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Original Research Article

How battery electric vehicles can contribute to sustainable urban logistics: A real-world application in Lisbon, Portugal

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ABSTRACT

Concerns with environmental impacts of urban mobility have led to the development of alternative solutions, such as battery electric vehicles (BEV), highly applicable to certain sectors namely in urban logistics, since BEV powertrain characteristics are extremely suited for urban driving context. This research work evaluates the adequacy of BEV in urban logistics in Lisbon, based on a real-world application. Vehicle second-by-second data was collected during regular operation of both the internal combustion engine vehicle (ICEV) and the BEV (for 7 and 3 months respectively). The results demonstrate that BEV allows maintaining the same operation patterns, regarding the number of kilometers travelled per day (60 km), recharging time (6 h), and vehicle dynamics (average speed of 16 km/h for ICEV and 19 km/h for BEV). When comparing the energy impacts of shifting to electric mobility, the BEV allows reducing vehicle usage energy consumption by 76% and by 57% when considering the energy production stage. The logistics operations performance was not affected by the vehicle technology shift, since the operational requirements of the service were maintained and no issues on electric autonomy and recharging periods were observed, confirming the suitability of this vehicle technology for specific urban logistics applications.

Introduction

Over half of the world population lives in urban areas [1], creating enormous challenges in terms of urban mobility, namely due to congestion problems, private transport dominance, air quality, noise and energy dependency issues [2]. The transportation sector is one of the major sources of local pollutants (such as carbon monoxide – CO, particulate matter – PM, hydrocarbons – HC, nitrogen oxides – NO_x, etc.) [3] and, consequently, air pollution has become one of the major concerns for those who live and work in these areas. Local pollution is known to have negative impacts on human health [4], leading to the introduction of guidelines regarding their emission limits [5]. Urban mobility also presents an increasing energy demand aggravated by dependency on fossil fuels [6] and noise problems in urban centres [7] is also a cause for concern.

Therefore, the introduction of alternative solutions to overcome all these issues is of crucial importance. In Europe, a strong effort to reduce the transportation sector local emissions has been applied, namely in light-duty vehicles, by introducing stricter Euro standards to regulate exhaust emission of CO, HC, NO_x and PM [8]. Furthermore, an agreement between European Commission and vehicle manufacturers has also been established to improve the overall vehicle's energy efficiency, by setting a target of 95 g/km of CO_2 in new vehicle sales in 2021 [3].

The fulfilment of these targets has led conventional technologies to become more efficient and with lower emissions of local pollutants. Additionally, alternative vehicle technologies have been introduced in an attempt to improve vehicle efficiency and reduce emissions (e.g. hybrid electric vehicles, plug-in hybrid electric vehicle, battery electric vehicles). These technologies address urban mobility challenges while being approximately 3 times more efficient [9], eliminating local emissions and significantly reducing noise [10]. However, the share of these vehicles in the market is generally low and the impacts of these technologies are not immediate, due to the slow fleet turnover associated to fleet renewal [11].

Urban logistics operations are responsible for one of the most important vehicle flows in urban centres, accounting for 8–15% of total traffic flow in urban areas [12]. Due to the intensive type of service provided within urban areas on a daily basis [12], it is an important sector concerning air quality in cities. As a result, the use of alternative vehicle technologies is seen as adequate for

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urban logistics, since the BEV powertrain characteristics are extremely suited for urban driving context, due to low power requirements and high braking regeneration potential [13,14]. For example, BEVs can contribute to reduce some of the environmental burdens of urban logistics, namely due to their zero local pollutant emission, low noise emission and lower dependency on oil price fluctuation compared with conventional propulsion technologies [15]. The use of BEVs for logistics is part of the EU vision for cities in the next decades. As stated in the 2011 EU Transports White Paper [28], one of the ten goals for a competitive and resource efficient transport system is to: "Halve the use of 'conventionally-fuel led' cars in urban transport by 2030; phase them out in cities by 2050; achieve essentially CO_2-free city logistics in major urban centres by 2030". In this sense, electric mobility is seen as a vital part for the EU accomplishment of this "CO_2-free city logistics".

However, the acquisition costs of BEV are still higher than similar vehicles with conventional propulsion technologies [16,17]. This issue is of crucial importance, since it leaves a gap to be filled in the urban logistics business model that currently is reducing the penetration opportunity of these alternative vehicle technologies. Moreover, there are still uncertainties regarding the operational competitiveness of electric trucks when compared to conventional diesel vehicles, which further hinders its wider adoption [18]. Even if the running costs of electric vehicles are reduced, on a total operational cost analysis, the differential is still not favourable to electric vehicles [19]. Furthermore, there is still some uncertainty regarding the price of electricity if electric mobility becomes global [16]. In this sense, the high purchase cost is reported to be the major issue postponing the widespread adoption of electric vehicles [20–22]. Complementarily, the technical limitations of electric vehicles such as limited range, speed, increased weight, and reliability may also contribute to the low adoption levels [18], in spite of the fact that these limitations may be soon resolved through technological improvements.

In terms of recharging infrastructure, EU regulation is likely to become more demanding on the existence of recharging stations, namely with the Directive of the European Parliament and of the Council on the deployment of alternative fuels infrastructure [29], which sets quite high targets on the number BEV recharging stations. For example, in the case of Portugal 123 thousand recharging points are envisaged, as well as 12 thousand publicly assessable.

Several examples of the potential application of electricity based solution in urban logistics have risen. The e-mobility NSR Project [23] performed an assessment of experiences in using electric freight vehicles in almost 60 implementation examples in the North Sea Region (Denmark, Germany, the Netherlands and Norway) gaining an insight into the most important barriers and opportunities. On one hand, the identified barriers were higher vehicle purchase and charging infrastructure costs, smaller size of vehicles or reduced loading capacity which can result in a lower payload, limited vehicle range, uncertainties in vehicle performance and maintenance, vehicle incompatibility with existing public charging infrastructure, need for operational pre-planning due to BEV specificities, etc. On the other hand, the identified opportunities and strengths were the possibility for a company marketing strategy, favourable environmental outcome, higher driver job satisfaction, higher driving comfort, higher driver manoeuvrability, lower operational costs, possibility of use of public charging spots already in place, etc. Specific examples of electric mobility use on urban logistics can be identified, namely the experiences in La-Petite-Reine, Paris, with the use of electric cargo cycles, demonstrating the viability of this transport mode for last-mile delivery. The use of electric bicycles and trucks in London lead to 54% reductions of CO_{2eq} emissions and in Brussels for a 2 year period of operation almost 30 ton of CO_2 emissions were avoided [24,25], which also confirms the suitability of electric mobility in urban delivery applications. The implementation of electric mobility in urban logistics has also been promoted through the development of European Projects. The FR-EVUE Project [26] has enabled the deployment of electric vehicles performing urban logistics services in several European cities, such as Lisbon, Amsterdam and Madrid. These demonstrations have resulted in a "good environmental performance", as well as in a "good technical performance", with companies being satisfied with electric vehicles and often seeking for opportunities to enlarge their BEV fleets [27].

The appearance of examples of electric vehicles applications in urban logistics, when there still are so many uncertainties on their suitability and real-world performance, means that further detailed assessments on these topics must be performed, particularly when BEV usage has already been implemented permanently, beyond pilot test usage. In this context, it is relevant and innovative to evaluate the adequacy and the real-world performance of electric vehicles in urban logistics, so that technical and operational constraints are monitored and assessed in real-world application. This work presents a real-world application of BEVs in urban logistics in comparison with the corresponding internal combustion engine vehicle (ICEV), considering a case-study on park meter maintenance, in which the routes are usually defined daily according with specific circumstances and needs, but always maintaining a similar operation level.

On-road monitoring methodology

Case-study

This work presents the use of electric vehicle in an urban logistics application in the city of Lisbon, in particular the use of BEV for parking meters maintenance, as part of the Lisbon's Municipal Parking and Mobility Company (EMEL). To characterize the effectiveness of the BEV in its operation routines and the potential changes in behaviour, this work was divided in two periods:

- *Period 1*. Real-world conventional technology – ICEV characterization of mobility patterns, energy and environmental impacts (January to July 2014). The monitored ICEV was a Renault Kangoo with 55 kW of maximum power, 180 Nm of maximum torque, 1461 cm^3, 1280 kg of mass and circa 3 m^3 of cargo volume and 650 kg of allowable load.
- *Period 2*. Real-world BEV (in an urban logistics application) monitoring characterization of mobility patterns, energy and environmental impacts (September to November 2014). The monitored BEV was a Renault Kangoo EV with 44 kW of maximum power, 226 Nm of maximum torque, 1426 kg of mass and circa 3 m^3 of cargo volume and 650 kg of allowable load.

This experimental design enabled the characterization of the two periods in terms of mobility patterns (kilometers, time, number of trips, speed, etc.), recharging routines and energy consumption and pollution emissions impacts.

On-board laboratory for data acquisition

The real-world monitoring of the conventional and electric vehicles was done using an on-board monitoring unit. The device used is named I2d (intelligence to drive) [30] and collects, at 1 Hz, information on driving dynamics (speed, acceleration, road topography, etc.) for both ICEV and BEV, as well as engine parameters (such as mass or air flow, engine rpm and load, throttle position, etc.) just for ICEV. The data logger also includes a barometric altimeter to collect road grade and a GPS for positioning and speed.