SCENARIOS AND PERSPECTIVES OF THE ELECTRIFICATION OF PUBLIC ROAD TRANSPORT

A benchmark analysis for Italy based on an innovative methodology: the Total Cost and Revenues of Ownership (TCRO)

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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.

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)

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) without incentives.

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.

Italy

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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.

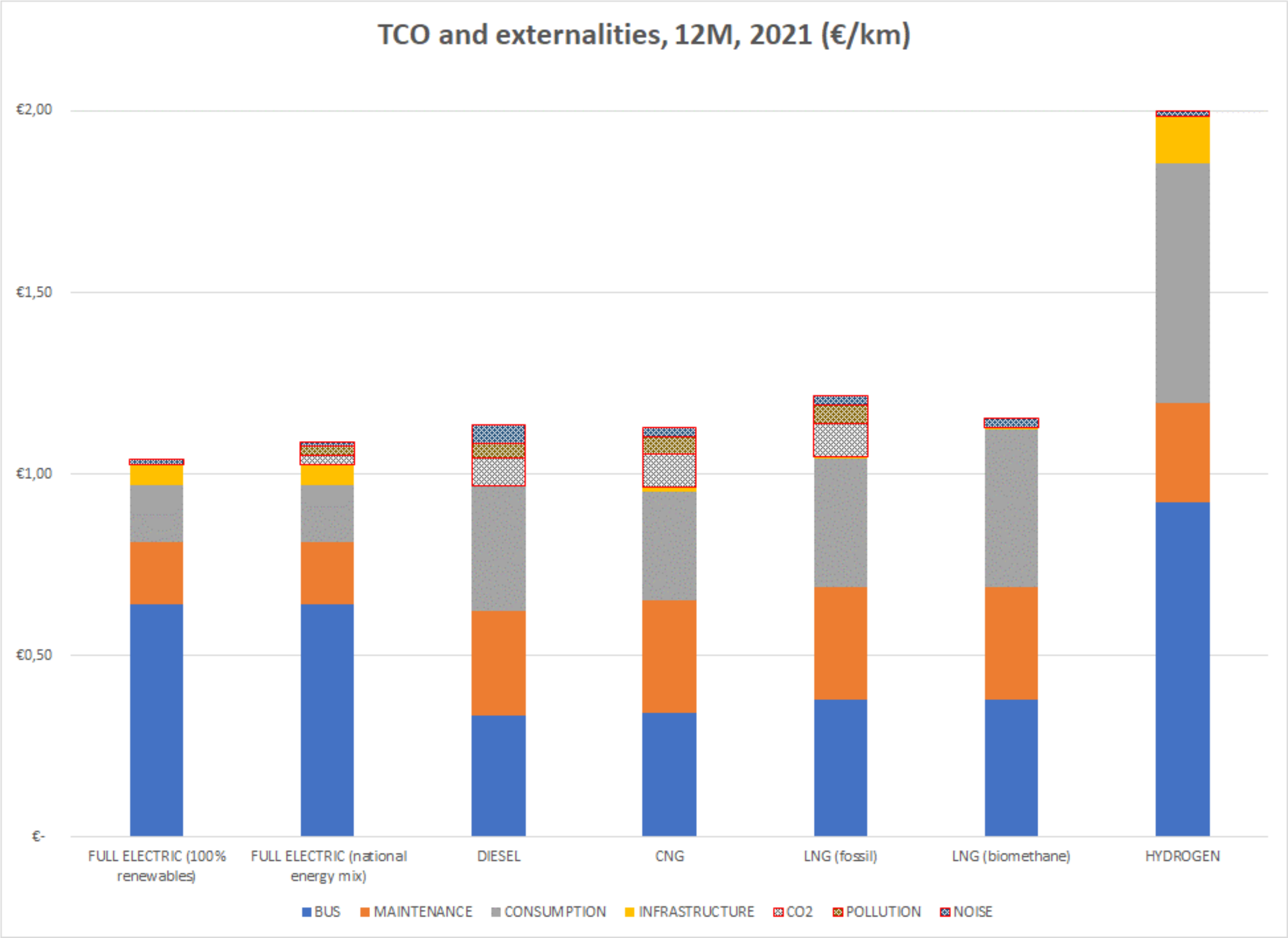
- Differentiations between the engines for some types of OPEX are not considered as they are minimal and are compensated between the different engines (e.g. insurance costs, road taxes or fuel costs of tyres).

- 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



GREEN Elaborations

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 .

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

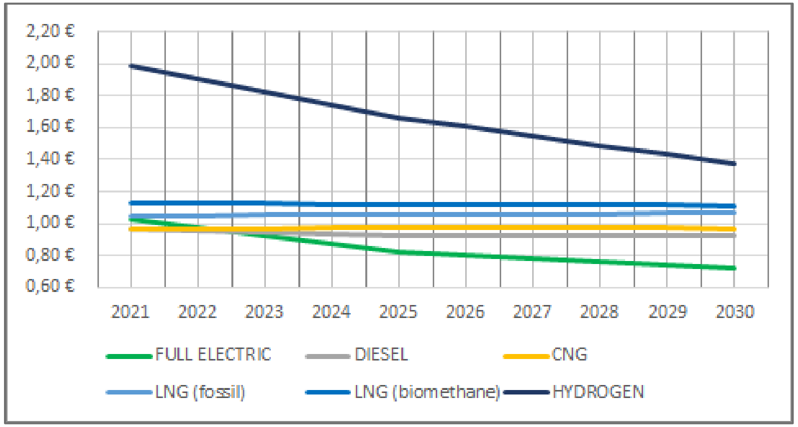
Source: GREEN Elaborations on data from Handbook on the external costs of transport del 2019 e EEA, Cost of air pollution from European Industrial Facilities 2008-2017 (2021), PNSMS from MIMS (2018) and CNR study (2021)

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

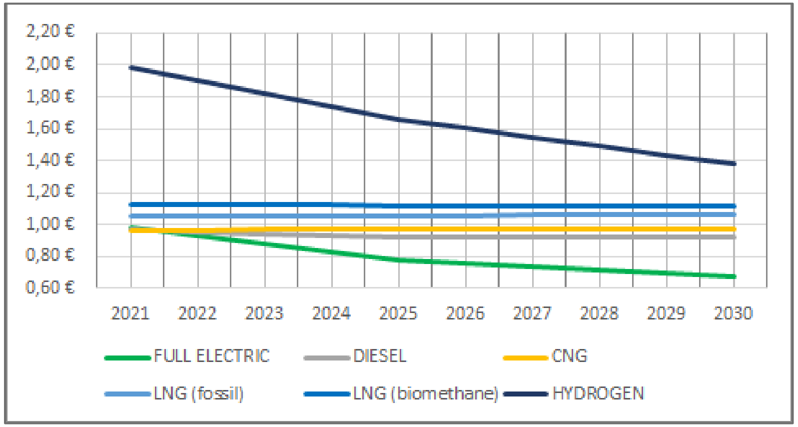
Dynamic comparison of TCO over time for 12 m buses shows the Full Electric option already competitive against diesel at the beginning of 2022. This is even more evident when looking at TCRO.

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

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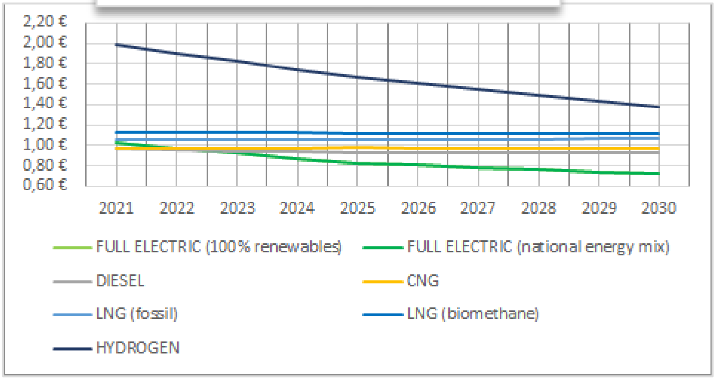
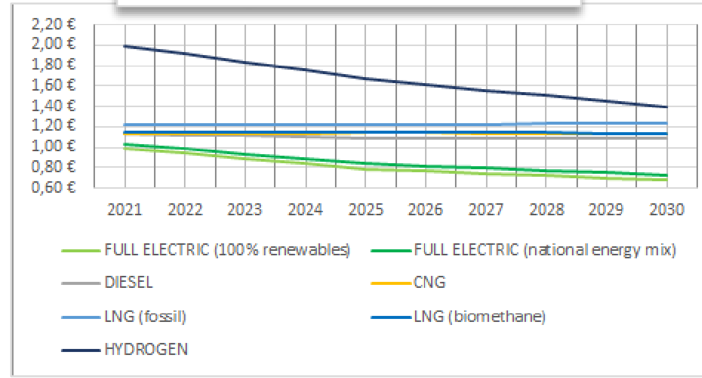
Current Policy (€/km)



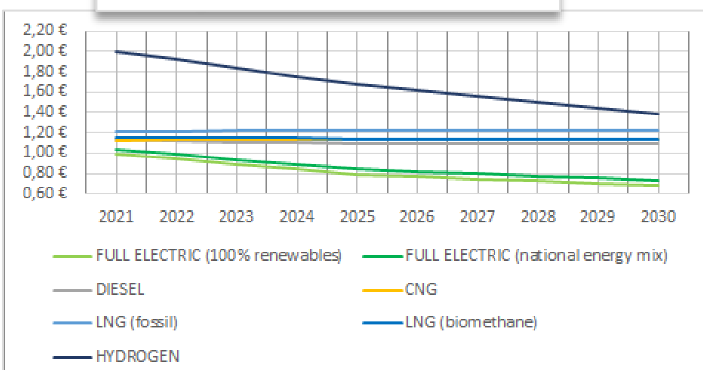
For Italy, the role of incentives is limited to the co-funding available according to Alternative Fuel Initiative (within the CEF), focused on electric charging infrastructure (in storage and online) and to initiatives for energy storage and grid connection (max 30% investment with no-repayable funds). 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.

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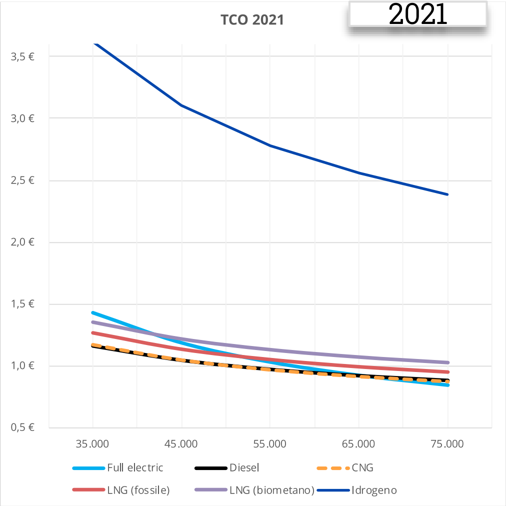
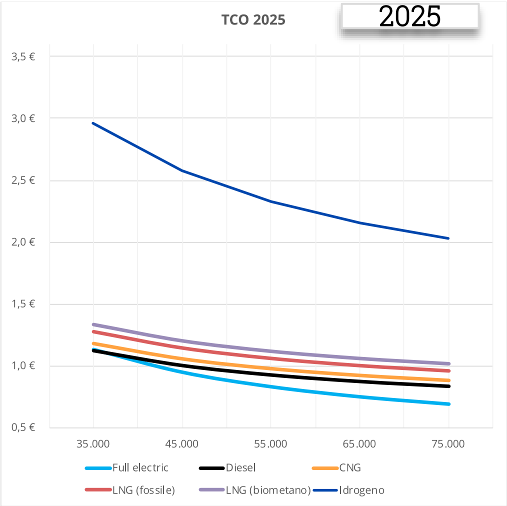
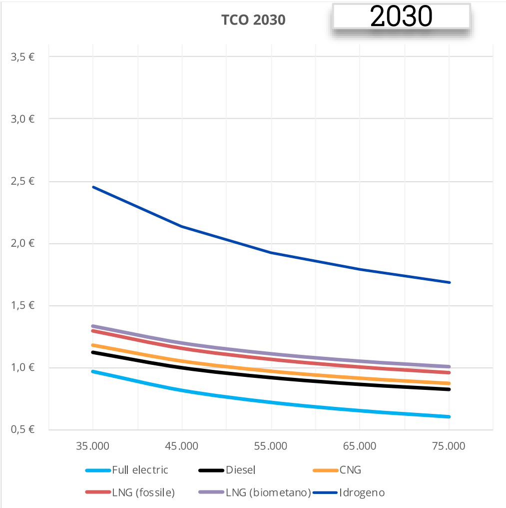
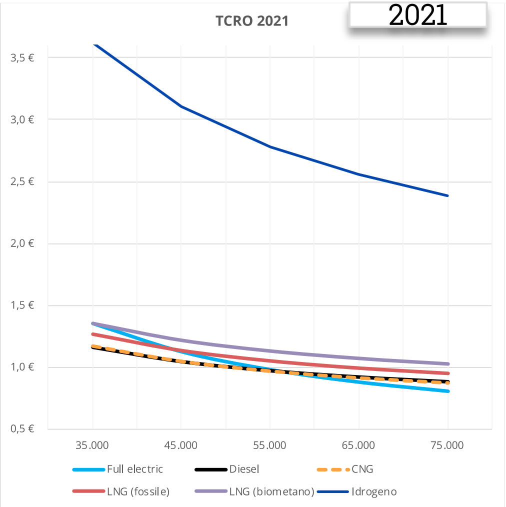
Sensitivity analysis TCO & TCRO (€/km)

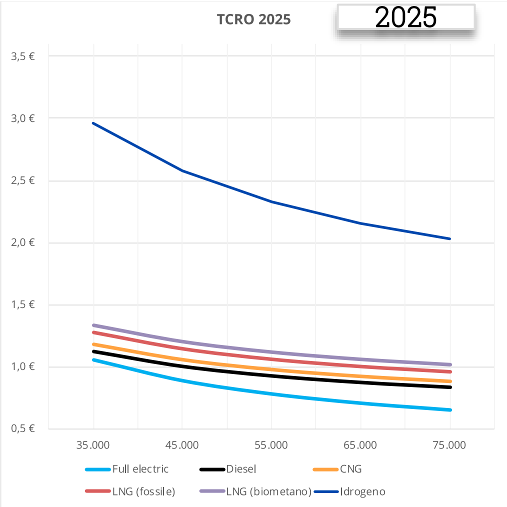


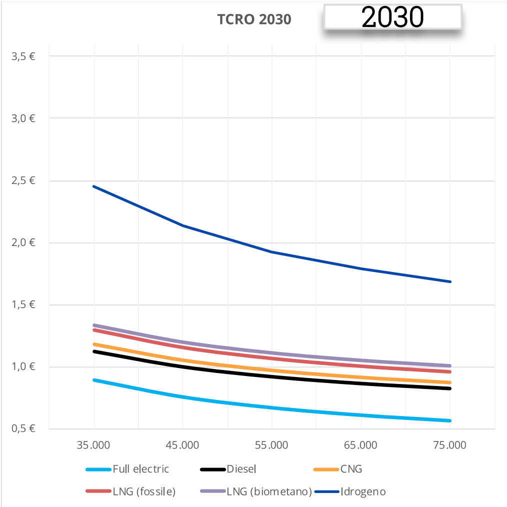




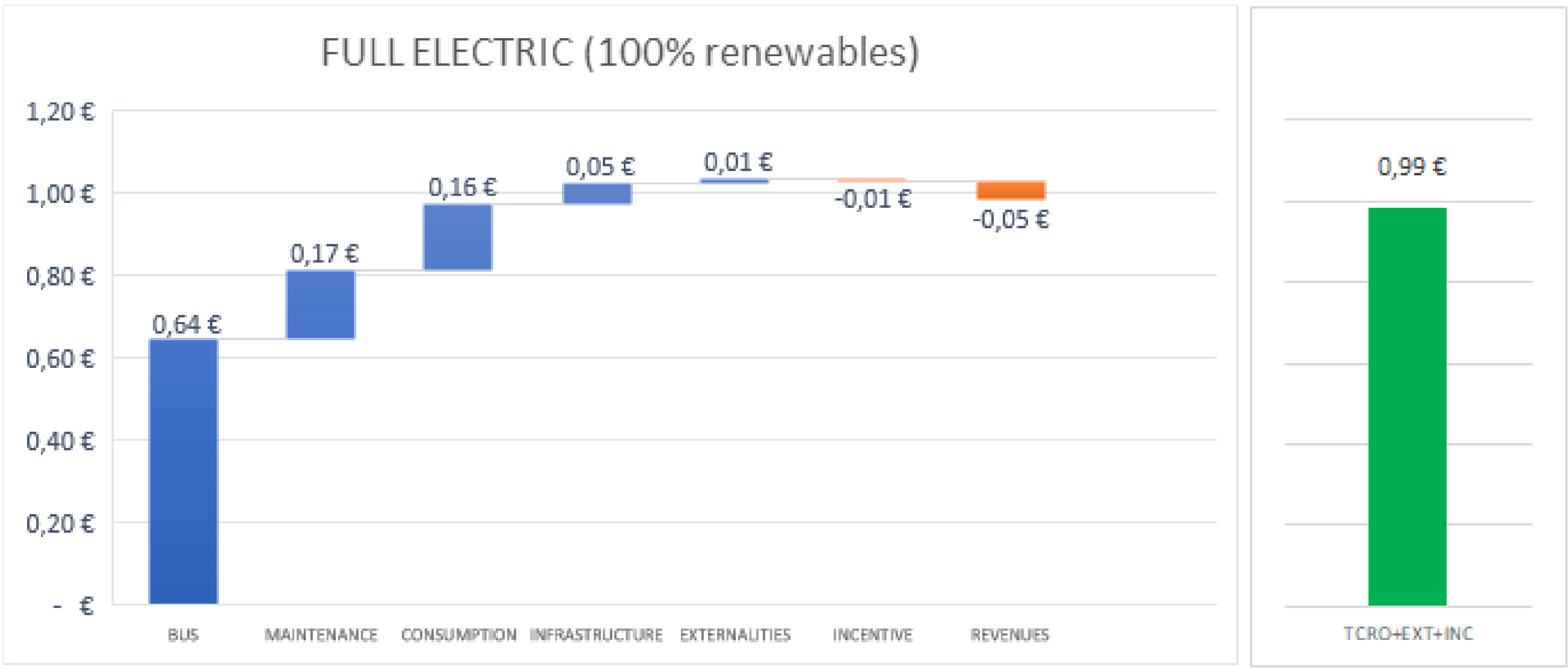
GREEN Elaborations (2021, 2025, 2030)







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.**

Thanks for your attention!

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