Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 60 (2022) 84–91

Transportation Research Procedia

www.elsevier.com/locate/procedia

XXV International Conference Living and Walking in Cities - New scenarios for safe mobility in urban areas (LWC 2021), 9-10 September 2021, Brescia, Italy

Transformation of an existing urban bus line: Milan Full Electric project

Fabio Borghetti[a], Michela Longo[b,*], Renato Mazzoncini[c], Alfredo Panarese[d], Claudio Somaschini[e]

[a]*Politecnico di Milano, Design Department, Mobility and Transport Laboratory, Via Candiani 72, Milano – 20158, Italy*
[b]*Politecnico di Milano, Department of Energy, Via La Masa 36, Milano – 20156, Italy*
[c]*CEO of A2A S.p.A., Corso di Porta Vittoria 4, Milano – 20122, Italy*
[d]*ATM S.p.A, Foro Buonaparte 61, Milano – 20121, Italy*
[e]*Politecnico di Milano, Department of Mechanical Engineering, Via La Masa 1, Milano - 20156, Italy*

Abstract

The main goal of this work is to perform a preliminary analysis about the feasibility and implications of the ongoing Full Electric project implemented by ATM, the public company that manages the collective transport in Milan (Italy). The project aims to upgrade the bus system by creating a fleet composed by 1150 full electric buses by 2030 (Scenario 1). In addition to that, a second goal is to analyze the convenience of anticipating the full electrification of the fleet in 2026 (Scenario 2), when the Winter Olympic Games will take place in Italy in Milan and Cortina. In order to perform this analysis satisfactorily cost analysis of the project is described. In particular, all the expenses with respect to both scenarios are calculated and compared to the hypothetical situation in which no project (Scenario 0) is carried out. In this way, it is possible to estimate the incremental expenses that these projects would imply during the years. Within this paper, these aspects are presented: investment and sensitivity analysis.

Zero-emission buses; Sustainable transport, Transport management.

* Corresponding author.
E-mail address: michela.longo@polimi.it

10.1016/j.trpro.2021.12.012

1. Introduction

The emissions associated with transport sector affect not only the city's air quality, but also climate change. In 2017, the average per capita emissions of CO_2 associated with transportation were higher in Italy (1.7 tons) than the G20 European Commission (2021) average (1.2 tons). Regarding CO_2 emissions, transportation is second only to electricity production and heating. In fact, the transportation sector has more than doubled its emissions over the past 45 years, producing about 25 % of total carbon dioxide emissions.

Carbon dioxide emissions from road, air, and maritime transport account for 74%, 12% (excluding non-CO_2 impacts, which are estimated to double the sector's heating impact) and 12%, respectively. From this point of view, the decarbonization of the transport sector offers an opportunity to combine climate and environmental protection while ensuring an economic and social balance (Carnevale and Sachs,2019). With the aim to solve these problems, Italy pledged to the European 2030 climate and energy framework, adopted by the European Council in October 2014. In order to achieve these goals, the Italian National Energy Strategy includes a target for 21% of final transport energy demand to be provided by renewable sources by 2030 (Ke, 2016). In the public urban mobility context, the way to achieve this goal is twofold: increase both the collective transport demand and the electric vehicle share of the system. In this context, ATM - Azienda Trasporti Milanesi, the public company that manages the collective transport in Milan (Italy), launched in 2017 the Milan Full Electric project to equip the city by 2030 with a public transport service entirely powered by electric traction, retiring gradually the current diesel vehicles, and promoting sustainable mobility in the urban area (Wen, 2016; Wang, 2020). Several studies in the literature have addressed the issue of energy consumption by highlighting the importance of how electricity is produced (Abdelaty and Mohamed, 2021; Pietrzak and Pietrzak, 2021).

The plan (ATM, 2018) involves, in addition to the creation of a new fleet of electric buses, the renewal of the depots, through the restructuring of the existing ones and the construction of new structures technologically advanced, plus the realization of suitable infrastructure in the terminals for the recharge in service of the vehicles (An, 2020; Meishner, 2020).

The main goal of this work is to perform a preliminary analysis about the feasibility and implications of the ongoing Full Electric project implemented by ATM where the new fleet will be at zero local emissions. It aims to upgrade the bus system by creating a fleet composed by 1150 full electric buses.

Two-time scenarios were implemented to achieve this goal:

- Scenario 1. In this scenario the renewal costs of the entire fleet incurred by the company are to be analyzed considering the year 2030 as the time horizon. This means that over the years the buses will be progressively replaced according to their age.
- Scenario 2. In this second scenario the aim is to evaluate what happens if the 2030-time target is advanced to the year 2026 when the Winter Olympic Games will take place in Italy in Milan and Cortina. Basically, the costs of renewing the fleet are compared by assuming that all buses will be progressively replaced by 2026 and not by 2030. How do purchase and operating costs change over time?

With reference to the technical-scientific literature, the added value of this work consists in analyzing a real case study: in this way it is possible to create scenarios over time to support the decision-making process. The method adopted, which includes the introduction of costs and assumptions, can be used in other contexts.

In order to perform this analysis, the following issues are described in this work:

- *Cost analysis of the projects*. In this study all the expenses with respect to both scenarios are calculated and compared to the hypothetical situation in which no project (scenario 0) is carried out, to estimate the incremental expenses that these projects would imply. For this analysis, a conservative criterion is applied, considering almost no future change neither in the employed technologies (e.g., battery capacity) nor their prices. This part of the work comprises: i) a CAPital EXpenditure (CAPEX) analysis, including the acquisition costs of all the buses along the project as well as all the investment needed to create the required infrastructure; ii) An OPerating EXpenses (OPEX), considering all the operational and maintenance costs related to the fleet along the 2020-2030 period; iii) A final expenditure evaluation, analyzing the total costs in the three scenarios considered.

- *Sensitivity analysis*. In this part the aim is to analyze the possible impact and consequence on the total expense of the projects if some of the estimated values or the assumptions change.

2. Current Situation: Public Transport System in Milan

The public transport in the city is a subsidized service, receiving public resources which usually cover a substantial part of the operating costs. From a statistical point of view, about 17% of public transport passengers travel for more than 2 hours every day. In a single trip with public transport, the average distance that people usually cover is about 8 km, while 16% of passengers travel more than 12 km in one direction. Obviously, these statistics differs from the current COVID-19 situation. Focusing on the urban bus network, among the 1150 buses running in the city, 974 (85%) of them are diesel, 149 (13%) are hybrid and only 27 (2%) are electric. The average age of the diesel buses is 11 years, while it is slightly more than one year for the hybrid ones and almost 2 years for the electric. The useful life of an urban bus is generally considered to be about 12 years. Comparing this number to the age of the current diesel buses it can be observed that most of the vehicles need to be replaced now or in a very close future. Milano Full Electric project attempts to replace all the old diesel buses with full electric ones in the next few years. In fact, it could be necessary to firstly replace the oldest diesel buses with new electric ones that would be the last to be replaced ATM (2018). Not all the current diesel buses have the same emission level: 414 (42.5%) of them accomplish the Euro III norm with FAP filter, 299 (30.5%) accomplish Euro V with FAP filter and 261 (27%) accomplish Euro VI. This implies differences in NOx, CO and particle emissions. Regarding the length of these buses, there are only two types in the actual fleet. There are 925 (80%) vehicles that are 12 m long, while the rest of them are 18 m long. Usually, 12 m buses have a capacity of 25 seating and 75 standing passengers, while 18 m buses have a capacity for 30 passengers seating and 120 standing (U.S. Customary Units, 2018). These values may be slightly lower for electric buses due to battery space. The total length of the bus network in the city is about 870 km. Figure 1 shows an electric bus model adopted by ATM.

Fig. 1. Example of Electric bus adopted by ATM.

3. Cost analysis of the projects

The average cost for 12 meters electric buses varies from 500 k€ to 650 k€ except for about 700 k€ depending on different technology of the e-buses. The considered cost of the buses is always the same for Scenario 1 and 2. As previously mentioned, the current fleet of ATM is a mix of 1150 buses, 225 of them are 18 meters and 925 are 12 meters. The cost of the entire electrical fleet is 723.75 M€, with an estimation of a price of the 12 meters buses of 600 k€ and 750 k€ for the 18 meters buses. However, some of these electric buses are already acquired and thus, the total remaining acquisition cost is 708.75M€. The aim of this cost analysis is not only to evaluate the overall expenditure, but also to compute the expenses year by year. With this aim, it is possible to assume the following hypotheses: i) by the end of 2020, all the buses with an age higher than 16 years are replaced; ii) along the rest of the project, all the buses that end the year with an age higher than 12 years are replaced; iii) by the end of 2029, all non-electric buses are replaced, regardless their age, in order to accomplish the fully electric target.

The age for replacement is set in 12 years because it is generally considered as the lifetime for diesel and hybrid buses. For the first replacement step, however, it was decided to move this limit to 16 years because, otherwise, ATM would have to acquire 411 electric buses (35.7% of the final target) in only one year. The lower capacity of electric buses due to the volume of the battery can be a problem for the assumption that every bus is replaced by just one non-electric bus.

Considering the infrastructure, the total number of opportunity chargers required by this estimation is 174. These stations must be summed by the 36 opportunity chargers already installed. In this way, the total number of opportunity chargers required is 126 with a cost of 30.72 M€.

3.1. CAPEX and OPEX description

Companies and enterprises organize costs by considering several categories: the two most common are CAPital EXpenditures (CAPEX) and OPErating EXpenditures (OPEX). The first case, CAPEX, includes physical assets, such as buildings and infrastructure, equipment, machines, and vehicles. The second case, OPEX, includes employee salaries, rent for goods and services, utilities, property taxes, etc. In the present work a preliminary cost analysis is carried out not considering, for example, the depreciation of vehicles.

3.2. CAPEX Analysis

It is possible to perform a comparison between the three scenarios previously described. Figure 2 represents different scenarios for CAPEX. It is observable that anticipating the end of the electrification project from 2030 to 2026 (Scenario 2) does not imply a huge increase of the expenditure in the years before 2026 (red line). It is remarkable that for Scenario 1 (blue line) and Scenario 2 (green line), the expenditure is at its maximum at the beginning of the project (year 2020) and continuously decreases. The reason for this is that in 2020 there is already a large quantity of diesel buses that must be replaced immediately due to their age. This leads to high initial costs of bus purchase and a high amount of expenses related to the new depots for stocking and charging these electric buses (Paul, 2014; Wang, 2017).

In the Scenario 1, there is a peak in 2029 (A) due to all the electric buses that must be acquired to replace those non-electric buses that have not been replaced before because they are less than 12 years old (assumption). In Figure 2, it is possible to observe the significant high variability of the expenditure from one year to the other. The red line represents the boundary between scenario 2 and scenario 1.

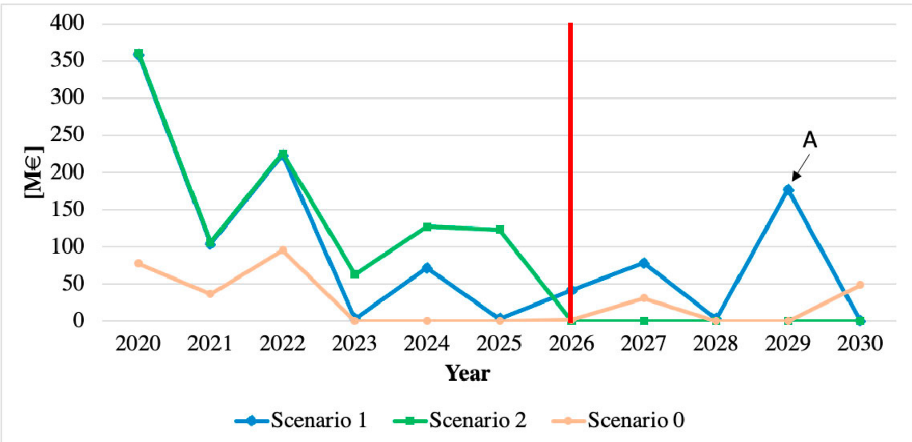

Fig. 2. CAPEX comparison in the three scenarios: Scenario 1 – 2030, Scenario 2 – 2026, Scenario 0 – no project.

It is important to remark again that the applied discount rate is 0% considering the current situation. With the upcoming post-virus economic crisis, it is probable that the central banks implement measures that lead even to negative rates. As it can be observed, the CAPEX of the Scenario 1 is slightly higher than for the Scenario 2, since it is possible to account the revenue coming from sales of old buses. In Figure 2, it is also remarkable the high difference between the electrification projects (Scenario 1 and 2) and the scenario with no project (Scenario 0 – Orange line).

3.3. OPEX Analysis

The OPEX analysis is performed considering two hypotheses applied to each Scenarios. These hypotheses are referred about the revenue generated by the battery pack after its usage, i.e., second life of the battery:

- *Hypothesis 1*: in this case, it is possible to assume that there would be no extra cost for disposing the battery pack and, hence, it does not generate any revenue to the ATM either.
- *Hypothesis 2*: in this case, the analysis considers an estimate that the second life of the battery generates a revenue equal to 30% of its initial cost.

In each hypothesis, there are three situations: best, average and worst-case. In the best-case situation, lower values are adopted, mean values in the average situation and maximum values in the worst case.

Figure 3 represents the results of the OPEX analysis in the Scenario 0. It is possible to observe that the OPEX remains almost constant along the years, since the composition of the fleet does not change in this scenario. The effect of the possible revenue from the old batteries is very low, just 1M€ (0.29%) in 2025.

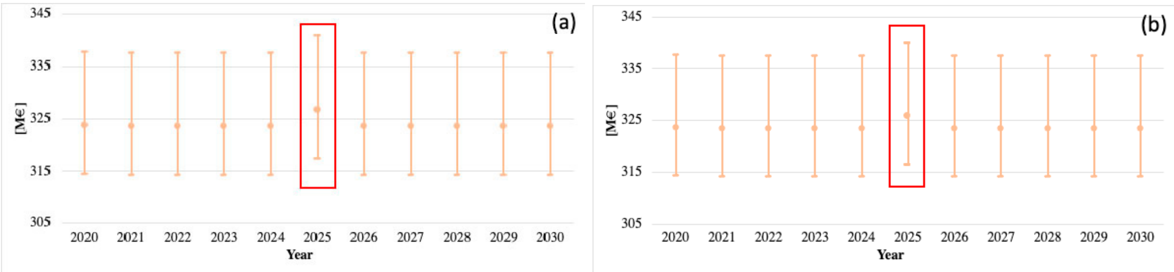

Fig. 3. Box Plot of OPEX related to Scenario 0: (a) Hypothesis 1 and (b) Hypothesis 2.

With reference to Scenario 2 (Figure 4), in which all the busses are replaced by 2026. Scenario 2 has a lower OPEX than the Scenario 1 because electric buses have lower operation and maintenance costs than diesel buses. It is possible to observe that the OPEX change in the period between 2027 – 2030. The possible revenue from old batteries in this case is more significant than in the Scenario 0 (see Figure 5).

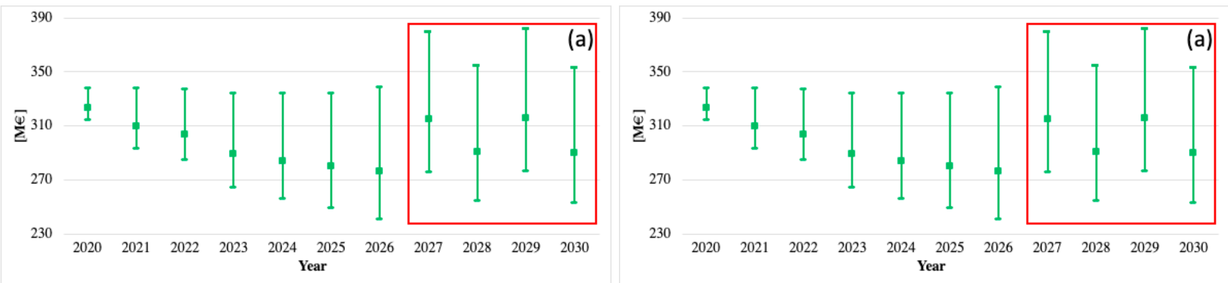

Fig. 4. Box Plot of OPEX related to Scenario 2: (a) Hypothesis 1 and (b) Hypothesis 2.

Figure 5 shows the box plot for the Scenario 1 into hypothesis. While the Scenario 0 has an almost constant OPEX, Scenario 1 shows a variation of 11.9% from 2026 to 2027.

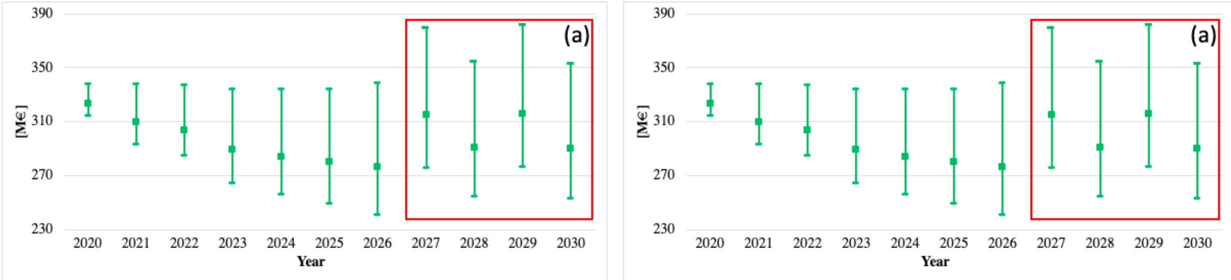

Fig. 5. Box Plot of OPEX related to Scenario 1: (a) Hypothesis 1 and (b) Hypothesis 2.

Considering the OPEX analysis, a summary for the three scenarios considering the two hypotheses is shown in Figure 6. It can be seen that scenario 0 has a constant trend over time (orange line), while scenarios 1 and 2 foresee a decrease until the year 2026 and then two peaks: the first in 2027 and the second in 2029.

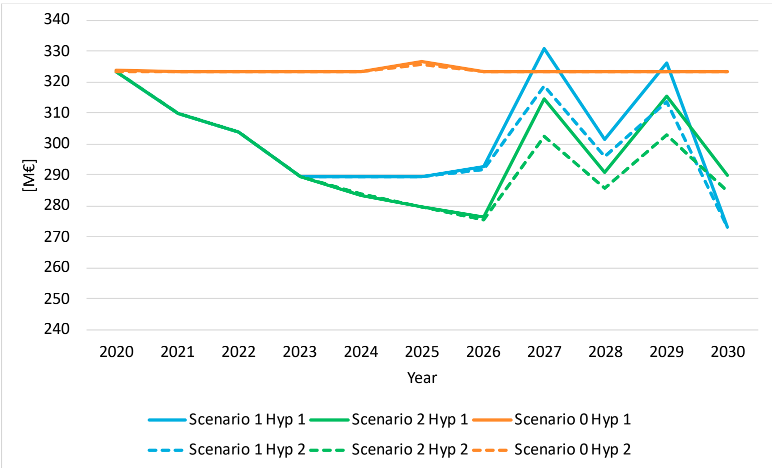

Fig. 6. OPEX representation the three scenarios analyzed.

3.4. Total Expenditure

It is important to note that, although the impact of the hypothesis previously described (possible second life of batteries) is very low along studied time intervals with a mixed fleet, it is probable that this impact will be higher in the years after year 2030, with a full electric fleet running. It is also interesting to evaluate the total expense year by year, where some remarks can be asserted:

- The possible second life of batteries has a neglectable impact on the total cost of the project. It may play an important role in the future costs of the electric bus system after 2030, but that analysis is out of the scope of this study.
- The electrification project does not imply a high increase of the bus systems expenditure. The total expense of the Scenario 1 is just 13.7% (about 530M€) higher than in the Scenario 0.
- Scenario 2 has a very low impact on the total expenditure, especially if the differences in terms of residual value of the fleet are considered. Therefore, to evaluate the convenience of this anticipation, other types of

studies should be conducted, such as analyses on the environmental impact, the possibility of external investors or foreseeable future changes of the technology.

Figure 7 represents the trend of cumulative expenditure for each Scenario analyzed.

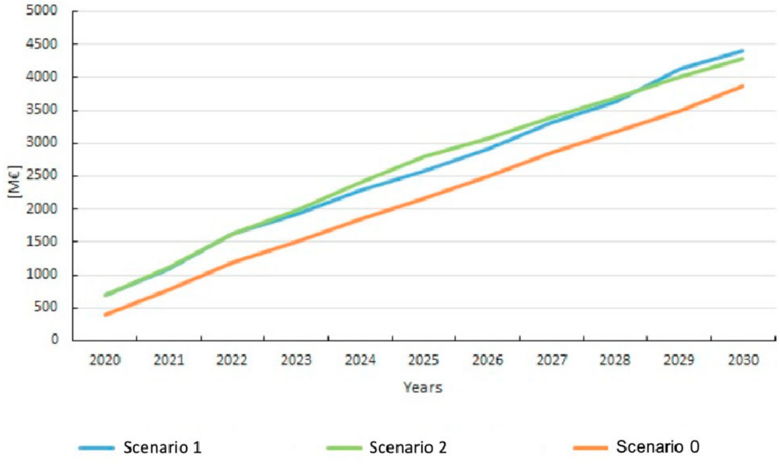

Fig. 7. Cumulative total expenditure for each Scenario.

4. Sensitivity analysis

The aim of the sensitivity analysis is to highlight and discuss the differences that could happen related to the assumptions and parameters used in the previous evaluation. The analysis performed is on the cost of buses and battery costs. A decrease of the price of the buses of 10% can be reasonable because, especially in European countries, there will be more suppliers of electric buses to reach the goal of the European targets. Starting from the analysis on the total expenditure related to the cost of buses, it is possible to note that assuming a 10% decrease in the purchase price of buses after 2025, the situation on the total expenditure changes: the cost of the Scenario 1 becomes lower than the cost of the Scenario 2. Therefore, under this assumption, the Scenario 1 is more favorable than the Scenario 2, even if the advantage of Final Residual Value (FRV) remains. A second issue concerns the battery cost analysis; assuming a 10% decrease in battery cost after 2025 it follows that there is not much difference between Scenario 1 and Scenario 2. In fact, in Scenario 1, 863 batteries need to be replaced; while in Scenario 2, 738 batteries need to be replaced. Figure 8 shows the expenditure comparison with 10% decreasing for busses and battery cost.

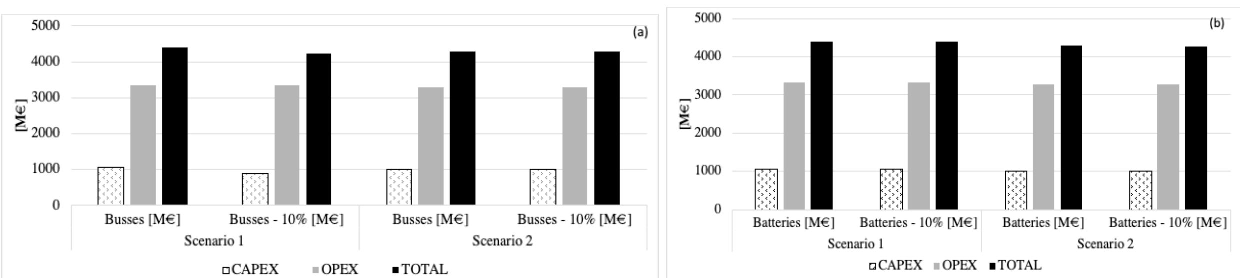

Fig. 8. Expenditure comparison with 10% decreasing (a) busses cost and (b) battery cost.

5. Conclusions

The main goal of this work is to perform a preliminary analysis about the feasibility and implications of the ongoing Full Electric project implemented by ATM, the public company that manages the collective transport in Milan (Italy). The project aims to upgrade the bus system by creating a fleet composed by 1150 full electric buses by 2030 (Scenario 1). In addition to that, a second goal is to analyze the convenience of anticipating the full electrification of the fleet in 2026 (Scenario 2), when the Winter Olympic Games will take place in Italy in Milan and Cortina. In addition, some sensitivity analyses were performed with reference to bus and battery cost. After the several analyses and evaluations carried out along this work, it is possible to extract some conclusions:

- Anticipating the deadline of the project from 2030 to 2026 would decrease the total expenditure of 2.4%.
- The OPEX of anticipating at 2026 is more favorable than the actual target of 2030 for 1.4%.
- The total expense of the Scenario 1 is 13.7% (about 530 M€) higher than in the Scenario 0.
- Future possible variations of the electric bus costs could make the Scenario 1 more favorable than the Scenario 2.
- Even while carrying out an electrification project, the OPEX are around three times higher than the CAPEX.
- Revenue generated by selling the used batteries taking into account the hypotheses in which the second life of the battery generates a revenue equal to 30% of its initial cost, does not have a significant impact on the total expenditure of the project.

Possible developments of the work may concern an environmental impact analysis considering for example CO_2 production and noise pollution. In addition, other kinds of analysis can be carried out, such as cost-benefit analysis and/or multi-criteria analysis, in which different elements and parameters can be considered in order to assess the validity and effectiveness of the study from different points of view. Regarding the sensitivity analysis, a variation of the discount rate currently equal to 0% could also be considered. Finally, this study can also be used to perform evaluations in other contexts to support decision-making about e-mobility planning policies. Finally, it will also be important to consider the energy mix related to power generation in order to verify the effectiveness of the project as a whole.

References

Abdelaty, H., Mohamed, M., 2021. A Prediction Model for Battery Electric Bus Energy Consumption in Transit. Energies, 14, 2824. Available at: https://doi.org/10.3390/en14102824

An, K., 2020. Battery electric bus infrastructure planning under demand uncertainty. Transportation Research Part C: Emerging Technologies, 111, 572-587. doi:10.1016/j.trc.2020.01.009

ATM. Available at: https://www.sustainable-bus.com/interview/atm-milano-electric-buses-are-the-present/ (Last update 10 April 2021)

Carnevale, P., Sachs, J.D, 2019. Roadmap to 2050: A Manual for Nations to Decarbonize by Mid-Century. Published by Sustainable Development Solutions Network (SDSN) and Fondazione Eni Enrico Mattei (FEEM).

European Commission. Available at: https://ec.europa.eu/info/food-farming-fisheries/farming/international-cooperation/international-organisations/g20_en (Last update 10 April 2021)

Ke B-R, Chung C-Y, Chen Y-C., 2016. Minimizing the costs of constructing an all plug-in electric bus transportation system: a case study in Penghu. Appl Energy; 177:649–60.

Meishner, F., & Sauer, D. U., 2020. Technical and economic comparison of different electric bus concepts based on actual demonstrations in european cities. IET Electrical Systems in Transportation, 10(2), 144-153. doi:10.1049/iet-est.2019.0014

Paul T, Yamada H., 2014. Operation and charging scheduling of electric buses in a city bus route network. IEEE 17th International Conference on Intelligent Transportation Systems (ITSC). Qingdao, China pp. 2780-2786.

Pietrzak, O., Pietrzak, K., 2021. The Economic Effects of Electromobility in Sustainable Urban Public Transport. Energies,14,878. https://doi.org/10.3390/en14040878

Wang, J., Kang, L., & Liu, Y., 2020. Optimal scheduling for electric bus fleets based on dynamic programming approach by considering battery capacity fade. Renewable and Sustainable Energy Reviews, 130 doi:10.1016/j.rser.2020.109978

Wang Y, Huang Y, Xu J, Barclay N., 2017. Optimal recharging scheduling for urban electric buses: a case study in Davis. Transp Res: Part E: Logist Transp Rev 2017; 100:115–32

Wen M, Linde E, Ropke S, Mirchandani P, Larsen A., 2016. An adaptive large neighborhood search heuristic for the electric vehicle scheduling problem. Comput Oper Res; 76:73–83.

U.S. Customary Units, "Transit Capacity Manual". Available at: http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_webdoc_6-b.pdf (Last update 10 April 2021)