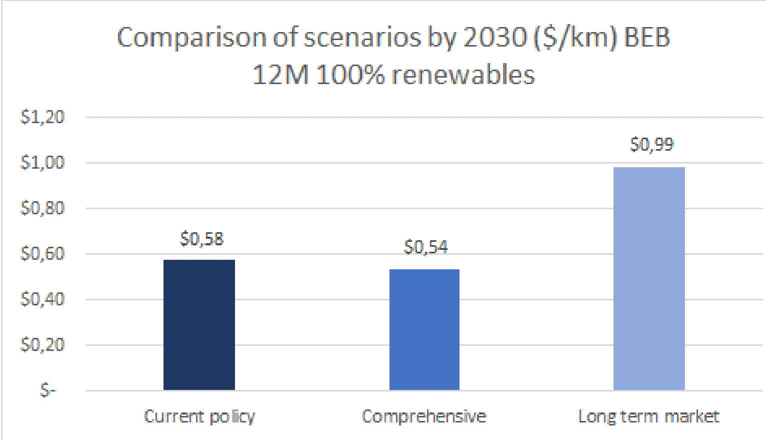


GREEN Elaborations

Scenarios including externalities and incentives

In order to compare the effects of a) potential revenues from B2G and 2nd life battery reuse b) available incentives (**85% on BEB and Hydrogen**, **90% on infrastructure**) and c) monetary valuation of negative externalities, 3 TCO scenarios have been elaborated and compared.

1. "**Current policy**" scenario
2. "**Comprehensive**" scenario
3. "**Long term market**" scenario



GREEN Elaborations

Synthesis of the results for transit buses

Policy context in USA is very favorable to the introduction of electric transit buses thanks to:

1) Clear **environmental policies** based on long term commitment to ZEB through specific target goals and dedicated public funds at federal and national level
2) Presence of **industrial policies** supporting local procurement and partnership with multinational bus manufacturers;
3) Specific **circular policies** supporting 2NDLIFE and B2G services (large pilot projects supported by public utilities companies and investment funds).

Market context is very favourable, thanks to**:**

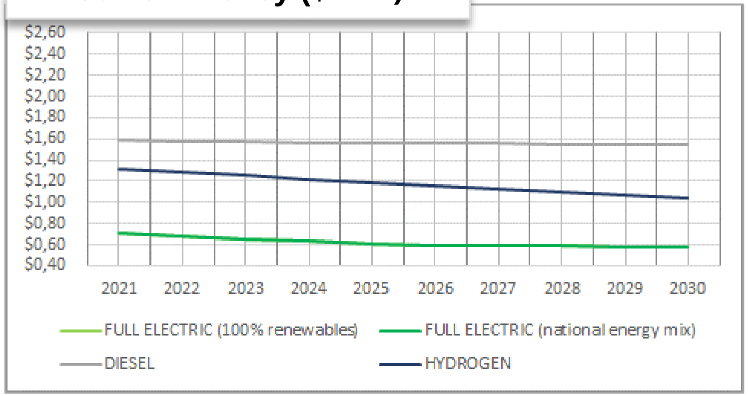
1) Presence of large and multinational PT operators and PT agencies able to quickly generate **economies of scale** in procurement process and depots construction with specific operational knowledge in BEB;
2) Low **cost energy** tariffs for PT;
3) USA is a favorable test bed for supporting **innovative business models**;
4) Presence of new players proposing **innovative asset ownership** and sources for scalable financing.

- In 2021 TCO of full electric buses (in the 12-meter version) is still not competitive, compared to DIESEL (+0,241 +0,061 USD*km) due to very high CAPEX, even if OPEX are much lower in particular as regards consumption (0,14 USD*km, compared to 0,50USD*km of a diesel bus).

- In 2025 and 2030 the average yearly mileage necessary for reaching the break-even in terms of TCO for BEBs compared to diesel buses will be very low and therefore they will be always more competitive compared to all the other motorizations, parity will be reached in 2022.

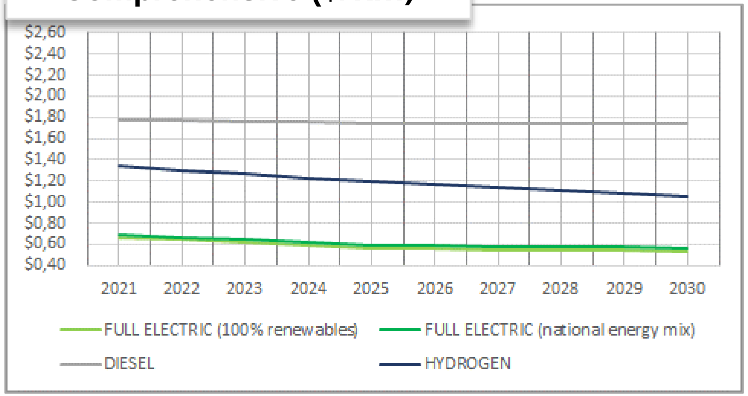
Scenarios

Current Policy ($/km)

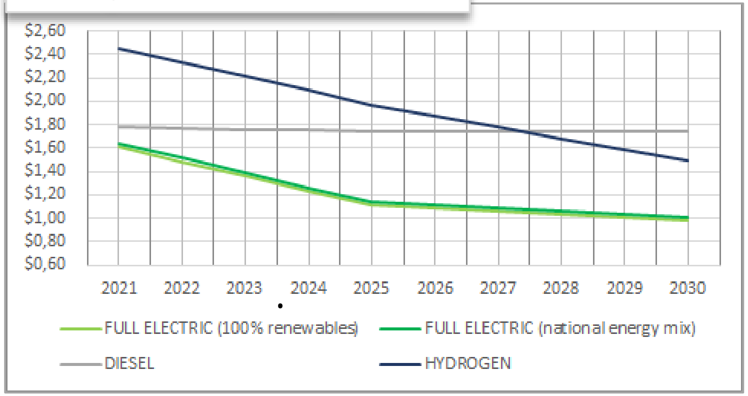


In USA incentives cover up to 85% of vehicle costs and 90% of infrastructure for BEBs and Hydrogen Buses. In the TCO & TCRO models, this results in a decrease of 95 $cents per bus*km (considering the maximum available grant rate). The current policy ensures that the TCO of ZEBs is well below the one of ICE alternatives, by lowering for example the average price of a BEB to 27% of the equivalent Diesel

Comprehensive ($/km)



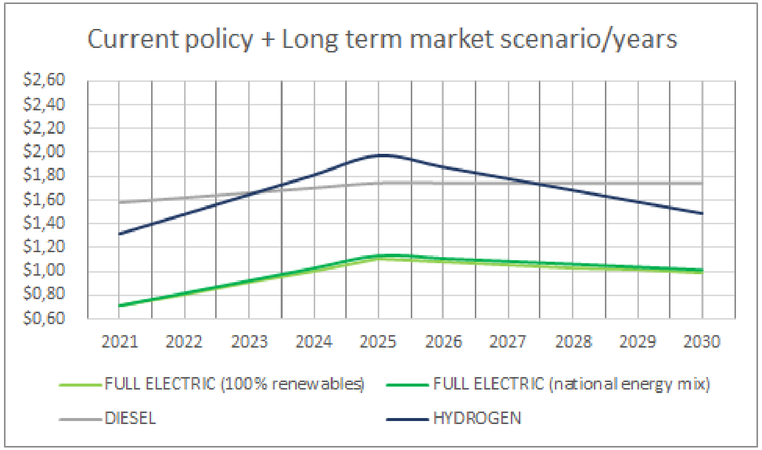
Long-term market ($/km)



It's evident how the combination of the 3 factors generates even further competitive advantage for electrified public transport. Another interesting aspect is that, thanks to the integration of externalities, the costs of the diesel option raises significantly.

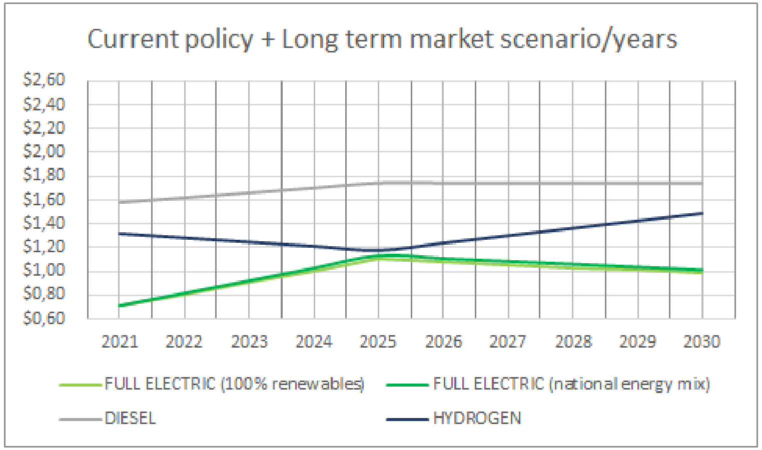
The 3rd scenario is interesting in particular when looking at the long term, since it implies that no incentives are in place while externalities shall be valuated and compensated. For US, the valorisation of externalities, B2G and 2nd life batteries determines a strongly increasing competitive advantage on the long term, almost reaching the policy scenario monetary benefits in 2030.
Strong incentives in the **first market period** are important to create the conditions for the ramp up, while on the long run the potential of B2G, 2nd life battery reuse and market for emissions seems to become the most effective policy approach.

Combined Scenarios



'CURRENT POLICY' + 'LONG-TERM MARKET'

Incentives progressively decreasing until 2025, then market scenario takes over. Policy (technological and infrastructural) measures creating the conditions for revenue generation, and emission taxes, sustain the convenience of BEBs.

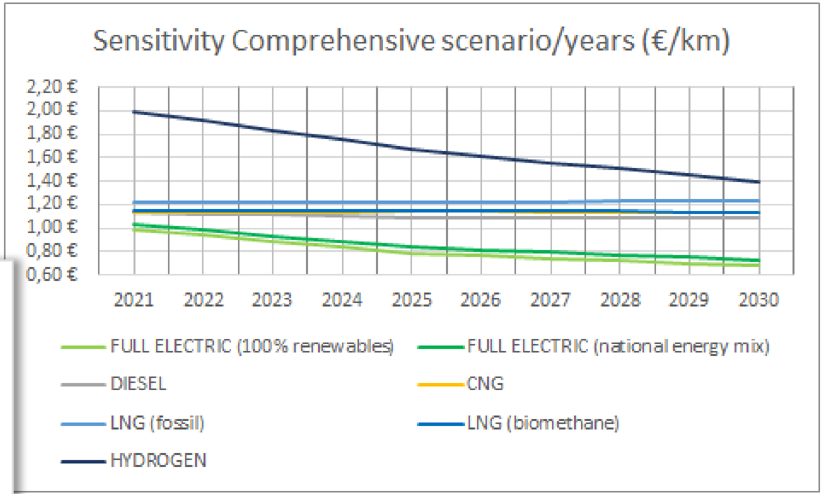


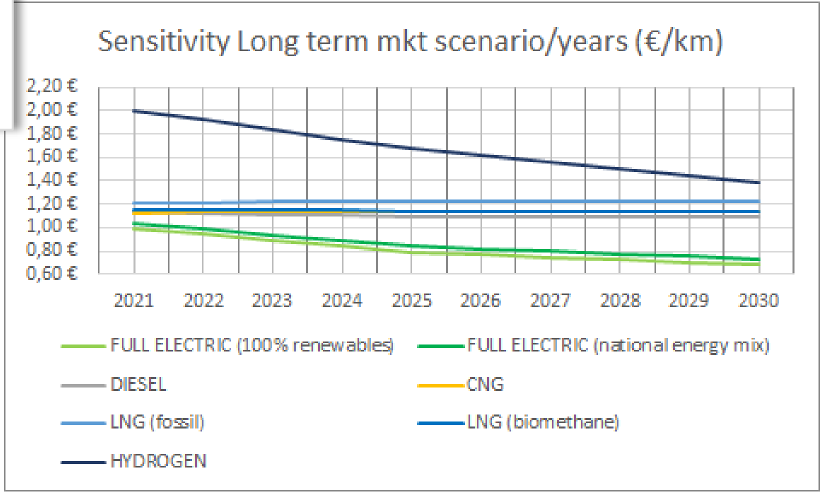
'CURRENT POLICY' + 'LONG-TERM MARKET' + HYDROGEN BOOST

If Hydrogen received full strong support until 2025, its TCO would get close to BEBs, bus as soon as the incentives started decreasing the efficiency gap would show again.

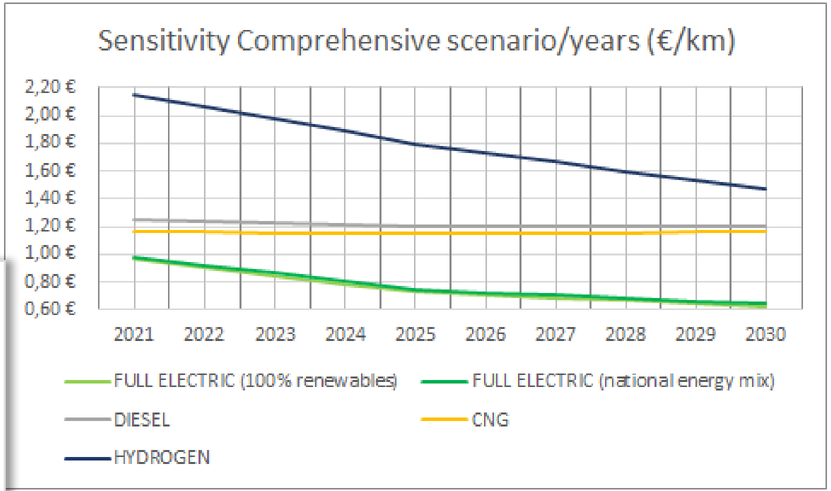
Comparisons: IT and ES

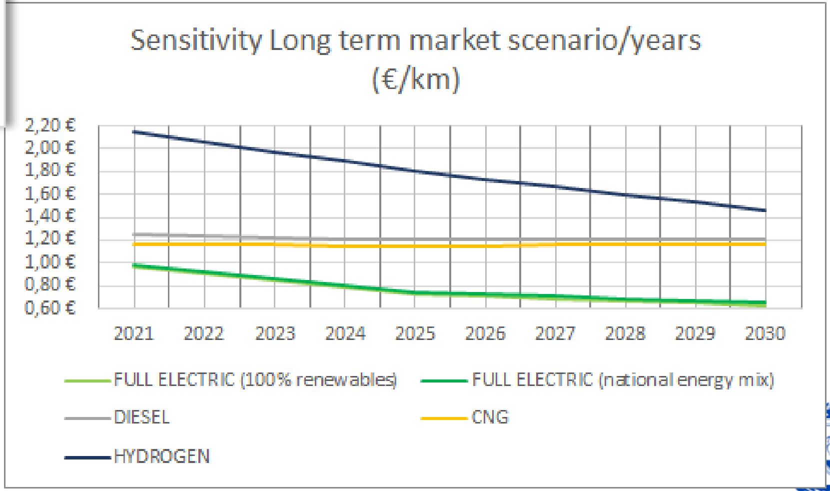
ITALY





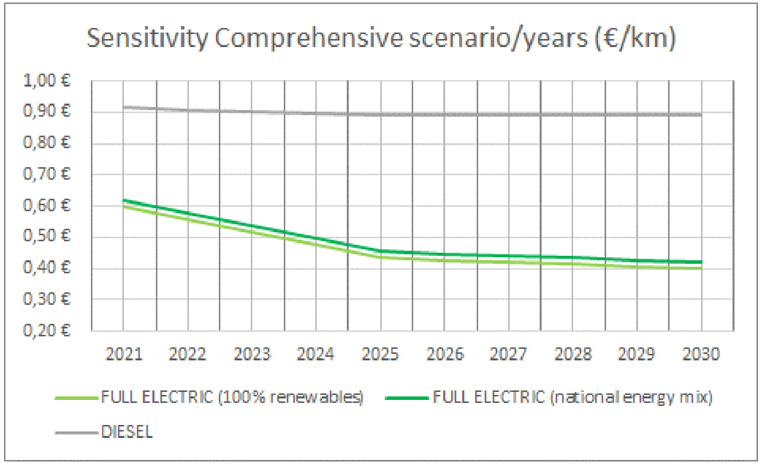
SPAIN

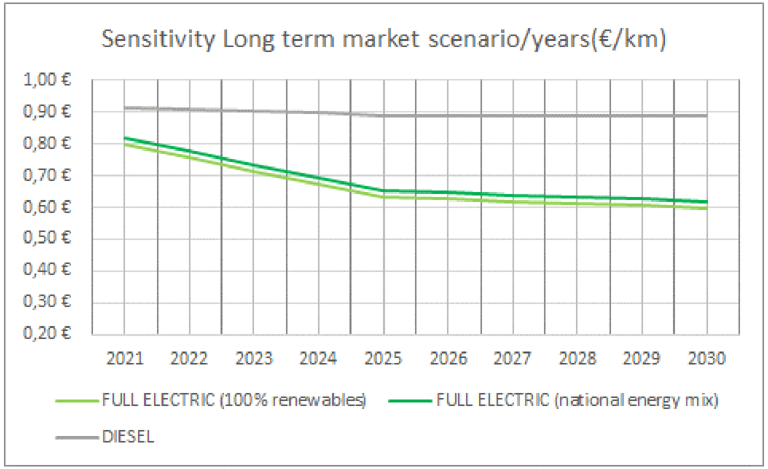




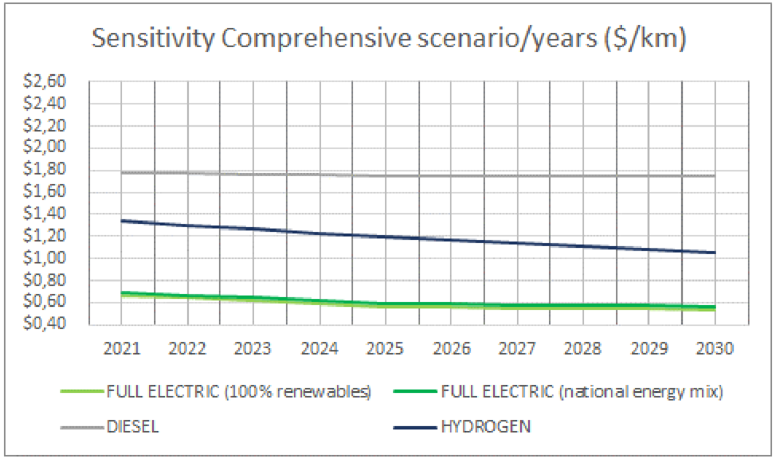
Comparisons: UK and USA

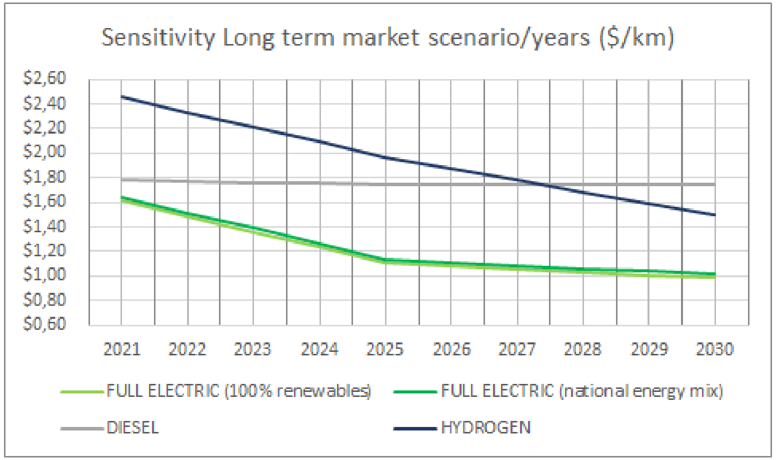
UK





USA





Mexico

Università
Bocconi
GREEN
Centro di ricerca sulla geografia,
le risorse naturali, l'energia,
l'ambiente e le reti

The specific Mexican market and policy context

- In Latin America, municipalities in countries including Mexico have been making significant progress deploying ebus fleets. Governments in each country, along with many others, have committed to supporting the electrification of urban transport using private sector-led business models.

- Transportation is a key sector included in Mexico's Intended Nationally Determined Contribution (2015), which commits Mexico to a **22% reduction** in **GHG** and short-lived pollutants **by 2030**. Municipalities in Mexico are recognizing the importance of adopting clean energy technologies in the transport sector to improve local air quality and reduce carbon emissions.

- Mexico has only 38 ebuses (8-11m long) operating in Guadalajara (E-bus Radar, July 2021) and a small fleet of 10 ebuses (Yutong 18m articulated), operating on L3 Metrobus (Mexico City), underling the early-stage context for sustainable buses market.

- In 2017, Mexico City's Mayor (at the time) José Ramón Amieva joined eleven other mayors from global cities in a pledge to purchase only zero-emission buses as of 2025 (C40 Green and Health Streets Declaration). Mexico City is one of the four key cities (with Sao Paulo, Medellin and Santiago) for the **Zero Emission Bus Rapid-deployment Accelerator (ZEBRA) Alliance** (a partnership between C40 Cities) and the International Council on Clean Transportation (ICCT), developed to shift all new bus procurements in leading Latin American cities to zero-emission technologies.

- City government is developing a **2020-2026 Climate Change Program** —Programa para la Reducción de Emisiones del Transporte—which includes a chapter on electromobility, required by law.

The specific Mexican market scenario

- Currently, the **Mexican market** is considered one of the **most promising markets in the world** and it is expected to **lead the demand for ebuses** over the forecast period.
- **Mexico City** is acting as a **pioneer** for this transformation, as its public transportation fleet is increasingly being electrified, starting from Trolebici project, an investment of **35 millions** of USD in **trolleybuses**.
- The slow speeds and frequent stops that characterize bus routes in dense and congested cities, like Mexico City and Guadalajara, make them particularly conducive to electrification according to study carried on by USAID-NREL Partnership in 2020.
- The **driving factors** for the market are **increasing adoption of electric** vehicles and **buses** in order to reduce the carbon footprints and improve the air quality and **investments made by several global OEMs** (European and Chinese), including Volvo, Daimler, BYD, Yutong, Zhongtong Bus, and King Long in the country because of the availability of low-cost labors and other tax benefits offered by the government is supporting the market.
- Local companies, such as Advanced Power Vehicles, are also tapping the market by converting IC buses to fully electric buses.
- Mexico is a well-known producer of natural gas, therefore the whole industry linked to this energetic is very strong and involves a very important part of the workforce in the country. GNC buses market is a strong competence and therefore the speed of transition towards more sustainable buses could be slowed by government occupational worries and by the necessity of a national plan of reconvertion to become a competitive actor in the electric buses manufacturing sector.

Public transport buses: main parameters and main assumptions for Mexican market

- The main source for ebuses specifications is the “Análisis de CAPEX y OPEX y plan financiero para el corredor de transporte público con autobuses cero emisiones en el Área Metropolitana de Guadalajara”, a specific report on ZEBs in Guadalajara presented by C40 Cities Finance Facility (January 2021).
- The driven kms per year are differentiated among operators:
  - 12 m: the standard 55.000 km/year utilised for most of the other coutries analyses for Mexico are modified in **89.000 km/year** due to the specific characteristics of Mexican metropolitan area that require operations of 245 km/day for 331 day/year on average.
  - Information on 8 and 18 m buses were not available to complete the analysis for all the different types of motorization (indeed, 18 m ebuses and hydrogen buses have still not been procured by PTO or Agencies in Mexico and the number of 8 m buses are limited to a pilot project in Guadalajara).
- Battery replacement for BEV and H2 buses after 7 years.
- In order to extend body life and to improve body appearance and amenity of ICE buses at 10 years is necessary to consider a 60.000 USD for a diesel transit bus, while for a CNG 12 meters the cost of revamping is 95.000 USD.
- No specific differentiation of consumption related to air-conditioning or intensive winter heating is considered due to the average temparature of the main Mexican cities (19°C per Mexico City and 20°C for Guadalajara).

Market trends in e-buses sector

TRENDS THAT WILL CHANGE TCRO IN 2025 AND 2030 (GLOBAL TRENDS)

- Initial investment cost reduction due to the economies of scale in manufacturing process at global level*
- Cost reduction of investment costs due to the economies of scale and local production, operational costs reduction due to power consumption thanks to the use of new and lighter materials, weight reduction of batteries and better efficency in reusing braking energy)

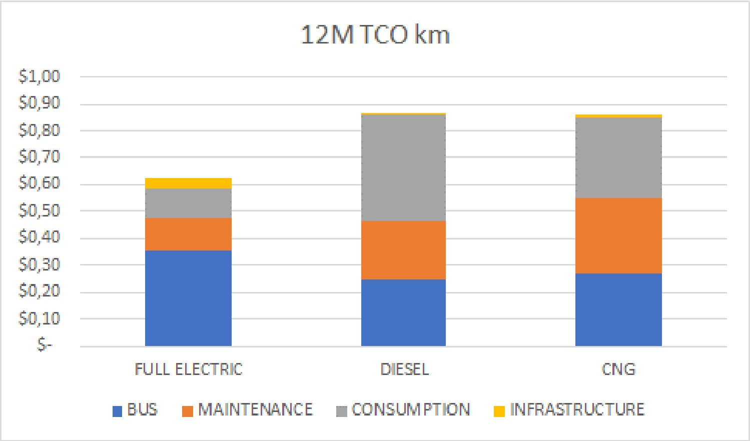
POTENTIAL REVENUES FOR 2° LIFE OF THE BATTERIES AND BUS TO GRID (B2G) REVENUES (GLOBAL TRENDS)

- **2° life batteries.** At EU level many projects have been supported by OEMs, for istance Volvo Bus , Solaris Bus&Coach ,or Irizar . In Latin America we have not found similar pilot projects.
  In 2025 in Mexico the residual value of the bus battery, could be estimate in **20% of the value of new batteries**, that is **lower than** the **EU** context because of the absence of specific policy related to circular economy for batteries and of the absence of specialised battery manufacturers in the area. For 12 m buses, the additional revenues expressed in USD are equal to 14.057 USD.

- **B2G SERVICES.** At present, there are not specific studies or pilot projects in Mexico. Estimates of potential revenues could be calculated on a parametric and analogic way compared to European experience in medium-long period (after 2030, therefore not considered in the present analysis).

* According to the April 2021 market research report " Electric Bus Market by Propulsion (BEV, PHEV & FCEV), Application (Intercity & Intra-city), Consumer Segment (Fleet Operators & Government), Range, Length of Bus, Power Output, Battery Capacity, Component, Battery type & Region", published by MarketsandMarkets™, the global Electric Bus Market size is projected to grow from 81 thousand units in 2021 to reach 704 thousand units by 2027, at a CAGR of 43.1%.

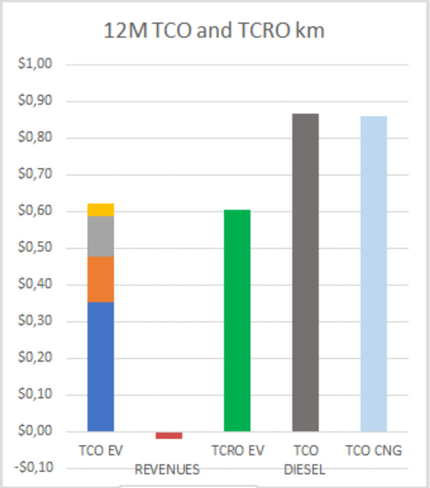
Costs and revenues by component for 12m (2021)



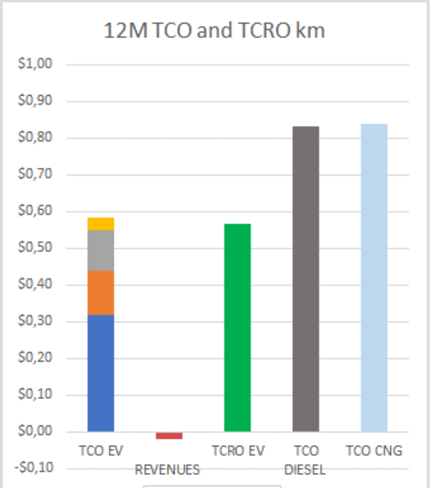
	FULL ELECTRIC		DIESEL		CNG	
BUS	$	0,355	$	0,245	$	0,272
MAINTENANCE	$	0,121	$	0,221	$	0,281
CONSUMPTION	$	0,112	$	0,392	$	0,297
INFRASTRUCTURE	$	0,036	$	0,009	$	0,010
B2G	$	-				
2ND LIFE	$	0,018				
Total TCO	$	0,623	$	0,866	$	0,860
Total TCRO	$	0,605	$	0,866	$	0,860

GREEN elaborations (2021)

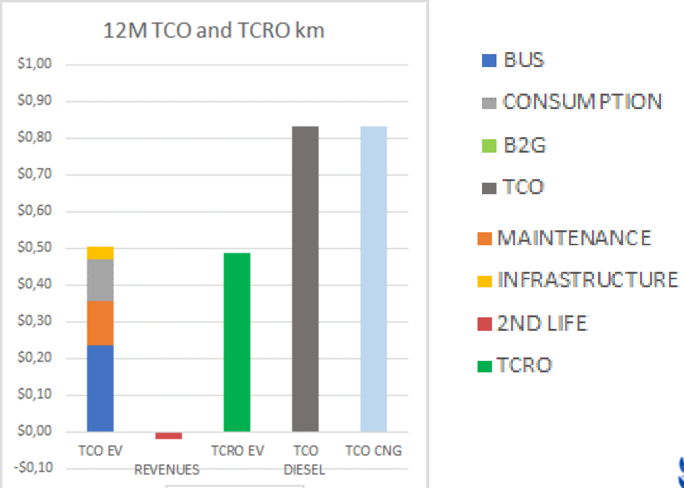
The role of revenues – TCO & TCRO



2021



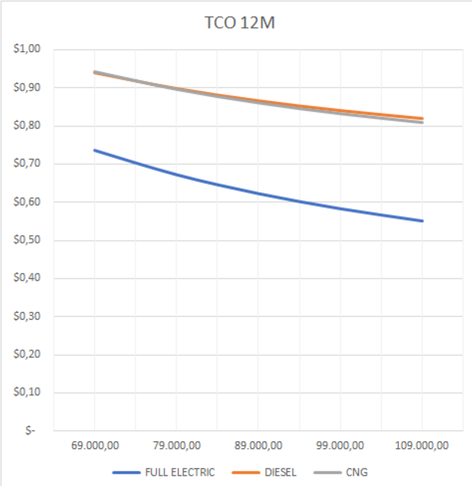
2025



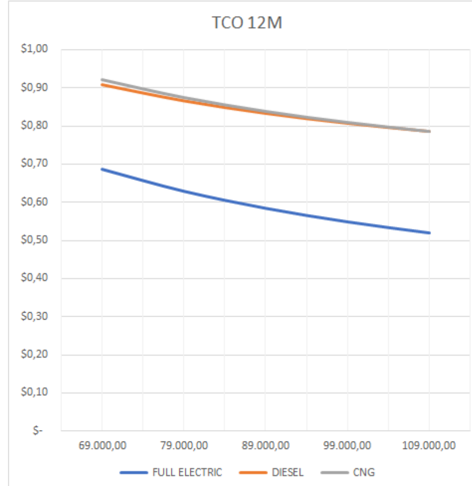
2030

GREEN Elaborations (2021, 2025, 2030)

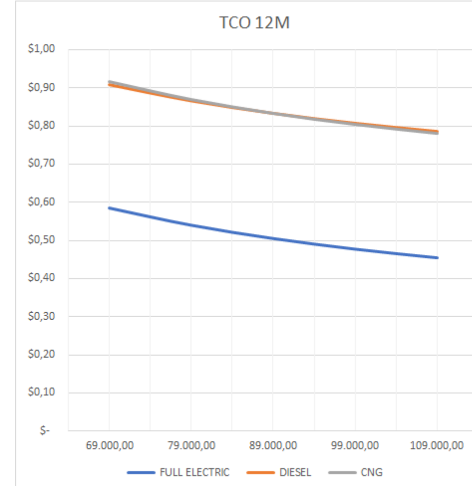
Sensitivity analysis TCO & TCRO



2021

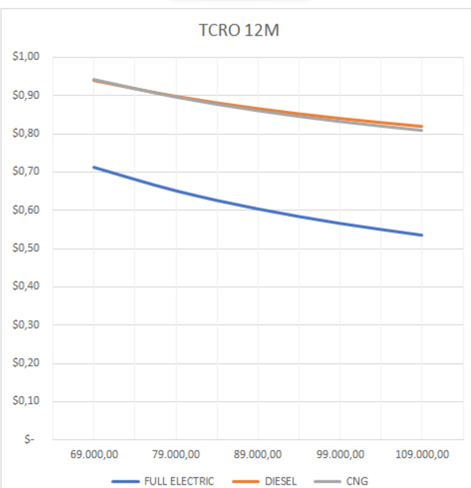


2025

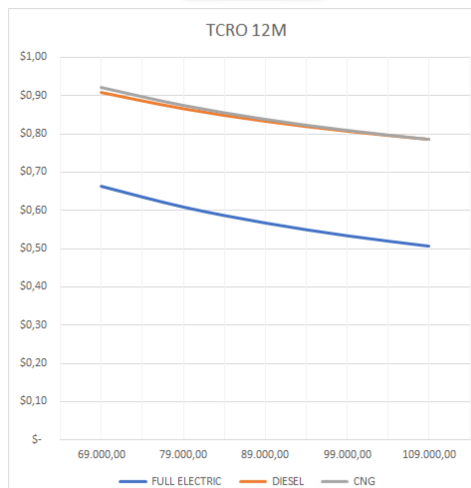


2030

GREEN Elaborations (2021, 2025, 2030)



2021



2025

2030

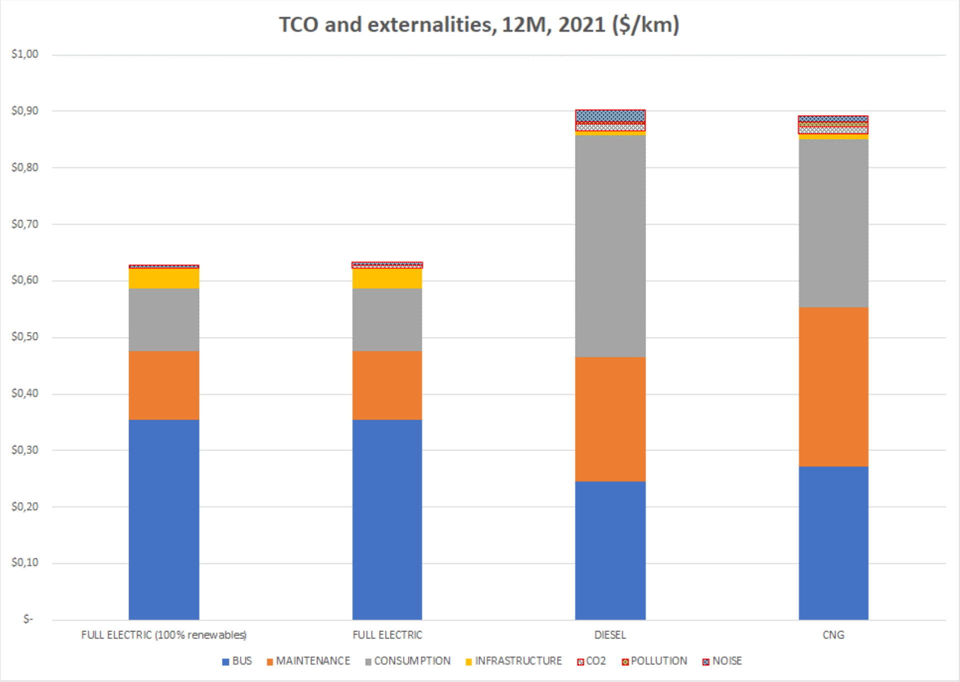
GREEN Elaborations (2021, 2025, 2030)

TCO and externalities

To fully understand the potential of electrification of bus fleets, externalities (CO2, PM10*, Nox*, HC*, Noise) have been added to the calculations.

The comparison between TCO, TCRO and TCRO+externalities highlights the role of economic and social benefits enhancing further the convenience for electrification in the basis year 2021 compared to diesel and CNG.

The advantages of FULL ELECTRIC are even more relevant considering that the estimated revenues from Second Life would lower the TCO further by 2 $cents.



GREEN Elaborations

Source for monetary parameters of externalities and for specific carbon intensity of electricity: World Resources Institute "The Costs and Benefits Appraisal Tool for Transit Buses", Technical Note October 2020. We localized the Social Cost Factor for noise to Italy by using the income data of GDP (PPP) per capita from each country; we assumed income elasticity to be 1

**not considered for full electric cases*

Synthesis of the results

Even if there are no specific circular policies supporting 2NDLIFE and B2G services and in 2021 the number of BEBs in PT fleets was still limited, **policy context** in Mexico is favorable to the introduction of BEB, thanks to:

1) Environmental policies based on long term commitment to ZEBs through specific target goals (e.g. BEB fleets will be prioritized in both Mexico City and Guadalajara).
2) Multinational bus manufacturers (European and Chinese) have already entered in the Mexican market thanks to specific industrial policies supporting automotive industry (tax benefits).

Although the PT operators market is very fragmented and the organizational model is still based in a large part on minivans and for large operators trolleybuses are considered a priority, even **market context** is favorable thanks to**:**

1) Low cost energy tariffs for PT;
2) Presence of new players proposing innovative asset ownership and sources for scalable financing.

Since 2021 **TCO of full electric buses is particularly competitive** in the 12-meter version, especially compared to DIESEL (-0,043 USD* km), but also to CNG buses (- 0,037 USD*km); they have lower operating costs in particular as regards consumption (0,138 USD*km, compared to 0,47 USD*km of a diesel and 0,36 USD*km of a CNG bus).

The role of TCRO should also be highlighted: although the values introduced are largely based on experimental estimations, the impact is not negligible (0,018 USD per km).

In all scenario BEBs are always more competitive compared to other ICE buses both in terms of TCO and TCRO in a growing manner in the decade.

Brazil

Brazilian policy context

- In 2021, Brazil had only 47 e-buses (all 12 m-long standard buses, and just 2 shorter ones) operating in Sao Paulo (18), Campinas (15), Brasilia (6), Volta Redonda (3), Maringa (3), Bauru (3), Santos (1) (E-bus Radar, July 2021), underling the very early stage context for sustainable buses market.
- Brazil asked for Institutional collaboration with multilateral institutions (CAF, C40, CS, ITDP, WB, WRI) in order to support electrification program of urban mobility.
- Since 2016, electric buses are exempt from taxes in 7 Brazilian states (Maranhão, Piauí, Ceará, Rio Grande do Norte, Pernambuco, Sergipe and Rio Grande do Sul) and have a reduced tax rate in Mato Grosso do Sul, Sao Paulo and Rio de Janeiro. This is sponsered by the National Development Bank (BNDES).
- **Rio de Janeiro** signed the C40 Green & Healthy Streets Declaration (Municipal Decree nº 46081/2019): As of 2025, **any new fleet provision contract must predict the entrance of zero emission vehicles**. The Municipal Sustainable Development Plan defines the target of **electrifying 20%** of **public transport fleet** until **2030**. In 2021 the mayor prioritized the revamp of the Bus System's governance as one of his main mandate objectives.
- In January 2018, **São Paulo** (the biggest potential market in LATAM for sustainable bus in consideration of the 14.200 bus fleet) set pollution reduction targets for all buses, including **100% reduction in CO2** within 20 years and 95% for particulate matter and nitrous oxide.
- The Bus Rapid Transit (BRT) electrification initiative in Salvador, Bahia, and the ebuses pilot project in Belo Horizonte, Minas Gerais, Campinas (area Branca project with 339 e-buses) are also underway.
- It's worth noting that **currency instability in Brazil remains a significant barrier to international financing of bus transportation** (Brazilian Peso vs USD was 3.7355 in January 2019, and it was 5,4282 in September 2021 with a devaluation of about 45%).

Brazilian market context

- The economic recession and slump in passenger numbers (due to poor services and high motorization rates) have drawn attention to failing bus operators. The inadequacy of Brazil’s public transportation system (mostly comprised of privately owned bus fleets) could be one impetus for the expansion of electric buses.
- In the last decade, most informal operators became large companies with access to credit and scale gains, making up about 42% of São Paulo’s public transportation system. However, legalized minibuses still operate in favelas, semiformal operators still have a relevant market share in medium cities.
- Brazil is already in a position to migrate to ebuses more speedly compared to other Latam countries. A major challenge for electrification going beyond current solutions for GHG mitigation and energy security currently focused on biofuels (still the vast majority of the existing buses are diesel).
- Brazil is among the biggest motor manufacters in the world and the recent free trade agreements with other Latam countries offer national stakeholders possibilities of market gains (concerning vehicles and components) in international markets.
- BYD has a **bus factory** in Campinas and planned (with partner Marcopolo) to deliver 12 examples of the articulated electric bus (22 m-long) to be used on Brazil’s first all-electric bus corridor in São José dos Campos (October 2021). BYD also commissioned a new lithium iron phosphate **battery factory** locally in 2020. The new production facility in Manaus, the capital of the Brazilian state of Amazonas, can manufacture 18,000 LiFePO4 battery modules for electric buses annually.
- Mercedes-Benz do Brazil is home to Daimler’s global competence centre for the development of the brand’s bus chassis (up to 200 bus chassis/year). Mercedes-Benz do Brazil plans to offer customers comprehensive advice on the application and use of the new technology, the charging infrastructure and fleet management, covering the entire life cycle of the vehicles.

Market trends in ebuses sector

TRENDS THAT WILL CHANGE TCRO IN 2025 AND 2030

- Initial investment cost reduction due to the **economies of scale** in manufacturing process at global level*
- Brazil is already in a position to migrate to ebuses more speedly compared to other Latam countries, considering the potential economies of scale of the market, **labor costs** (also due to currency devaluation) **and production capacity advantage.**
- Cost reduction of power consumption thanks to the use of new and lighter materials, weight reduction of batteries and better efficency in reusing braking energy) .

POTENTIAL REVENUES FOR 2° LIFE OF THE BATTERIES

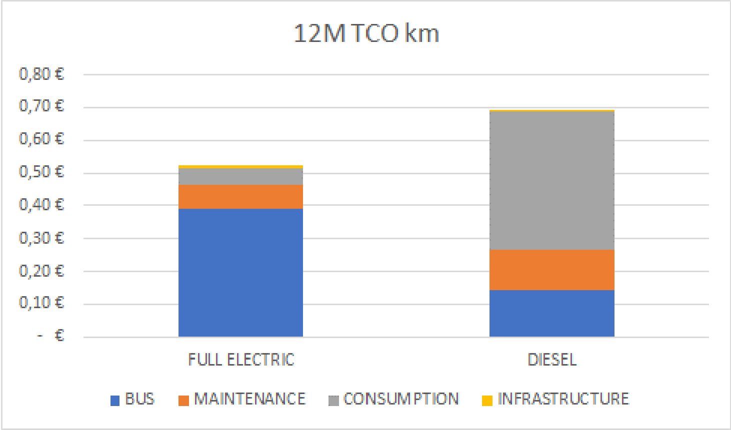
- **2° life natteries.** In 2025, in Brasil the residual value of the bus battery, could be estimated in **30% of the value of new batteries** (expressed in USD per KWh), that is higher compared to other Latam countries thanks to the presence of specialised battery manufacturers in the area (BYD).
- For 12 m buses the additional revenues expressed in USD is equal to 28.200 USD in 2025

*According to the April 2021 market research report " Electric Bus Market by Propulsion (BEV, PHEV & FCEV), Application (Intercity & Intra-city), Consumer Segment (Fleet Operators & Government), Range, Length of Bus, Power Output, Battery Capacity, Component, Battery type & Region", published by MarketsandMarkets™, the global Electric Bus Market size is projected to grow from 81 thousand units in 2021 to reach 704 thousand units by 2027, at a CAGR of 43.1%.

Transit buses: main parameters and main assumptions

- The driven kms per year are differentiated among operators:
  - 12 m: 70.000 km/year*Source: World Bank 2020 and Promob-e and ICCT (2018)
  - Information on 8 and 18 m buses were not available to complete the analysis for all the different types of motorization (indeed, 18 m CNG buses, ebuses and hydrogen buses have still not been procured by PTO or Agencies in Brazil, while the number of 8 m buses is very low).
- Battery replacement for BEV and H2 buses is needed after 7 years
- In order to extend body life and to improve body appearance and amenity of ICE buses at 10 years is necessary to consider a 27.600 USD for a diesel transit bus.
- No specific differentiation of consumption related to air-conditioning or intensive winter heating is considered due to the average temparature of the main Brazilian cities

Costs and revenues by component for 12m (2021)



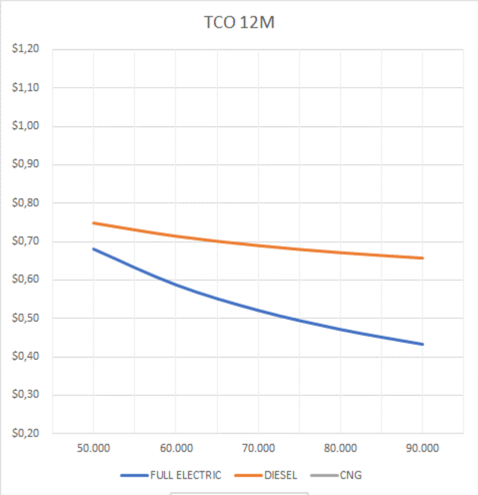
	FULL ELECTRIC		DIESEL	
BUS	$	0,391	$	0,143
MAINTENANCE	$	0,073	$	0,124
CONSUMPTION	$	0,052	$	0,421
INFRASTRUCTURE	$	0,006	$	0,002
B2G	$	-		
2ND LIFE	$	0,046		
Total TCO	$	0,521	$	0,690
Total TCRO	$	0,476	$	0,690

GREEN Elaborations (2021)

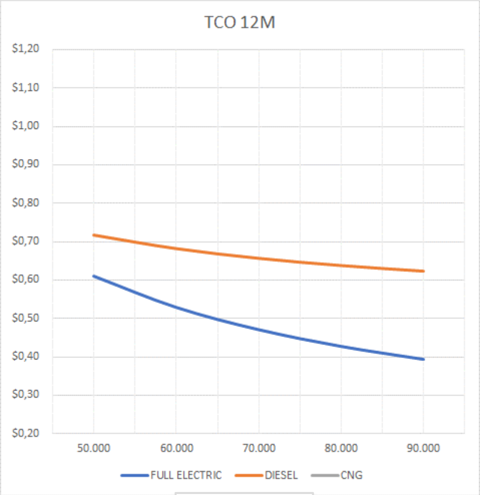
The role of revenues – TCO & TCRO

GREEN Elaborations (2021, 2025, 2030)

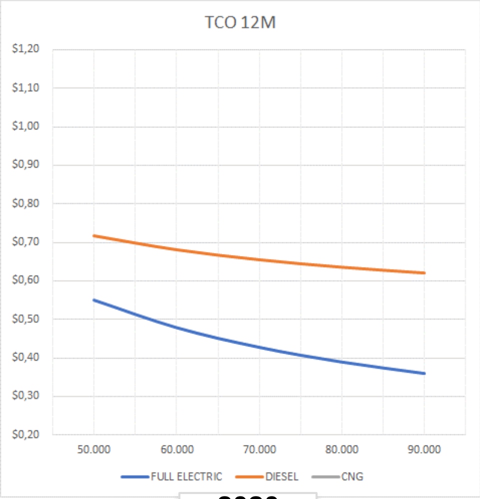
Sensitivity analysis TCO & TCRO



2021

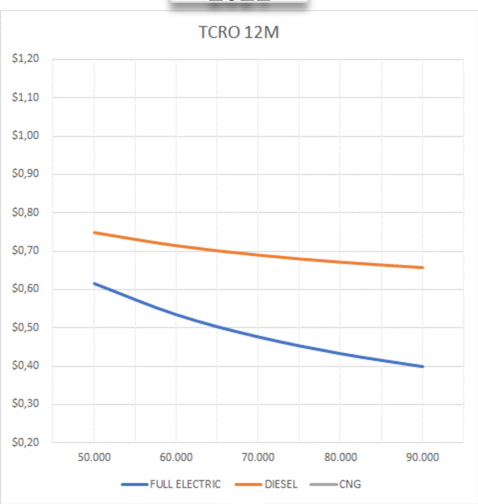


2025

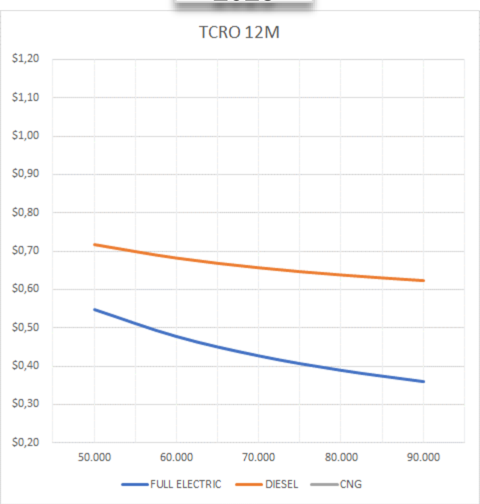


2030

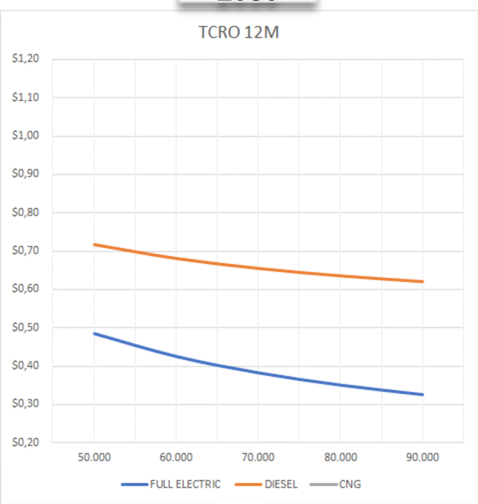
GREEN Elaborations (2021, 2025, 2030)



2021



2025



2030

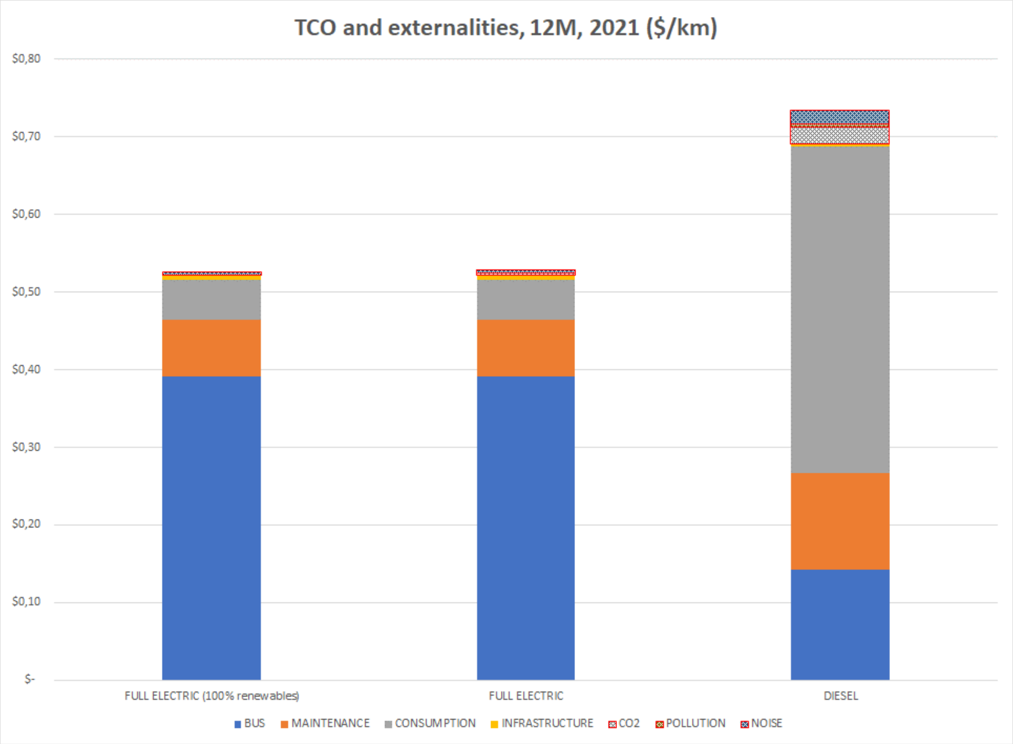
GREEN Elaborations (2021, 2025, 2030)

TCO and externalities

In order to fully understand the potential of of bus fleets electrification, externalities (CO_2, PM10*, Nox*, HC*, noise) have been added to the calculations.

The comparison between **TCO**, **TCRO** and **TCRO+externalities** highlights the role of economic and social benefits enhancing further the convenience for electrification compared to diesel in the basis year 2021.

The advantages of Full electric are even more relevant considering that the estimated revenues from Second Life of batteries would lower the TCO further by 4,6 $cents.



GREEN Elaborations

Source for monetary parameters of externalities: World Resources Institute "The Costs and Benefits Appraisal Tool for Transit Buses", Technical Note October 2020, for specific carbon intensity of electricity IEA, 2022 .

**not considered for Full electric cases*

Synthesis of the results

- Although there are no specific circular policies supporting 2NDLIFE and B2G services and in 2021 the number of BEBs in PT fleets was still limited, **policy context** in Brazil is relatively **favorable** to the introduction of BEBs due to environmental policies based on long-term commitment to ZEB through **specific target goals** (e.g. Moves program).

- PT operators market is very fragmented, the organizational model is still based mostly on minivans and there's a lack of bus and battery manufacturers. However, the **market context** in Brazil is relatively favourable thanks to:

    1) **Low cost energy** tariff for PT;

    2) Presence of new players proposing **innovative asset ownership** and sources for scalable financing.

- Since 2021, TCO of full electric buses is particularly competitive for 12-m model, especially compared to DIESEL (-0,179 USD*km); indeed, BEBs have very low operating costs, especially regarding consumption (0,064 USD*km).

- The role of TCRO should also be highlighted: although the values introduced are largely based on experimental estimations, the impact is not negligible (0,046 USD per km).

- In all scenarios, **BEBs** are **always more competitive** compared to diesel buses both in terms of TCO and TCRO in a growing trend for the decade.

Colombia

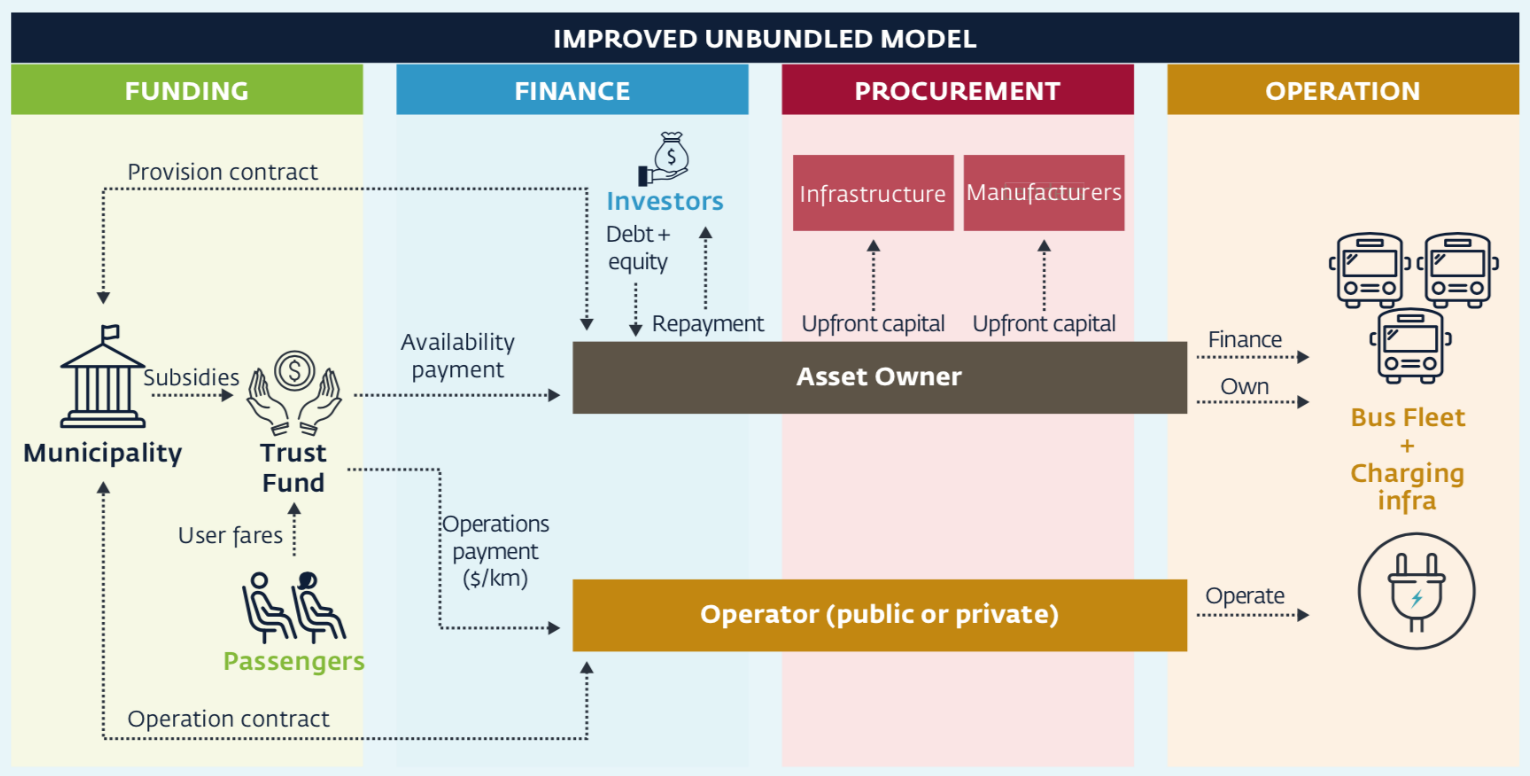
Colombian national policy context

- Colombia committed at the World Climate Change Summit in Paris (COP21), with Nationally Determined Contributions (NDC), to **reduce** its **GHG emissions by 20%** compared to projected emissions **by 2030**. However, the country pledged to reduce its emissions by up to 30% if supported by international cooperation.
- The national government considered that **6 priority sectors** of the economy should implement innovative adaptation actions: **transport, agriculture, energy, housing, health, finance, and trade**.
- Given Colombia's **relatively clean energy matrix**, electric mobility presents itself as a great opportunity to reduce the negative impacts that the sector has on the environment and its population.
- Colombia has developed a **National Development Plan 2018-2022**. Within the transport sector, among the 10 proposed measures is the "*Introduction of vehicles with new technologies*", which set as a high priority action to replace part of the urban public transport fleet with electric buses. With this, the government projects a reduction of **22 million tons of CO2 to 2040**.
- Law No. 1964 of 2019 "*Promoción de uso de vehículos eléctricos*" introduced an increasing **quota of electric and low emission vehicles of all vehicles procured for public transport operations**. This target applies to the municipalities with more than 250.000 inhabitants, starts with **10% in 2025** and grows to **100% in 2035**. For this purpose, the new National Development Plan allows a co-financing of rolling stocks for these technologies of up to 70% with federal funds.
- Currently, within Colombian regulations there are several **tax benefits** (e.g., the exclusion of VAT, exemption of tariff, deduction of income, among others) established in resolution UPME 463 of 2018 and Law 1715 of 2014, which apply to electric vehicles of public transport and related components (battery, charging stations, substations for recharging).

The specific procurement process in Colombia

The introduction of new business models by Transmilenio (Bogotá City Public Transport Authority) and financial products designed to replicate the fleet company experience from other industries gives electrified transit a considerable edge.

The diagram below highlights some of the key “pain points” that created a virtuous cycle of technology investment, scale, cost reductions, transparency and, ultimately, greener transit that could very quickly begin to resemble the successes of the wind and solar energy markets.



Source: C40 Cities, October 2020

The specific Colombian metropolitan policy context

Bogotá

The model under which the Integrated Public Transport System (SITP) of Bogotá seeks to incorporate new electric vehicles into its fleet offers a promising scheme to combat the high levels of pollution concentrated in the city.

The separation of supply and operations of the buses has proved to be essential in order to allow for the participation of investors in Bogotá tenders.

2020 tenders favour **100% electric buses**, with contracts that last for 15 years (rather than 10 years) and lower requirements for autonomy (260km instead of 300km). The move is expected to prevent the release of 16.000 metric tons of carbon dioxide, or its equivalents, every year.

3 BYD's global strategic partners finally adopted BYD's integrated electric bus solutions for their bids and successfully won the tender, (totally 1.002 pure electric buses). Yutong, Mitsui – Caetano, Siemens, Sunwin, Yinlong, Dongfeng, Sinotruck, Foton, and Zhongtong also participated in the 2 bids.

This was the largest order for pure-electric buses outside of China to date and that is why cities such as Guadalajara, Monterrey, Santiago de Chile, Medellin, among others have requested Bogotá's advisory to implement ZEBs. This batch of buses was scheduled to be delivered during 2021 and into the first half of 2022, and put into operation on 34 bus routes across five regions of the capital.

In summer 2021, *Proyecto de Acuerdo 127 de 2021* "**Por medio del cual se impulsa la movilidad sostenible y la electrificación de la flota de transporte público para enfrentar la emergencia climática en Bogotá**" has been approved. This project guaranteed that, from January 2022, the **100% electric fleets would have been prioritized** in the tenders and, if declared void, they would have been adapted according to the supply of the cleanest technologies at that time.

On a continental level, Bogotá is a referent in electrical mobility along with Santiago de Chile.

Medellin

Medellin City government has committed to **electrify 100%** of the **city's bus fleet by 2030** (C40 Green and Health Streets Declaration), with the goal of becoming the "**capital of electromobility**" in Latin America.

The specific Colombia industrial context

BYD has a market share of over 96.5% in the Colombian electric bus market, and 99% in Bogotà. BYD will partner with local bus manufacturers Superpolo and BUSSCAR respectively on the bus body parts.

The main operator is **Transdev Group**, a leading operator and global integrator of daily mobility, that signed an €874 million electric bus contract with TransMilenio S.A. for the 15-years operation and maintenance of 406 ebuses in Bogotá, starting from the end of November 2021.

It's worth noting that **currency instability in Colombia remains a significant barrier to international financing of bus transportation** (Colombia Peso vs USD was 0.00031 in January 2019, and it was 0.00026 in September 2021, with a devaluation of approx.16%).

Buses: main parameters and main assumptions

- The driven kms per year are differentiated among operators:
    - 12 m: 55.000 km/year
    - Information on 8 and 18 m buses were not available to complete the analysis for all the types of motorization (because 8 and 18 m ebuses and hydrogen buses have still not been procured by PTO or Agencies in Colombia)
- Battery replacement for BEV and H2 buses is needed after 7 years
- In order to extend body life and to improve body appearance and amenity of ICE buses at 10 years is necessary to consider a 51.175 USD for a diesel transit bus, while for a CNG 12 meters the cost of revamping is 52.000 USD
- No specific differentiation of consumption related to air-conditioning or intensive winter heating is considered due to the average temparature of the main Colombian cities in the 10-30° C range

Market trends in e-buses sector

TRENDS THAT WILL CHANGE TCRO IN 2025 AND 2030 (GLOBAL TRENDS)

- **Initial investment cost reduction** due to the **economies of scale** in manufacturing process at global level*
- Thanks to economies of scale in procurement and in local production **the investment cost for ebuses in Colombia is estimated to be one of the lowest in the world already in 2021**.
- **Cost reduction of power consumption** thanks to the use of new and lighter materials, weight reduction of batteries and better efficency in reusing braking energy

POTENTIAL REVENUES FOR 2° LIFE OF THE BATTERIES AND BUS TO GRID (B2G) REVENUES (GLOBAL TRENDS)

2° life of Batteries

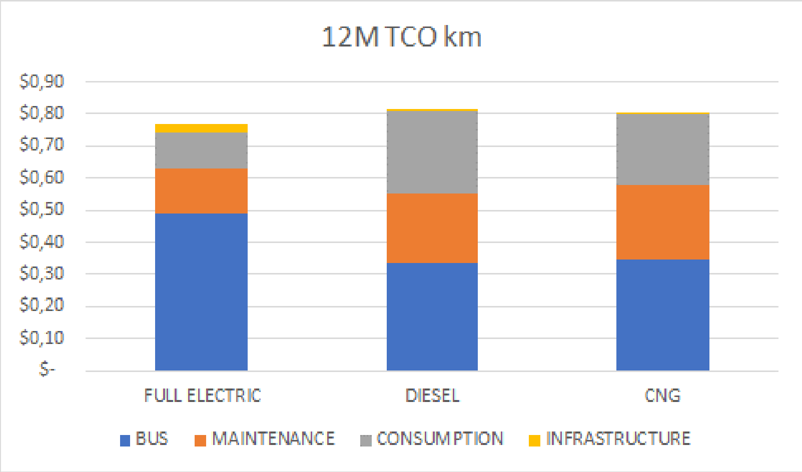
- In 2025, the residual value of the bus battery could be estimated in **20% of the price of new batteries per KWh**, that is lower compared to the EU and Latam context, because of the absence of specific policy related to circular economy for batteries and of the absence of specialised battery manufacturers in the area. For 12 m buses, the additional revenues expressed in USD is equal to 16.000 USD in 2025 and 2030.

POTENTIAL REVENUES FROM B2G SERVICES

- At present, there are not specific studies or pilot projects in Colombia. Estimates of potential revenues are calculated on a parametric and analogic way compared to European experience in medium-long period (after 2030 and not considered in this analysis).

* According to the April 2021 market research report " Electric Bus Market by Propulsion (BEV, PHEV & FCEV), Application (Intercity & Intra-city), Consumer Segment (Fleet Operators & Government), Range, Length of Bus, Power Output, Battery Capacity, Component, Battery type & Region", published by MarketsandMarkets™, the global Electric Bus Market size is projected to grow from 81 thousand units in 2021 to reach 704 thousand units by 2027, at a CAGR of 43.1%.

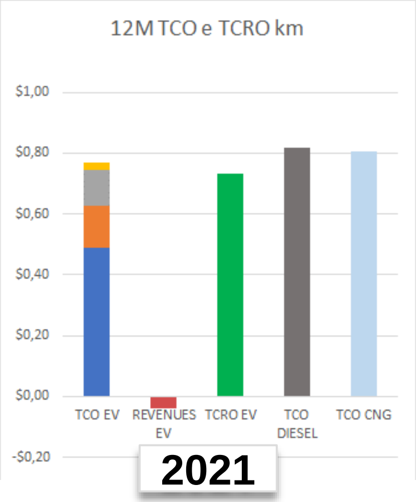
Costs and revenues by component for 12m (2021)

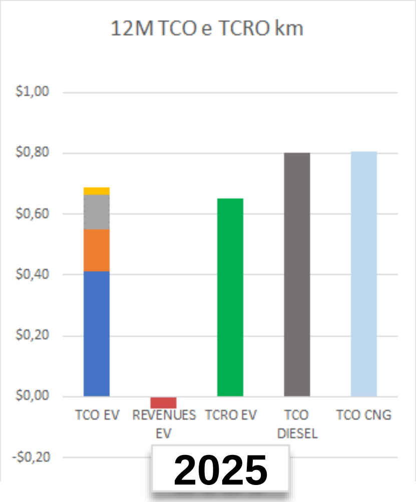


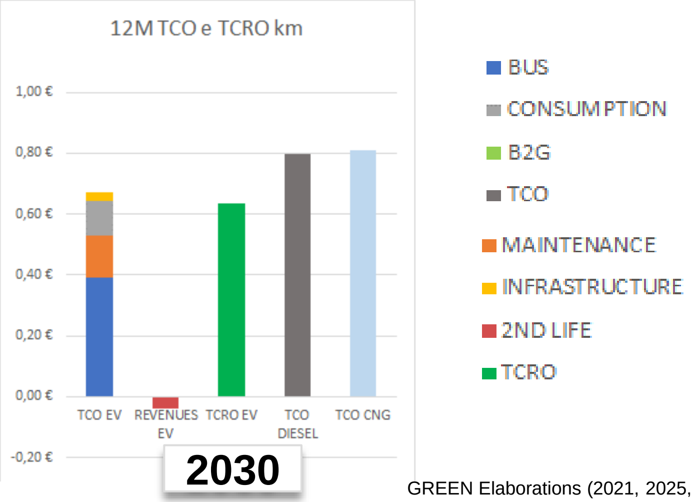
	FULL ELECTRIC		DIESEL		CNG	
BUS	$	0,490	$	0,334	$	0,346
MAINTENANCE	$	0,137	$	0,216	$	0,231
CONSUMPTION	$	0,115	$	0,262	$	0,223
INFRASTRUCTURE	$	0,027	$	0,003	$	0,005
B2G	$	-				
2ND LIFE	$	0,038				
Total TCO	$	0,770	$	0,816	$	0,805
Total TCRO	$	0,731	$	0,816	$	0,805

GREEN Elaborations (2021)

The role of revenues - TCO & TCRO

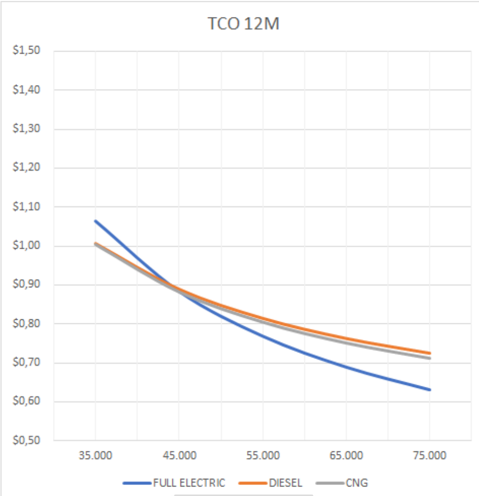




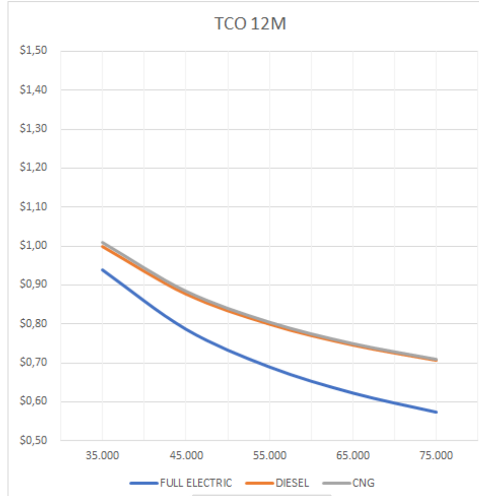


GREEN Elaborations (2021, 2025, 2030)

Sensitivity analysis TCO & TCRO



2021



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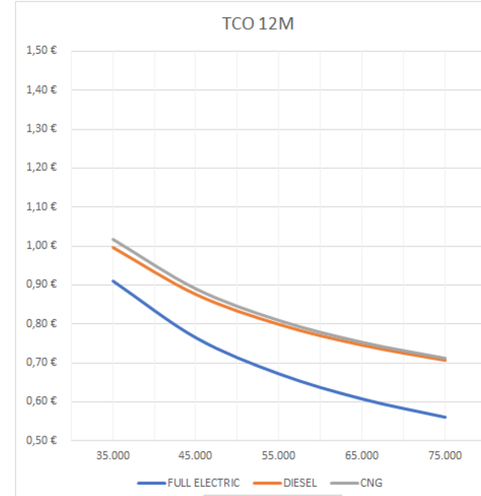

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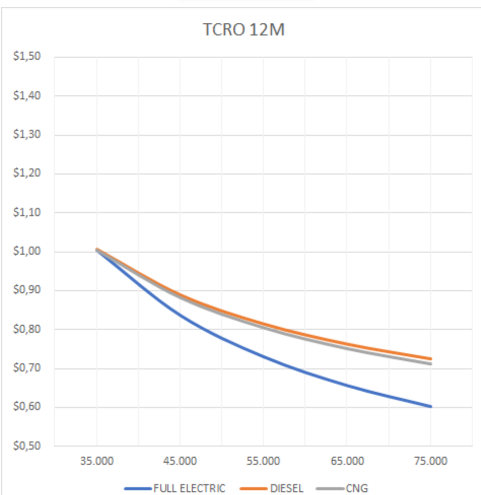
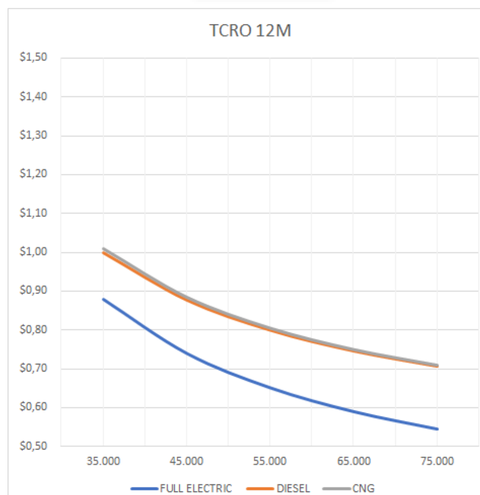
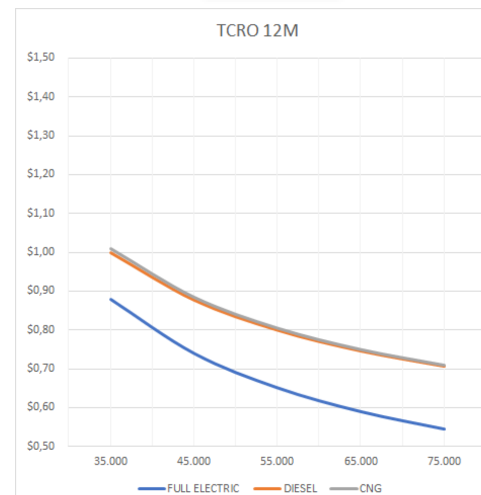
GREEN Elaborations (2021, 2025, 2030)



2021



2025



2030

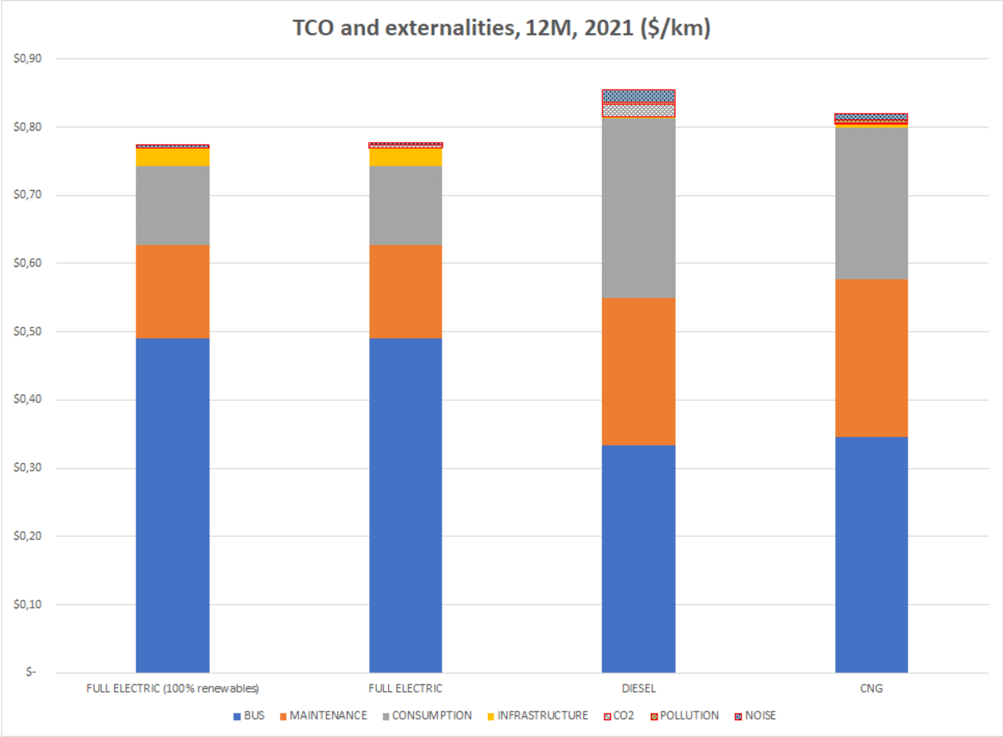
GREEN Elaborations (2021, 2025, 2030)

TCO and externalities

In order to fully understand the potential of bus fleets electrification, externalities (CO2, PM10*, Nox*, HC*, noise) have been added to the calculations.

The comparison between **TCO**, **TCRO** and **TCRO+externalities** highlights the role of economic and social benefits, enhancing further the convenience for electrification compared to diesel and CNG, in the basis year 2021.

The advantages of Full Electric are even more relevant considering that the estimated revenues from Second Life would lower the TCO further by 3,8 $cents.



GREEN Elaborations

Source for monetary parameters of externalities: World Resources Institute "The Costs and Benefits Appraisal Tool for Transit Buses", Technical Note October 2020, for specific carbon intensity of electricity: IEA, 2022.

*not considered for full electric cases

Synthesis of the results

- There are no specific circular policies supporting 2NDLIFE and B2G services, however **policy context** in Colombia is very favourable to the introduction of BEB thanks to:

  1) Clear **environmental policies** based on long term commitment to ZEBs through specific target goals (e.g. BEB fleets are prioritized both in Bogotá and Medellin).
  2) **Multinational bus manufacturers** have already entered in the Colombian market in collaboration with local bus body parts manufacturers (Superpolo and Busscar), introducing modern charging and refueling infrastructures, thanks to **specific territorial policies** for new modern depots.

- Even the **market context** is favourable, thanks to:

  1) presence of **large** and **multinational PT operators** and PT agencies able to quickly generate **economies of scale** in procurement process and depots construction with specific operational knowledge in BEB;
  2) **Low cost energy** tariffs for PT;
  3) Presence of new players proposing **innovative asset ownership** and sources for scalable financing.

- Since 2021, **TCO of full electric buses is particularly competitive** in the 12m version, especially compared to diesel (-0,046 USD* km), but also to CNG buses (- 0,035 USD*km); indeed, they have lower operating costs, especially those regarding consumption (0,143 USD*km, compared to 0,32 USD*km of a diesel and 0,28 USDt*km of a CNG bus).

- The role of TCRO should also be highlighted: although the values introduced are largely based on experimental estimations, the impact is not negligible (0,038 USD per km).

- In 2021, the average yearly mileage necessary for reaching the break-even for BEB, compared to diesel and CNG bus, is approximately 42.500 Km in terms of TCO, and 35.000 Km in terms of TCRO.

- In 2025 and 2030, BEBs are always more competitive compared to other ICE buses both in terms of TCO and TCRO.

Chile

The specific policy context for Chilean bus market

- **Santiago de Cile** is one of the most polluted cities in Latin America, therefore, since 2018, Santiago has exerimented numerous and **innovative initiatives in the public transport sector**, thanks to the direct involvement of **energy compan**ies (EnelX Chile ed Engie) and **Chinese bus manufacturers** (mainly BYD, YUTONG, Foton and King Long). Already in 2021, in Santiago were running more than 800 electric buses.
- In April 27th 2021, the Ministry of Transport and Telecommunications (MTT) has finalized the biggest public tender for buses in Latin America history for 2030 buses, divided in 6 Units. The buses will be part of the MTT property and rented to public transport operators (as opposed to the 2018-2020 period, when the buses were bought and owned by energy companies or public transport operators).
- The aim of the **new MTT model** is to **reduce entry barriers for new players**, who no longer require investments in fleet and terminals, which allows to **increase competition** and deliver a **better quality service** for people. Moreover, MTT will have enough flexibility to replace deficient operators.
- 3 specific lots, for CNG, LNG and for 18 m ebuses were declared void as no offers were submitted.
- The 12 assigned lots included 4 different types of buses: 3 types of diesel (less than 9 m, 12 and 18 m) and 2 BEBs (less than 9 m and 12 m).

The scheme shows the winning manufacturers

Source: MTT, 2021

Market trends in ebuses sector

TRENDS THAT WILL CHANGE TCRO IN 2025 AND 2030 (GLOBAL TRENDS)

- **Initial investment cost reduction** due to the economies of scale in manufacturing process at global level*
- **Cost reduction of power consumption** thanks to the use of new and lighter materials, weight reduction of batteries and better efficency in reusing braking energy)

POTENTIAL REVENUES FOR 2° LIFE OF THE BATTERIES

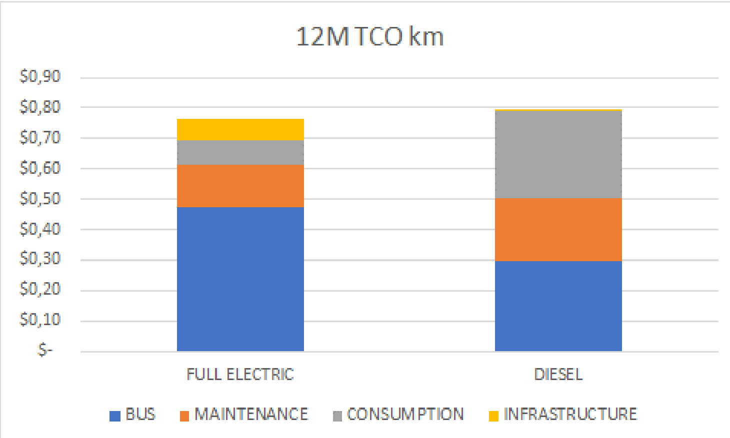
- **2° life batteries.** In 2025, the residual value of the bus battery, according to the willingness to pay of battery manufacturers that are able to regenerate the single battery pack and update the software of the battery management system, could be estimate in **€ 40 per KWh**, that is lower compared to the EU context because of the absence of specific policy related to circualr economy for batteries and of the absence of specialised battery manufacturers in the area. For 12 m buses, the additional revenues expressed in USD is equal to 15.680 USD (equal to 0,02576 USD*km in a life cycle approach). For 18 m buses, the additional revenues expressed in USD is equal to 6.000 (equal to 0,01064 USD*km in a life cycle approach).

POTENTIAL REVENUES FROM B2G SERVICES

- The MTT public procurement tender for ebuses indicated that all the new buses shall have the technical components in order to allow the supply of B2G services, but at present no pilot projects have been implemented. Estimates of potential revenues are calculated on a parametric and analogic way compared to European experience in medium-long period.

* According to the April 2021 market research report " Electric Bus Market by Propulsion (BEV, PHEV & FCEV), Application (Intercity & Intra-city), Consumer Segment (Fleet Operators & Government), Range, Length of Bus, Power Output, Battery Capacity, Component, Battery type & Region", published by MarketsandMarkets™, the global Electric Bus Market size is projected to grow from 81 thousand units in 2021 to reach 704 thousand units by 2027, at a CAGR of 43.1%.

Costs and revenues by component for 12m (2021)



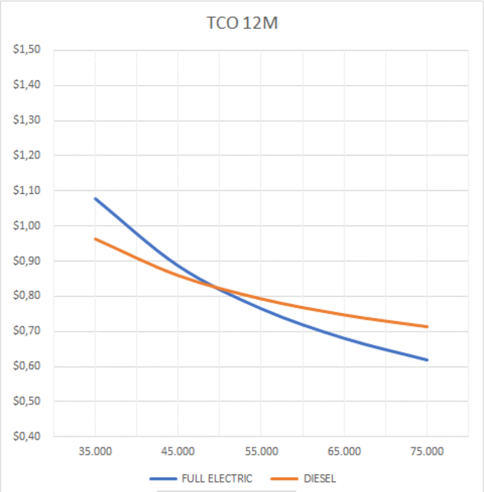
	FULL ELECTRIC		DIESEL	
BUS	$	0,474	$	0,295
MAINTENANCE	$	0,139	$	0,208
CONSUMPTION	$	0,081	$	0,286
INFRASTRUCTURE	$	0,071	$	0,004
B2G	$	0,019		
2ND LIFE	$	0,040		
Total TCO	$	0,766	$	0,792
Total TCRO	$	0,707	$	0,792

GREEN Elaborations (2021)

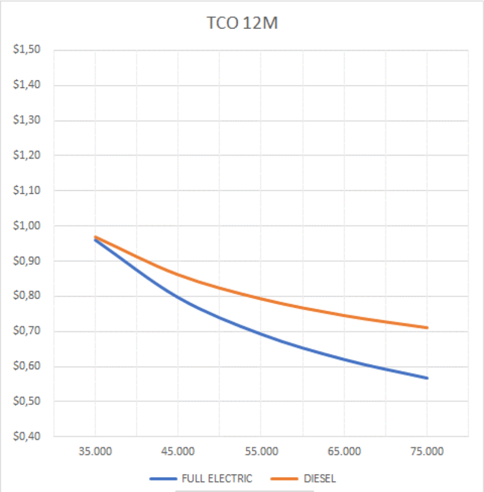
The role of revenues - TCO & TCRO

GREEN Elaborations (2021, 2025, 2030)

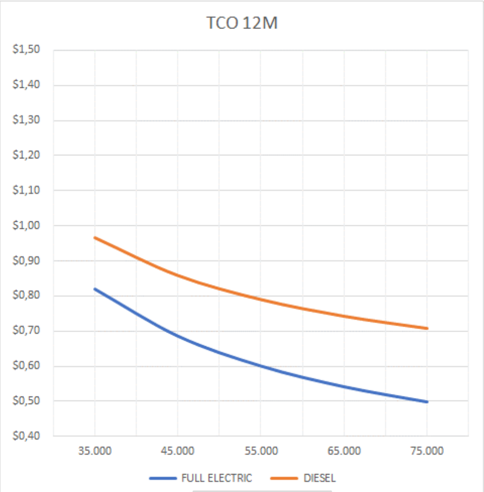
Sensitivity analysis TCO & TCRO



2021



2025



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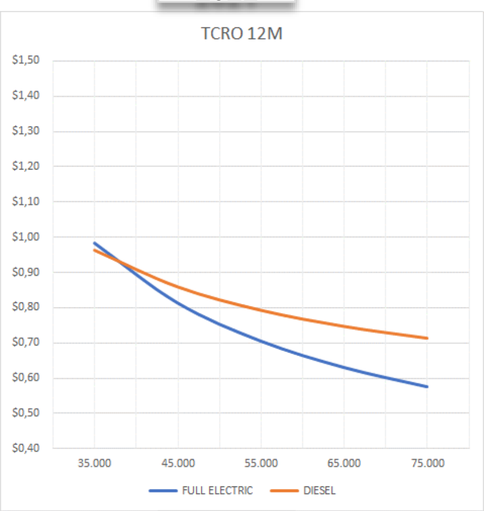
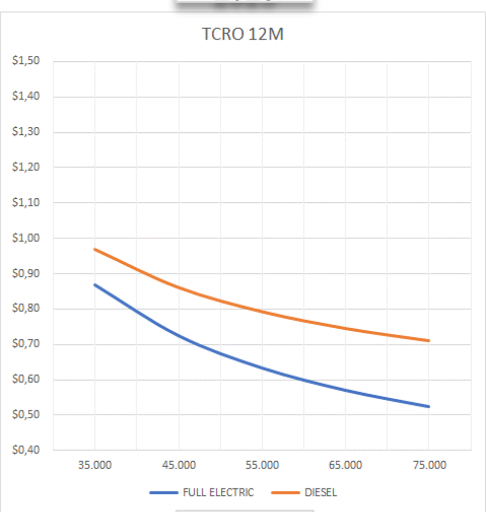
GREEN Elaborations (2021, 2025, 2030)



2021



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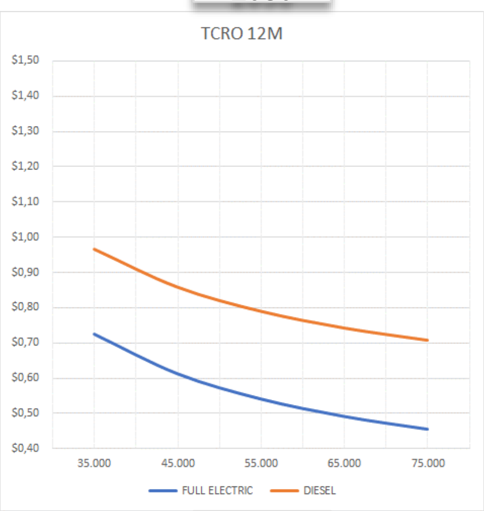


2030

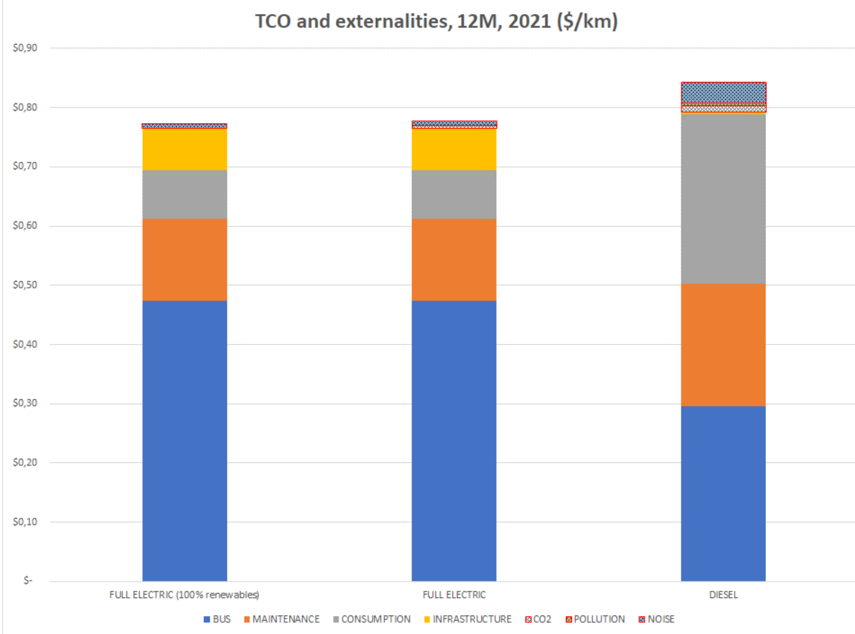
GREEN Elaborations (2021, 2025, 2030)

TCO and externalities

In order to fully understand the potential of bus fleets' electrification, externalities (CO2, PM10*, Nox*, HC*, noise) have been added to the calculations.

The comparison between **TCO**, **TCRO** and **TCRO+externalities** highlights the role of economic and social benefits, further enhancing the convenience for electrification compared to diesel in the basis year 2021 .

The advantages of Full Electric are even more relevant considering that the estimated revenues from Second Life batteries and B2G would lower the TCO further by 5 $cents.



GREEN Elaborations

Source for monetary parameters of externalities: World Resources Institute "The Costs and Benefits Appraisal Tool for Transit Buses", Technical Note October 2020, for specific carbon intensity of electricity: IEA, 2022.

**not considered for full electric cases*

Synthesis of the results

- The **policy context** in Chile is very favourable to the introduction of BEBs (even with no specific circular policies supporting 2nd life batteries and B2G services), thanks to:

1) Clear **environmental policies** based on long term commitment to ZEB through specific target goals (e.g. BEB fleets are prioritized in Santiago de Chile and other main Chilean cities).
2) Multinational **bus manufacturers** have already entered in the Chilean market in collaboration with local utilities introducing modern charging and refueling infrastructures, thanks to **specific territorial policies** for new modern depots

- Although there are no buses or batteries manufacturers based in Chile, the **market context** is favourable too, thanks to:

    1) Presence of large PT operators and PT agencies able to quickly generate **economies of scale** in procurement process and depots construction with specific operational knowledge in BEB;
    2) **Low cost energy** tariffs for PT;
    3) Presence of new players proposing **innovative asset ownership** and sources for scalable financing.

- Since 2021, TCO of full electric buses are particularly competitive in the 12 m version, especially compared to diesel (-0,026 USD* km); indeed, they have lower operating costs, especially regarding consumption costs (0,1 USD*km, compared to 0,33 USD*km of a diesel bus). The role of TCRO should also be highlighted; although the values introduced are largely based on experimental estimations, the impact is not negligible (0,059 USD per km).
- In 2021, the average yearly mileage necessary to reach the break-even for BEB compared to diesel bus is approximately 47.500 Km in terms of TCO, and 42.500 Km in terms of TCRO.
- In 2025 and 2030, BEBs will be more competitive compared to diesel buses, both in terms of TCO and TCRO (even with very low average yearly mileage).

Peru

The specific Peruvian market and policy context

- Perù has only 1 ebus (8-11 m long) operating in Lima (E-bus Radar, July 2021), underling the **very early stage context for sustainable buses market**. In Lima and Callao, the public transport fleet is composed by 21.259 buses, 48% of them regular buses and 52% minivans. **All the buses are private. 50% of Lima's buses and minivans are over 20 years old.**

- In 2014, the World Health Organization ranked **Lima worst for air pollution among all Latin American cities**, citing a 75% contribution of mobile sources. One of the reasons for this ranking comes from the mass transit system. Regular buses, bus rapid transit (BRT), and small vans account for about 75.5% of trips and most of these vehicles do not have appropriate emissions and fuel standards.

- Lima's Transit Agency is *Autoridad de Transporte Urbano para Lima y Callao (ATU),* and it is undergoing reforms intended to improve services and regulate (and legalize) all modes of transportation, including Metro, BRT, buses and minivans.

- In 2015, Lima signed onto the C40 Cities Clean Bus Declaration of Intent, one of 24 cities committing to rapidly accelerating the uptake of clean bus technologies. At the **end of 2019**, **Lima began testing its first battery electric bus**,(into a public transportation route known as the *Red Corridor),* within a project developed by GSEP with Enel X and Hydro-Québec. This initiative is part of a larger project that seeks to develop charging infrastructure and study the replicability of electric buses in this country.

- Lima was selected as a study city for PAYS for Clean Transport ("*Análisis y diseño de modelos de negocio y mecanismos de financiación para buses eléctricos en Lima, Perú*"). In August 2021, ATU developed and approved the technical specifications for the standardization of the electric buses, ranging from 9 to 27 meters in length.

- It's worth noting that **currency instability in Perú** remains **a significant barrier to international financing of bus transportation (P**eru Sol vs USD was 0,30 in January 2019, it was 0,24 in September 2021, with a devaluation of approx. 20%).

Transit buses: main parameters and main assumptions

- The driven kms per year are differentiated among operators:
  - 8 m: 45.000 km/year
  - 12 m: 55.000 km/year (note that in IADB study for ebuses the driven km/ year considered is 56.000 km)
  - 18 m: 60.000 km/year
- Battery replacement for BEV and H2 buses needed after 7 years
- In order to extend body life and to improve body appearance and amenity of ICE buses at 10 years is necessary to consider a 37.500 USD for a diesel transit bus while for a CNG 12 meters the cost of revamping is 37.000 USD
- A specific differentiation of consumption (+20%) related to air-conditioning or intensive winter heating is considered for ebuses, due to the average temperature of the main Peruvian cities (30-33°C yearly average during the day for Lima)

Market trends in ebuses sector

TRENDS THAT WILL CHANGE TCRO IN 2025 AND 2030 (LOCAL AND GLOBAL TRENDS)

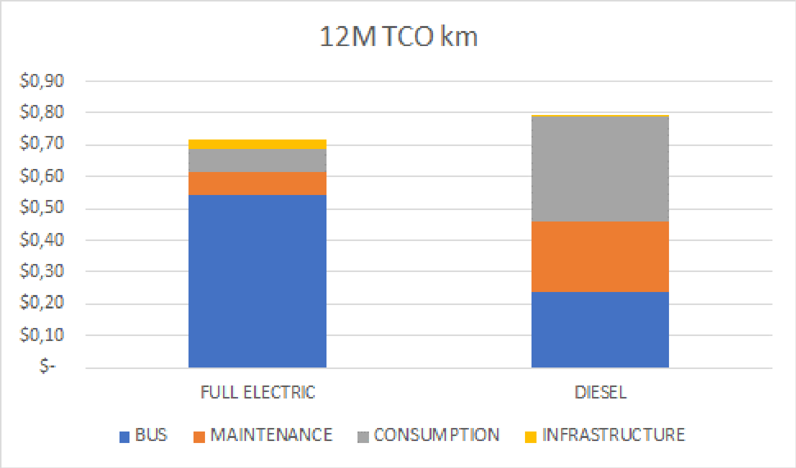
- In Peru, there is not a local supply chain or local market for BEB manufacturing and assembly yet, which also drives up the maintenance cost of the buses. Due to the lack of in-country parts availability, cost to import parts and associated duties, as well as the learning curve of this new technology to maintenance workers, **maintenance costs are estimated to be higher in Peru than in other Latin America locations.**
- **Cost reduction of power consumption** thanks to the use of new and lighter materials, weight reduction of batteries and better efficency in reusing braking energy
- **POTENTIAL REVENUES FOR 2° LIFE OF THE BATTERIES AND BUS TO GRID (B2G) REVENUES (GLOBAL TRENDS)**

2° life batteries - In Latin America there we no 2° life pilot projects at 2021. In 2025, in Perù the **residual value** of the bus battery, could be estimated in **20% of the cost of a new battery in USD per KWh**, much lower compared to the EU context, because of the absence of specific policy related to circular economy for batteries and of the absence of specialised battery manufacturers in the area. For 12 m buses (240 kwh battery), the additional revenues expressed in USD will be equal to 18.200 USD in 2025.

POTENTIAL REVENUES FROM B2G SERVICES

At present, there are not specific studies or pilot projects in Perù. Estimates of potential revenues are not considered for 2025 and 2030 scenarios.

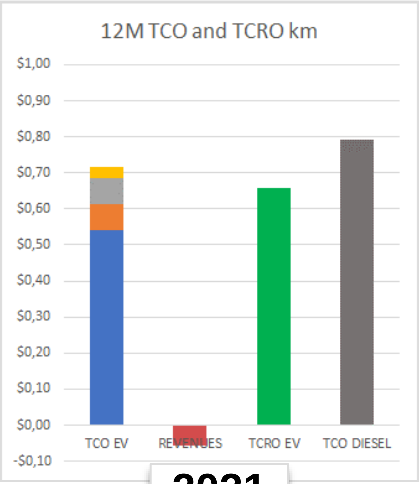
Costs and revenues by component for 12m (2021)



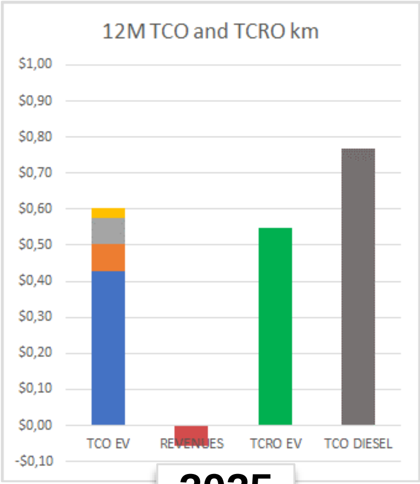
	FULL ELECTRIC		DIESEL	
BUS	$	0,540	$	0,236
MAINTENANCE	$	0,074	$	0,225
CONSUMPTION	$	0,073	$	0,327
INFRASTRUCTURE	$	0,029	$	0,003
B2G	$	-		
2ND LIFE	$	0,057		
Total TCO	$	0,716	$	0,791
Total TCRO	$	0,659	$	0,791

GREEN Elaborations (2021)

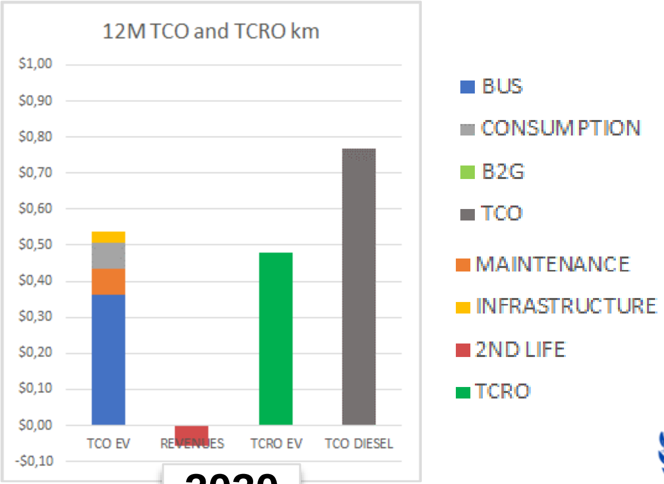
The role of revenues - TCO & TCRO



2021



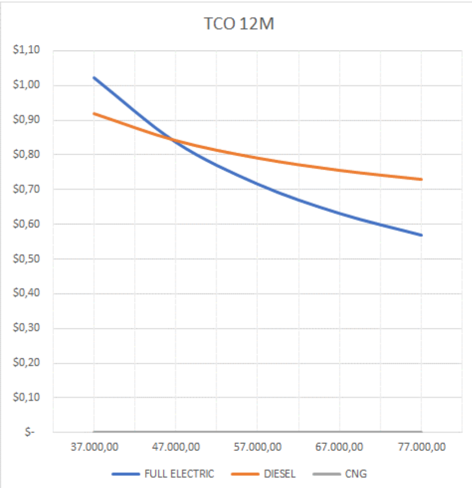
2025



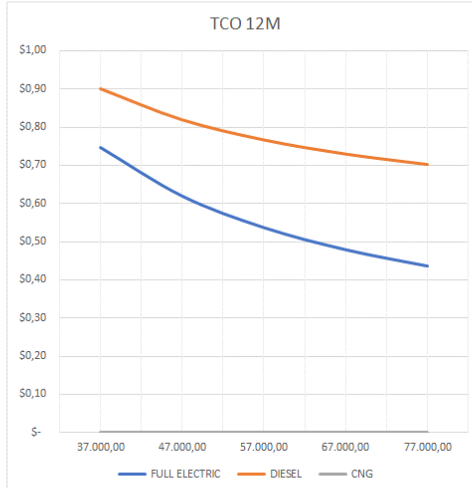
2030

GREEN Elaborations (2021, 2025, 2030)

Sensitivity analysis TCO & TCRO



2021



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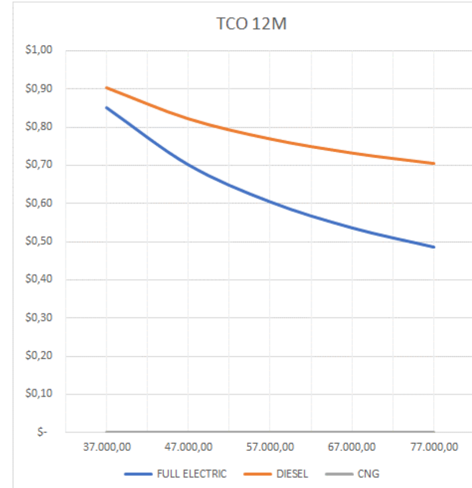
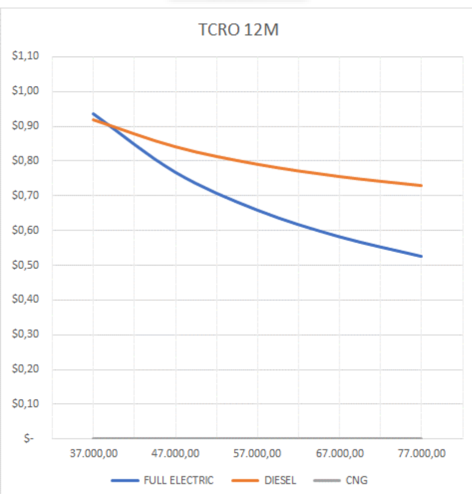


2030

GREEN Elaborations (2021, 2025, 2030)



2021

2025

2030

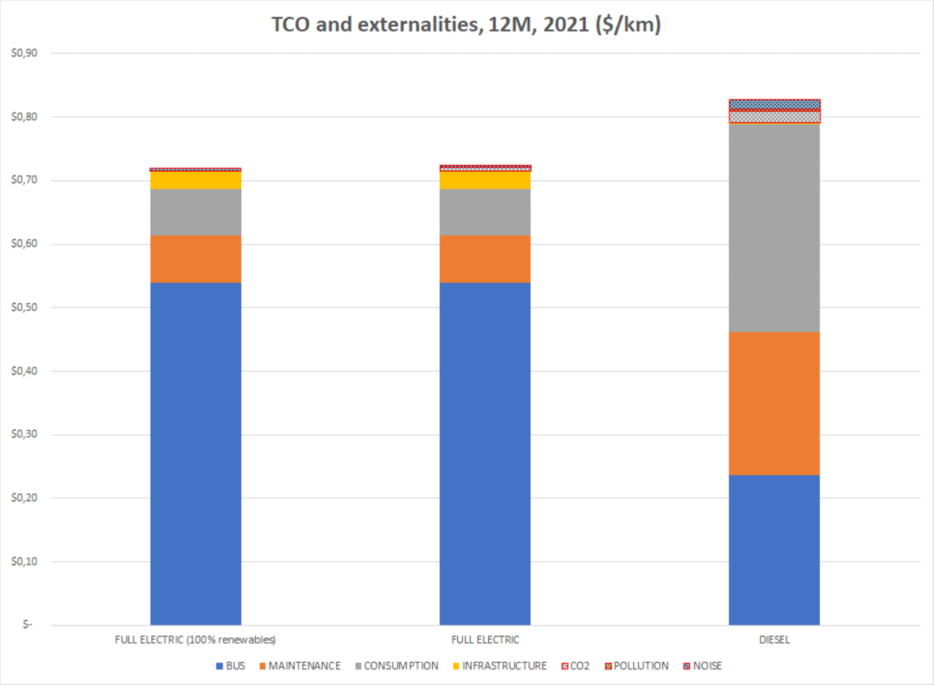
GREEN Elaborations (2021, 2025, 2030)

TCO and externalities

To fully understand the potential of bus fleets' electrification, externalities (CO_2, PM10*, Nox*, HC*, noise) have been added to the calculations.

The comparison between **TCO**, **TCRO** and **TCRO+externalities** highlights the role of economic and social benefits enhancing further the convenience for electrification in compared to diesel, the basis year 2021.

The advantages of Full Electric are even more relevant considering that the estimated revenues from 2nd Life batteries would lower the TCO further by 5,7 $cents.



GREEN Elaborations

Source for monetary parameters of externalities: World Resources Institute "The Costs and Benefits Appraisal Tool for Transit Buses", Technical Note October 2020, for specific carbon intensity of electricity: IEA, 2022.

*not considered for Full Electric cases

Synthesis of the results for Peru

- Even if, in 2021, the number of BEB in PT fleets was limited to a single pilot project and there were no specific circular policies supporting 2nd life and B2G services, the **policy context** in Peru is relatively favourable to the introduction of BEB, thanks to:

    Environmental policies based on long term commitment to ZEB through specific target goals (e.g. Lima C40 Cities Clean Bus Declaration of Intent)

- Also, in Peru the PT operators market is very fragmented and the organizational model is still based in large part on minivans; moreover, there's a lack of bus and battery manufacturers and of specific know-how. However, the **market context** is relatively favourable due to**:**

    1) **Low cost energy tariffs** for PT;
    2) Presence of new players proposing **innovative asset ownership** and sources for scalable financing.

- Since 2021, **TCO of Full Electric buses is particularly competitive** in the 12-m model, especially compared to diesel (-0,075 USD*km); they have <u>very low operating costs,</u> especially regarding <u>consumption</u> (0,073 USD*km).

- The role of **TCRO** should also be highlighted: although the values introduced are largely based on experimental estimations, the impact is not negligible (0,057 USD per km) thanks to revenues coming from 2^{nd} life of batteries.

- In all the scenarios, BEBs are **always more competitive** compared **to diesel buses,** both in terms of TCO and TCRO in a growing trend during the decade.

Main results of for 12m e-buses

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Main results of the TCO benchmark analysis for 12m buses

TCO of 12m eBuses by 2021

Source: GREEN Elaboration (2021)

- TCO comparison between Battery Electric Buses (BEB) and ICE (with reference to Diesel) in transit in 2021 is in favor of the former in most of the countries analyzed: **Spain, Colombia, Chile, Peru, Mexico, Brazil**

- Main differences among countries: **initial costs** of bus infrastructure**, maintenance costs** (depending on the cost of labor and the availability of spare parts) and **energy consumption** (depending on electricity costs).

- Countries where BEB TCO is higher than ICE in 2021: **Italy, United Kingdom, United States**

- In these countries the break-even price that would equal the TCO of BEB to the one of diesel buses has been calculated between 93 (UK, the highest) and 49 (Italy) thousand euros.

Main results of the TCO benchmark analysis for 12m ebuses

Foundation

TCO of 12m Ebuses by 2025 and 2030

Source: GREEN Elaborations (2025 and 2030)

- **Most relevant BEB investment cost reductions will happen in the next years** (before 2025) thanks to **economies of scale** generated by the **demand growth** and by the **diversification of the supply**
- Big improvements will occur as result of the important **investments** that manufacturers have made in recent years in the **batteries field** and in **new factories dedicated to e-buses**, especially in US (e.g. Navistar, Thomas Built, Lion's Electric), Brazil (BYD and Mercedes Benz) and United Kingdom (e.g. Alexander Dennis -ADL- factories in Scarborough and Falkirk, Switch Mobility near Leeds and Wrightbus in Ballymena, Northern Ireland).
- **Significant advantage over endothermic alternatives**

Main outcomes of the analysis

- The analysis of **TCO** and **TCRO** for the selected countries has shown the **consistent increase in competitiveness** of the electrification of public transport fleets **within the next 10 years**.
- While in most of the countries BEBs are already more convenient than the alternative options in 2021, in some others the **revenues generated by the valorization of the second life of batteries as well as of Bus to Grid operations** would speed up the process and enhance the positive impacts.
- In **UK** and **US**, the **strong coordination between policies and industry** represents the backbone of the strategy that will guide the electrification process.
- In **Italy**, **environmental policies** play a decisive role in the take up of the market

Recommendations

- **Policy initiatives in the fields of environment, industry and circular economy** represent an important factor in fostering and accelerating the transition toward zero emission fleets, **anticipating the social and environmental benefits** and **enhancing the contribution to climate change targets.**
- 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.**

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