Electrifying Last-Mile Deliveries: A Carbon Footprint Comparison between Internal Combustion Engine and Electric Vehicles

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Abstract. Last-mile management distribution is a growing challenge in big cities that affects to quality of life of many citizens. A way to mitigate greenhouse gas (GHG) emissions and congestion, as well as to promote and develop Smart Cities, is electrifying urban distribution by means of electric tricycles. This article evaluates the GHG of a tricycle logistics company (B-Line) in downtown Portland, OR. The goal is to analyze carbon footprint potential savings between electric tricycle last-mile distribution against a traditional diesel-powered van system. Real-world GPS and warehouse data were collected to assess B-Line operations. Results show a huge GHG emissions reduction, being tricycle logistic system twice more efficient that the traditional one.

Keywords: Smart city · Externality · Electric vehicle · Last-mile distribution

1 Introduction

Cities are evolving towards sustainability and efficiency; cities are moving to be smart. Globalization and the constant growth of world trade [1] have made transportation a key sector and a major contributor to progress and development. However, transportation activities frequently make indirect negative impacts on the environment such as air pollution and noise, usually named externalities. At the same time, people are concentrating around major urban areas. Actually, more than 50 % of world's population in 2014 lived in urban areas [2] what implies a high number of commercial deliveries in cities [3]. Consequently, commercial vehicles presence in urban areas has dramatically increased as some studies showed that vehicle miles of travel has rose 20 % from 1996 to 2006 [4].

Indirect effects of an economic activity are said to be externalities since those are out of the price system [5]. Research interest in externalities of freight transportation has continuously expanded because of the increasing impacts on economy, environment, climate, and society. Air pollution, noise, congestion, road damage and accidents are the usual externalities related to transport activities, nevertheless, due to the fact that

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transportation activities account for a third of total greenhouse gas (GHG) emissions in the United States [6], air-pollution-related externalities are the most studied ones [7]. Air pollution is caused by emission of air pollutants such as particulate matter (PM), NOx and non-methane volatile organic compounds that affect people, vegetation, global climate and materials. Climate change or global warming impacts of road transport are, mainly, generated by emissions of greenhouse gases (GHG): carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Nevertheless, CO_2 is the dominant anthropogenic GHG, and the remaining GHG can be expressed as CO_2 equivalent (CO2e) [8].

With regard to urban freight transportation, also known as last-mile distribution because it covers the movement of goods from a central hub in the city to a final destination [9]; several studies have shown that its contribution to total GHG emissions is extremely relevant. Actually, a fifth of CO_2 emissions come from urban freight vehicles [10]. Additionally, urban freight internal combustion engine vehicles (ICEV), commonly diesel-powered, are known to seriously affect public health. Diesel motor vehicles are a major source of air contaminants produced during the diesel combustion, like NOx which is responsible for acid rain.

In order to mitigate externalities, transportation policy makers are evaluating the possibility of electrifying urban delivery vehicles [11]. Advantages concerning Electric Vehicles (EV) in last-mile distribution have to do with their higher efficiency in the urban environment [12] and that is feasible the regular charging or battery swapping [13]. Thus, the switch from a fossil fuel combustion fleet to an electric-powered fleet seems like a suitable solution to reduce urban emissions. Moreover, actual cities go towards Smart Cities where a sustainable and efficient management of their resources must be considered [14]. Therefore, in the context of Smart Cities, EV development and adoption play a critical role. Even though there are several types of EV that could be used in urban freight transportation, electrically-assisted cargo tricycles are an ideal low-carbon alternative to transport light cargo in city centers. This situation is due, not only because their emissions-free nature, but also because their small size and easy access to congested city centers. Unlike conventional internal combustion vans, tricycles can legally use bike paths and be dropped on and off, on sidewalks or inside business [15]. Because the freight that is delivered by tricycle is often light and small, diesel vans are the natural competitor. Although electric tricycles do not produce tailpipe emissions, GHG emissions from electricity generation should be considered leading us to consider a Life Cycle Assessment (LCA) [16] ranging from extraction of resources to build up the vehicles, the operation phase, and disposal at the end.

Thus, this article aims to analyze the greenhouse gas (GHG) emissions potential savings of electric tricycles over their life time for last-mile delivery operations. B-Line [17], a tricycle logistics company in downtown Portland, OR, is used to record data related to route and warehouse and to test the methodology. The goal is to compare B-Line's carbon footprint against the footprint that B-Line would make using traditional diesel-powered vans.

The next section presents a brief literature review, and the following sections present the methodology used to compare different vehicle technologies, the case study, the results, and some concluding remarks.

2 Literature Review

Literature about EVs is spreading out during the last years due to a growing interest among researchers [18], mainly focused on Smart City contexts [19]. Most of them focus on challenges regarding batteries limitations [20] and their final adoption [21]. Hybrid vehicles are also studied in the literature as a mix alternative between ICEV and EVs [22]. Real cases analyses are also performed, for instance, how charging points distribution affect EVs [23]. However, from the best of the authors' knowledge, there are no published carbon footprint assessments of a tricycle logistics company in the existing literature. Urban distribution is often called last mile distribution because it occurs in the final echelon of the logistics chain, when goods go from an urban distribution center to final customers. Literature regarding last mile distribution using EV is mainly focused on European cities such as Brussels, London and Paris [24, 25].

In this paper, a Life Cycle Assessments (LCA) [16] will be carried out using real tricycles and diesel-powered vans in order to elicit their carbon footprint, which is the total set of greenhouse gas emissions caused directly and indirectly as a consequence of providing the transport service expressed as CO_2 equivalent (CO_2e), that is, translating all GHG into CO_2 using the Intergovernmental Panel Agency recommendations [26]. According to the GHG Protocol (an accounting tool to understand, quantify, and manage GHG emissions [27]), there exist 3 different scopes of GHG emissions depending on whether the emission sources are controlled by the company. Hence, Scope I is used to categorize all direct emissions, Scope II includes indirect emissions from consumption of purchased electricity, heat or steam; and Scope III consists of other indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the company. While carbon footprint distinguishes between the 3 broad scopes, LCA considers the life cycle phases (ranging from extraction of resources to build up the vehicles, the operation phase, and disposal at the end) in such a way that it avoids shifting emissions from one phase to another.

Tricycles used in this paper have a maximum payload of 600 lbs. with curb weight of 500 lbs. Their maximum speed is around 10 mph being able to cover 30 miles and usual tricycle life expectancy estimation is around 5 years. On the other hand, alternative internal combustion engine vans can load 4,160 lbs. with a curb weight of 4,781 lbs. Their maximum speed is approximately 50 mph covering up to 465 miles when the tank is full and we will assume that van life expectancy is approximately 12 years [28]. Urban areas characteristics make tricycles as an ideal way to deliver light goods given the possibility of reducing and shortening the route by using pedestrian areas or riding up one-way streets on a sidewalk in the opposite directions as well as using sidewalks or business to park. Furthermore, taking into account that riders have to pedal, energy tricycle energy efficiency improves given the fact that on average fitted person could pedal a bicycle with the power output of 75 watts without suffering fatigue for 7 h [29]. Among cargo tricycle disadvantages, it is remarkable their limited payloads capacities which may make them reject orders that exceed the vehicle limit. In addition, the short travel range and the low speed in free-flow conditions are also highlighted.

3 Methodology

In order to compare carbon footprint of both logistic systems (electric tricycles and traditional vans such as the previously specified), the GHG Protocol methodology using the Scope III was followed; that is, including all life cycle emissions associated with the production, use and disposal of vehicles [30]. Splitting the logistic service into sources of emissions, we consider the following ones:

1. Vehicle. It covers the emissions made during the whole life of the van/tricycle, from raw material extraction (aluminum, plastic…), transport and disposal or recycling.
2. Well-to-tank. Emissions coming from energy production and distribution: electricity in tricycles and fuel in the van case.
3. Tank-to-wheel. Derived from the service provided itself. In that case emissions only came from diesel-powered vans.

Data necessary to carry out the analyses were collected from the Environmental Protection Agency [31] and, the eGRID database [32]. Finally, Life Cycle Assessment was performed using the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET [36]) a full life-cycle model that evaluates energy and emission impacts.

3.1 Vehicle

Applying the information about physical characteristics of the vehicles proposed, it is possible to estimate the carbon footprint of the vehicle life using GREET. In this phase we are considering the whole vehicle life cycle: extraction of raw materials (aluminum, iron, plastic…), transport to factories to product the materials needed, transportation to the plant where the materials are going to be assembled, final production of vehicles, transport and distribution of them to dealers, and lastly, disposal. By using the mass as the functional unit (in lbs.) vehicle life cycle GHG emissions are 2,677 lbs. of CO_2e for an electric tricycle and 32,073 lbs. of CO_2e for a diesel-powered van.

Note that the tricycles batteries were not considered in the previous calculation. Usually, electric tricycles use Lead-Acid (PbA) batteries, which last, on average, for 4 years. By using GWP values recommended by the International Panel on Climate Change it is estimated that battery life cycle GHG emissions are 3.94 lbs. CO2e per PbA battery lb.

3.2 Well-to-Tank

The fuel that a diesel-powered van consumes has been extracted as oil, transported, refined and transported again to stations. These upstream GHG emissions were estimated to be about 5.10 lbs. of CO_2e per gallon of conventional diesel using average values from GREET model.

The electricity that a tricycle consumes does not produce emissions when it is running. However, some emissions have been made to generate and distribute the electricity. Using the information of eGRID [33] with the U.S. average coal-based electricity generation as well as adding the estimated electricity that is lost due to transmission and distribution, we get 1,238.5 lbs. of CO2e/MWh.

3.3 Tank-to-Wheel

According to Environment Protection Agency [34] burning one gallon of diesel makes 22.47 lbs. of CO_2. By applying the GHG equivalent ratio, CO_2e emissions are estimated as 22.75 lbs. CO_2e/gallon. Electric consumption in tricycles is computed by measuring energy in batteries before and after a route is run. However, we should take into account the battery efficiency because it is a function of it state of charge [35]. This implies that from 0 % to 85 % of charge, batteries efficiency is almost 90 % meanwhile it decreases to 55 % when batteries are charged upper 85 %. Finally, CO2e emissions in both cases are converted in terms of distance travelled (lbs./mile).

4 Case Study

The methodology proposed was applied to a real case in order to compare carbon footprint between the two logistics configurations: electric tricycles and diesel-powered vans. The case study was held in Portland, OR; a bike-friendly city in U.S which its rather flat downtown area makes biking very convenient. Consequently, a company such as B-Line Sustainable Urban Delivery [17], a last-mile distribution service provider that operates in Portland downtown, has succeeded. B-Line transports a wide range of products (baked goods, office suppliers, bike components…) to businesses using electric tricycles. Moreover, B-Line also diversified its business by advertising and promoting companies and products through their eye-catching cargo box. B-Line logistics business model, which consisted of 8 partners and 80 final destinations, is organized as follows:

– Four partners, those that are far away from city center, deliver their products to B-Line distribution center and then B-Line transports them to final destinations.
– Four partners, those that are in the city center, wait for B-Line to picks-up products of their locations and distribute to final destination.

Data from B-Line operations were collected on May–June 2015 and it includes many days of detailed B-Line GPS routes and warehouse operations. B-Line fleet is compounded of 6 electric tricycles with 2 PbA batteries each in order to allow swaps. Using private information, fuel economy median is estimated at 48.50 W-h/mile. B-Line Carbon footprint can be calculated using the previous data.

Then, a hypothetical scenario is built considering that B-Line would provide the same service as it currently does using diesel vans as well as maintaining the previous partner structure. B-Line managers made hypothetical routes that diesel-powered vans would do in order to minimize the total distance traveled keeping customer service level. In this hypothetical scenario, neither time windows nor capacity constraints are assumed, because the van payload is much greater than the tricycle payload. However, service time per client using a van is likely to be greater than service time using a tricycle because tricycles can park on sidewalks while vans have to find parking slots. Hence, to cover the 80 final destinations and assuming 10 min service time each, at least two vans are required to maintain the tricycle service level. GHG emissions made by those partners that have to transport their product to B-Line's warehouse are also included in the computation as they are inside Scope III we have adopted. On average, the daily distance covered by B-Line's partners, from their depots to the B-Line distribution center is 25 miles.

Therefore, a comparison between the B-Line current carbon footprint, against the footprint of a traditional diesel van delivery company can be made.

5 Results

Current B-Line carbon footprint is assessed and compared against traditional diesel-powered van system carbon footprint. Figure 1 shows that CO_2e emissions as a result of tricycle delivery system fall from 23 to 12 tons of CO2e emissions per year, which implied a 50 % of reduction. Thus, B-Line is avoiding approximately 11 tons of CO_2e emissions per year. However daily distance traveled increase significantly resulting in an increment of 50 % of miles traveled, even though here we are not including the 25 miles that the four farther partners have to travel to transport their products to B-Line's depot. That is not trivial at all because those 25 miles per day account for 60 % of total GHG emissions tricycle system does. Nevertheless, we should take into account that diesel-powered vans travel in congested streets at slow speeds. Subsequently, the global impact is not a reduction in CO_2e emissions for the traditional diesel company.

Figure 2 distinguishes between partner activity impacts showing lbs. CO2e emissions per delivery using electric tricycles and vans. Thus, a huge reduction can be achieved without including partner's transport activities: 6 tricycles have 80 % less environmental impact in terms of CO2e emissions than 2 common diesel cargo vans. Actually, a delivery made by an electric tricycle emits just 0.2 lbs. of CO2e while the same trip made by a van would emit 5 times more: 1 lb.

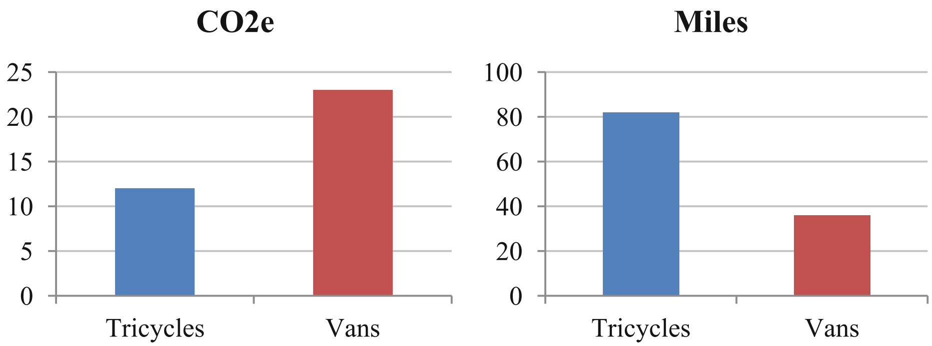

Fig. 1. Tons CO2e emissions/year [left] and miles travelled/day [right]

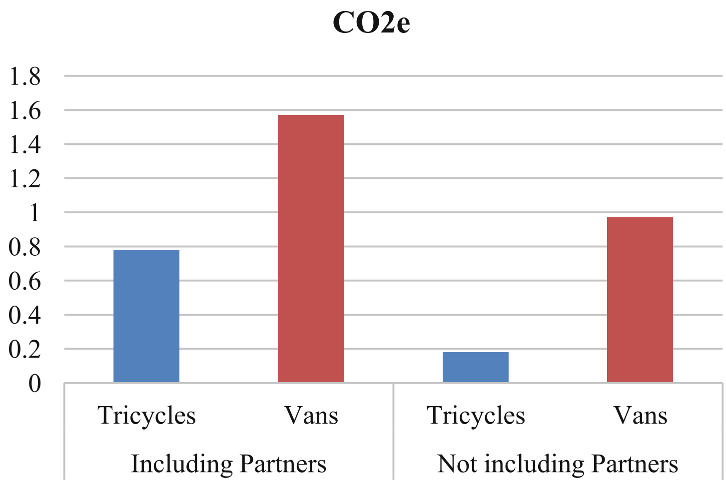

Fig. 2. Lbs. CO2e emissions/delivery

6 Conclusions and Ongoing Work

Last-mile management distribution is a growing challenge in big cities that affects life quality of citizens due to GHG emissions, noise or congestion. Therefore, sustainability and efficiency in that environment is threatened along with the concept of Smart City itself. Thus, electrification of last-mile deliveries, for instance using electric tricycles, would play an important role in reducing GHG emissions noise, congestion or service time. In this article, we have developed a methodology to evaluate carbon footprint of electric tricycle and common vans. This methodology was tested in the real case of B-Line [17], a logistic company that works in Portland, OR. B-Line currently operates an electric fleet of 6 cargo tricycles in last-mile urban distribution. Then, we compared its carbon footprint with the one that B-Line would make if they use traditional diesel-powered vans. Results show a huge saving of GHG emissions of electric tricycle with respect to a traditional fleet by halving them. This result is consistent with Browne et al. [36] that estimated a reduction of 54 % CO_2e emissions due to the use of an urban distribution center and electric vehicles in London.

Future research directions will face the economic aspect of electric vehicles adoption. This should be done taking into account the operation cost of both policies as well as the investment on vehicles. Moreover, a monetary valuation of GHG savings should be done in order to incorporate to the previous analysis to cover not only internal cost but also external. Finally, since this paper has compared a current electric logistic system against its hypothetical diesel-powered alternative; it would be interesting to do the same in an actual diesel-powered fleet against its electric alternative.

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