Current trends and innovations affecting the potential for a widespread adoption of electric buses — A comparative case study of 22 cities in the Americas, Asia-Pacific, and Europe

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ABSTRACT

Electric buses have environmental, economic, and health benefits, which many cities want to achieve by transitioning their fleets. However, the actual worldwide electric bus adoption is geographically uneven and limited in scale, and few studies analyzed what factors can potentially shape a wider adoption. The paper is based on real world experiences, and applies a comparative multi-case study to 22 cities in 14 countries. A common framework is used for analysis, which includes non-reimbursable funds, investment capital, and legal arrangements. Results show that four key factors are shaping the widespread adoption of electric buses. Firstly, public and private grants, which, when dedicated to cleaning the fleet, appears as a strong factor underpinning existing clean bus systems. Secondly, less costly sources of financing can reduce financial risks and enable more adoption, and it is where innovation can happen. Also, innovative ways of structuring contractual implementation effectively connect stakeholders and involve third-party players, which leads to shared and mitigated risks, increased efficiency and improved performance. In addition, some other elements outside of the business model framework also prove to be enabling the adoption of electric buses.

1. Introduction

Electric buses can create economic, environmental and health benefits, such as reduced local and global emissions (Clark, Zhen, & Wayne, 2009; Ercan & Tatari, 2015; United States Department of Transportation, 2016), improved service quality by reducing vibration and noise (Ross & Staiano, 2007), and potentially lower lifecycle costs due to lower fuel requirements and less expensive maintenance (Eudy et al., 2016; United States Department of Transportation, 2016).

Despite recent growth in the market for electric buses, worldwide implementation is geographically uneven and limited in scale (Figure 1). For example, the North American market for electric and hybrid buses has grown by more than 400% from 2005 to 2010 (Marlay, 2013). In 2016, more than 40 cities worldwide were operating battery-powered electric buses (Castellanos & Maassen, 2017), with 87% of the buses in China (International Energy Agency, 2017). Shenzhen, China, is home to the largest urban electric bus fleet and aims to fully electrify public bus transport by 2017 (International Energy Agency, 2017). Early June, 2017, the largest bus operator in Shenzhen has fully upgraded with electric bus and exited the fossil fueled bus market (Guangzhou Daily, 2017). However, the geographical concentration of electric buses remains mainly in North America, East Asia, and Europe.

This paper seeks to identify current trends and innovations shaping the potential for a widespread adoption of electric transit buses in cities. We use the “trend” to refer to general directions and characteristics that can be observed in real world phenomena (here electric bus adoption), in contrast to “innovations”, which we use to indicate novel or unusual elements that may be limited in occurrence but potentially significant in the adoption process. This is an important question for cities hoping to reap the environmental, social, and economic benefits of transitioning their fleets to electric buses. It is a particularly topical question given that 26 cities worldwide signed a “Clean Bus Declaration” in 2015, a statement of political commitment that is tantamount to switching over 45,000 of urban buses to be low or zero emission by 2020 (C40, 2015). Given current market penetration, this may seem ambitious, as the number accounts for around 25% of these cities’ current fleets. However, the target represents only 75% of buses planned to be procured in these cities by 2020 (C40, 2015), and likely only a fraction of global market potential.

The paper begins with an overview of the extant literature relevant to understanding the factors shaping the potential for widespread adoption of electric vehicles and bus fleet transitions (Section 2). Based on current knowledge and existing gaps, Section 3 describes the comparative multi-case study method used to further knowledge on this question. It aims to uncover current trends and innovations in cities worldwide, combining literature reviews with expert and practitioner interviews. A description of findings and discussion is provided in Section 4, presenting the main conclusions of the analysis. Section 5 offers conclusions and future avenues of research and action. The research focuses primarily on understanding how cities overcame barriers related to upfront cost of electric buses and they how risks of the new technology were allocated between stakeholders. The research is based on currently available technology instead of a projection of future, and its main focus is not the technical aspects that affect electric bus operations such as battery technology, city topology or climate, nor does it delve deeply into differences in socio-economic conditions between the cities researched.

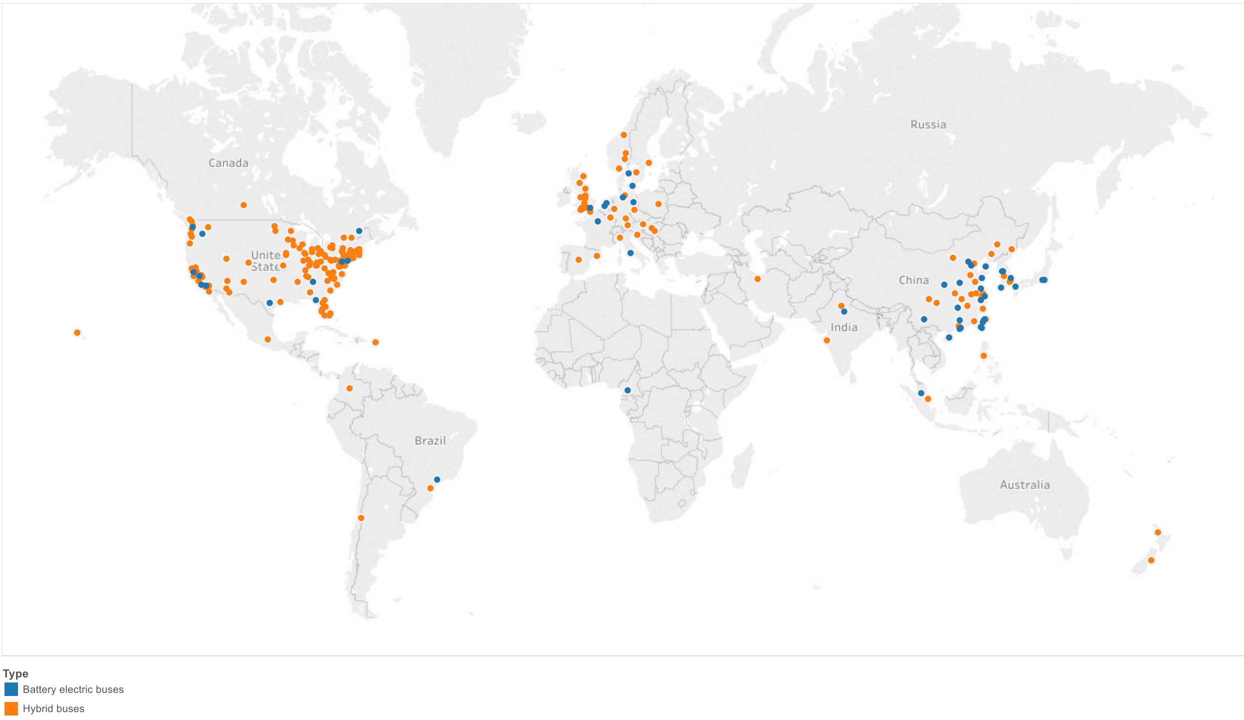

Figure 1 Hybrid and electric buses adoption around the world. The figure shows cities operating hybrid and electric buses around the world. The data are illustrative of general trends rather than exhaustive. It was compiled by authors by October, 2016.

2. Literature review

The objective of this paper is to understand the current trends and innovations that are shaping the potential for a widespread adoption of electric buses in public transit fleets around the world. We carried out a broad review of different literatures in order to understand the current state of knowledge on electric bus adoption. We identified several relevant contributions from different disciplines and identified the principal knowledge gap for urban electric bus adoption, around which we designed our research methodology (Section 3). Overall, we found that there is a substantial and growing body literature on technical aspects of electric buses (lifecycle cost, emissions, system performance or environmental benefits) and studies focusing on the private (i.e. not mass-transit) electric vehicle market, which is relatively more mature than the electric bus segment (International Energy Agency, 2017).

There is a knowledge gap when it comes to understanding the electric transition of bus fleets used for public transit, in particular in relation to paying for a presently high-cost technology than its incumbent (diesel buses), and risks of transitioning to new technologies can be reasonably allocated between different actors in the value chain.

We briefly review the main findings of the literatures on technical aspects of electric buses and private electric vehicles, to situate the evolution of the technology in general, and glean potential lessons from a closely related industry, respectively. We then consider the particular challenges of understanding the public transit segment's electric transition.

2.1 Technical studies of electric buses

Technical studies on the performance of electric buses provide valuable evidence of their benefits and operational attributes. While they do not specifically address market transformation, they are useful to situating the evolution of the technology.

In recent decade, the development of rechargeable energy storage systems, and the integration of more advanced lithium-ion batteries with lighter weight and higher energy content have facilitated the adoption of electric buses for transit use; and multiple successful deployment projects showed that the electric bus technology has reached a certain stage of maturity, with improvement in efficiency, environmental performance, safety, reliability etc. (Brecher, 2014). Different charging strategies, such as regular charging with back up vehicles, battery swapping and fast opportunity charging have also been developed to address issues under different conditions (J.-Q. Li, 2016).

These improvements and insights helped us to understand the general technological maturity of electric buses and particularities of specific cases. For example, Eudy et al. (2016) analyzed results from the Foothill Transit electric bus demonstration project, and concluded that the fuel efficiency of battery electric buses can be four times that of CNG buses under certain conditions. Choi, Jeong, and Jeong (2012) analyzed the commercial electric bus operation in Seoul, which adopted light weight vehicle body and high speed charging infrastructure that can reduce energy consumption and improve reliability. In the Milton Keynes electric bus demonstration project, Kontou and Miles (2015) investigated wireless and inductive charging technology, and proved the relative maturity of the technology to secure reliable and efficient public transit service; Miles & Potter (2014) also went beyond the technical aspects of the technology and analyzed the financial part of the Milton Keynes project.

However, there are two major limitations that currently still facing the technology for mass adoption:

- Improving the operational reliability of buses, which need to address issues such as battery energy content and storage (California Environmental Protection Agency Air Resources Board, 2015; Lajunen & Lipman, 2016), different kinds of efficiency (Hu, Murgovski, Johannesson, & Egardt, 2013; Ott, Zurbriggen, Onder, & Guzzella, 2013), route conditions such as operational length (J.-Q. Li, 2016) and stops, curves and elevation (Perrotta et al., 2014), and charging conditions (Lajunen & Lipman, 2016; J.-Q. Li, 2016).
- Reducing the lifecycle cost of electric buses, especially the cost of battery, which has been decreasing over time, but is still challenging the wide adoption of electric buses (Bi, De Kleine, & Keoleian, 2016; California Environmental Protection Agency Air Resources Board, 2015; Lajunen & Lipman, 2016; Lajunen, 2014).

At the same time, some knowledge gaps still exist which limit the improvement of technology even though it has come a long way. Studies and real world case performance show that the batteries degrade more with increased temperature (Norregaard, Johnsen, & Hedegaard Gravesen, 2016), and the performance is limited in cold weather (Bullis, 2013). Also, the energy efficiency fluctuate with the temperature due to the extra need of energy when temperature is high or low (Prohaska, Kelly, & Eudy, 2016). These studies show the knowledge gaps to improve battery and electric bus performance in different climatic situations, which increase the uncertainties to adopt electric buses in tropical and cold areas. While this is not a main focus of our analysis, we point this out as a future avenue for research in the conclusion.

These leads to one set of research on optimization and lifecycle analysis of cost and emissions for electric buses, with the aim to identify the cost-efficient option to reduce energy consumption which increase the reliability of buses, and to reduce emissions which reduce the negative externalities of buses. These studies addressed the need to improve technology and efficiency (Lajunen & Lipman, 2016), other impacting factors for total cost such as operational factors (Nurhadi, Borén, & Ny, 2014) and fuel price (Bi et al., 2016), and the importance of a electricity grid with more renewable energy component and less emissions to maximize the environmental benefits of electric buses (Cooney, Hawkins, & Marriott, 2013; Ercan & Tatari, 2015). These models and scenarios developed based on real performance data for optimization and lifecycle analysis have an important place in terms of identifying factors to improve and driving forward technological innovation, however are limited in terms of their attention to market dynamics. For the latter, we reviewed the relatively more established literature on the evolution of the market for private electric vehicles.

One study (Van der Straten et al., 2007) closest to our research question analyzed 21 alternatively powered bus adoption cases in Europe and identified their enablers, such as supporting infrastructure, and public acceptance; and barriers such as high cost, and lack of understanding of the technology. This study, however, does not provide insights into the financial and economic factors that led to adoption, focuses only partly on electric buses, and does not capture the rapid development of electric buses in the past 10 years.

2.2 The private electric vehicle segment

The private electric vehicle (EV) segment consists of smaller vehicles that are not used for mass-transit and can be either owned by individuals for personal consumption or companies that lease vehicles on a short- or long-term basis, either on an exclusive basis or as shared mobility solutions (Boutueil, 2016; Shaheen & Cohen, 2013). As with electric buses, part of the literature on private EVs focuses on the technical aspects of the technology, such as performance evaluation and cost-emission analysis (Karner & Francfort, 2007; Offer, Howey, Contestabile, Clague, & Brandon, 2010; Parks, Denholm, & Markel, 2007). Another part focuses on spill-over effects of private EVs onto electricity supply and distribution, and their environmental impact (Clement-Nyns, Haesen, & Driesen, 2010; Hawkins, Singh, Majeau-Bettez, & Stromman, 2013; Perujo & Ciuffo, 2010; Sioshansi & Denholm, 2009).

The most relevant insights for our objective of understanding current trends and innovations in the adoption of electric urban transit buses come from several studies focusing on factors shaping the emerging private EV market. Some focus on studying the impact on EV adoption of policies that are directed at the end-user such as tax credits, vehicle purchase rebates, road tolling exemptions, bus lane access (Bjerkan, Norbech, & Nordtomme, 2016), free parking (Kley, Wietschel, & Dallinger, 2010) and leasing options. While others focus on studying the impact that policies directed at the ecosystem have, such as encouraging research and development (Gong, Wang, & Wang, 2013). Finally, there are studies on non-policy factors like the impact of fuel prices on EV adoption (Gallagher & Muehlegger, 2011) and addressing charging infrastructures (Sierzchula, Bakker, Maat, & Wee, 2014). Results from these studies show a positive correlation between faster adoption of EVs and subsidies, but acknowledge that the complexity of the market makes it difficult to correctly assess the effectiveness of these measures.

Another part of the literature focuses on identifying the main barriers for adoption and studying possible innovations that can help overcoming them. Hall, Shepherd, & Wadud (2016) conducted stakeholder interviews to identify the needs of the industry and possible innovations that can meet these needs. Their results suggest that experimenting with different tariff policies by utility companies, developing common charging standards, establishing minimum coverage standards for on-the-road charging, addressing barriers to switching utility companies and a closer coordination between city institutions for better infrastructure provision, can accelerate vehicle adoption. Weiller et al. (2015) identified the main barriers for EV adoption as "limited driving range, limited availability of charging infrastructure, long recharging times, and high costs". By conducting case studies, they concluded that innovations such as fast charging stations, battery swapping schemes, and shifting the ownership of the vehicle from the user to a third-party company (e.g. Autolib in Paris) can address some of these issues. Insights from industry professionals, policy makers and researchers show that alternative ownership, financing and leasing models are also important to establish profitable EV business model (Beeton & Meyer, 2015).

2.3 Public transit procurement and financing

As will be explored in our results section, many of the emerging findings from the private EV segment are relevant and applicable to the mass-transit bus segment. There are, however, important aspects and targets of mass-transit bus systems that substantially affect the direct applicability of these findings. For example, public transit system usually has fixed routes and operating length, higher frequency of stops and higher idling time (California Environmental Protection Agency Air Resources Board, 2015), , less "last-mile" flexibility (Sharp, 1967), which may require better system planning to secure the reliability of service and better approaches to increase affordability of consumers; and the different stakeholders involved in procurement and operational process, and different ownership mechanisms compared to private vehicles, may require appropriate mechanisms and incentives to encourage cooperation.

Generally, urban transit services can be provided under two mechanisms: public sector provision, which is the major public transit provision mechanisms in countries like United States and China; and private sector involvement with subcategories such as economic deregulation, competitive tendering, and negotiated contracts, which are the major mechanisms in Europe, Oceania, and Latin America (Hensher & Stanley, 2010). For public sector provision, the transit agency procure and operate buses, thus bear the costs for bus procurement, operation and maintenance (O&M), which are often subsidized by the government in different ways (Cox & Love, 1991; Gwilliam, 2010). For private involvement structure, public and private sectors bear variable costs with different contracts or structures (Gulibon, 2006; Hensher & Stanley, 2010). And a good public transit service contract would include social goals reflected through performance, and the aim to achieve financial sustainability for the system (Galilea & Batarce, 2016), both are key characteristics need to be considered for electric buses.

Electric buses adoption also accompanies with additional infrastructure construction, especially the charging facilities, besides the potential need to adjust existing roadways, stops and depots. Some studies analyzed alternative ways to subsidize BRT, which ensembles a transit system upgrade option with additional need of infrastructure. Major mechanisms for BRT financing are national grants and subsidies, public-private-partnership (PPP), loans from development banks, cooperation between national and local government, local financial incentives and tax credits, other fees collected, etc. (Hook & Fjellstrom, 2006; Lindau, Senna, Strambi, & Martins, 2008), which show the importance of the cooperation between different sectors, such as public, private, and multinational banks, to mobilize funding and reduce financing risks.

The procurement, operating, and funding mechanisms are different between public agencies and private operators to adopt electric buses, but the general concerns on costs and risks are similar. Traditional funding and financing mechanisms for both public and private bus systems do not have specific measures encouraging the procurement of buses with higher upfront purchase cost, and the environmental benefits are not reflected in current mechanisms. Thus, mechanisms under these two structures can be reconfigured to suit the needs of electric bus business models, and multi-sector coordination is highly required. Also, Li et al. (2014) found that several factors will impact the procurement decision of transit agencies, such as manufacturer brand and location, environmental regulations, and subsidies, which are important factors when considering to adopt electric buses.

Based on the important aspects shown in above studies in multiple related sectors, such as financial and funding related incentives, policy best practices, and other enabling conditions such as multi-sector cooperation and manufacturer status, this study uses a multi-case study approach and applies an interdisciplinary business model for each case. The paper conducts original research on real world experiences for electric bus adoption, and provides primary contributions on detecting trends and innovations that shaping the potential for a widespread adoption of electric buses.

3. A comparative multi-case method

To meet the objective of understanding current trends and innovations in the adoption of electric urban transit buses we designed a comparative multi-case method that would allow us to explore different contexts of adoption in a single market segment (mass-transit public bus fleets). The research consisted of three main steps: (1) Formulation of detailed research questions, to break down our overarching objective, (2) Case selection, to scope the universe and sample of cases to be analyzed, and (3) Identification of trends and innovations. Each is described in turn below.

3.1 Formulating a common framework

When studying multiple cases, it is important to collect comparable data across different instances. A useful technique is to develop standardized questions that will be asked of each case (George, 1979; Yin, 1994). The questions, which guided our subsequent data collection, fall into four dimensions:

- Technical components: what kinds of technology, infrastructure, and other costs arose during implementation?
- Non-reimbursable funds: what revenues, incentives, and other budgets were used to cover expenses?
- Investment capital: if any, what types of capital, investors, and credit-enhancement options were used for mobilizing investment capital?
- Legal arrangements: what policy frameworks, ownership structures and contracts shaped implementation?

These questions aim to capture the technical, financial, legal and policy dimensions of the cases of electric and hybrid bus implementation and help us collect qualitative data on the intricacies of each case that will help us draw conclusions about trends and innovations.

3.2 Case selection

Studying multiple cases is a good approach for investigating different dimensions of a larger phenomenon (Hesse-Biber & Leavy, 2010; Stake, 1995), such as the electric bus fleet transitions, as it enables to compare and contrast through juxtaposition of different contexts. As a starting point, we undertook an exploratory mapping exercise, which included both electric and hybrid technologies in urban bus operations. We included hybrid buses, based on the assumption that investment for needs for both technologies are similar (e.g. batteries, specialized equipment and training). Additional criteria in the exploratory mapping included:

- Inclusion of different energy sources (diesel-electric hybrid vs. gasoline-electric hybrid) and charging technologies (plug-in charging, off-vehicle charging or opportunity charging).
- Exclusion of city-to-city buses or coaches.
- Some cases of electric mini-vans were included (one in India, a few cases in Africa) as they are used for urban transit buses.
- Inclusion of buses operating for at least 6 months and exclusion of short-term project, with a few exceptions including different stages of piloting project, as they include specific trends and innovations.

Subsequently, we created a sample of cases that we short-listed for further investigation. This time our main criteria favored 1. Larger fleets sizes, 2. Geographic representativeness (as far as possible), 3. Information availability. We also favored cases that illustrated greater diversity in terms of their contractual and financial characteristics, as much as exploratory research had revealed it at this point. This scheme resulted in the selection of 26 cases, which are located in 22 cities and cover 14 countries from 5 continents (see summary information of cases in Table A.1 in Appendix).

3.3 Data collection

After selecting cases and formulating common questions, we triangulated several methods to capture data on each case. The research included 8 interviews with practitioners involved in different implementation cases, a review of academic and industry peer-reviewed papers, government and corporate reports (grey literature), and a review of recent press release, blogs. Each time, we collected information in the four dimensions we defined in the previous step.

3.4 Data analysis

After the cases had been developed, our principle objective was to identify meaningful patterns and insights about the implementation of electric transit buses in cities. We developed sub-codes in each of the high-level dimensions (Technical components, Non-reimbursable funds, Investment capital, Legal arrangements) that reflected the different options that had been used in each case. For example, we used “Capital Expenditure Grant”, “Public Grants”, “Payroll Tax” (among others) under reimbursable funds. Table 1 provides an overview of the sub-codes that were generated in the process for the three of the four dimensions, and from which implementation cases we developed them.

Once coded, we carried out a second type of analysis to answer our principal question about the “current trends and innovations” in urban electric bus implementation. We use the “trend” to refer to reoccurring elements and directions across different cases, in contrast to “innovations”, which we use to indicate novel or unusual elements that may be limited in occurrence but potentially significant in the adoption process.

3.5 Limitations

Limitations exist for this study. First, selection bias may exist, because no exhaustive case selection and comprehensive case analysis could be conducted; also, the technologies are relatively new, and the adoption is expanding over the years, by the time case collection and analysis period finished, more cases may rise with more innovations. Second, the focus of the paper is from bus operators’ and cities’ perspectives, trying to identify factors that could reduce upfront purchase costs, operational risks, and other uncertainties when adopting hybrid and electric buses. Thus, the paper will not address adoption barriers related to city’s natural or socio-economic characteristics, such as topology, climate, and economic conditions, nor will address technology barriers such as battery range or charging technology. These are important for better performance of hybrid and electric buses, but are not related to this paper. The last limitation is not enough real world performance evaluation for all projects, because the technology diffusion process has just begun. Cities are learning by doing in the process, and more are to be learnt in the future.

Detailed results are discussed in Section 4.1, with further analysis and implications in Section 4.2. The summary information for the cases in our current database can be seen in Table A.1 in Appendix, which is based on the questions asked and case identified.

4. Findings: current trends and innovations in the implementation of urban electric bus fleets

The current section presents the results of our comparative analysis of 26 cases of electric and hybrid bus implementation. We divided the results into the 3 main codes shown in Section 3.1**Error! Reference source not found.** that link to the key questions of our research ([i] non-reimbursable funds, [ii] investment capital and [iii] legal arrangements). For each of these we then identified if our observations corresponded to either a *trend* (where the variable is present in multiple cases) or an *innovation* (when a variable only appears in one or a few cases, but it differs significantly from the regular way of bus contracting, which can lead to infer that the variable plays a specific role in the way electric buses are procured and operated). Where relevant, the current section presents more in-depth information from the case studies where they were identified to provide additional context.

Table 1 Sub-codes generated through analysis

Code	Sub-code	Cases where it was found[1]
Non-reimbursable funds	Private Grants	Bogota, Gothenburg*, Gumi, Milton Keynes, Singapore
	Public Grants	Auckland, Bogota, Berlin, Colombo, Gothenburg*, Gumi, London*, Nanjing, Milton Keynes, Philadelphia*, Pomona Valley, Rome, Seattle*, Shenzhen, Singapore, Stockholm, Tianjin, Turin, Zhuhai
	Capital Expenditure Grant	Auckland, Bogota, Berlin, Colombo, Gothenburg*, Gumi, London*, Nanjing, Milton Keynes, Philadelphia*, Pomona Valley, Rome, Seattle*, Shenzhen, Singapore, Stockholm, Tianjin, Turin, Zhuhai
	Operational Expenditure Grant	Berlin
	Research and Development Grant	Berlin, Gumi
	Public Transportation Budget	Bogota, Curitiba, London*, Paris, Philadelphia*, Singapore, Shenzhen, Toronto
	Farebox Revenue	Curitiba, Paris, Turin
	Bus Scrappage payment	Bogota, Curitiba, Pomona Valley, Shenzhen
	Sales Tax	Seattle*, Pomona Valley
	Environmental Impact Tax	Rome, London
	Payroll Tax	Paris
Investment capital	Soft Loan	Bogota, Curitiba
	Green bond	Tianjin
Legal arrangement	Bus Lease	Nanjing, Shenzhen, Zhuhai
	Battery Lease	Bogota, Shenzhen
	Lease-Purchase Contract	Shenzhen, Stockholm, Tianjin
	Leaseback Agreement	Nanjing, Shenzhen
	Concession	Bogota, Colombo, Curitiba, London, Milton Keynes, Paris, Singapore, Stockholm, Shenzhen, Pomona Valley
	Public Procurement Contract	Auckland, Bogota, Curitiba, London, Milton Keynes, Rome, Seattle
	Advertising Contract	Bogota, Philadelphia

[1] * We looked at separate implementations that happened in the same city (e.g. London hybrid buses and London electric buses), so there may be some elements which fit either of these implementations.

4.1 Non-reimbursable funds: incentivizing investment

The first trend that arises from analyzing the data is that most cities are using a form of grant; whether it is a grant from the public sector (trend) or from the private sector (innovative). The variety of grants differs from city to city, but they seem to be grouped in two large categories: (1) grants to overcome the higher upfront costs of clean buses and its accompanying infrastructure, and (2) grants to reduce the uncertainty of operating new technologies, and therefore directed at paying operational expenditures. The form the grants take is also diverse; there are grants in cash (direct subsidies to purchase or operation), tax breaks to lower the up-front costs, particularly where providing direct cash grants may be financially or politically difficult (e.g. Bogota, a mid-income city in a developing country) and finally in kind (training, land, infrastructure, maintenance, R&D). The first two are generally provided by the public sector, while the last one is generally provided by the private sector.

Since all of the cases explored have some form of grant, it can be hypothesized that (at this time[2]), this is a sine qua non condition for the implementation of clean buses. This finding may not come as a surprise considering that currently the price of electric buses is higher than that of regular diesel buses, even more so when considering the cost of additional charging infrastructure. Having a perfect substitute at hand, in order to be competitive against fossil fueled buses, electric buses need to find ways to reduce this price difference. As an emerging technology, it is therefore not surprising that both governments that see potential in the technology to solve some of their city's problems (e.g. air quality), and sellers wishing to promote the technology, provide grants that result in a more level playing field against more well established technologies. This is similar to what is happening in the private EV sector as explained in the literature review section.

4.2 Investment capital: reducing the cost of financing

Cities might need access to reimbursable funds to pay for the higher costs of capital associated to electric buses. Although some cities that operate the transport systems themselves (i.e. public operation) may have direct access to grants and subsidies from national and local governments, there are cases where either these are simply not available, or it is the private sector that operates the bus system in which case making a transfer of such benefits to them is hard to justify. In the first case, an innovation that arose from the research was the use of green bonds that can finance the purchase of the electric buses, such as in the case of Tianjin in China. Th Tianjin Public Transportation Group accessed financing through green bonds that was used to pay, amongst other things, their electric buses. In the second case where private operators source the buses themselves, two innovations arose from the research that led to lower cost of financing, and therefore to a reduction in the overall purchase cost of the more expensive electric buses. In the case of Curitiba, the Brazilian Development Bank (BNDES) provided concessional loans to operators that purchased hybrid buses that had been produced inside the country. In the case of Bogota, an international climate loan from the Clean Technology Fund was used to provide

[2] Since battery prices account for a large portion of the price differential with fossil fueled buses, it could be hypothesized that as battery prices continue to go down, subsidies will no longer be needed in the future.

concessional loans through a series of intermediaries (Bancoldex, a second-tier bank in Colombia, and then through commercial banks) that eventually reached the operators who used this source of financing to purchase their hybrid buses.

4.3 Legal arrangements: experimenting with risk allocation

An interesting innovation that became clear during our research was the changes that cities and operators have been introducing to their contractual mechanisms, to ensure a better distribution of risks. This in turn has led to an increasing involvement of stakeholders that previously were not part of the transport ecosystem. This can be seen in Bogota, for example, where the manufacturer of the hybrid buses became more involved in the operation of the fleet by providing training to the operator's technicians, as well as a 5-year contract for maintenance (when previously technicians did not need training as they knew diesel technology well, and the standard maintenance contract was shorter). The expectation is that after 5 years, the operator's personnel will be fully capable, and the training and maintenance contracts will not be needed anymore. This innovation allows the smoother adoption of new technologies by the operators, since, although the risk is kept with the operator, they will have a sort of "safety net" to rely on when dealing with new technologies.

In addition to this form of involvement, utility companies have also shown interest in getting involved in the transport business by assuming certain risks. In Gothenburg for example, the utility company (Gothenburg Energy) paid for investments in electric infrastructure, including an electric substation adaptation and bus chargers. Another example of utility company involvement is Foothill where the utility company (Edison) provided a demand surcharge waiver for buses that were being recharged at peak times, therefore taking the risk of changes in the cost of electricity. Since utility companies were not previously part of the transport ecosystem, this involvement can be categorized as "innovative". As with investment incentives, this innovation puts clean buses on a more level playing with diesel buses by giving operators predictable operating costs which diesel cannot provide, and lowering upfront capital costs.

One of the stand out innovations is the emergence of leasing contracts for buses and batteries. Rather than owning buses, operators in in cities such as Shenzhen and Bogota are leasing both buses and batteries. This innovation has interesting implications for other cities, as it tackles several potential challenges to electric bus adoption. On the one hand, both the risk of poor battery performance as well as their upfront cost are transferred from the operator (who normally would own the buses) to the lessor. This addresses the reluctance that operators may have to transition to a new technology, since they are not responsible for replacing batteries and paying for them. On the other hand, leasing arrangements may lead to greater specialization in the value chain, where the lessor focuses improving the quality of the bus and battery infrastructure, while operators specialize on high quality service delivery to the end user.

4.4 Legal arrangements: extraneous factors

We identified additional elements that seem to have played an important role in the adoption of clean vehicles on the cities researched. A first element is the political will, shown by public officials in the adoption of these technologies which was present in multiple case studies, so can be considered a trend. The political will was observed in multiple forms; some city officials made public commitments driven by specific situations (e.g. Paris launched its first electric buses during the COP21) or to position their city from a specific angle (e.g. In 2007 Stockholm's City Council announced the Vision 2030 goal of becoming the "green capital of the world" (City of Stockholm Executive Office, 2007)). Others developed specific plans (e.g. climate action plans, transportation plan, or technological adoption plans) that include the transition to cleaner vehicle technologies as part of measure to be taken under these plans, ensuring that their vision transcended political periods.

A second element identified was the relationship between specific local or national policies that served as enabling factors for the adoption of cleaner technologies. Such is the case of London's Ultra Low Emission Zone that provided a clear incentive for bus operators to move towards zero-emission vehicles. Others, such as China's national green bond policy, allows for public transportation procurement to access this source of financing. Again, this was a trend identified in multiple case studies.

Finally, the location of manufacturers seems to be correlated to the adoption of newer technologies in neighboring locations such as Campinas and Curitiba in Brazil, Zhuhai in China and Gothenburg in Sweden, and can therefore be considered a trend.

4.5 Summary

A summary of current trends and innovations identified in the 26 cases can be seen below. The table (Table 2) gives a better picture of the major factors appeared in different cases around the world. Public grants and innovative ways to reduce costs and risks are key for adopting electric buses.

Table 2 Key messages and innovative mechanisms

City	Country	Public grants	Private grants	Less costly financing	Innovative contractual implementation
Auckland	New Zealand	X			
Berlin	Germany	X			
Bogota	Colombia	X	X	X	X
Colombo	Sri Lanka	X			
Curitiba	Brazil			X	
Gothenburg*	Sweden	X	X		X
Gumi	South Korea	X	X		
London*	United Kingdom	X			
Milton Keynes	United Kingdom	X			
Nanjing	China	X			X
Paris	France				
Philadelphia*	United States	X			
Pomona Valley	United States	X			
Rome	Italy	X			
Seattle*	United States	X			

Shenzhen	China	X			X
Singapore	Singapore	X	X		
Stockholm	Sweden	X			X
Tianjin	China	X		X	X
Turin	Italy	X			
Toronto	Canada				
Zhuhai	China	X	X		X

Notes: * Cities with 2 cases

5. Conclusion

We set out to identify current trends and innovations in cities that are experimenting with electric buses to transition their fleets. Given known barriers to electric bus adoption, we focused in particular on how cities are paying for the additional upfront cost of electric buses and how they are allocating risk and responsibility between different stakeholders. We identified trends, as well as innovations that could be adapted to other locations to help to overcome some of the barriers of transitioning to clean fleets.

When it comes to trends, we found out that to overcome the additional capital expenses of electric buses, most cities use grants. These could originate from local, national or international sources and take the form of cash or. in-kind (e.g. land) and tax reductions. The presence of different types of incentives is an encouraging message for cities that not access to cash grants. Land and fiscal measures could be more accessible to a larger number of cities.

On the side of innovations, two linked elements came across as potentially useful for other locations. First, the involvement of new stakeholders, in particular utility companies and bus and infrastructure manufacturers, which can provide solutions to knowledge and experience barriers associated with the technology transition. These actors may provide training and may pay for the charging infrastructure. Second, leasing of batteries and buses can overcome the higher up-front costs of these new technologies. It is also a potential way of achieving larger economies of scale, and allocating technology risks where they could be better handled.

Through the research, we identified several areas for further research and methodological refinement. For one, we identified the need to focus additional research on the ancillary charging infrastructure, such as the involvement of city planners in certain decisions, including how to pay and maintain it.

Further, future research should focus on additional sources of funding for electric buses that are theoretically viable but that we did not encounter in practice in the sample we analyzed. These include land value capture and new international climate finance sources such as the Green Climate Fund. Additionally, contractual amendments that extend depreciation time for new buses could also be an important procurement change that could change the financial payback in favor of electric buses.

Finally, although the goal of this research was not to delve into technical questions of the technology, it became clear from interviews conducted that future research and knowledge sharing could usefully focus on increasing access to data on several technical aspects. These include sharing of real operational data, including maintenance frequency and costs, and impacts of topology and climate on operational performance and optimal charging station location. More data is also needed on several variables outside of the immediate transport system, such as energy demand and supply and its impact on existing grids.

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Appendix

Table A.1. Summary information of cases

No	City and Project	Country	Fuel type	Status & Size*	Project Legal Entities	Funding sources	Financial product	Legal framework and other Plans
1	Auckland - City Circuit	New Zealand	Hybrid Electric	Retired <10	Public-Private Mix Owned and Managed	Public Grants Capital Expenditure Grant	N/A	Clean Tender Requirement
2	Berlin - E-Bus Berlin	Germany	Battery Electric	Pilot <10	Public Owned and Managed	Public Grants Capital Expenditure Grant Operational Expenditure Grant Research and Development Grant	N/A	Local Government Act City Climate Action Plan Transportation Plan
3	Bogota Hybrid Bus	Colombia	Hybrid Electric	Operating 100-500	Public-Private Mix Owned and Managed	Public Grants Capital Expenditure Grant Private Grants Public Transport Budget Bus Scrappage payment Corporate Tax Break	Soft loan	Public procurement Contract Battery Lease Concession Advertising contract Local Government Act Transportation Plan
4	Colombo e-BRT	Sri Lanka	Battery Electric	To be pilot 10-100	Public-Private Mix Owned and Managed	Public Grants Capital Expenditure Grant	N/A	Concession Transportation Plan
5	Curitiba HibriBus	Brazil	Hybrid Electric	Operating 10-100	Public-Private Mix Owned and Managed	Farebox Revenue Public Transport Budget Bus Scrappage payment	Concess-ional Loan	Public procurement Contract Concession City Climate Action Plan Transportation Plan
6	Gothenburg HYPER Bus	Sweden	Hybrid Electric	Operating <10	Public-Private Mix Owned and Managed	Public Grants Capital Expenditure Grant Private Grants	N/A	Clean Tender Requirement City Climate Action Plan Transportation Plan
7	Gothenburg ElectriCity	Sweden	Battery Electric	Operating <10	Public-Private Mix Owned and Managed	Public Grants Capital Expenditure Grant Private Grant	N/A	Clean Tender Requirement City Climate Action Plan Transportation Plan
8	Gumi OLEV	South Korea	Battery Electric	Operating <10	Public Owned and Managed	Public Grants Capital Expenditure Grant Private Grants Research and Development Grant	N/A	Transportation Plan

No	City and Project	Country	Fuel type	Status & Size*	Project Legal Entities	Funding sources	Financial product	Legal framework and other Plans
9	London Hybrid Bus	United Kingdom	Hybrid Electric	Operating 10-100	Public-Private Mix Owned and Managed	Public Grants Capital Expenditure Grant Environmental impact tax Public Transport Budget	N/A	Public procurement Contract Concession City Climate Action Plan Transportation Plan Limited Traffic Zone
10	London Electric Bus	United Kingdom	Battery Electric	Operating 10-100	Public-Private Mix Owned and Managed	Public Grants Capital Expenditure Grant Environmental impact tax Public Transport Budget	N/A	Public procurement Contract Concession City Climate Action Plan Transportation Plan Limited Traffic Zone
11	Milton Keynes Electric bus Demonstration	United Kingdom	Battery Electric	Operating <10	Public-Private Mix Owned and Managed	Public Grants Capital Expenditure Grant Private grants	N/A	Public procurement Contract Concession City Climate Action Plan Transportation Plan
12	Nanjing Electric Bus	China	Battery Electric	Operating 10-100	Public Owned and Managed	Public Grants Capital Expenditure Grant	N/A	Lease back Agreement Bus Lease City Climate Action Plan
13	Paris Electric Bus	France	Battery Electric	Operating 10-100	Public-Private Mix Owned and Managed	Farebox Revenue Payroll Tax Public Transport Budget	N/A	Concession Transportation Plan
14	Philadelphia Hybrid Bus	United States	Hybrid Electric	Operating 500-1000	Public Owned and Managed	Public Grants Capital Expenditure Grant Public Transport Budget	N/A	Advertising Contract City Climate Action Plan Transportation Plan
15	Philadelphia Electric Bus	United States	Battery Electric	Operating 10-100	Public Owned and Managed	Public Grants Capital Expenditure Grant Public Transport Budget	N/A	Advertising Contract City Climate Action Plan Transportation Plan
16	Pomona Valley (Foothill Transit)	United States	Battery Electric	Operating 10-100	Public-Private Mix Owned and Managed	Public Grants Capital Expenditure Grant Sales Tax Bus Scrappage payment	N/A	Concession Transportation Plan
17	Rome MIRACLES Project	Italy	Battery Electric	Operating 10-100	Public Owned and Managed	Public Grants Capital Expenditure Grant Environmental Impact Tax	N/A	Public Procurement Contract Transportation Plan Limited Traffic Zone
18	Seattle Hybrid Bus	United States	Hybrid Electric	Operating 100-500	Public Owned and Managed	Public Grants Capital Expenditure Grant Sales Tax	N/A	Public Procurement Contract City Climate Action Plan

No	City and Project	Country	Fuel type	Status & Size*	Project Legal Entities	Funding sources	Financial product	Legal framework and other Plans
19	Seattle Electric Bus	United States	Battery Electric	Operating <10	Public Owned and Managed	Public Grants Capital Expenditure Grant Sales Tax	N/A	Public Procurement Contract City Climate Action Plan
20	Shenzhen Electric Bus	China	Battery Electric	Operating >5000	Public Owned and Managed	Public Grants Capital Expenditure Grant Public Transport Budget Bus Scrappage payment	N/A	Lease back agreement Bus lease Lease-purchase contract Battery lease Transportation Plan
21	Singapore Hybrid Bus	Singapore	Hybrid Electric **	Pilot <10	Public-Private Mix Owned and Managed	Public Grants Capital Expenditure Grant Private grants Public Transport Budget	N/A	Concession Transportation Plan
22	Stockholm Hybrid Bus	Sweden	Hybrid Electric **	Pilot <10	Public-Private Mix Owned and Managed	Public Grants Capital Expenditure Grant	N/A	Lease-purchase contract Concession City Climate Action Plan Transportation plan Clean Tender Requirement
23	Tianjin Electric Bus	China	Battery Electric	Operating 100-500	Public Owned and Managed	Public Grants Capital Expenditure Grant	Green Bond	Lease-purchase contract City Climate Action Plan Transportation Plan Green bond policy Clean Tender Requirement
24	Toronto Hybrid Bus	Canada	Hybrid Electric	Operating 500-1000	Public Owned and Managed	Public Transportation Budget	N/A	Transportation Plan
25	Turin STAR	Italy	Battery Electric	Operating 10-100	Public Owned and Managed	Farebox Revenue Public Grants Capital Expenditure Grant	N/A	Transportation Plan Limited Traffic Zone
26	Zhuhai Electric Bus	China	Battery Electric	Operating 100-500	Public Owned and Managed	Public Grants Capital Expenditure Grant	N/A	Bus Lease Transportation Plan

Notes:

(1) * Data retrieved by October 2016

(2) ** Singapore, Stockholm have electric buses testing now.

(3) Some cities may have more than one project or procurement package in one city, but because the general structure are similar, detailed information not shown here.

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