

Total Costs and Revenues of Ownership (TCRO): an innovative approach to assess the potential of bus electrification

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The objective of a Total Costs and Revenues of Ownership (TCRO) approach is to support the decision-making process of local public transport (LPT) companies and LPT services contracting bodies on bus fleets renewal in urban contexts. This strategic choice has become particularly complex over the last few years due to various factors, and requires an innovative approach in order to include new elements of both costs and potential revenues over the entire lifetime of the vehicle. This complexity is determined by the rapid and pervasive growth of a range of innovations aimed at greater environmental and economic sustainability of the LPT systems, namely:

- Policy and regulation innovations at different levels (international, national and local);
- Organizational innovations creating synergies between LPT operators, energy utilities and the financial sector;
- Industry innovations, with the entry of new players in the vehicle supply market that are able to offer technologically advanced buses.

The analysis model proposed here, provides a systemic view on the costs and revenues components of buses across their lifetime, integrating vehicles and infrastructures, operational management and maintenance, and including circular economy related elements such as second life management of batteries and Bus2Grid opportunities as revenues for electrified options.

This strategic approach, defined as TCRO – Total Costs and Revenues of Ownership - provides guidance for an efficient selection of solutions to be deployed in different contexts and time scenarios, allowing through sensitivity analyses a better understanding of potential effects of policy instruments, as well as possible modifications in operational parameters as mileage or energy costs¹.

The following table summarizes the main components considered for the analysis of TCO and TCRO for the comparison among different bus power supplies in different countries.

Figure 1: Buses TCO and TCRO 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, electrolyzers, 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

¹ According to International Energy Agency Report “World Energy Outlook 2021” published in October 2021, the world is not investing enough to meet its future energy needs, and uncertainties over policies and demand trajectories create a strong risk of a volatile period ahead for energy markets, as clearly demonstrated in the 2021 second semester. All data in the report are updated at 15th of October 2021, but the highly volatile period for energy market could change the results of the scenario analysis even in short term.

Second-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 electric buses, the sale of batteries for other purposes (for example stationary applications in grids, buildings etc.), is a source of revenue
SOCIAL COSTS	DESCRIPTION
Environmental externalities	Externalities (CO ₂ , PM ₁₀ , NO _x , SO ₂ , NMVOC, Noise) are also added in the calculations. Values are expressed in Euro* km and have been considered related to tank to wheel (TTW) and production to wheel (PTW) process for electricity

Source: EF and GREEN elaboration on Grauers et al. (2020), World Bank (2019) e TOI (2018) data

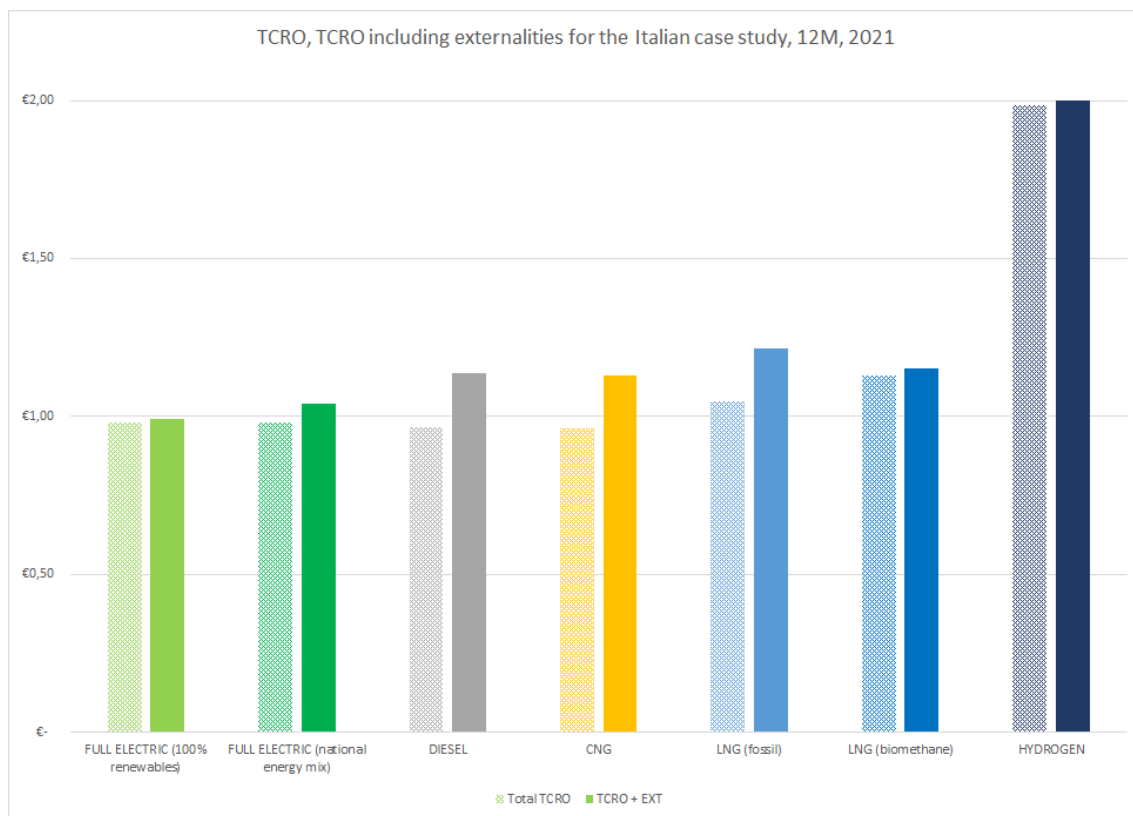
The components of the TCRO depend on several contextual factors, in addition to the technological maturity ones, linked to drivers such as regulatory elements, taxation and facilitation systems, labor costs, energy costs, market structures, weather and climatic conditions, which they can significantly affect the range of values. In addition, the values of the different components also depend significantly on the average annual mileage of the vehicles, which is often a reflection of commercial speeds and hours of use throughout the day.

To elaborate scenarios to 2025 and 2030, the model primarily takes into account the expected evolution of power supply technologies in terms of costs and performance, of the regulations and of the strategies of manufacturers and public transport operators, in particular with respect to issues related to the utilities managing the electricity grid.

The power supplies selected for comparison are electric (EV), diesel, compressed natural gas (CNG), liquefied natural gas (LNG, fossil and biomethane), and hydrogen, when relevant in the countries chosen for the analysis. Monetary values of cost and revenue have been expressed in terms of net present value (NPV): this choice allows a correct valorization of the different investment strategies connected to power supply choices, discounting those costs occurring in the future². In the following graph, the calculation of environmental externalities (social costs) is added to the TCRO of different fuel alternatives in the Italian case study.

² The evaluation is done from a first-user perspective over a 15-year analysis period. Since the TCO and TCRO values per km processed by the model are the result of the sum of discounted variables, the monetary value of the operating components of TCO and TCRO will be lower than the starting value indicated in the starting sources used for the calculation.

Figure 2: Calculation of TCRO and externalities in 2021, the case of Italy (12 meter buses)



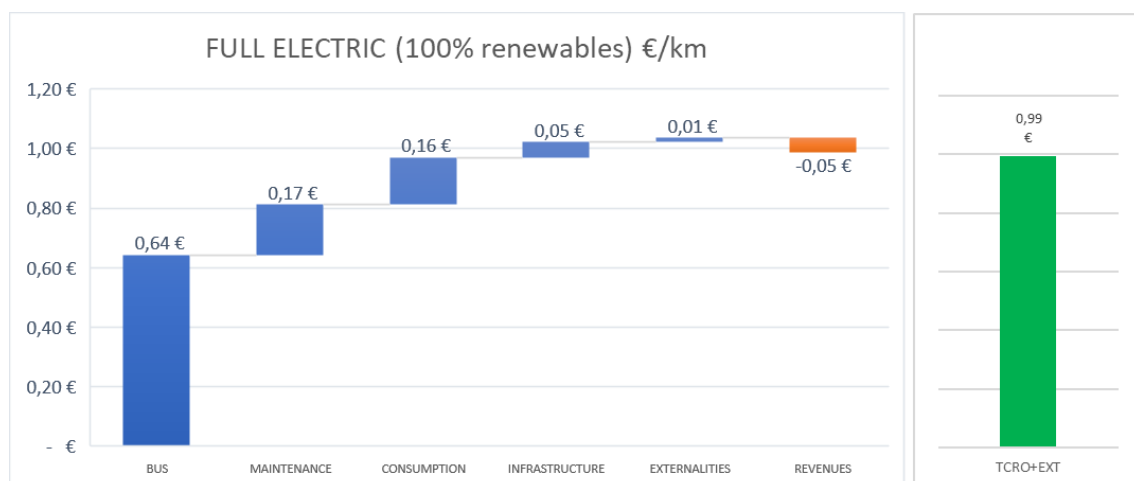
Source: EF and GREEN elaboration

The comparison across different fuel alternatives highlights the economic and social benefits deriving from the electrification choice already in the basis year 2021. Further enhancements have been estimated for e-buses in years 2025 and 2030, when the TCRO of electric buses including externalities drops respectively by 19% and 30% compared to 2021, thus increasing even more their competitiveness towards other fuel alternatives.

Furthermore, it is worth to underline that the benefits are absolutely striking when considering the option of consuming energy coming from 100% certified renewable sources (first histogram), as it is the case for the public transport operators in Milan and Turin, for example.

The following graph shows the calculation of all TCRO components including economic costs (TCO), social costs (externalities) and revenues (B2G and valorization of 2nd life batteries).

Figure 1: Calculation of TCRO and externalities in 2021, the case of Italy (12 meter buses)



Source: EF and GREEN elaboration

Thanks to the calculation of the full TCRO including externalities, the advantages of electrification are even more relevant, considering that the estimated revenues from B2G and Second Life would lower the TCO further by around 5 €cents in 2021.

In the Italian case study, 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 our 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** will contribute to reduce the risks for public transport operators and accelerate the transition, requiring a **clear regulation framework** and a **proactive role by financial and utilities operators**.

Revenues deriving from B2G and valorization of 2nd life of the batteries will contribute to keep the operating cost for public transport operators to be as low as possible, with **potential benefits for public finance**.

Monetization of externalities underline the **opportunities for the society as a whole of decarbonising bus sector**, that benefits are absolutely striking (-92% compared to diesel) when considering the option of consuming energy coming from 100% certified renewable sources as it is the case for the public transport operators in Milan and Turin, for example, **this means up to 10.000 Euro annual value reduction of the cost of externalities for each bus**.

The calculations of TCRO and TCRO + externalities will be available for ten other investigated countries (Spain, UK, US, Australia, Brazil, Chile, Colombia, Mexico, Peru, Uruguay) and completed with a sensitivity analysis identifying the breakeven year for electric buses in those countries where this had not been reached already in 2021.