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From on-road trial evaluation of electric and conventional bicycles to comparison with other urban transport modes: Case study in the city of Lisbon, Portugal

Patrícia Baptista [a,*], André Pina [b], Gonçalo Duarte [a], Catarina Rolim [a], Gonçalo Pereira [b], Carlos Silva [b], Tiago Farias [a]

[a] LAETA, IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal Av. Rovisco Pais, 1, 1049-001 Lisboa, Portugal
[b] IN+, Center for Innovation, Technology and Policy Research, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1, 1049-001 Lisboa, Portugal

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ABSTRACT

Increasing energy costs, energy consumption and emissions profiles prompted the promotion of different transportation alternatives. This research work addresses the comparison of trip dynamics, energy consumption, CO_2 and NO_x Well-to-Wheel impacts of 5 transportation alternatives (conventional and electric bicycles, conventional and electric vehicles and an urban bus) in Lisbon, Portugal. On-road monitoring of a specific route in Lisbon revealed that bikers using electric bicycles increased their average speed between 8% and 26% compared to their use of the conventional bicycle, especially in the route sections with positive slopes (up to 49% increases). Electric bicycles result in a Tank-to-Wheel energy consumption of 0.028 MJ/km, allowing an average autonomy of 46 km between recharging. When comparing the 5 transportation alternatives, the electric bicycles presented a higher travel time of 13.5%, 1.9% and 7.8% over the bus, low powered electric vehicle, and standard electric vehicle/conventional technologies, respectively. Regarding the Well-to-Wheel energy consumption analysis, the results indicated that, when compared to the other transportation solutions, the electric bicycle only uses 11%, 3%, 1%, 2% and 4% of the energy required when using the low powered electric vehicle, standard electric vehicle, conventional gasoline and diesel technologies and bus, respectively. Furthermore, the analysis of Well-to-Wheel emissions reveals that the electric bicycle has 13% and 4% lower CO_2 emissions and 12% and 4% lower NO_x emissions when compared to the low powered and standard electric vehicles, respectively. This research work allows sustaining that bicycles can be considered interesting solutions for urban trips, with comparable trip times to other transportation modes, as well as zero local emissions and reduced Well-to-Wheel pollutant impacts, contributing significantly for the improvement of the overall urban air quality.

1. Introduction

Over the last decades a growing concern with increasing energy consumption accountable to the transportation sector has been observed, leading to increasing challenges on how to decrease energy consumption as well as local and global emissions. In 2011, the road transportation sector was responsible for 33% of the European final energy consumption, with the road transportation sector accountable for 82% of that energy consumption [1].

Vehicle's efficiency improvement and promoting alternative vehicle technologies and energy sources have been the main focus of action to address this issue [2]. The use of alternative fuels such as hydrogen and electricity is regarded as a solution to significantly reduce the amount of CO_2 emitted by the transportation sector and increase renewable energy penetration [3–5]. Furthermore, the shift to hydrogen or electricity would bring a particularly beneficial impact for urban systems due to their zero local emissions. However, such technologies still face major downsides that prevent them from being true alternatives, mainly because they will only have a significant impact on a long-term scale due to the fleets low renovation rates [6]. Furthermore, this technology driven

Abbreviations: B, biker; CB, conventional bicycle; CO_2, carbon dioxide; EB, electric bicycle; EV, electric vehicle; GPS, global positioning system; ICEV-CI, internal combustion engine compression ignition; ICEV-SI, internal combustion engine spark ignition; L-EV, low powered electric vehicle; NO_x, nitrogen oxides; OBD, on-board diagnostic port; TTW, Tank-to-Wheel; VSP, Vehicle Specific Power; WTT, Well-to-Tank; WTW, Well-to-Wheel.

* Corresponding author at: IDMEC/IST, Instituto Superior Técnico, Department of Mechanical Engineering, Av. Rovisco Pais, Pav. Mecânica I, 2° Andar, 1049-001 Lisbon, Portugal. Tel.: +351 218419555; fax: +351 218417640.

E-mail address: patricia.baptista@tecnico.ulisboa.pt (P. Baptista).

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approach may not be completely successful unless a behavioral change happens enabling users to be more efficient when using the different transportation modes. Considering the transportation users choice and drivers behavior is, consequently, vital to the reduction of the transportation sector's environmental foot-print [7].

One alternative to mitigate the impacts of the transportation sector, particularly in urban environments, is to decrease the demand for energy intensive modes of transportation and to promote alternatives that provide a low-priced, less noisy and more sustainable alternative than a daily car commute. Generally, these alternatives are related with the use of more efficient vehicle technologies and with a shift to the public transportation system (bus, trains, subway systems and others), encouraging users to adopt vehicle sharing schemes (such as cars or bicycles), and alternative transportation modes such as walking, private bicycles or others [8]. The promotion of each of these pathways requires the development of diversified transportation policies, considering both their strengths and drawbacks, in order to encourage people to use them.

The use of more efficient vehicles or technologies is usually associated with higher purchase costs [9]. Electric vehicles present significant benefits in the Tank-to-Wheel stage (which corresponds to its usage stage) with lower energy consumption impacts and zero local pollutants emissions [6,10,11]. Moreover, the acceptance and adaptation to electric vehicles has been positive, but some issues related to charging routines and range anxiety still persist [12].

Additionally, while most cities offer some sort of public transportation system, the promotion of vehicle sharing schemes and alternative transportation modes has risen only recently [13,14]. More than 400 cities in the world have car-sharing systems, mostly located in Europe (≈80%), followed by North America (≈18%) and by Oceania (≈2%) [15]. The most widely known operators reveal a growing tendency. In Paris, the main operator has 1750 electric vehicles, offers 4000 charging points and has more than 65,000 registered subscribers. A US based system has been expanding worldwide, reaching 777,000 members and offering nearly 10,000 vehicles, while a Germany based system that started in 2008 has already expanded to 18 cities worldwide with over 350,000 customers and offering 6000 conventional and alternative vehicles. Another system deployed with a vast distribution in US, Europe and Australia since 2008 has reached 150,000 users. These 4 operators are the biggest systems with more than 100 vehicles per city, representing 47% of the total systems and have been promoting the use of alternative vehicles in their fleets [15].

Considering the alternatives presented earlier, the use of bicycles can be one of the most advantageous since it allows users to move at significant speeds for short distances (typical in urban environments), resulting in health benefits and zero emissions [16]. Using bicycles enables people to travel longer, faster and with less effort than walking, while having a low impact on the environment, thus making it an efficient transportation mode for urban mobility. As a result, there has been a growing awareness on the importance of cycling worldwide [17]. In many developing countries, namely in Asia, two-wheelers are a first inexpensive step towards individual mobility. A growing number of cities have been trying to integrate them in the daily mobility of their citizens, which for some countries has resulted in a significant share of trips being done with bicycles, such as the Netherlands (26%), Denmark (18%) and Germany (10%) [18]. In 2008 in the city of Amsterdam, 38% of all trips were performed by bicycles, with 50% of Amsterdam's residents riding a bike on a daily basis and 85% riding one at least once a week [19]. The promotion of bicycles in urban mobility requires the development of specific policies that impact the trip at all levels, whether when riding (through traffic calming and safe bikeways), parking (by offering secure locations) or moving it around the city (through the integration of bicycles with public transportation systems). Safety is one of the most relevant issues to consider when promoting bicycles. Due to being physically unprotected, bikers are more vulnerable to accidents than vehicle drivers and riders of public buses [20]. The safety concerns can be aggravated in the case of electric bicycles due to their ability for higher speeds, which can impact maneuverability and visibility [21].

Over 300 bike sharing systems have been deployed around the world, with a higher concentration in Europe (≈78% of the systems) and mainly owned by municipalities (≈72%) [22]. While the use of conventional bicycles in an urban context has been promoted with significant success in several cities, namely Paris and London with 25,000 and 8000 deployed bicycles respectively [23–25], they still have several problems that make their widespread use difficult. Some of the drawbacks associated with conventional bicycles include the difficulty to travel for long distances and in hilly conditions, the possibility of arriving sweaty or fatigued to the final destination, such as the work place [26], and being exposed to extreme cold or hot climates, among others. Several of these problems can be solved through the use of electric bicycles [26]. Electric bicycles can help reduce the trip effort required as well as travel time [27], though at a higher cost due to the additional requirement of electricity.

Despite the high expectations for electric bicycles, few studies have tried to understand the real world benefits that they convey in an urban environment. Furthermore, while previous studies addressed the estimated environmental impacts of electric bicycles compared to other transportation modes in China [28] and the users characterization and acceptance of this alternative technology in China [29] and in the United States [26], the experimental monitoring of bicycles has focused mostly on conventional bicycles [30,31].

In this sense, this research work addresses the impacts comparison of 5 transportation solutions focusing on a typical hilly route in Lisbon, Portugal. Taking advantage of on-road monitoring of a specific route in Lisbon, the trip time, distance and WTW energy consumption and emissions impacts were quantified for a conventional and electric bicycle, 2 conventional vehicle technologies, 2 electric vehicle solutions and an urban bus.

2. Methodology

2.1. Monitored route and transportation modes

In order to perform a transportation mode comparison of trip dynamics and energy impacts, a round-trip tour of approximately 8.5 km in Lisbon was chosen based on its diverse characteristics. The tour consisted on a round trip with departure from Instituto Superior Técnico (IST) main campus (point A and H of Fig. 1a) to downtown Lisbon, passing through the top of Parque Eduardo VII (sections C and F) and Avenida da Liberdade (sections D and E). Different parts of the city of Lisbon are covered in this route, including traffic intensive avenues, side roads with very little traffic and a street with a bike lane. This route corresponds to typical destinations and driving contexts in the city of Lisbon, close to possible locations of future bike-sharing stations. This tour has significant slopes, as shown in Fig. 1b, which presents the altitude profile of the tour.