Maria Pia Valentini, Valentina Conti, Matteo Corazza,
Maria Lelli, Silvia Orchi

ROAD PUBLIC TRANSPORT DECARBONISATION: A COMPARISON AMONG VEHICLE TECHNOLOGIES

Maria Pia Valentini, ENEA, Via Anguillarese 301, Rome, Italy
Valentina Conti, ENEA, Rome, Italy
Matteo Corazza, ENEA, Rome, Italy
Maria Lelli, ENEA, Rome, Italy
Silvia Orchi, ENEA, Rome, Italy

Overview

Transport is presently one of the most critical sectors for decarbonisation, due to its strictly dependency on fossil fuels. A technical and behavioural revolution is needed to get the 2050 target of 90% GHG emissions cut fixed by the EU Green Deal, based on the actions prescribed in the Fit for 55 Package for cleaner road vehicles and a wider availability of alternative fuels and infrastructures (mainly electric recharge and hydrogen refuelling).
Although urban PT accounts for a minority of the total energy consumption and GHG emissions of passenger road mobility, it is considered an optimal testbed for new vehicle technologies, due to the possibility of taking advantages from "economies of scale" and scheduled vehicles operation.
Moreover, a consistent modal shift from private to public mobility, mainly in urban areas, is encouraged in overall strategies for transport sustainability, considering the highly better performances of collective transport per transport unit, respect to private vehicles.
Batteries and Hydrogen Fuel Cell Electric Vehicles (BEVs and HFCEVs) are considered the most promising solutions to reduce climate impacts of transport, if well linked to low carbon energy sources.
Numerous PT Companies all over the world are already experimenting battery buses (BEBs) since the early 2000ies (Bloomberg calculates that almost 600,000 e-buses are already into operation) [1] and, more recently, also hydrogen fuel cells buses (HFCBs) have been introduced.
In this paper we analyse the effective GHG reduction, internal costs and operational changes for PT companies of this revolution, mainly comparing battery and FC solutions for road PT electrification in the near future.

Methods

An economic analysis of the whole vehicle operating life is performed for different bus technologies, conventional and innovative, from the operator point of view, considering a real Italian case study.
Moreover, an analysis on "Well-to-Wheels" (WTW) greenhouse-gases emissions and energy consumption is carried out for 12 m urban buses powered with both batteries and hydrogen fuel cells, considering different energy production pathways.

Results

A Total Cost of Ownership (TCO) analysis is applied to the bus-lines of Rome in order to compare the comprehensive costs of different bus technologies [2].
First of all, the limits of battery buses in terms of range and recharge needs are taken into account. Results show that BEBs are applicable in more than 94% of the 282 examined bus lines, while HFCBs, as expected, are 100% applicable, as well as conventional technologies like Diesel and CNG buses.
Moreover, HFCBs appear as flexible as conventional technologies and almost as much easy to operate (shorter refuelling time respect to electric recharge); finally, they require less usable areas for refuelling installations.

Yet, from an economic point of view, BEBs result more convenient for 26% of lines, while HFCBs are still too expensive, when compared to other technologies, both for CAPEX and OPEX cost components. These results have been obtained considering the 2019 energy price for electricity from grid and "grey hydrogen" from Natural Gas Steam Reforming (Italian tariffs).

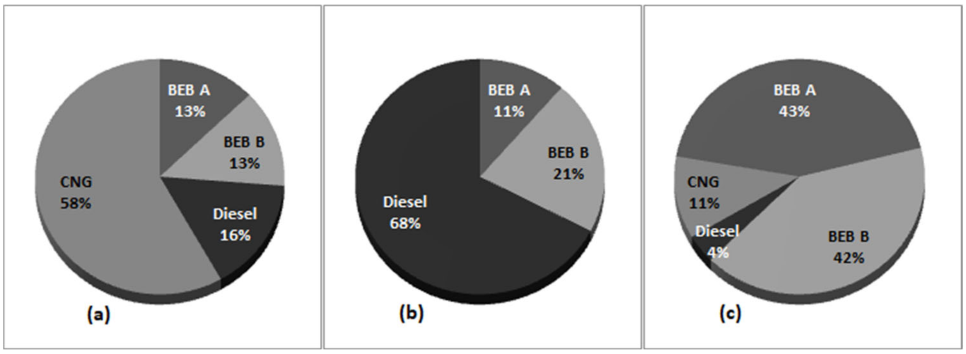

Figure 1: Economic prevalence of bus technologies in the Rome PT network along the operating life according to different energy prices (2019 (a), 2021 (b) Italy end-user tariffs) or also taking into account the cost of externalities (c)

Legend:

BEB A: Battery Electric Bus mostly recharged at deposit, overnight
BEB B: Battery Electric Bus mostly recharged at bus terminals, during daily operation

Taking into account the recent rise of energy prices (2021), BEBs result even more competitive (32% of bus lines) than in the 2019 case, CNG buses being the most penalised. By introducing in the analysis the incidence of the externality costs, such as local pollution, noise and GW, BEBs result more convenient than any other vehicle technological solution along the operation cycle for most of lines.

In other words, energy and environmental costs are extremely relevant in determining the economic prevalence of a vehicle technology on the others.

The more we approach to the 2050 horizon, for which net zero carbon emissions are required to avoid an increase of the global average temperature higher than +1.5 °C, the more carbon costs can result prevalent on other external costs, as it can be deduced from the graph below.

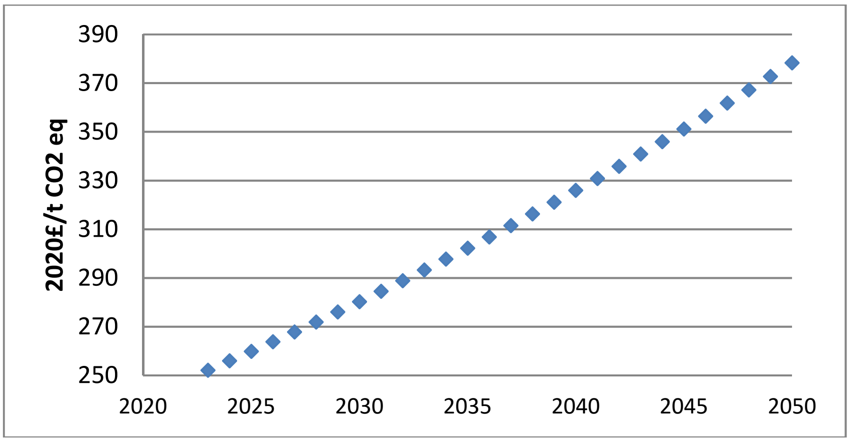

Figure 2: Carbon costs forecast to 2050 according to BEIS
Dept of UK Government - 2020 [3]

Total carbon emissions along the Well-to-Wheels cycle for vehicles operation are strictly connected to the pathway chosen for producing the “fuel” employed during operation, whether it is diesel, methane, electricity or hydrogen. This is quantitatively analysed in the JRC-Eucar - Concawe study periodically updated on this subject [4].

From their analysis it emerges, first of all, that Battery and Fuel Cells vehicles can make transports less carbon intensive only if electricity and hydrogen are produced from green sources, as renewable energy sources (RESs) or, at least, natural gas steam reforming with CCS. On the other hand, we notice that also for ICE vehicles relevant overall carbon improvements are possible when using biofuels instead of fossil fuels.
The following graph compares estimates of energy and GHG emission factors of 12 m urban buses for selected low carbon WTW pathways in 2030.

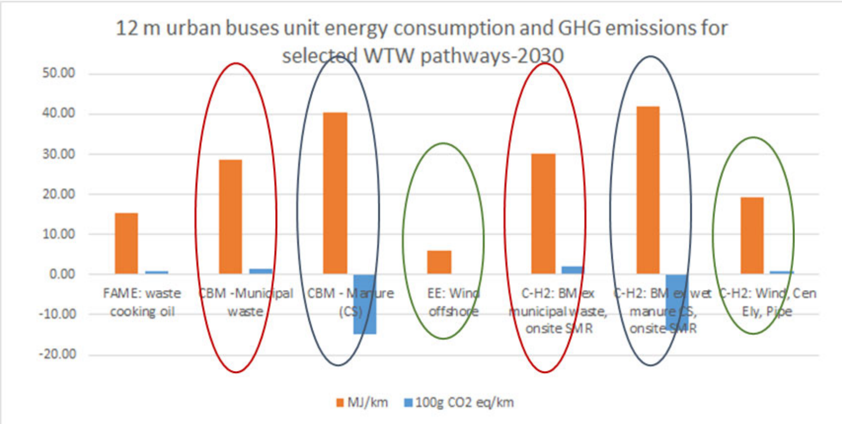

Figure 3: Energy and carbon WTW balance of urban buses according to vehicle technology and energy pathway

Source: ENEA on JRC-EUCAR - Concawe data [4]

In particular, some pathways for biomethane production from municipal waste or farm manure are very promising from a carbonic point of view, as they are able to absorb CO_2, if compared with a no-recycling scenario of the organic wastes. Unfortunately, these processes from organic materials to fuel are also highly energy intensive, and consequently also economically expensive.
In case of BEBs, if the electricity is produced from wind and directly input into the grid, the total energy required along the whole energy cycle is definitively less than for biofuels, but the net CO_2 balance is zero rather than negative.
Finally, in case of HFCBs, mainly two ways to produce green hydrogen are possible: from biomethane via SMR and from green electricity via electrolysis.
Both these processes require additional industrial activities to convert a green fuel (biomethane from waste biomass or electricity from RES) into another green fuel (green hydrogen), implying a surplus of energy consumption and GHG emissions in the WTT phase. This can be justified in case of hydrogen from biomethane, because the net WTW balance of energy consumption and GHG emissions is similar for the two cases of compressed methane engine and HFC, as can be observed in the previous graph (additional upstream consumption and GHG emissions are counterbalanced by a more efficient process at point of use).
On the contrary, comparing the net balances of battery vehicles powered with electricity generated from RES to the ones of a HFC vehicle fuelled with hydrogen produced from green electrolysis (see graph above), it appears that battery cycle is globally more efficient than HFC one.

Conclusions

In a comprehensive strategy for Transport decarbonisation, battery and HFC technologies for electric vehicles should coexist, also considering the potential of Power to X (P2X) technologies to store the excess of RES generation as hydrogen. However, at the current state of technologies and commercialisation, hydrogen in road transport should be preferred for those applications where wide ranges and flexibility are leading requirements, like long haulage.
In general, a mindful use of electricity for automotive uses (both directly o by e-fuels) must be carried out in a future where electricity demand is expected to strongly grow for all end uses, not only for transport, and electric energy will be more and more “green”, expensive and scarce respect to demand. For any transport mission, the most efficient solutions along the WTW cycle must be preferred.
Further analysis is being carried out on the energy and carbon impacts of vehicles and infrastructures construction and dismantling, for a more comprehensive comparison of different vehicles technologies role in the EU energy transition and decarbonisation.

References

[1] https://www.sustainable-bus.com/ 19 May 2020 editorial
[2] M.P. Valentini et Al., Research in Transportation Economics,, https://doi.org/10.1016/j.retrec.2021.101117
[3] BEIS Dept. of UK Government https://www.gov.uk/government/collections/carbon-valuation--2
[4] Prussi, M., Yugo, M., De Prada, L., Padella, M., Edwards, R., Lonza, L. JEC Well-to-Tank report v5, EUR 30269 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-19926-7, doi:10.2760/959137, JRC119036