Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 58 (2021) 103–110

Transportation Research Procedia

www.elsevier.com/locate/procedia

14th Conference on Transport Engineering: 6th – 8th July 2021

Charging operations in battery electric bus systems at the depot

Magín Campos[a,*], Josep Mensión[b], Miquel Estrada[a]

[a]Barcelona School of Civil Engineering. Universitat Politècnica de Catalunya · BarcelonaTech, C/ Jordi Girona 1-3 Edificio B1, Barcelona 08034, Spain

[b]Transports Metropolitans de Barcelona, Calle 60 n.º 21-23 sector A Polígono Industrial de la Zona Franca , Barcelona 08040, Spain

Abstract

This paper analyzes the effect of the limited range of battery electric bus on the operation of the bus services charged at the bus garage. A model has been built to calculate the performance of the routes according to the type of charging scheme. It evaluates the total cost of the bus service, considering the necessary resources due to range limitations and electric constraints. Based on the analysis of the real data of a bus line in the city of Barcelona, diesel or hybrid vehicles are still found to be more competitive than electric vehicles because of the acquisition costs of electrical technology. The study shows that the charging operation at the bus garage, without being the most profitable option a priori, is adequate when the design and operation parameters of the bus route fall below certain values.

Keywords: battery electric bus; overnight charging

1. Introduction

Most of the largest bus fleets in our cities are made up of traditional vehicles that present internal combustion engines (ICE). A large part of the pollutants present in urban areas can be attributed to these vehicles, which contribute to the global warming problem and affect the health of citizens in metropolitan areas. Changing this type of vehicle to fully electric fleets would contribute to reducing carbon dioxide (CO2) emissions, reducing the consumption of fossil fuels, and improving energy efficiency, as can be seen in Jang et al. (2016), Corazza et al. (2016), Miles and Potter (2014) and Zhou et al. (2016).

Fully electric fleets involve the use of battery electric buses (BEB), whose only source of energy is a battery pack equipped on board. Charging these batteries can be done in various ways, but the most common are opportunity

---

* Corresponding author. Tel.: 34-934017090
E-mail address: magin.campos@upc.edu

10.1016/j.trpro.2021.11.015

charging during the service and overnight charging (Miles and Potter, 2014). Opportunity charging is performed on the street using fast chargers, which take 5-10 minutes to restore full power. Overnight charging is performed in the bus garage, using slow or fast chargers, while the vehicles are not in service. In the case of overnight charging the battery size is significantly larger than in the opportunity charge to provide large travel ranges between two consecutive charging operations. This means long charging times (up to 5 hours).

To guarantee a wide deployment of BEB in cities, it is necessary to consider new operations and the limitations that their use implies in bus fleets, as explained in Mahmoudzadeh et al. (2017). In Li (2014) the operational limitations of these vehicles and the effect of different factors (driving, air conditioning, etc.) on energy consumption are explained. Likewise, Xylia and Silveira (2018) show the results of experimental implementations of electric buses in Europe.

A basic point in the implementation of BEB is its implementation cost. As shown in Teoh et al. (2017) and Feng et al. (2013) the cost of capital and the cost of charging stations are significantly high. On the contrary, this type of bus can reduce operating costs by up to 80% compared to ICE vehicles. In this way, it turns out that the total cost of ownership (TCO) and the life cycle cost of BEB are essential to evaluate the profitability of their implementation. In this sense, Lajunen (2014) presents an in-depth analysis of the TCO of electric buses, the conclusions of which show that there is a lot of uncertainty in its estimation.

In Lajunen and Lipman (2016) we can find a broad life cycle analysis for different bus technologies, considering capital, maintenance, energy consumption and emission costs. Here it is shown that diesel hybrid buses are still competitive in terms of life cycle cost with respect to other powertrains, but it is suggested that improved BEB will be able to compete with diesel and natural gas in the future. Another important point indicated in this work is that a significant public investment is necessary to create efficient fast charging infrastructures.

Regarding the influence of energy demand on the provision of bus services, we can highlight the work of Vepsäläinen et al. (2018), where the effect of a wide list of factors and characteristics of the route is analyzed, validating a predictive model of electricity demand. Bi et al. (2017) analyze the life cycle cost of charging infrastructure, comparing conductive and inductive systems. And, for their part, Chen et al (2018) compare the profitability of charging lane technologies, charging stations and battery exchange stations.

In this paper, the effect of the new requirements of battery electric vehicles on the operation of the bus services charged at the garage is analyzed. To do this, a model has been developed, that analyzes the most suitable charging operation and performance. They are evaluated based on the total cost of the system on a given bus route, and the calculation of the resources required due to electrical limitations. The model considers two different charging strategies or schemes: garage charging (day or night) and opportunity charging at bus terminal stations on the given route. The modeling of the charge at the garage is based on the proper scheduling of the vehicle deadheading movements to the garage, to satisfy the electrical limitations and the attributes of the service.

An improvement procedure has also been incorporated to optimize the total cost of the system, based on advancing the charging operations before the moment when the vehicles begin to run out of battery, similar to Gao et al. (2017). This minimizes the additional vehicles required, compared to the usual procedure where charging operations are performed just when the vehicles are running out of power.

Finally, the calculation of the performance and the resources required in the opportunity charging is based on the queue theory at the charging facilities, taking into account the irregular arrivals of buses to the on-route chargers and the available loading time. This severely limits the viability of electrical systems on routes with busy headways.

2. Modeling framework

2.1. Problem formulation

We consider a linear bus route of length $2L$, where the buses travel in two directions and the stops are evenly spaced at a distance s. Buses can enter and exit service only at the terminal stop furthest from the garage, located l_G units away.

We assume that the bus service is performed in a period of time h_{day} on a typical day, with N stationary periods or time windows of size hi $(i = 1 \dots N)$, in which the external variables of the system, such as hourly demand Λ_i and the cruising speed v_i, remain constant. It is assumed that the duration of the stationary periods is greater than the dead times of traveling to the garage, that is $(2l_G / v_i) \ll h_i$. Furthermore, a constant time headway H_i is assumed for each time window. The number of necessary vehicles $M^0(i)$ and the commercial speed $vc^0(i)$ in time window i when no charging operation is required, are defined in Equation (1). From now on, the superscript *0* represents the value of the corresponding variable when the electric charge operation does not affect it, and the superscript *1* the opposite case. We also assume that at the end of the last stationary period an additional period of time of length h_{night} begins in which there is no bus service. All vehicles are sent to the garage for maintenance until the next day.

$$M^0(i) = \frac{2L}{H_i v_c^0(i)} \tag{1}$$

Using this notation, the fleet size required for bus route operation on a typical day would be $M_T^0 = max\, M^0(i)$. Said fleet size will not be constant, but we will have a fleet size variation $\Delta M^0(i)$ defined in Equation (2) and for which $M^0(0) = 0$ veh. This assumes that in each period there will be a number of vehicles introduced on route $M_{in}^0(i)$ and a number of vehicles removed from route $M_{out}^0(i)$ at the beginning of period i. These variables will be equal to zero if there are no restrictions that affect the autonomy of the vehicles, but they will present a positive value when the electric vehicles run out of batteries and must be charged.

$$\Delta M^0(i) = M^0(i) - M^0(i-1) = M_{in}^0(i) - M_{out}^0(i) \tag{2}$$

The energy consumption of a vehicle is calculated by the product of the distance traveled by the energy consumption factor associated with the vehicle technology in service f_C (kWh/veh-km). The effective capacity of the batteries is calculated by $E = E'(1-SOC_{min})$, where we subtract from the nominal capacity of the battery E' the minimum energy value ($E' * SOC_{min}$) that the buses need at any time of service in emergency case. This minimum value depends on the minimum threshold for the state of charge of the batteries (SOC_{min}) defined by the manufacturer.

If in a time period *k* vehicles are introduced into the system ($M_{in}(k) > 0$), it will be necessary to check whether these vehicles can provide service throughout the day or should be recharged in an intermediate period j> k. We define the energy consumed by the vehicle until the beginning of period *i* as *C(i)* (determined by Equation 3) and the energy remaining in the battery at the beginning of period *i* by *B(i)*. For the vehicle to be able to provide service up to a period of time *i*, Equation (4) must be fulfilled, where *B(k)* represents the energy available when the vehicle was introduced in the period of time *k*. We generally assume *B(k) = E'.*

$$C(i) = f_c \sum_{j=k}^{i-1} h_j v_c(j) \tag{3}$$

$$B(i) = B(k) - C(i) \geq 0 \qquad k < i \tag{4}$$

We will define $T_{end}(i) = T_R(i) + \sum_{j=1}^{i-1} h_j$ as the absolute time in which the vehicles entered into the service at the beginning of time window *i* will remain without batteries, where $T_R(i)$ is the maximum operating time of the vehicles that start in the period of time *i*. To calculate this value, we need to know how many full-time windows and how long in the next time window (t_{k^*}) the vehicle will be able to travel until the batteries are exhausted, which results from solving Equation (5). In this way we can rewrite $T_R(i)$ as $T_R(i) = \sum_{j=i}^{k^*-1} h_j + t_{k^*}$.

$$t_{k^*} | \quad E = f_C\left(\sum_{j=i}^{k^*-1} h_j v_c^0(j) + t_{k^*} v_c^0(k^*)\right) y \;\; 0 \leq t_{k^*} < h_{k^*} \tag{5}$$

A vehicle entered in time window *i* will run out of batteries in time window $N_{end}(i)$, the calculation of which involves complying with Equation (6). With the values of $T_{end}(i)$ and $N_{end}(i)$ we can define exactly the moment when a vehicle entered in the time window *i* needs a charging operation. We will consider that if a vehicle entered in time window *i* has enough charge to complete the service until the end of the day, then $N_{end}(i) = N + 1$.

$$\sum_{j=1}^{N_{end}(i)-1} h_j \leq T_{end}(i) < \sum_{j=1}^{N_{end}(i)} h_j \tag{6}$$

In this way, it will not be necessary to carry out charging operations during the h_{day} service period when $T_{end}(1) > h_{day}$ and $N_{end}(1) = N + 1$. In this case, the transport company can only carry out the night charging scheme in the garage (G-Scheme) if the h_{night} period is long enough to fully charge the battery pack. Under these conditions, the stored energy $B^0(i)$ will always be positive.

2.2. Overnight charging operations at the bus garage

In this case, we are going to consider that the buses are charged in the garage with slow chargers (with speed S_N) in the period of non-provision of the transport service, this being a complementary charging operation of the daily load in the garage (with speed $S_D > S_N$). In this way, the vehicles charged in this period can be used the next day according to service needs.

We will call T_{el} the moment at which the night charge scheme (G-Scheme) begins with respect to the initial service time, and N_{el} the time window after which the night charge begins ($T_{el} = \sum_{i=1}^{N_{el}} h_i$). The vehicles recharged at night must be those that belong to the subset $M_{inv,N}(i)$ in each period of time $i \leqslant N$.

To simplify the problem, we will assume that all daily services present the same stationary periods, demand, speeds and, therefore, vehicle needs in each time window $i = 1 \dots N$. However, if the services corresponding to different days have different temporal patterns, this methodology can be easily adapted.

With these premises, Equation (7) shows the condition to be fulfilled in order to fully charge the batteries at the beginning of the period of time k, when the vehicle has arrived at the garage in period i of the previous day. If this condition is not met, it is not possible to recharge the batteries between time periods i and k.

$$E' < \left\{\left(h_{day} + h_{night} + \sum_{m=1}^{k-1} h_m\right) - \sum_{n=1}^{i-1} h_n\right\} \frac{1}{S_N} \tag{7}$$

3. Cost analysis

The total cost of a day of service for the transport company will be calculated by $Z = Z_M + Z_B + Z_V + Z_C$, where ($Z_M$) represents the sum of the depreciation of the vehicle plus labor costs, (Z_B) is the cost of batteries, (Z_V) is the cost of the distance and (Z_C) is the cost of the charging infrastructure.

We will consider here a series of operational parameters that directly affect the variable costs of transport companies. The first of these is the total distance traveled by the bus fleet during the entire day of service, calculated as vehicles-kilometer traveled in one day, VKT (veh-km/day). The second in importance is the total time that the vehicle-driver pair is providing service throughout the day, either on the corresponding route or in the dead movement to the garage, defined as the vehicle-hours traveled in service, VHT (veh-h/day). Finally, the vehicle-hours depreciated throughout the day, VHD (veh-h/day), will be calculated, representing the total number of vehicles needed throughout the day, either on the road or in the garage.

Equation (8) shows the calculation of ZM. In this equation, the cost ratio c_{t1} represents expenses related to drivers, and cost ratio c_{t2} represents vehicle depreciation, insurance, and other fixed costs of the vehicle throughout the day.

$$Z_M = c_{t1} VHT + c_{t2} VHD \tag{8}$$

Equation (9) calculates the cost of the battery, considering the energy capacity of the batteries equipped in each vehicle (E') and the unit cost of the battery per kWh acquired c_b.

$$Z_B = E' \cdot c_b \cdot VHD \tag{9}$$

In Equation (10) the cost of the distance traveled is calculated, where c_d is the unit cost of the distance, which considers the cost of energy to operate the vehicles and other expenses related to the kilometers traveled.

$$Z_V = c_d VKT \tag{10}$$

Finally, Equation (11) calculates the cost of the charging infrastructure. Here, the c_{cg} parameter considers the cost of capital and the daily operating cost.

$$Z_C = c_{cg}\left(N_{ch,N}\right) \tag{11}$$

4. Results

To verify the goodness of the generated model, an analysis of a real case of a bus line in the city of Barcelona has been carried out. Within the city's urban bus network, route V13 has been selected, on which the model has been applied to calculate the costs of the bus company when implementing a fully electric bus service with its auxiliary charging facilities.

In the short-term scenario, the values obtained in pilot tests in Barcelona for the operational parameters of the service and the average cost of capital in developed countries have been considered for the analysis. On the other hand, other scenarios have been considered and sensitivity analysis have been carried out to estimate the influence of the cost of electrical technology on long-term efficiency.

The reference values for the analysis of the performance of the battery, the charger and the electric vehicle, as well as those necessary to compare with the diesel and diesel-hybrid engines, have been obtained from the operational data monitored by the TMB bus operator in 2018 (TMB, 2018).

4.1. Discussion

Table 1 shows the values obtained for the most significant variables of the model carried out. With these values, it is possible to analyze the operational performance of the route, the amount of resources required, and the operational costs for the different types of engine and bus loading schemes on route V13 in the city of Barcelona.

Table 1. Modelling results for different vehicle technologies and charging schemes in route V13

	Diesel	Hybrid	Electric		
			G-Charge Opt.	O-Charge Reg.	O-Charge Skip
VHT (Veh-h/day)	281.5	281.5	281.5	291.9	281.5
VHD (Veh-h/day)	456.0	456.0	456.0	480.0	456.0
VKT (Veh-km/day)	2974.2	2974.2	2974.2	3010.6	2974.2
Charging/Fuel stations	1	1	0	0	0
Opportunity chargers	0	0	0	2	2
Overnight chargers	0	0	10	2	9
Fleet size (veh)	19	19	19	20	19
Z_M (Euros/day)	17,215.1 €	17,639.2 €	18,122.6 €	18,911.6 €	18,122.6 €
Z_V (Euros/day)	4,491.0 €	3,212.1 €	2,260.4 €	2,288.1 €	2,260.4 €
Z_C (Euros/day)	109.7 €	109.7 €	283.8 €	214.8 €	352.0 €
Z_B(Euros/day)	0.0 €	0.0 €	1,191.2 €	1,253.9 €	1,191.2 €
Z (Euros/day)	21,815.8 €	20,961.0 €	21,857.9 €	22,668.3 €	21,926.0 €

As we can see, the operating cost of fully electric vehicles is slightly higher than the cost corresponding to diesel or hybrid vehicles. This is because BEB technologies are more expensive than diesel and hybrid vehicles. In this way, the cost savings that can be obtained in the operation do not compensate for the higher cost of electric vehicles and batteries. However, the variation in operating cost between the different alternatives analyzed stands at 4%, so it is to be expected that a reduction in the prices of batteries and electric vehicles in the near future due to the maturity of these technologies will favor a competitive advantage of BEB systems.

Regarding the distribution of system costs, the time component of the cost (depreciation of the vehicle plus labor costs) is the most important in all cases (83% in BEB systems, 80% in ICE and 85% in hybrids), followed by the distance-based component (10% in BEB systems, 20% in ICE and 15% in hybrids), with the cost of batteries being 6% and the cost of installing charging systems 1% in the BEB systems. With these values, the G-Charge charging scheme can equalize the costs of diesel and hybrid systems if the price of vehicles and batteries decreases by 28% and 2%, respectively.

For the route that has been analyzed in this case, the most suitable BEB alternative is night charging in the garage (G-Charge). This is due to the fact that the buses have large battery packs to ensure their operation throughout the working day, which makes the size of the fleet in this case equal to that required in ICE and hybrid technologies. On the other hand, if the opportunity charge is used in the regular option (O-Charge Regular), it would be necessary to increase the size of the fleet in a vehicle with respect to the G-Charge scheme or the diesel system. This increase is justified by the time spent on the chargers installed on the street after completing each round trip on the route. To equalize the total cost of the G-Charge scheme, the company should skip the charge operation in predefined time windows throughout the day (O-Charge Skip).

4.2. Sensitivity analysis

The sensitivity analysis carried out aims to analyze the influence of the variation in battery capacity. For this, the same type of BEB analyzed in the real route V13 of Barcelona has been maintained, but allowing to modify the size of the battery pack installed in it. A variable energy consumption factor that depends on the weight of the batteries has been considered, as described in Gao et al. (2017). With the values of the analyzed route, a consumption factor - battery capacity relationship equivalent to $f_c = 0.0005E' + 1.2243$ *(kWh/km)* has been obtained for standard buses.

For the route analyzed, the most profitable charging scheme is the one of opportunity that allows to skip charging operations in certain periods of time (O-Charge Skip), provided that the capacity of the batteries is $E' \leqslant 275$ kWh, as you can see at Figure (1). On the other hand, if the omission of charge is not allowed in the opportunity charge (O-Charge Regular), it turns out that it is much more expensive than the optimal charge in the garage (G-Charge Optimum) for a capacity $E' > 250$ kWh .

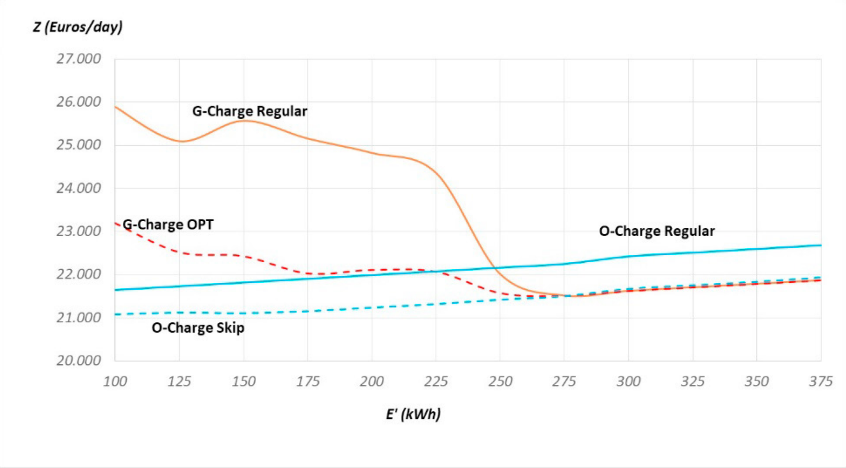

Fig. 1. Total cost in the different charging schemes versus battery capacity

If we increase the capacity of the installed batteries, the cost of the O-Charge system increases linearly, thus approaching the cost of the G-Charge system. In this way, if the capacity of the batteries increases (E’> 275 kWh), the charge in the garage (G-Charge Optimum and G-Charge Regular) presents the same performance as the O-Charge scheme. In fact, the threshold E'= 275 kWh defines the minimum battery pack to provide all-day service on G-Charge.

With a capacity E'<275 kWh, the smaller the battery pack, the more vehicles are required in G-Charge Optimum. This means that G-Charge Optimum presents a monotonous decreasing fleet size with respect to the battery capacity until reaching the value E'= 275 kWh, which does not happen in the G-Charge Regular scheme.

An interesting fact is that in the G-Charge scheme the size of night charging facilities is minimal when the size of the fleet is maximum. This is because a charger can serve more vehicles in the night period the smaller the battery pack is and because there are idle vehicles that can be charged at time $t > T_{cl}$.

5. Conclusion

After the analysis carried out, we can conclude that the costs of current BEB technologies are even higher than conventional ICE or hybrid technologies. However, this cost difference is at a fairly low level, located in a range of 4 to 8%, thus a reduction in the acquisition costs of electrical technology, combined with the greater awareness of reducing polluting emissions makes electric buses a more attractive option for companies. With the results of the line analyzed in Barcelona, a battery cost of less than € 300 / kWh and a reduction in the purchase cost of vehicles of 12% - 30% are needed, so that BEB systems will be more efficient than the ICE and hybrids, respectively.

It is important to note that operation with BEB implies a personalized design of the vehicle in terms of batteries and charging system, depending on the characteristics of the route to be served. This makes BEB vehicles, unlike ICE or hybrids, only interchangeable on routes with similar characteristics. If this premise is not met, it is very possible that the transport company needs to increase the size of its fleet to guarantee the correct provision of the service. Therefore, we can conclude that BEB technology does not allow flexible fleet management.

From the sensitivity analysis carried out, we can infer that the O-Charge opportunity charging system is always more profitable than the G-Charge garage charging if the service shows good regularity and the chargers are at the terminal stops along the route. As a condition it is necessary that the minimum capacity of the batteries is 100-125 kWh to guarantee a complete circuit. This charging system can be enhanced by allowing vehicles to skip charging during peak periods. This reduces vehicle travel times and equates the necessary fleet to that of ICE technology. In this sense, it is shown that it is more appropriate to carry out a configuration of several chargers in a single terminal stop of the route (scheme N-0) than to have chargers in both terminal stops (scheme N-N), which is only profitable on very long routes where the capacity of the batteries could not guarantee a complete round trip route. Therefore, if the loading operation can be skipped in the time windows of higher demand, the cost of the company can be reduced by 3 - 4%.

When the urban structure hinders or prevents the implementation of opportunity chargers at the terminal stops of the routes, the increase in the distance to travel to carry out the loading operation penalizes the opportunity load, favoring the use of the load in the garage. In this case, the garage charge equals the fleet size of the opportunity charge as long as the batteries have a capacity greater than 300-375 kWh, although it increases the cost of the batteries and requires long charging intervals.

On the other hand, if we analyze routes with low service regularity or routes with short distances, we obtain that the time spent charging is critical to guarantee the correct provision of the service. For this reason, the location of various tandem charging areas is required, which is difficult to implement in consolidated urban areas with a shortage of available public space and penalizes the opportunity charging system.

In this way, if we cannot implement the proper design of the opportunity charging facilities, we favor the use of garage charging. In this case, the buses must incorporate large capacity batteries to avoid having to go to the garage to charge during the service. If this is not fulfilled and the capacity of the batteries does not guarantee the complete provision of the service, it is necessary to increase the fleet to replace the vehicles that have to go to the garage to charge during the day.

In the analyzes carried out, a much higher performance of the G-Scheme Optimum algorithm has been demonstrated over the G-Scheme Regular algorithm, which tells us that we should not wait until the vehicles are about to exhaust the capacity of the batteries to perform the charge, but it is more appropriate to have a small additional fleet that begins to replace the buses from the start of the service.

References

Ajuntament de Barcelona, 2018. Dades bàsiques de mobilitat. Informe 2017.

Chen, Z., Yin, Y., Song, Z., 2018. A cost-competitiveness analysis of charging infrastructure for electric bus operations. Transportation Research Part C 93, 351–366.

Corazza, M.V., Guida, U., Musso, A., Tozzi, M., 2016. A European vision for more environmentally friendly buses. Transportation Research Part D: Transport and Environment 45, 48-63.

Feng, W., Figliozzi, M., 2013. An economic and technological analysis of the key factors affecting the competitiveness of electric commercial vehicles: A case study from the USA market. Transportation Research Part C: Emerging Technologies 26, 135-145.

Gao, Z., Lin, Z., Laclair, T. J., Liu, Ch., Li, J.M., Birky, A.K., Ward, J., 2017. Battery capacity and recharging needs for electric buses in city transit service. Energy 122, 588-600.

Jang, Y.J., Jeong, S., Lee, M.S., 2016. Initial energy logistics cost analysis for stationary, quasi-dynamic, and dynamic wireless charging public transportation systems. Energies 9 (7), 483.

Lajunen, A., 2014. Energy consumption and cost-benefit analysis of hybrid and electric city buses. Transportation Research Part C 38, 1–15

Lajunen, A., Lipman, T., 2016. Lifecycle cost assessment and carbon dioxide emissions of diesel, natural gas, hybrid electric, fuel cell hybrid and electric transit buses. Energy 106, 329–342.

Li, J.Q., 2014. Transit bus scheduling with limited energy. Transport. Sci. 48, 521–539.

Mahmoudzadeh Andwari, A., Pesiridis, A., Rajoo, S., Martinez-Botas, R., Esfahanian, V.A., 2017. Review of Battery Electric Vehicle Technology and Readiness Levels. Renewable Sustainable Energy Rev. 78, 414−430.

Miles, J., Potter, S., 2014. Developing a viable electric bus service: the Milton Keynes demonstration project. Res. Transp. Econ. 48, 357–363.

Teoh, L.E., Khoo, H.L., Goh, S.Y., Chong, L.M. 2017. Scenario-based electric bus operation: a case study of Putrajaya, Malaysia. International Journal of Transportation Science and Technology 7:1, 10-25.

TMB (2017). Operabilitat de les noves línies de busos elèctrics: el cas pràctic de l'H16. ZeEUS Project. Personal communication.

TMB (2018). Total cost of ownership of diesel, hybrid and electric vehicles in Barcelona. Transports Metropolitans de Barcelona. Personal communication.

Vepsäläinen, J., Kivekäs, K., Otto, K., Lajunen, A., Tammi, K., 2018. Development and validation of energy demand uncertainty model for electric city buses. Transportation Research Part D 63, 347–361.

Xylia, M., Silveira, S., 2018. The role of charging technologies in upscaling the use of electric buses in public transport: Experiences from demonstration projects. Transportation Research Part A 118, 399–415.

Zhou, B.Y., Wu, Y., Zhou, B., Wang, R.J., Ke, W.W., Zhang, S.J., Hao, J.M., 2016. Real-world performance of battery electric buses and their life-cycle benefits with respect to energy consumption and carbon dioxide emissions. Energy 96, 603–613.