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CLEANER VEHICLES AND CHARGING INFRASTRUCTURE

Greening Passenger Fleets for Sustainable Mobility

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TRANSPORT DECARBONIZATION INVESTMENT

Table Contents

Transport Decarbonization Investment (TDI) Series

The TDI Series is a partnership between the World Bank, the Government of the Netherlands, and the World Resources Institute (WRI) with the goal of sharing recommendations for overcoming investment barriers to decarbonizing transport and spurring joint action by governments, companies, civil society, and international development and financial institutions. This discussion paper on “Cleaner Vehicles and Charging Infrastructure” is the second in a series of technical notes in the lead up to COP26 in November 2021. Other TDI series discussion papers include: Motorization Management and Used Vehicles; Greening Freight and Logistics; Decarbonizing Cities with Public Transport; Active Mobility and Improving Land Use Policies; and Financing Decarbonization of Transport.

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1. Context: Electric Mobility and Influencing Factors

Mobility is essential for economic and social development, but the transport sector in most countries is not sustainable in its existing form.

Reducing Greenhouse Gas (GHG) emissions and local pollutants in the transport sector will create a cleaner, healthier and more livable future for everyone. The transport sector contributes about one-fifth of total global carbon dioxide emissions, and road transport was responsible for more than 77 percent of global transport-related carbon dioxide emissions in 2020 (ICCT 2020). At the same time, the transport sector remains a major contributor to the air pollution burden globally. Globally, particulate matter (PM2.5) and ozone concentrations from transport's tailpipe emissions resulted in health damages equivalent to an estimated 7.8 million years of life lost and approximately US$1 trillion in health damages in 2015. (Anenberg et al. 2019)

Electric mobility (e-mobility) represents a crucial opportunity to develop a more sustainable transport system.[1] The need for sustainable and clean transport systems to combat climate change, coupled with technological progress in the transport and power sectors, is making e-mobility increasingly popular worldwide. Within the avoid–shift–improve (ASI) framework,[2] e-mobility fits under the "improve" dimension, but it can also play an important role in the "shift" dimension if the comfort offered by e-buses or convenience offered by e-bikes catalyzes modal shift. Adoption of e-mobility needs to be combined with transport demand management strategies to reduce vehicle miles traveled and to curb greenhouse gas emissions from the transport sector.

Electrification of transport offers significant environmental benefits and at the same time produces a long-lasting economic impact. E-mobility is an important way to mitigate air pollution by reducing carbon intensity of the transport sector as it has better efficiency than internal combustion engine (ICE) vehicles and has zero tailpipe emissions. Through electrification of transport, the International Energy Agency (IEA) estimates that electric vehicles can reduce GHG emissions by almost half compared to an equivalent fleet of ICE vehicles under existing government policies (IEA 2020). Moreover, e-mobility can effectively cut down noise pollution in densely populated areas. Research shows that the advent and diffusion of electric propulsion systems will lead to significant reductions of the urban noise pollution and result in new soundscapes (Maffei and Masullo 2015). Beyond environmental gains, the electrification of transport could offer numerous other benefits: (i) economic gains from the development of electric mobility value chains and lower total cost of ownership (TCO) for users, especially if the prevalent decrease in battery production costs continues; (ii) increased energy efficiency of the transport sector; and (iii) energy independence as diversity in the fuel portfolio of countries and reduced dependence on fossil fuels, in particular imports of fossil fuels, would foster national security.

The Note identifies tangible actions and policies that governments can adopt to facilitate the adoption of e-mobility in passenger transport. In doing so, it identifies practical considerations that governments should keep in mind when facilitating e-mobility adoption. Passenger transport includes public, shared, and private transport. This technical note places a strong emphasis on public and shared transport as improving it: (i) helps make the transport system less congested, reducing the need for many separate trips by private vehicles; (ii) can benefit people across all income strata; and (iii) can, with higher utilization, harness the operational cost savings of electrification faster than relatively low utilization private vehicles.

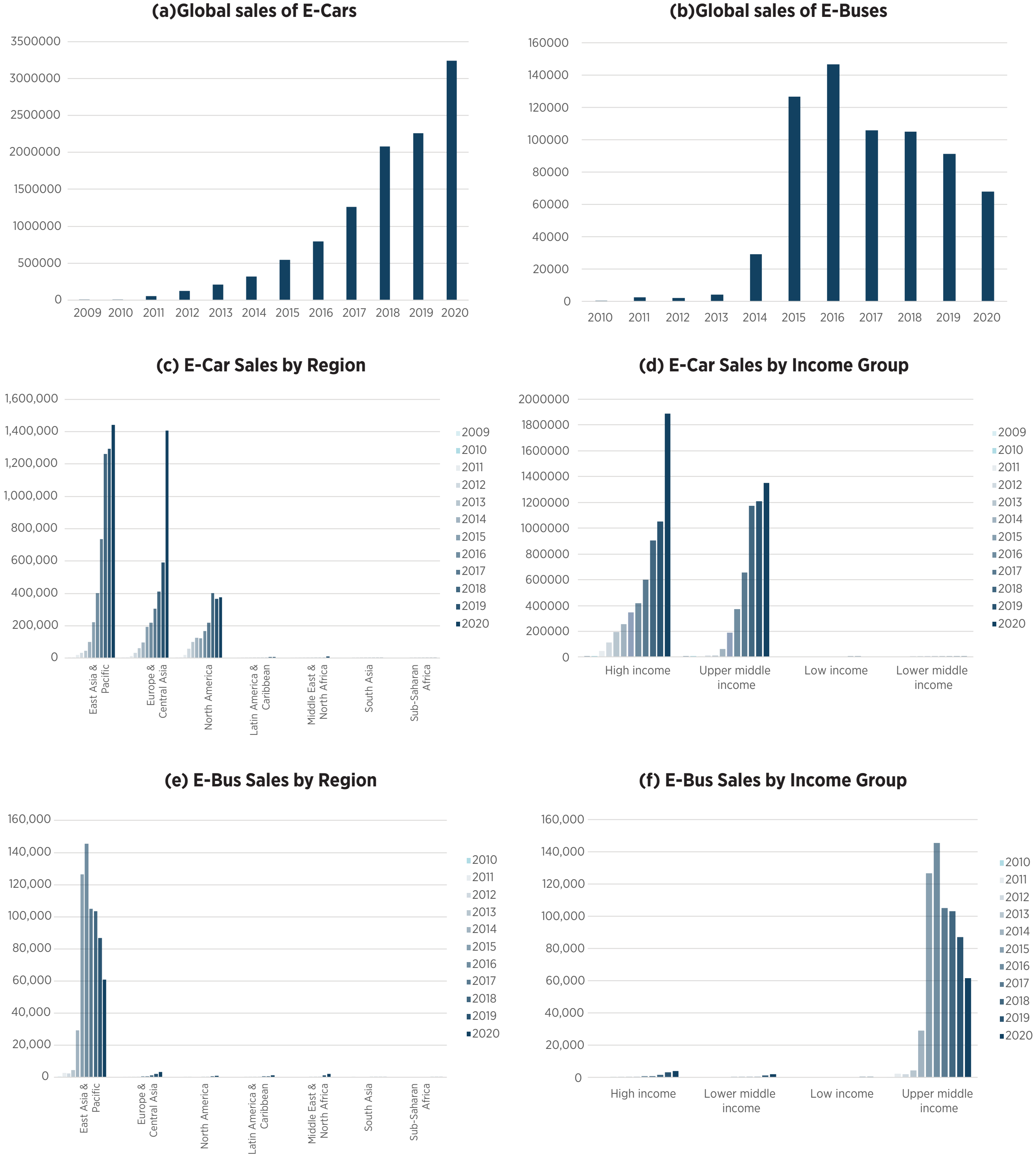
I. E-Mobility Adoption

The electric vehicles (EVs) market, including e-cars, electric two- and three-wheelers, and e-buses, has overall experienced growth over the last decade. Global sales of e-cars grew rapidly between 2010 and 2020—sales grew by more than 40 percent every year over the past decade except for 2019. Starting with sales in the thousands in 2009, the one-million annual sales mark was crossed in 2017 and three million last year—when the COVID-19 pandemic resulted in a crash in car sales overall (IEA 2021a). For the two- and three-wheelers, the number grew from around 516 million in 2013 (WHO, 2017) to approximately 900 million today (BNEF, 2020). While the growth in e-bus sales has been nonlinear owing to a drop in e-bus sales in China, e-bus adoption in countries outside China has been exponential over the last few years (figures 1-1a and 1-1b).

Sales of EVs have been heterogenous across regions and income groups. Ninety-three percent of the cumulative e-car sales from 2009 to 2020 were in China at 46 percent, the United States at 16 percent, and Europe at 31 percent (BNEF, 2020). In 2020, 11 countries crossed ten percent market shares[3] in electric car sales: Denmark (14 percent), Finland (16 percent), Germany (13 percent), Hong Kong SAR China (13 percent), Iceland (47 percent), Luxemburg (11 percent), the Netherlands (22 percent), Norway (62 percent), Portugal (12 percent), Sweden (30 percent), and Switzerland (13 percent). Even in many of these leading countries, market shares have a long way to go for full electrification, and growth is not guaranteed without continuous government action and support. Only thirty-eight countries crossed the one-percent market share mark, with no low-income country crossing the one-percent threshold and only three middle-income countries crossing the one-percent mark.[4] In contrast, about 95 percent of the global e-bus sales in 2020 were in China. Unlike electric car sales, which are dominated by high-income countries and China, the top two countries for e-buses sales were middle-income, namely China and India (figures 1-1 c to f). Two- and three- wheelers shares show a similar trend. According to the official data of electric two- and three- wheeler stock counted by IEA in 2019, China took the lead with 300 million two-wheelers and 50 million three-wheelers. India followed next with 0.6 million two-wheelers and 1.5 million three-wheelers. The rest of the world including Vietnam, Indonesia, and Thailand marked less than one million in stock for both two- and three-wheelers (IEA 2020). Like EV sales, the manufacturing of EVs is also highly concentrated in a few regions of the world with China producing 44 percent of EVs sold worldwide, followed by Europe (25 percent) and USA (18 percent) (ICCT 2021).

The zero emissions vehicle (ZEV) ambition especially makes pivotal the provision of charging infrastructure. Each vehicle type—two-wheelers, three-wheelers, cars, and buses—has unique charging needs. Two-wheelers have relatively small batteries of 2 or 3 kilowatt-hour, which are often removable and can be charged at home and office from a standard wall socket. Three-wheelers have slightly larger batteries of 8–12 kilowatt-hour and come in variations with fixed and removable batteries. Cars come with various sizes of batteries and utilize different charging standards. And buses typically have large batteries and high-power requirements (RMI 2020). Charging infrastructure has expanded in line with EV sales. The global stock of EV public charging

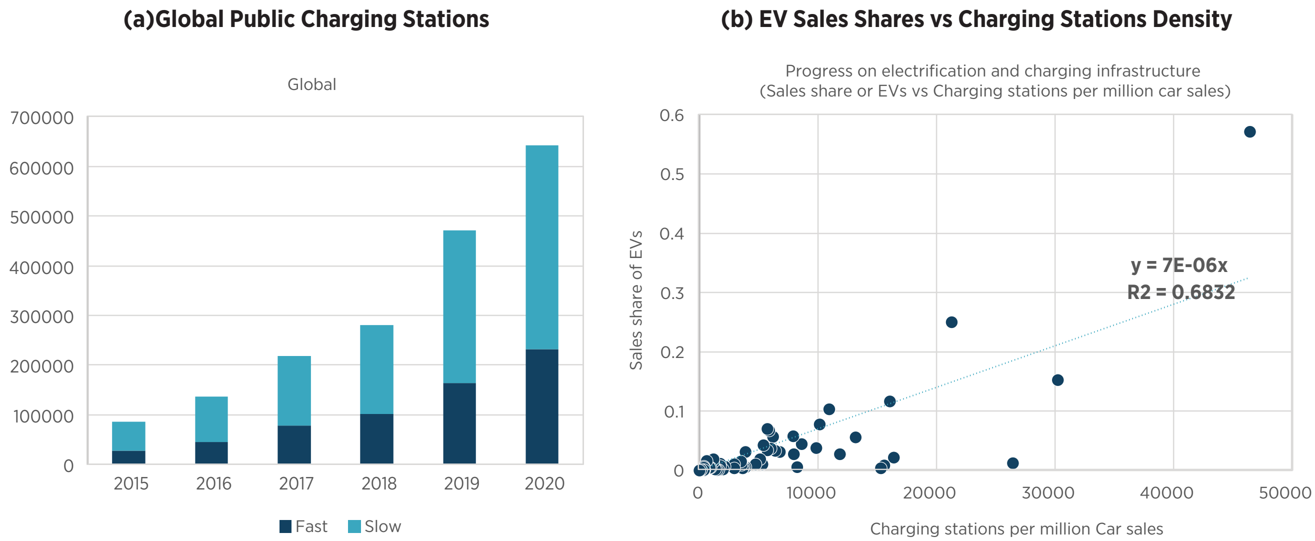
Figure 1-1: E-cars and e-buses' sales.



Source: EV-Volumes.Com (2021)

stations increased nearly seven times from 87,000 stations in 2015 to 642,000 stations in 2020. While most EVs charge at home, public charging remains important. A positive correlation seems to surface between vehicle sales shares that are EVs and the density of charging stations per million cars sold. Without an adequate charging infrastructure network, e-mobility adoption at the scale and speed needed to curb climate change will not materialize (figure 1-2).

Figure 1-2: Public charging stations.[a]



Source: EV-Volumes.com. 2021.

Note: a. Data represent public charging stations. As some of the stations have both slow and fast chargers associated double counting might be encountered. Figure 1-2-b is based on 58 countries for which all data sources are available.

II. Challenges for Developing Countries

Despite the global commitment to move toward the electrification of transportation, many countries and cities are facing the daunting task of managing the transition from internal combustion to electric vehicles. The development and adoption of EVs has been slow but is gaining momentum in both developed and developing countries. The impact of the e-mobility transition will be felt gradually in all areas of the transport and energy sectors because turnover of the vehicle stock takes time. This transition is underway in many high-income countries and some emerging economies, and will eventually also gather momentum in middle- and even low-income countries (LMICs).

The deployment and growth of e-mobility requires a transition, which involves all levels of government, private companies, and the civil society, and all with their respective roles and responsibilities. In this context, countries can learn significantly from the experience of early adopters of e-mobility to manage the transition.[5] However, when analyzing the actions taken by developed countries to deploy e-mobility, it is important to understand the overall enabling environment under which these actions were taken for EV deployment to be successful. Some of the challenges for LMICs, as in the case of India, include unclear market rules on grid upgradation, land use issues for private investments in charging, operational difficulties related to the open-access regulation threshold, and absence of subsidy support to battery swapping (WBCSD 2021a).

While some of these challenges are common to all modes of transport, others are specific to public transport.

Common factors include:

Strong and well-coordinated public and private institutions: Consultation and coordination between governmental entities, the private sector, and the civil society for EV adoption remain key barriers in many developing countries (Grütter and Kim 2019). E-mobility requires a cross-sectoral approach and many of the stakeholders have not worked together in the past. In addition, public and private stakeholders in developing nations may also lack the technical, financial, and regulatory capacity of low carbon electric mobility in relation to EVs and their charging infrastructure, renewable energy installation, innovative electricity distribution systems, and grid integration of renewable energy systems. Without capacity in these areas, local stakeholders are unable to design policy frameworks effectively, and manage and monitor interventions for transitioning to low carbon mobility (Patella et al. 2018).

Well established standards and regulations: Many developing countries have no vehicle emissions and fuel economy standards and, in some instances, no technical restrictions on vehicle importation, and limited restrictions on fuel standards, which can allow for high sulphur context in fuel.[6] These countries need to establish standards for the importation of EVs including used vehicles, and care should be exercised to ensure developing countries do not become a dumping ground for used EVs. Very few developing countries have legislation regarding the type, characteristics, and installation requirements for the deployment of electric vehicle charging infrastructure for either private or public areas. If such infrastructure is installed without legislation, it could damage the power generation and distribution system, block pedestrian pavements, and increase congestion in urban areas (Grütter and Kim 2019). For example, the Government of India's Ministry of Power published a memorandum urging regulation of the installation of power supply equipment for electric vehicles. All electric vehicle supply equipment (EVSE) shall be designed, installed, tested, certified, inspected, and connected in accordance with these guidelines (Government of India Ministry of Power 2020). In the same way, the Government of Bangladesh restricted the use of battery-assisted pedal rickshaws and e-rickshaws in the city because of concerns over the design and safety of the vehicles, claims of low speed for main roads, obstructing traffic, and especially due to illegal electric connections used by e-rickshaws, which created stress on the grid, safety problems, and lack of payment. (Grütter and Kim, 2019)

Adequate road infrastructure: Road infrastructure—roads, pavements, and walkways—in developed countries is better placed to incorporate electric vehicles and their charging infrastructure than developing countries. Roads and highways can cope with the additional weight of EVs, which in the case of buses and trucks can be significant, and pavements and roads can incorporate vehicle charging docks without generating additional traffic congestion or blocking the way for pedestrians and people with reduced mobility.

Public awareness: In developing countries, the general public's lack of awareness of the environmental, health, and economic impacts of the prevailing fossil-based energy and transport sectors, and of the benefits and viability of low carbon energy and transport systems, resulted in a lack of bottom–up pull from civil society for transitioning to renewable energy and electric mobility. (Rajper and Albrecht 2020; and Wahab and Jiang 2019).

Factors specific to public and shared transport include:

Well established formal transport systems and transit operators: In many developing countries, the public and shared transport system is informal, and system indicators like passengers transported, fares collected, system costs, and overall economic performance are unknown. This makes EV adoption in the public and shared fleets difficult. This issue has been exacerbated by the COVID-19 pandemic, where even regulated public and shared transport has slowed the transition to EVs, given the demand shift induced by the pandemic.

Strong financial institutions: Fewer developed financial institutions, lack of available financing, and inherent uncertainty in the technoeconomic performance of EVs in developing countries as well as the informality of public and shared transport make the financing of EVs and requisite infrastructure challenging.

At the same time, e-mobility policies, interventions, and investments need to be placed in the context of the larger transport and energy issues that developing countries face. Including e-mobility adoption as one of the key elements of sustainable transport and energy policies will not only help countries decarbonize the transport sector more effectively but also help better manage the transition to e-mobility. Box 1-1 presents some of the key elements that should be born in mind to foster a cleaner and greener transportation system. Several other considerations like industrial development and energy independence also play an important role in countries approach to e-mobility.

Box 1-1. Placing E-mobility in the Larger Context of Transport and Energy Issues

Transitioning to e-mobility is only one of the levers available to decarbonize the transport sector and should be combined with additional measures designed to foster a cleaner and greener transport system.

- Establish urban air quality monitoring networks and standards: This will help monitor the emissions by the transport fleet as a whole and take corrective measures including EV deployment.
- Enforce vehicle emission standards: While developing countries have in place Euro VI or equivalent standards, most of developing countries lag behind; for example, Peru has Euro III, and Uruguay has Euro V standards in place. Costa Rica, which is normally a considered an early mover in the region has Euro IV standards in place for automobiles and LDVs with future plans to advance to Euro VI standards. However, the country still has no active emission standards for heavy-duty vehicles, with no clear plans to improve this aspect in the near future.[a] Another important reason to impose vehicle emissions standards is to reduce the dumping of old vehicle technology of developed nations on developing ones.
- Enforce fuel quality standards: Developed countries have capped the sulfur content of their fuels to less than 10 parts per million ppm. However, in most developing countries the sulfur content of fuel remains high (UNEP 2020).[b] While low sulfur content is aimed mainly to reduce the particulate matter and sulfur oxide emissions of the overall transport fleet, as a biproduct, it has also enabled the countries to impose high emission regulations for new vehicles and reduce the total cost of ownership gap between conventional vehicles and zero emission vehicles.
- Enforce vehicle disposal legislations and standards: Many developing countries have little to no capacity on the reuse, recycle, or disposal of used vehicles, both conventional and electric, and electric vehicle batteries. Training and building local capacity in the management of hazardous and nonhazardous waste is essential for ensuring a long-term environmentally sustainable transition to a low-emission transport sector.

Notes:
a. Centro Mario Molina, Regional Workshop for emission standards update for heavy duty vehicles in Latin America, Santiago de Chile, 2016.
b. UN, "The sulphur campaign," 2020. Available: https://www.unep.org/explore-topics/transport/what-we-do/partnership-clean-fuels-and-vehicles/sulphur-campaign.

Notes

1. In this report, "electric vehicles" refers to either a battery electric vehicle BEV or a plug-in hybrid electric vehicle PHEV in the passenger vehicle segment. It does not include hybrid electric vehicles HEVs that cannot be plugged-in."

2. Achieving major reductions in GHG emissions from the transport sector in the long-run will require a strong focus on Avoid and Shift components.

3. Market share is defined as the share of electric vehicles in total sales of light-duty passenger vehicle segment.

4. Three exceptions and their market shares are China 5.5%, Bulgaria 2.1%, and Ukraine 1.5%.

5. For example, how to manage the loss of tax recovery from sale of fossil fuels as the transition to EVs gathers momentum.

6. R. S. Castaño, "Informe sobre la situación de colombia en materia de movilidad eléctrica," Estrategias Nacionales de Movilidad Electrica, 2018.

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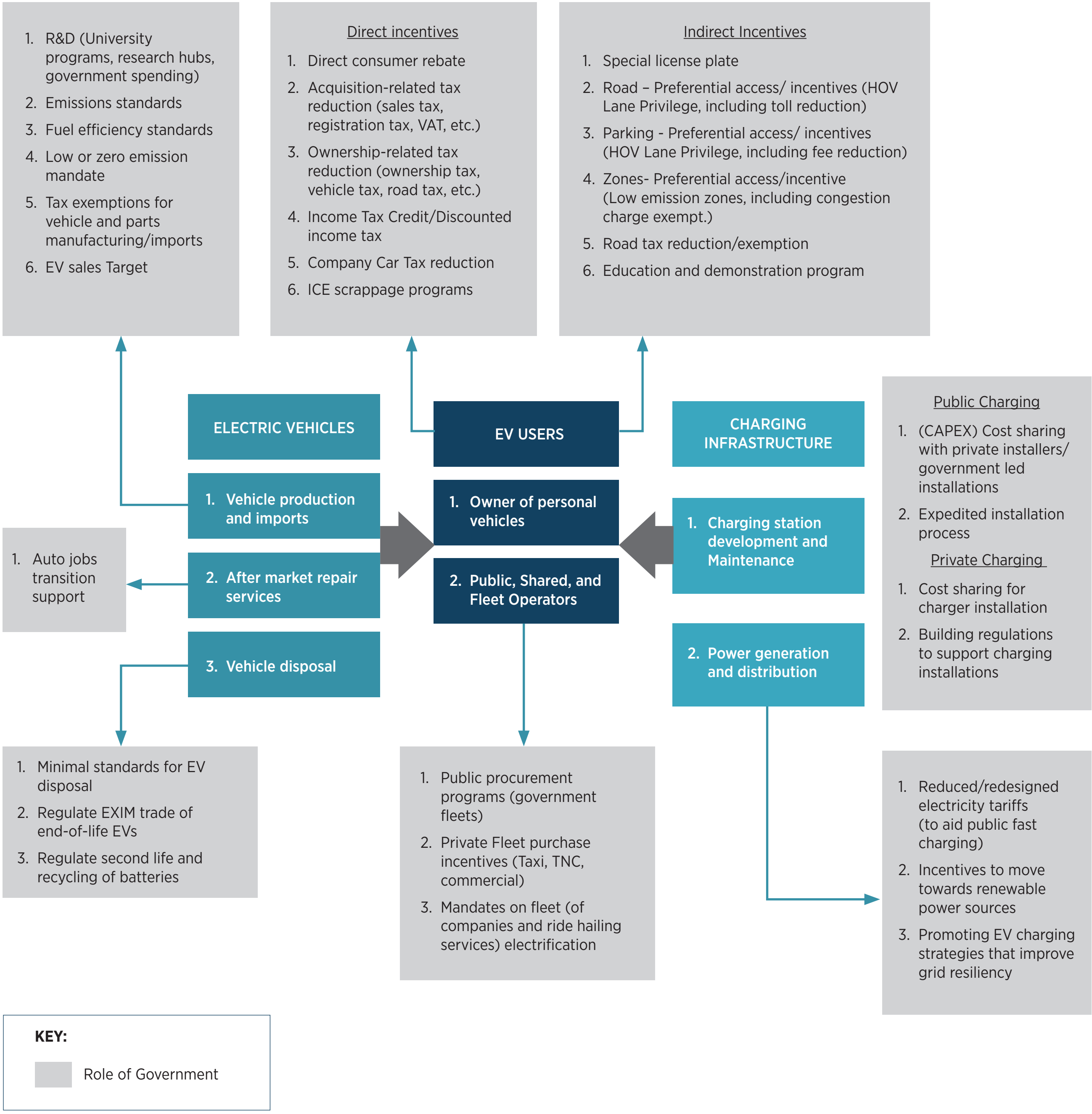
2. Technical Aspects

EV uptake requires the development of a new ecosystem that comprises two building blocks.

It necessitates: (i) transitioning the vehicle fleet from ICE to EVs, and (ii) deploying the needed charging infrastructure[1] to power the EV. The adoption of EVs goes hand-in-hand with the deployment of public and private charging infrastructure. While charging infrastructure is considered as a steppingstone over which e-mobility deployment builds on,[2] the deployment of charging infrastructure alone does not ensure EV uptake by the general public if it is not supported by the development of a regulatory and financial framework and incentives to foster adoption. For example, on one hand, no matter how many chargers are deployed in the streets, if potential users cannot cope with the high upfront costs of EVs, only a low proportion of them will purchase a vehicle, and market penetration will not grow any further. On the other hand, the absence of chargers in public spaces[3] makes it difficult for EV users to travel, and dulls any positive effect of monetary incentives, reducing the number of users who might purchase a new EV.

Governments need to use several tools to foster the transition towards EVs, covering the full spectrum of EVs and charging infrastructure. A consumer's decision on whether to transition to EVs from ICEVs is determined by a host of factors, including: (i) technical factors like the EVs range, reliability, performance and battery life; (ii) social factors like knowledge and environmental awareness about EVs; (iii) economic factors like EV purchase costs, battery replacement costs, and electricity prices; and (iv) infrastructure factors like availability of charging stations and EV repair and maintenance workshops. Governments use a variety of tools to influence these factors (figure 2-1). Governments provide direct incentives to promote EV adoption for personal use such as direct consumer rebates and various tax exemptions and reductions, and indirect incentives like special license plates, preferential access or incentives on roads—like high occupancy vehicle HOV lane privileges and special zones and parking— demonstration programs, and road tax reductions. Governments also launch public procurement programs, private fleet purchase programs for taxis and commercial vehicles, and mandates for fleet electrification to promote fleet adoption.[4] On the vehicle supply chain side, governments not only need to establish standards and incentives for production and imports of EVs, but also nurture the aftermarket repair and services sector for EVs, and support job transition programs for those engaged in aftermarket services for internal combustion engine vehicles[5] (ICEVs). Governments also need to establish protocols for disposal or second life of batteries and recycling for EVs. In addition, governments need to focus on and ease structural changes in the full value chain for vehicles—both along the original equipment manufacturer (OEM) value chain, as well as the aftermarket or dealer network. On the charging infrastructure side, governments launch public charging infrastructure development programs, provide financial incentives for private sector-led installation programs for both public and private use, and establish expedited procedures for installation. In doing so, governments need to bear in mind the differing charging infrastructure needs of different types of vehicles—e-two- and three-wheelers, e-cars, and e-buses. Governments also support the reduction and redesign of electricity tariffs to lower the operating costs of EVs.

Figure 2-1: E-Mobility ecosystem and role of government



Source: Authors' own elaboration.
Notes: VAT stands for Value-Added Tax, CAPEX stands for Capital Expenditure and TNC stands for Transport Network Companies.

While governments around the globe have to date provided generous consumer subsidies to support the EV market, this strategy is not sustainable. As a result, many governments are reducing consumer subsidies to promote EV adoption and have tightened the segment of EVs to which the subsidy applies. For example, the Plug-in Car Grant in the UK was launched in 2011, with eligible cars—selected plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs)—given a £5,000 subsidy. Over time these incentives were reduced; in 2018, PHEVs were excluded and as of March 2021, the grant is limited to £2,500 for electric cars of a maximum price of £35,000 (Ambrose 2020; Department for Transport 2021). Similarly, effective since 2010, the US federal government provided a federal income tax credit to new EV buyers based on each vehicle's battery capacity and the gross vehicle weight rating, with the amount ranging from US$2,500 to US$7,500, with a phase-out target of 200,000 EVs sold (Li et al. 2017). The Chinese government also has in place a policy plan to promote EV adoption at both central and local levels, with the main instrument being consumer subsidy, contingent on vehicle quality attributes; between 2013 and 2018 the offered central subsidies fell over time by approximately half. In Montevideo, Uruguay, the Public Transport Operators (Operadores de Transporte Público: OTP) are subsidized US$100,000 though MOVÉS funds to purchase EV and perform upstream technical analysis of charging infrastructure (MOVÉS 2021). This initiative has been expanded with approval by the government and subsidies have been approved for approximately 130 buses.

Supporting the deployment of charging infrastructure is an important and cost-effective way of promoting EV adoption in the early stages. Three separate studies analyze the role of government in the rapid growth of the EV market in three important EV markets: China (Li et al. 2020), Norway (Springel 2017), and the US (Li et al. 2014). While all three studies found that consumer subsidies explain a significant share of the EVs sold in each country, subsidizing charging station deployment was estimated to be twice as effective in Norway and the US, and about four times as cost effective in China, as compared to a policy of equal-sized spending. This means that every dollar spent on subsidizing charging stations—as compared to price subsidies for EVs—resulted in more than twice as many additional EV purchases in Norway and the US, and four times as many in China.[6] While the effects of subsidies on charging stations taper off as the charging network gets larger, it appears that supporting the deployment of charging infrastructure is a key enabler of EV deployment in the early phases.

Developing countries face many barriers that make it difficult for them to apply similar measures as developed countries for the development of charging infrastructure to support the deployment of e-mobility at large scales. These include but at not limited to the lack of clear EV and infrastructure deployment strategies and targets, the lack of clear standards to enable interoperability between the infrastructure and the vehicles, low electric grid stability and heterogeneous electric infrastructure quality, and lack of fiscal space and economic shocks.

I. Vehicle Fleet

Countries have a myriad of tools available to foster the transition toward EVs. Many factors affect the success of EV adoption in a country, which are not limited to awareness and trust in the technology, the availability of charging infrastructure, and overall popularity and environmental awareness of customers. The overall economic performance of EVs, when compared to ICEVs, is affected by upfront purchase cost, operating costs of electricity pricing and maintenance, frequency of use over the vehicles lifetime in kilometers driven, and vehicle disposal or resale price.

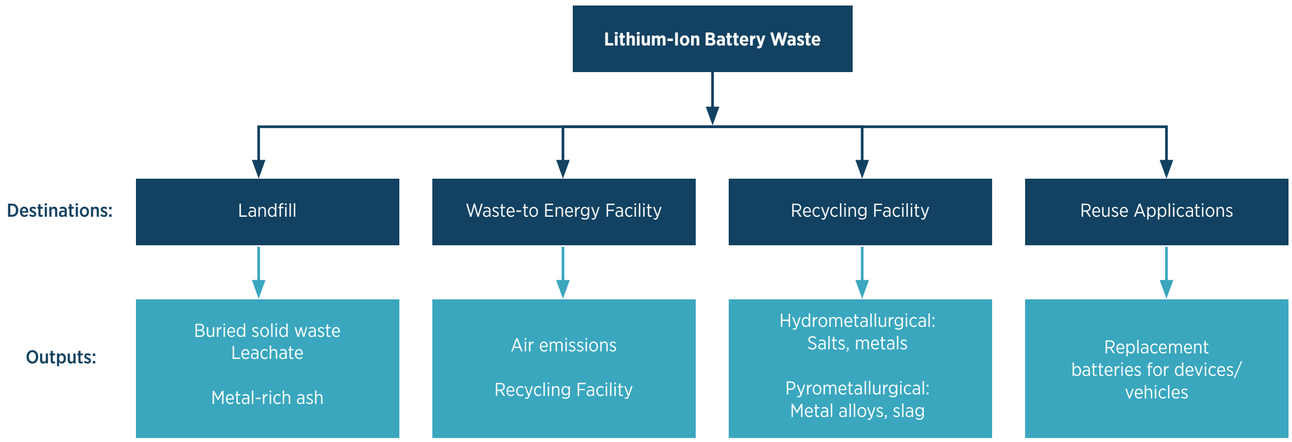
The promotion of electric mobility adoption consists of a series of common government policies that tend to boost the economic viability of EVs, but country roadmaps have been different according to each of their unique local contexts. Regardless, they share some commonalities in the approaches adopted. First, because of the greater upfront cost of EVs relative to ICEVs, the impact of upfront taxes has significantly influenced adoption levels. Establishing different taxation rates for EVs versus ICEVs, therefore, has become a tool used in many countries to even the upfront cost. Second, relative differences in fossil fuel and electricity prices have a major impact in the attractiveness of EVs. Taxes or subsidies in these prices shift the economic viability of these alternative technologies. Many countries have developed incentives to address the upfront EV purchase costs and downstream EV usage costs. For example, in Latin America and the Caribbean region in 2019: (i) EV purchase incentives were offered in Colombia, Costa Rica, Ecuador, Mexico, and Paraguay; (ii) import tax reductions were offered in Antigua and Barbuda, Argentina, Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, Mexico, Paraguay, and Uruguay; (iii) either property tax or toll or both taxes, parking and other exceptions were offered in Colombia, Costa Rica, Ecuador and Uruguay; and (iv) differentiated electric fees were charged in Chile, Costa Rica, Ecuador, and Mexico (UNEP 2019). The overall total cost of ownership (TCO) differential between EVs and ICEVs varies by vehicle type. Thus, the economic viability of EVs relative to ICEVs also varies by vehicle type. At the same time, the average annual distance driven by the vehicles also influences their relative economic viability. Because EVs are overall cheaper to operate, their overall TCO is typically lower than ICEV at higher vehicle-kilometers traveled. This, in some instances, has driven the types of vehicles and the segments of the vehicle fleet that have electrified as a priority.

While, in many cases, policies that are used to promote the private adoption of EVs apply to other types of uses as well. Specific use cases—buses, taxies, fleet cars and so on—need additional sets of incentives or regulations. Most notably, the deployment of electric buses around the world is often boosted locally by cities that complement national policies and seek to deploy e-buses to reduce GHG emissions and improve their air quality. E-buses not only have a positive impact on the environment but have also been seen to increase the popularity and demand of the public transport sector. E-bus deployment poses some financial and technical challenges. While e-buses cost two to three times more than conventional buses, they are cheaper to operate (Sclar et al. 2019). In addition, their implementation requires the deployment of high-power electric charging infrastructure as well as adaption of the prevailing operation to serve the vehicle's charging needs. Therefore, selecting the systems or routes in which e-buses are to be deployed is not a trivial task when wanting to maximize the impact of e-buses and bring their TCO as close as possible to ICE buses. In addition, it important to adapt existing public transport subsidy schemes designed for ICE buses where capital expenditure (CAPEX) is low but operating expenditure (OPEX)is high, relative to e-buses.

The electrification of public and shared transport requires a congruous approach that combines both demand creation or management and supply management measures. Demand creation strategies play a key role in accelerating the adoption of EVs and developing the EV market in any given place. In addition, they guide EV adoption strategies implemented by the government and influence financing options offered by banks and funding agencies, and investments from the private sector and international organizations, among others. Supply management strategies complement the demand creation strategies by ensuring a sufficient flow of EVs, enabling the decarbonization of the transport system. Multiple facets of supply, such as manufacturing, import, financing, infrastructure development, and skill development, work toward developing a holistic ecosystem nurturing EV adoption. Thus, the demand strategies define the path for EV uptake, and the supply strategies define the ways to achieve it.

Increasing the penetration of EVs globally, entails a hidden challenge, which is the management of waste generated, particularly of Lithium-ion batteries (LIBs). The lack of a clear battery disposal strategy can lead to serious environmental pollution problems and risks to human health. The incorrect disposal of LIBs can result in soil contamination, contamination of water tributaries and reservoirs, and air pollution. The final disposal methods of LIB[7] in the world are: (i) solid waste landfills; (ii) waste-based power generation plants or incinerators, and (iii) specialized recycling plants. Batteries can also be put toward reuse applications such as for power grid rebalancing (figure 2-2).

Figure 2-2: Common destinations for residual lithium-ion batteries and their products



Source: A review on the growing concern and potential management strategies of waste lithium-ion batteries (Winslow et al. 2018).

After reuse applications, recycling is the most environmentally friendly option, as it not only prevents battery metals from ending up in leachates, but also replaces extractive processes related to metal production, which have a high energy intensity. A study of battery life cycle in the US shows that GHG emissions embedded in battery production could reduce the pack cost up to 30 percent if recycled metals were used instead of virgin materials (Beaudet et al. 2020). On the other hand, the recycling of lithium cobalt oxide (LCO) batteries could result in a decrease of almost 100 percent of sulfur oxide emissions originating in the production of batteries because certain processes of recovery of virgin cobalt are avoided (Dunn et al. 2015). The manufacturers of batteries and vehicles should design and manufacture batteries bearing in mind the recycling process and second-life potential with the primary responsibility for recycling resting with the manufacturer.

Recycling should not be expected to appear spontaneously on the market. The generation of a value chain for the recovery and recycling of any component requires policies that qualify, control, monitor, and sanction their inadequate disposition. Safety and integrity standards for storage and transport of batteries also need to be developed. Only in this way can recycling appear as a competitive option in the market. Various attempts have been made for the second life usages for used two- and three-wheelers batteries. For example, in Thailand, CyFaia—a local company—is pairing solar power with electric two-wheelers and using the batteries as a source of household energy use. Similarly, in Malaysia, at some night markets, instead of using dirty and noisy diesel generator sets, some are using used electric two-wheeler batteries to power the lighting used, which does not require substantial power and is a good fit (UNEP, 2020b).

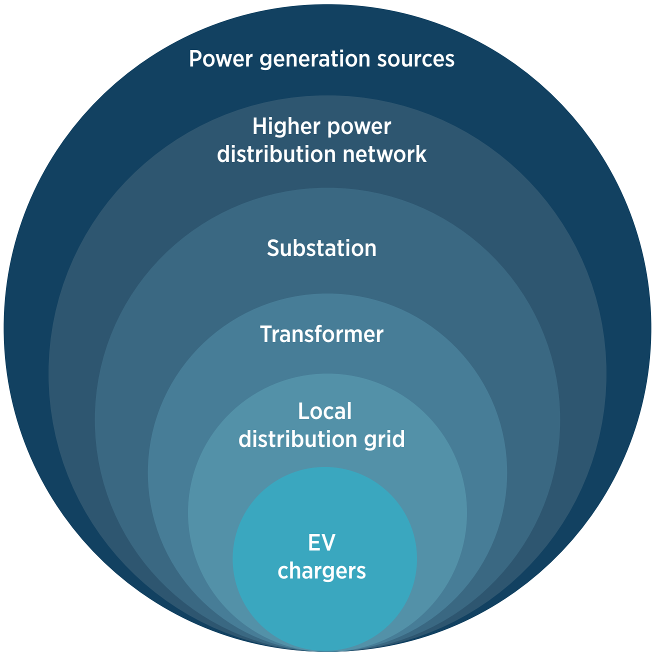
Globally, the main policy implemented to regulate the provision of LIB is that of extended responsibility to the producer (EPR). This implies that the battery producer is responsible for batteries until the end of their useful life, having to take care of their final treatment.[8] In particular, the ERP as a public policy for the management of post-consumer waste is a required obligation for member countries of the Organisation for Economic Cooperation and Development (OECD). In the European Union and some provinces of Canada, battery producers are required by law to have an LIB collection and recycling system. In China, producers are required to label batteries, and a collection and recycling system exists, but it does not have the capacity to absorb all discards generated by their market (OECD 2016; and Winslow et al. 2018).

II. Charging infrastructure

Charging infrastructure applications for EVs range from individual household chargers' low-demand usage, to high-demand public charging spots, to heavy duty applications like buses. Depending on the use case, slow charging (SC) or fast charging (FC) infrastructure can be used.[9] Low-demand usage of EV charging infrastructure for light duty vehicle applications occurs generally under situations where the vehicle is parked for several hours. These situations can be encountered, for example, in households, parking lots in public places like shopping malls, or offices, and for last-mile delivery of products. For these kinds of applications, low-power output wall-box type chargers are mainly used. These chargers require a monophasic connection to the electric grid, with typically no further upgrades of the electricity infrastructure if demand does not cluster. For high-demand applications for light duty vehicles, where vehicles need to recharge their batteries for short periods of time while the vehicle is parked, FC technology is used. For larger fleet demand situations, FCs are located at specific charging spots like charging stations for light duty vehicles, where the infrastructure supplies energy for larger number of vehicles such as public parking lots or sidewalks. In some cases, additional investments to the electricity grid like a transformer may also be needed.[10] For heavy-duty applications, like e-buses, both SC and FC technologies are used and grid upgrades are needed. SC technology is typically installed at depot where the vehicles are parked, and it is used to charge them overnight when out of service, whereas FC technology is used at the bus stations, where buses charge their batteries for short periods of time between each lap, or every two or three laps, during operation. Although popularity of charging modalities for two-wheelers varies depending on the region and countries, most of them are charged at home. For example, in India 95 percent of Indians charge at home (Sripad et al. 2019) and 80–90 percent of users drive for an average of 4 kilometers per trip (Singh 2019). On contrary, three-wheelers are almost entirely charged at a company depot or as part of a battery swapping scheme. As such, the locations for charging or swapping batteries outside of the home and workplace will likely take place in places that are well-integrated into the urban space, or at least should be. The complexity of introducing new charging infrastructure into the system scales disproportionately with the deployment of new vehicles, requiring large investments at higher levels of deployment.

As EV fleets grow, they demand higher charging capacity from the infrastructure. It is imperative to understand how the ecosystem responds to the introduction of a new charging infrastructure at each level to achieve a sustainable large-scale deployment of EV charging infrastructure. The development of new charging stations involves the setup of auxiliary systems such as local distribution grid reinforcement, transformers, and substations. Eventually, as the EV stock continues to grow, the power grid robustness needs to be upgraded. This has a direct impact over the transmission and distribution system and upstream in the power generation sources, which may result in out-of-proportion investment requirements compared to the scaling up of the vehicle fleet. Figure 2-3 represents a whole ecosystem that supports the charging infrastructure of EVs. The center represents the EV chargers' connection to the local distribution grid, and their power load has a direct impact over it. Continuing upstream to the larger circles of the figure, the local distribution grid's capacity to provide a certain power demand will directly depend on the transformer's availability. As the number of chargers increases locally, so should the number of transformers. Eventually, when a given sector of a city reaches certain levels of charging power demand, the local substation would require capacity upgrades, or even new substations might be needed as well. When EV charging infrastructure is deployed across a city and more electric substations are installed, the high-voltage distribution network will start experiencing stability issues, which will then require further upgrades of the system. At some point, the power generation and transmission capacity will not be enough to cover the peaks in electricity demanded by EV fleet, and thus further investments will be needed. These peaks can be levitated by coordinated charging, smart charging or vehicle to grid charging. Table 2-1 summarizes the different necessary electric infrastructure upgrades that may need to be incurred to deploy charging infrastructure for the different EV categories and fleet scales.

Figure 2-3: Electric power ecosystem scheme representing the different infrastructure levels of the system



Source: Authors' own elaboration.

Table 2-1: Necessary electricity infrastructure upgrades for different EV segments and fleet scales an approximation

Vehicle category	Local Distribution Grid	Transformer	Substation	High power distribution network	Power generation sources
Single Light Duty EV	✗	✗	✗	✗	✗
Medium-Large Light Duty EV fleets	✓	✓	✓	✗	✗
Small E-Bu Small E-Bus fleets s fleets	✓	✓	✓	✗	✗
Large E-Bus Large E-Bus fleets fleets	✓	✓	✓	✓	✓ (orange)

Note: Red means no upgrades are needed, green means upgrades are needed, orange means upgrades may be needed. These are highly dependent on the current capacity of the system. (*Source:* Author's own elaboration).

Another important aspect is the interoperability between infrastructures for EVs. Infrastructure interoperability refers to the capacity of the charging infrastructure and vehicle to provide the user with the possibility of charging the EV independently of the charge point provider, the charger standard, and the model of the vehicle. Interoperability is achieved by standardizing the infrastructure usage, that is, the type of connectors that the chargers provide, and the payment and usage methods that allow the user to operate the infrastructure. Moreover, other key enablers of interoperability are the communication protocols between the vehicles and the infrastructure, and safety standards for the user to operate the chargers. A certain type of EV, either SC or FC, can make use of a given type of charger only if the vehicle is prepared for the purpose. For instance, vehicles can use FC systems if they are equipped and designed to do so. If a vehicle can use a FC charger it will be equipped with the required hardware and the specific communication protocols to handle the high powers that FC chargers supply. On the other hand, the capability of a charger to supply energy to different vehicles with different charging powers also requires the charger to be equipped with the necessary hardware and software. Establishing standardized communication protocols between the chargers and the vehicles is an important aspect for interoperability.

When it comes to payment and charging accessibility, it is important for these aspects to be standardized across all the different charging points of the city to avoid confusion among users. The pay-as-you-go model is the most common method for charging EVs through public chargers.[11] Other payment models include a subscription model where the user pays a monthly fee to become a member of a charging network that provides charging services in different spots across the city. This allows the driver to make use of all the charging points of a certain charge provider. However, when several charge providers are present in the same region, users might find themselves in the need to hold a membership for each providing company. Moreover, different charge providers might use different pricing schemes to charge the users for the service, namely, charge time-based pricing at per-minute costs, which are the most commonly used, pricing per charging session, and per kilowatt-hour based pricing. Furthermore, charging station rates vary based on location, time of the day of use, duration of the charge and the power level (Enelx 2019). It is important that pricing and payment methods are harmonized across the system to enhance interoperability and make it more user friendly to attract more EV users.

To ensure interoperability, policy makers should not specify singled-standard protocols, but establish the basic principles required for the correct and safe operation of infrastructure

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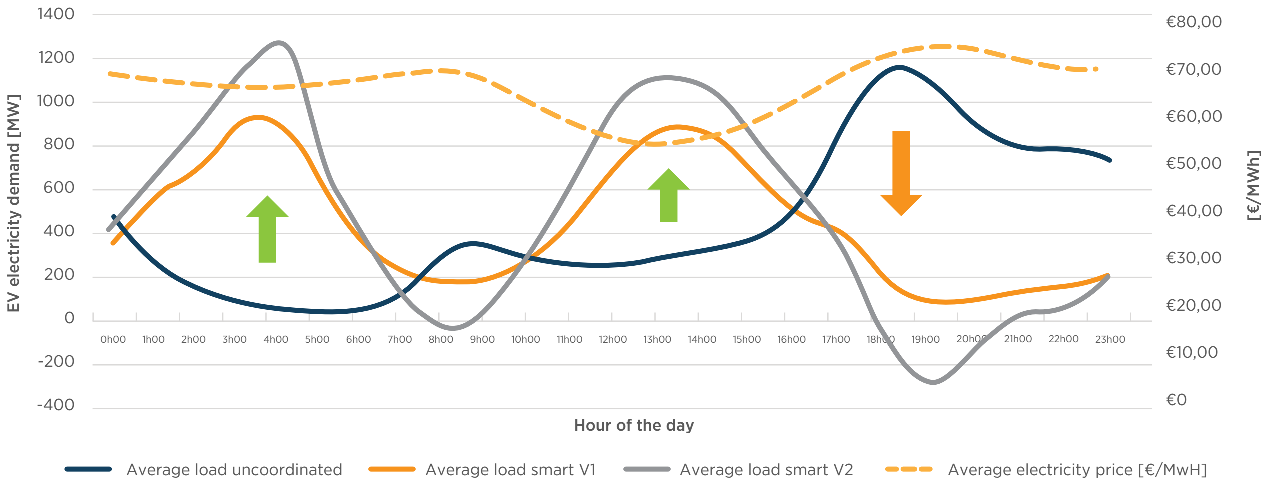
The correct management of charging infrastructure and the application of smart charging strategies can be used to lower the investments needed in the power grid as EV adoption accelerates. If EV charging is not coordinated with higher adoption levels, the demand for electricity is expected to have higher peaks in the evening as EV adoption rises (figure 2-4). However, smart charging strategies allow to reshape the EV load curve, increasing EV demand at times with lower overall electricity demand, during midday and later at night. In addition, with vehicle-to-grid (V2G) features, the vehicle can act as a power source, contributing not only to reducing the EV load, but also the overall load of the system by using the vehicle as a power source (ENTSO-E 2019).[12] While the ease with which smart charging can be adopted depends on the existing power sector infrastructure, countries may consider promoting coordinated charging as a way to elevate peaks in electricity demand.

Figure 2-4: Expected change in EV electricity demand curve for Belgium in 2030 with smart charging and vehicle to grid charging strategies compared to uncoordinated charging



Source: Accelerating to net-zero: redefining energy and mobility (Elia Group, 2020)

It is essential to support vehicle deployment with the introduction of charging infrastructure to transition toward low carbon electric mobility systems. However, given that this is a nascent industry, it usually requires monetary and non-monetary incentives for providers of EV chargers to enter these new markets. While some countries have developed national programs for the deployment of charging infrastructure along the main cities (table 2-2), others have relied on monetary and non-monetary incentives for the private sector to enter these new markets (table 2-3). It can be observed that most incentive programs applied by developed countries to encourage the deployment of EV charging infrastructure consist in government grants and subsidy programmes (table 2-2). While the overall number of charging stations is important, their location and use case is equally pertinent. Charging infrastructure subsidies should be designed to with a view of supporting the charging needs of various types of customers and support the necessary grid infrastructure.

Table 2-2: Summary of major national-level charging infrastructure programs

Country	Program	Budget	Support mechanisms
China	State Grid national fast charging corridors Regional investments by automakers City government-funded construction in pilot cities		State-owned utility programs Public-private partnership Grants to local governments
France	Funding given 3,000 cities for 12,000 charge points EDF power company building nationwide DC fast charging network		Local governments apply for grants
Germany	€300 million for 10,000 Level 2 and 5,000 DC fast charging stations	€300 million	Subsidies for 60% of costs for all eligible businesses

Japan	Next Generation Vehicle Charging Infrastructure Deployment Promotion Project Nippon Charge Service government-automaker partnership	Up to ¥100 billion	Grants to local governments and highway operators Public-private partnership
Netherlands	"Green Deal" (curbside chargers on request)	€33 million	Contracts tendered to businesses on project-by-project basis
Norway	Enova grant scheme from 2009 onward		Quarterly calls for proposals for targeted projects
UK	Curbside stations for residential areas Highways England building DC fast charging stations along major roads in England	£2.5 million £15 million	Municipalities apply for grants; installers reimbursed Grants and tenders administered by public body
USA	Grants for funding public charging stations through American Recovery and Reinvestment Act	$15 million	Matching grants for local governments

Source Emerging best practices for electric vehicle charging infrastructure, (Hall & Lutsey, 2017)

Table 2-3: Incentives incurred by European countries to encourage of EV charging infrastructure deployment.

Country	Incentive
Belgium	Companies operating under the corporate tax system can benefit from a 13.5% deduction on investments in charging infrastructure In Brussels, the tax of up to €75 on office parking spaces is waived for companies that fit charging units
Denmark	Tax exemption for commercial charging. Companies that supply EV charging on a commercial basis can receive an electricity tax rebate of around €0.13 per kilowatt-hour.
Finland	Helsinki has invested €4.8 million to build public charging stations over the last three years. The Finnish Government has recently announced a €5.5 million budget to increase charging infrastructure in 2020-2021. In 2016, the Ministry of Employment and Economy extended its EV charging subsidy program as part of an energy investment program. The program offered subsidies to commercial organizations that wanted to build charging infrastructure, of up to 35% of charging investments.
France	€300 tax credit on the purchase and installation of an EV charger at individual households Up to 40% of the purchase and installation costs of EV charging points for businesses Up to 40% of the purchase and installation costs of charging points installed by municipalities.
Germany	Grants offered by cities, municipalities, and federal states of up to €3,500 Grants offered by energy providers of up to €400 Subsidies for public charging stations: up to €3,000 for purchasing charging stations of up to 22 kW. up to €12,000 for purchasing DC chargers up to 100 kW. up to €30,000 for purchasing DC chargers above 100 kW. Connections to the grid are subsidized by up to €5,000 for low voltage and €50,000 for medium voltage grid connections

Italy	Italy offers to individuals, companies and condominiums a tax deduction of 50% on a maximum of €3,000 the purchase and installation costs of EV chargers from 1 March 2019 to 31 December 2021.
Norway	Public funding for fast charging stations every 50 km on main roads
Spain	Private individuals and companies can get subsidies of up to 30-40% of the purchase and installation costs (up to a total sum of €100,000) for the development of public and private charging infrastructure.
Sweden	Grant that covers up to 50% of the investment in both public and private charging stations “Charge at Home” program is a support scheme for individuals wishing to purchase home chargers: individuals can receive up to 50% or €960 for hardware and installation costs of home chargers
Netherlands	Citizens in most regions can request a free installation of a public charging point near their place of residence or work. Once installed, access to the charger is free and you only pay for the energy used to charge your car.
UK	The “Electric Vehicle Home Charge Scheme” enables individual buyers of eligible EVs to receive a grant for up to 75% of the total purchase and installation costs of one EV charger for their home and the associated installation costs. The “Workplace ChargePoint Grant” is a voucher-based scheme that provides the upfront costs for the purchase and installation of EV charging points at workplaces. Firms can cover 75% of all purchase and installation costs. Company Tax Benefits: businesses that install charging infrastructure can access tax benefits through a 100% first-year allowance for expenditure incurred on electric vehicle charging equipment.

Source: Wallbox, 2021.

Box 2-1: Smart Grid Concepts

Growing electricity demand by EVs can lead to grid instability. If an operating fleet of 100 public buses, for example, were to recharge at night, using an 80 kilowatt charger and assuming a low charging rate, the latter would demand 4 megawatts of power supply. This would be the same amount of power required by approximately 650 homes at their maximum capacity needs. Moreover, if fast charging electric buses were considered for this example using 300 to 500 kilowatt chargers, the resulting power demand would be even higher. It is estimated that charging of just 60,000 EVs in Texas could initiate a serious failure in the grid (Deign 2017).

It is necessary to implement new solutions, such as the smart grid concept to face these growing demands. This concept implies an advanced and controlled method of energy delivery, production, and consumption where each generator, load, and distributor can be adapted to work together (Lu and Hossain 2015). The smart grid uses bidirectional flows of electricity and information to create a distributed automated and flexible energy delivery network and allow for net metering. Moreover, the main objective of the smart grid is to make low voltage grids more visible, promoting the integration of new renewable energy sources through sustainable households, and encouraging consumer participation in the operation of the grid. The latter is possible using smart meters, through which the users are aware of their real consumption and electricity rates, and at the same time they can decide if they want to disconnect from the grid to consume energy of their own generation. In most countries, regulations need to be updated to allow for the possibility of net metering.

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The increasing number of RES such as wind, solar, geothermal, and hydroelectric, and the rising number of related distributor generators requires innovative strategies for the management and operation of the grid, to minimize fluctuations related to these energy sources and ensure a reliable energy provision. Under these circumstances, grid operators must estimate how much renewable energy generation is expected and how much energy is being generated at any given moment to be able to respond to changes in generation. Difficulties for the operator lie in the random nature of renewable energy sources and the wide range of size magnitude of the energy sources and distances between them throughout the grid (Cleary and Palmer 2020). In an ideal scenario, all the renewable energy generated would be injected into the grid, and if additional energy were required, conventional energy sources would be used. However, the peaks of renewable energy production do not match with the peaks of energy demand, hence storing energy methods are required. Energy storage systems are used to meet this requirement battery, but the high cost of these components may be prohibitive for some regions. For this reason, the development of alternative energy storage systems such as flywheels, super capacitors, compressed air systems and pumped hydroelectric energy, among others, will be important for an effective integration of renewable energy sources into the grid.[13] This integration process also brings benefits to the transport sector, simplifying access to clean energy for different companies. In addition, several transport companies are interested in reducing their emissions by using green energy.

Notes

1. Linked to this, is the need to bolster electricity supply and sources of electricity.

2. As it allows for users to operate EVs and overcome range anxiety

3. And the high charging prices set at existing stations.

4. Governments should also consider reforming the current tax and incentive systems to reduce explicit or implicit subsidies to ICE vehicles.

5. Governments must focus on mitigating the potential impact that EV adoption may have on employment for low-level employees in the transport sector, a large majority of whom are men with limited formal education, training, and skills. Thus, they have limited opportunities for employment in other fields.

6. Perhaps most strikingly, in China the policy which merely grants EVs a distinctive looking license plate in green was also found to be very effective, increasing EV sales by 18%.

7. In some cases LIBs can be reused, thus extending their lifespan for secondary applications that can operate with reduced battery capacity, for example, in stationary energy storage.

8. Either recycled or for treatment and disposal.

9. SC equipment handles low power outputs, and the charging process usually takes from 2 to 8 hours, depending on the vehicle being charged. In general, for light-duty-vehicle LDV applications power output ranges 3.5 - 7.5 kW for low-intensity usage but for heavy duty vehicle applications such as bus fleets, the charging power ranges 50 – 150 kW. FC technology has a much higher charging power than SC technology. For light duty vehicle applications power requirements range from 22 kW of power for small fleets with moderate usage demand, up to 50 to 100 kW for large vehicle fleets that require higher energy outputs. For heavy duty applications like bus fleets the chargers' power outputs range 250-400 kW.

10. These upgrades can be costly and, in some cases, can threaten the financial viability of a project without careful planning.

11. This model allows for the user to pay for the service each time it is required, and thus the user does not have to pay for a subscription each month, making it much easier to operate.

12. ENTSO-E, "Electric Vehicle Integration into Power Grids," 2021.

13. WBCSD's Value Framework for Sustainable Charging identifies 9 key enabling actions: addressing the needs of EV fleets, agreeing on data sharing principles, engaging and incentivize flexible consumers, subsidizing and facilitating charging integration, encouraging deployment of smart grid technology, facilitating microgrids, establishing coordinated strategic planning and management, sharing space and charging infrastructure and connecting intermodal mobility. WBCSD, 2021b

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3. Investments and Interventions Needed

Over the last 50 years the essence of the transport sector has remained untouched. While technologies, business models, insurance policies, and relations between OEMs and asset owners have evolved, its core remains the same. The technical requirements and overall economic efficiency of zero emission vehicle technologies such as electric vehicles or hydrogen-powered vehicles are completely different to that of conventional vehicles and therefore, optimizing their use requires a new approach.

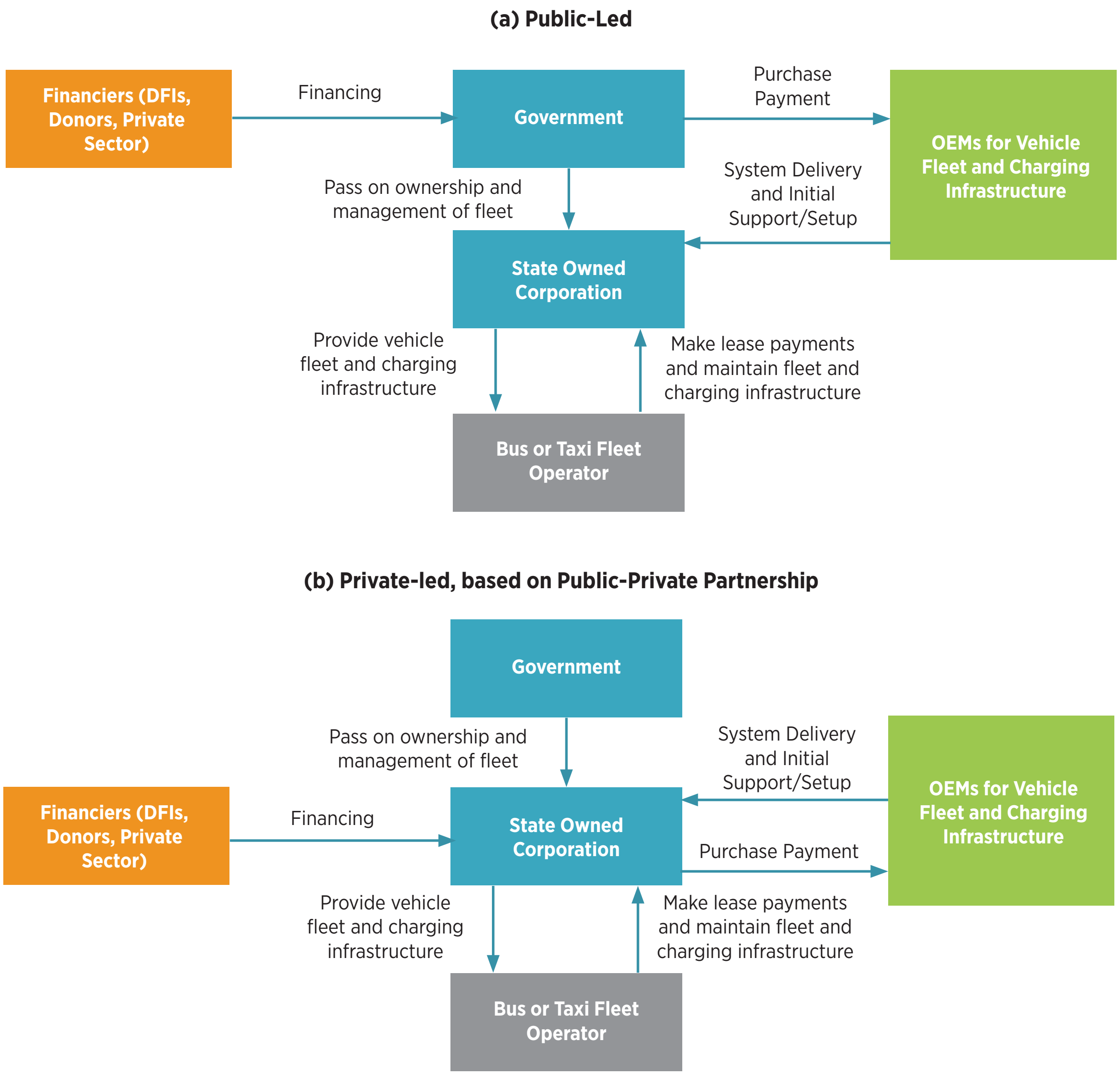
In conventional transport systems, normally the operator is the owner of the assets, acquired through a loan or a lease contract from a financial institution, or the OEM. The operator then covers operational costs with the system's revenue or, in the case of many public transport systems, with subsidies provided by the local or national government. In the case of zero emission vehicles, such as electric vehicles, the capital required to purchase the vehicles and set up the charging infrastructure is considerably greater than for a conventional application (IEA 2021b). On the other hand, operational costs especially those referred to energy expenses are considerably reduced. Therefore, based on existing technology, the vehicle must pay for itself and the requisite charging infrastructure for an EV to be economically viable with the savings it generates in energy and maintenance expenses, compared to an equivalent conventional vehicle. This possess many challenges, one of them being the need of additional financing to purchase the vehicles and deploy the charging infrastructure. Also, the fact that EVs are expected to pay for themselves through their savings in operational costs poses a dichotomy. On one hand, for an electric vehicle to be economically viable it must replace a vehicle with a high daily mileage, so that the OPEX displaces the CAPEX; however, EVs have a considerably lower range than conventional vehicles. Therefore, a workable equilibrium must be found between economic and technical viabilities. It is therefore important to understand the operation that wants to be electrified. Also, given that for these new technologies to break into the transport system and scale up, it is very important for government authorities to put in place short-, medium- and long-term objectives and regulations to reduce uncertainty and give private investors a clear signal.

Investments and interventions in e-mobility need a new business model

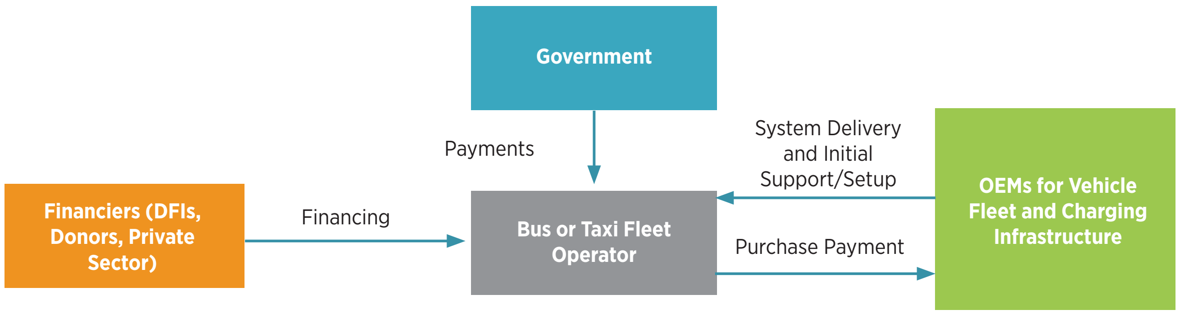
While many different financing models are possible, the financing and operating structure for the electrification of vehicle fleets, buses and taxies could be broadly classified as three groups: public-led, private-led based on "special purpose vehicle (SPV)" approach, and fleet operator-led. In the public-led model,[1] the government secures both the financing and ownership of the assets, vehicles and charging infrastructure, and the fleet operator leases the vehicles and charging infrastructure from the government or a state-owned corporation. Here the government directly absorbs any cost differential between TCO of ICE and EV fleets, and the vehicles are typically buses or taxis seeing public transportation as a government or state responsibility. In the public–private partnership model,[2] the government brings in a consortium of private sector players through an SPV. The SPV owns the assets—vehicles and charging infrastructure—and the fleet operator leases the vehicles and charging infrastructure from the SPV. Here the government helps the SPV secure financing through a sovereign guarantee and through asset availability payments, including subsidies, that absorb the TCO differential between ICEVs and EVs. In the fleet operator-led model,[3] the fleet operator directly finances and owns the assets—vehicles and charging infrastructure—as well as operates the fleet (figure 3-1). If needed, the government may help the operator secure financing through a sovereign guarantee and absorb the TCO differential between ICEVs and EVs. This kind of business models may also entail commercial fleets of last-mile delivery or heavy-duty cargo vehicles, with a smaller or non-existent governmental participation if the business model allows it.

Depending on the TCO differential, in all three models some form of cost absorption or subsidization will be needed from the government. As the government or state participation decreases, the importance of the financers rises. The exact model used to support and finance electric fleet operations depends on several factors, including the level of maturity of the private sector in the country and the requisite enabling framework, commercial viability of the operation, and so on. From a risk distribution and niche perspective, establishing an SPV is the most appealing option—as in this case, the risk is distributed across different entities, However, the more players that are involved, the costlier the overall operation becomes. Therefore, system optimization is a crucial factor to guarantee the technoeconomic feasibility of the operation.

Figure 3-1: Financing and operating model for EV fleets



(c) Fleet operator-led



Source: Author's own elaboration

Regardless of the financing model used, the investment bundles for deploying EV fleets must include some key components. These include: (i) vehicles—vehicle warranty and post sales service, and vehicle end of life disposal; (ii) vehicle charging equipment and charging infrastructure site preparation—civil construction and land requirements; (iii)charging infrastructure support equipment and facilities—backup generator, maintenance service and spare parts; and (iv) utility service electricity supply— transformers, substations, distribution capacity and power generation capacity. The size and the relevance of each of these items will vary based on the vehicle type, fleet scale, and operation requirements. While some of these items may have similar costs around the world, others will differ considerably from one country to the other. For example, the cost before tax and shipping of same quality and specification vehicles will be similar across the globe, however, construction and land costs will vary from one country to the other. Similarly, while charging equipment cost will be similar in different countries, utility investment requirements and how these are capitalized will change considerably.

I. Vehicles

The overall investment will vary for a given vehicle type based on fleet scale, import costs and taxes, registration costs, and extended warranty costs if applicable, among others. Typically, a fleet of 30 electric taxis, registered and ready to operate, would cost approximately US$900,000 while a fleet of 30, 18-meter electric buses would cost approximately US$20 million[4] (table 3-1). When comparing two vehicles with similar overall size and power, electric vehicles, based on existing technology, typically more expensive than their conventional counterpart. Price differential is lower in smaller vehicles like two-wheelers and three-wheelers. Therefore, EV usage makes much more financial sense in fleet operations where the operating costs savings from EV are much more significant due to high usage. This requires the existence of a fleet operator and coordinated service provision with a large enough size to produce scaled investments. Such an approach has already been seen in developing countries such as Mexico.

It is not uncommon for taxi or bus operations to be atomized in developing countries, making investments in EV fleets less economical and much riskier. Several business models can be used to circumvent this. First, these smaller players could come together to form a cooperative business. Such larger players, businesses, or cooperatives would have more potential to access bland credits or green funds for these purchases, such as the Green Climate Fund. Second, another business model could have drivers as employees, instead of asset owners. Taxi or ride-hailing drivers are usually owners of their vehicles, and therefore, of their own business. Especially, we can expect larger proliferation of the electric two-wheelers with this model, which has wider use cases by serving millions of consumers for daily mobility and urban delivery service in developing countries. Larger asset owners, having negotiated the financing of a fleet and infrastructure purchase with OEMs, can chose to lease these vehicles to drivers, or instead, hire the drivers. Finally, a business model that is growing in developed countries in the EU is mobility-as-a-service (MaaS). This concept transforms the way car ownership is perceived, since people stop owning cars but rather are subscribed to a service, which allows them to borrow or rent one when needed. This removes the CAPEX and maintenance costs from the atomized users, and they are faced by a larger player, again gaining efficiencies and bargaining power with OEMs and charging infrastructure providers.

Table 3-1: Costs of sedan cars and buses for different vehicle technologies.

Vehicle class	Technology	Vehicle cost [USD]
Sedan car	BEV	15,000 – 55,000
Sedan car	HEV	23,000 – 45,000
Sedan car	PHEV	22,000 – 182,000
12-m bus	FC	280,000 – 400,000
12-m bus	SC	340,000 – 500,000
12-m bus	HEB	250,000
18-m bus	FC	430,000
18-m bus	SC	550,000 – 650,000
18-m bus	HEB	315,000

Sources: ACT news (2020), Electrek (2021a), and Electrek (2021b).

The success of such business models requires clear short-, mid-, and long-term plans by the government. The profitability of these models relies on scale and growth, so businesses must have a clear vision of their playing field. Unstable or short-term policies can only boost short-term and limited growth, and discourages the deployment of larger investment bundles. Tax exemptions, for instance—which is one of the tools governments often use—can prove the difference between profit and loss for a business, and this is a risk that can be avoided through long-term planning. In some cases, governments have an even bigger influence in the economic viability of investment bundles. A government may subsidize the vehicles so that either its initial cost or TCO ends up matching that of the conventional alternative.

Proper vehicle warranties and post sales services, especially battery warrantees, are a vital part of successful electrification of transport fleets. As the vehicles are used, the overall capacity of the battery decreases, reducing the overall range of the vehicle. Such degradation depends on the way the battery is being used, namely, at what temperatures, currents, and state of charge it is operated. Thus, vehicle procurement and negotiations with OEMs must include warranties regarding the battery's state of health during its life. In the case of buses, for instance, it is common to include a clause in the contract that battery degradation will not exceed 20 to 30 percent by the year eight of its operations. And this must be guaranteed considering the operation the vehicle will be subjected to.[5] Another important aspect is the OEMs' presence in the region where the vehicles are to be deployed. This would allow quick access to maintenance and spare parts. Clear maintenance schedules should also be provided and negotiated to reduce operational risks.

EV end-of-life disposal is a complex and costly matter, mainly because of the battery's hazardous nature as a waste component. Different battery end-of-life alternatives go from full recycling of its main components, all the way to possible second-life applications as energy storage elements for off-grid renewable energy systems and other uses. However, given the constant evolution of the battery manufacturing industry, with LIB prices seeing a continued decline over the last decades, it is hard to believe that the end-of-life disposal or possible second-life market cost of the batteries today will be the same as in eight or ten years, which is the typical life expected for a LIB in the transport sector.

Equity considerations when promoting EV adoption are paramount. Governments can incentivize and dictate how private companies and other stakeholders go about EV deployment and play a key role in the design of EV incentives. For example, EV tax credits have the greatest benefit to high-income individuals, who pay the most in taxes. Additionally, this type of incentive is not available at the point of sale. Both of these attributes make it difficult for low-income individuals to take advantage of a tax credit program. There are several strategies that can be used to help all drivers, especially disadvantaged and low-income communities gain access to EVs.

II. Charging Infrastructure

Charging equipment investment needs scale with fleet size but is not necessarily directly proportional to the size of the fleet. These investment needs depend on the power capacity required, the type of chargers selected, and the time window available to charge the fleet, among other things. For example, in the case of a fast charge bus fleet, one DC/FC level 3 charger of 400 kilowatt with an estimated cost of U$S50,000 can be used to service five to ten buses. A slow AC level 2 buses charger of 80 kilowatt, on the other hand, can normally service up to two buses and requires a minimum investment of U$S25000.[6] In addition to the charging equipment itself, several factors influence charging station installation costs, and these costs may often surpass the cost of the hardware itself, depending on the site configuration. Consequently, various factors influence installation costs—wire run length, obstacles to routing wires, trenching length, pavement or concrete repair—as well as any needed utility infrastructure upgrades. Thus, before buying buses and chargers, the charging hub location, design, and costs must be well established (table 3-2). As with vehicle purchases, a key to accessing competitive prices is to unify players and negotiate as a bigger entity. Leasing models as well as charging as a service models exist and have been used in this context.

Table 3-2: EV supply equipment and installation cost

Type	Equipment cost [US$]	Installation cost [USD]
AC Level 1 Outlet	100	100 – 1,000
AC Level 1 EVSE	300 – 1,500	300 – 5,000
AC Level 2 EVSE (low power)	300 – 1,500	500 – 8,000
AC Level 2 EVSE	400 – 6,500	1,000 – 10,000
Level 2 - 150 kW to 160 kW (Buses)	25,000 – 35,000	–
Level 3 DCFC	50,000 – 100,000	

Sources: Authors' elaboration based on NYSERDA, 2018; Gladstein, Neandross and Associates 2019; and Lund 2020.

Note: a. High-power infrastructure and installation costs are highly dependent on the particular equipment to be installed and the region that is being considered. Thus, the high uncertainty and range in the estimated costs.

Site preparations, the necessary civil constructions, and the land requirements for the setup of new charging infrastructure vary greatly from country to country, and even between cities. The real estate sector, alongside the transport and energy sectors, plays a crucial role in facilitating a sustainable transition to e-mobility. As a result, the total costs to be incurred when addressing the development of new charging infrastructure are, up to certain extent, not generally known. This is primarily because not all countries and cities present the same degree of infrastructure readiness in electricity distribution, grid stability, civil works, and even space availability to support a charging station properly. Furthermore, the cost of real estate within cities could sometimes prove to be unmanageable under certain land requirements for the installation of a charging station, making it a financially unviable endeavor for a single party to carry out. This great variability in costs results in different strategies to finance these types of investments, which require the engagement of several stakeholders to carry them out (box 3-1).

Box 3-1: Examples of different risk sharing arrangements for provision of charging infrastructure for e-buses

In Buenos Aires, Argentina, a pilot test was carried out with two electric buses in 2019–20 within the Line 59 of the public bus transport system. A group of stakeholders including the bus line operator, the city government, Enel—a multinational energy company—and COLCAR—a local private sector company—took different responsibilities regarding the costs of the necessary assets. (i) Enel provided the chargers to the bus terminal; (ii) the government took responsibility of the installation of the infrastructure and provided all the necessary civil works; (iii) the line operator provided the space availability within the bus terminal to install the chargers and took responsibility for the operative expenses and maintenance of the buses; and (iv) COLCAR, owner of the buses, gave the vehicles to the operator on loan for a 1-year period (Government of the City of Buenos Aires - Gobierno de la Ciudad Autónoma de Buenos Aires, 2019). This bundle of assets allowed for the project to be developed, reducing the risk of the investment of the assets for the bus operator.

In India, through the FAME and FAME II schemes (Faster Adoption and Manufacturing of Electric Vehicles), the government has prioritized the provision of charging infrastructure for EV integration. Among other things, within the framework of these programs, the interministerial committee sanctioned 5,645 electric buses for operations in 65 Indian cities, which require a charging infrastructure that guarantees efficient operations. Consequently, under the FAME II scheme, 241 charging stations for electric buses were sanctioned and the allocated budget of INR 10 billion—INR 3 billion for 2019-20; INR 4 billion for 2020-21; INR 3 billion for 2021-22—will allow continued deployment of new stations. This program is particularly useful for fleet operators, since it proposes to offer the buyer a slow-charge charger for each bus purchased and a fast-charge charger for every ten electric buses (Gulia and Gupta, 2021).

In Mexico City, the first electric bus fleet of 10 units was deployed in 2020, within the Line 3 of Metrobus—the system of public passenger transport corridors of the city. This was done through the engagement of the Government of the City, Metrobus, Engie—private sector company of energy and services—and MIVSA, the company operating the fleet through a leasing contract. Engie, as the owner of the vehicles, leased the buses to the Government of the City through Metrobus, for a ten-year period to be paid through the tariff collection from the operation of the vehicles in the Metrobus system. Engie provided and deployed the necessary charging infrastructure for the buses' operation. And, MIVSA is responsible for operating and carrying out the maintenance services of the buses under its concession contract of Line 3 of the Metrobus system (Government of Mexico City - Gobierno de la Ciudad de Mexico 2020).

In the city of Santiago de Chile in November 2020, the private sector companies Enel X and Engie provided the installation of charging systems for electric buses, together with a fleet of vehicles, to be used within the Metropolitan Mobility Network of the city. These charging systems were to be used by three concession companies—Metbus, Vule and S.T.P. Santiago, with an active fleet of 436, 78 and 215 electric buses each—that operated within the transport network through a leasing contract. In this modality, the operators managed the provision of the urban transport service and the maintenance schedule of the bus fleet. Given that the operators did not own the buses, the risk of investment in this technology was held by the private sector companies (Lefevre and Rojas 2020).

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Care should be exercised that the charging facility operations do not interfere with other activities in the surrounding areas. A series of public EV chargers in the City of London in 2018, initially set in the street at a residential neighborhood, had to be relocated because of the neighbors' complaints about the loud noises and bright lights shining into the households, produced by the charging equipment at night. Complaints were also about the chargers reducing the space availability over the sidewalks and making it difficult for blind pedestrians to walk (Booth 2018).

Equity considerations are paramount when providing charging infrastructure. The cost of charging infrastructure deployment is not equal across all communities and depends on whether users have off-street parking or not. Often, this is the case in dense urban areas that are also most impacted by transport-related air pollution. Thus, a special focus needs to be placed on the provision of charging infrastructure in communities that that are overburdened by air pollution and for whom the cost of charging infrastructure provision is higher despite latent or realized demand for e-mobility. At the same time, the urban poor who often tend to live on the outskirts of cities are likely to be underserved by public transportation and are forced to rely on private transportation modes like two- and three-wheelers. In this case, the deployment of suitable charging infrastructure can help transition these communities to cleaner transport technologies.

Other crucial aspects about charging stations for EVs that must be considered are the support equipment and facilities, namely, backup generators, maintenance services, and spare parts for equipment replacement. These allow for the infrastructure to provide the best charging service as possible and help mitigate unexpected extreme events that could jeopardize the infrastructure operation. For instance, backup generators are put into place to maintain the chargers' capacity to provide electric power to vehicles even under electricity grid failures that create power outages.

Electricity infrastructure costs depend on the installed capacity that is required by the operator of the charging station. The local electricity provider must guarantee the balanced operation of the local substation, ensuring that the latter is able to balance the additional load from the charging station. If the power requirement demands a substantial upgrade of the system, with a full civil work development dedicated just for the station, the electricity provider can use a payment model where an upfront installation fee—for part of the electric equipment—is charged, followed by a monthly fee to maintain the installed capacity exclusively for the station. On the other hand, if the installed capacity required only the installation of a transformer, then utility companies usually only charge a monthly fee in accordance with the consumer category under which the power supply to the station is established. For example, in Buenos Aires, Argentina, the two electricity supply companies, Edenor and Edesur, distinguish the electricity demand in three categories: small, less than 10 kilowatt; medium 10–50 kilowatt; and large, greater than 50 kilowatt. In this case, the charging infrastructure for a bus fleet would be categorized as a large consumer. Within this category, the provider would charge the consumer a basic fixed fee for the availability of power provision, based on the power level and type of tension—high, medium, or low that was contracted—whether consumed or not. In addition, a fixed fee is applied for every kilowatt of maximum power registered during the charged period, based on the contracted power feed. Then, an additional fee is charged for the power supplied based on the registered consumption in each of the tariff schedules, peak or valley. Finally, if the power feed were done through a DC supply, an additional fee would be charged as a percentage of the electricity price (Edenor 2021).

Electric utility providers play a very important role in supporting EV charging infrastructure and enabling widespread EV adoption. Electricity providers have a crucial function in ensuring the success of EV deployment, through participating in the planning process and supporting vehicle-to-grid integration (VGI) or smart grid. They help address consumer education gap through utility education and outreach, among other critical roles. This is particularly true for charging public transport fleets and heavy duty vehicles.

It is crucial to develop a thorough electricity demand assessment of the operation of the charging station to achieve a cost-effective electric supply for the vehicle charging facility. This would allow planners and operators to determine the minimum installed capacity requirements for the correct provision of the EV charging service. It would reduce the utility service supply upfront costs and overall operational expenditures through the station's operative life span.

Critical priorities to consider when developing a smart grid V1G, such as telecommunications infrastructure, interoperability standard development, and management of grid interaction. In developed countries, modernization of power grids has been a reason for the rapid emergence of smart grids (Fadaeenejad et al. 2014). On the other hand, smart grids can help developing countries integrate renewable energies and energy management features. However, this requires multidisciplinary approach and addressing of the inherent weaknesses in the power grids of these countries. For example, Antigua and Barbuda recorded about 24 percent of electric energy losses in 2009 due to an inefficient distribution system and a great number of unregulated illegal connections (IRENA 2016). Similarly, the government in India is concerned about transmission and distribution losses, which are account for almost 20 percent of total electricity production, in addition with power theft that is a common problem in India due to little protection of grid and high poverty rate (EIA 2015) Therefore, smart charging may not be feasible in all countries.

V2G technology can help to supplement the grid over peak periods of energy consumption, providing additional energy from their batteries. A step further from smart charging or V1G, which allows regulating the charging power but in a single direction, vehicle to grid V2G technology allows EVs to act as both a flexible load charging mode or a storage source discharging mode. Deployment of V2G technology remains at an early stage in most developed countries. The application of V2G technologies in developing countries faces many additional barriers. Therefore, given the existing weaknesses in the power grids in developing countries, it may be prudent to first support: (i) the greening of the grid that has emission factor is greater than 0.8 kgCO2e/kWh (Grütter and Kim 2019); and (ii) promote coordinated charging could be a workable option to reduce the peak load on power grids on account of EV charging.

Notes

1. An example of a public-led model is the 2019 electric bus tender in Medellín. The public company Metroplús SA, in charge of infrastructure deployment, service planning and the operation of ground transportation services in Medellín, called for bids for the acquisition of 64 electric buses and 16 charging stations which were paid in full using public funds. Subsequently , the ownership and management of the fleet was transferred to the Medellín Mobility Secretariat, which in turn signed a bus fleet management contract with the bus operator Metro de Medellín Ltda.

2. An example of a private-led model (based on public-private partnership can be seen in Mexico City where in 2020, the first electric bus fleet of 10 units was deployed within the Line 3 of Metrobús, of the formal public mass public transport system of the city. This was done through the engagement of the government of the city, Metrobús, Engie and Auhaus (now integrated into VEMO), and MIVSA (Bus operator).

3. An example of a fleet operator-led model can be found in the city of Shenzhen, in China. In 2019 the city became one of the first to convert its entire bus fleet to electric technology. In this case, the role of the government was instrumental for the uptake of the electric buses. Apart from mandating the electrification of the fleet, it provided subsidies, coming both from national and local governments. The local government also facilitated charging infrastructure deployment. One of the three operating companies, SBG, bought the buses in partnership with a leasing company and delegated all maintenance of vehicle components to the local bus manufacturer company, BYD.

4. Calculations are based on costs in table 3-1.

5. The OEM, on the other hand may demand the battery be operated properly to avoid premature degradation. This means a proper monitoring of the bus must be made. This has typically been done with telemetry services provided many times by the OEMs themselves. However, the clear conflict of interest regarding the issue has given rise to third parties that provide monitoring services for the vehicles, ensuring both the OEMs and the vehicle owners that the battery is being operated properly.

6. Estimates are based on table 3-2.

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4. Conclusions

Electric mobility is an important way to decarbonize the transport sector but it needs to be couched in a comprehensive sustainable transport policy. Efforts to promote e-mobility need to be couched in a comprehensive approach toward sustainable transport; otherwise, e-mobility adoption will only lead to cleaner congestion. Care also needs to be exercised when using the e-mobility adoption experiences of the global North to inform the approach that would be most suitable for the global South. E-mobility requires differentiated approach by geography, level of development, nature of travel needs and aspirations, and sources of funding available to countries to support adoption efforts.

Promoting electric mobility requires an integrated approach between the transport and electricity sectors. Every country needs to develop its own long-term sustainable EV ecosystem—both in (i) transitioning the vehicle fleet from ICE to EV and (ii) deployment of charging infrastructure—based on its own infrastructure condition. Governments need to think about energy and mobility together from the outset, facilitating the transition toward EVs, deployment of charging infrastructure, and supporting the transition toward clean and smart electricity grids. Cooperation and holistic approach with different sectors such as energy and real estate is necessary to form and develop a successful EV market.

The overall investment needs for e-mobility adoption can vary significantly based on geography. The cost of vehicle fleet depends on the vehicle type, import costs and taxes, registration costs, and extended warranty costs. The cost of charging infrastructure deployment includes both the cost of the infrastructure and the necessary civil works. Costs for site preparation, construction, and land requirements for the setup of new infrastructure can vary greatly across countries and cities.

Many common government actions and policies can be adopted, but the roadmaps must be different due to unique circumstances. A congruous approach to demand creation and supply management is needed, especially in the case of public and shared transportation. Planning and coordination among the various sectors is an important element. It is important to map out electrification of all vehicles, bringing in the full ecosystem of stakeholders, including civil society organizations, private sector, utilities, and ministries of finance to map out cost structures.

Given that e-mobility is a nascent industry, targeted monetary and non-monetary incentives are needed. EV and charging infrastructure incentives, subsidies, and financial supports should be designed, targeted, and implemented in the long-term and in sustainable ways rather than using a one-time policy. It is important to differentiate user groups to determine right incentives. In addition, adoption should be promoted in EV types that are closer to cost parity with ICEVs or in modes that benefit the masses. Therefore, adopting a timebound cost-sharing or subsidization approach for public transport, shared fleets, and two- and three-wheelers may be prudent.

A special emphasis should be placed on cost-sharing or subsides for charging infrastructure in the early stages of e-mobility adoption. Several studies have demonstrated that supporting the deployment of charging infrastructure as a cost-effective way to facilitate e-mobility adoption, but the effect tappers off as a network gets larger. Charging infrastructure subsidies should also be structured in a way to avoid installing charging infrastructure for the sheer number, but rather for addressing customer charging needs and should be supported by grid infrastructure, which makes its operation efficient.

De-risking the sector is important for encouraging private sector investments. Governments need to develop and enforce standards in several areas to de-risk private sector investments. These include: (i) Use of innovative financing options like guarantees to de-risk financial investments from private sector; (ii) establishment of various standards including, standards for vehicles, for interoperability between EV charging infrastructure, and standardized payment models with easy accessibility; (iii)development of local capacities related to EVs, battery management and electric infrastructures, from installation to maintenance and operations; and (iv) developing and enforcing vehicle disposal strategy and standards including building local capacity in management of reuse and recycle of hazardous and non-hazardous materials is important.

A myriad of financial models for public transport and fleet operations. These range from public led-models, to private-led—but based on public–private partnership models—to fleet operator led models. Depending on the TCO differential and underlying conditions, different public–private financial models can be applied to share costs and distribute risk.

Charging infrastructure investment needs may scale disproportionately with the size of the EV fleet. Achieving sustainable large-scale deployment of EV charging infrastructure requires an understanding of how the power ecosystem responds to the introduction of new charging infrastructure and identifying needed investments. These investments can range from investments in the local power distribution grid, transformers, substrates, to high power distribution network.

To the extent possible, coordinated charging should be introduced as soon as possible. Charging management can significantly impact the need to increase electricity generation. Installation of charging infrastructure requires a host of complementary actions, including but not limited to establishing regulations, ensuring availability and augmentation electric power grid, and planning land use.

Equity considerations should be born in mind when facilitating e-mobility adoption. One-size-fits-all type incentives for purchase of EVs or deployment of charging infrastructure can perpetuate existing inequalities in the transport sector. In particular, charging infrastructure should be deployed in a sustainable manner to optimize use of EVs and make EVs accessible for all: (i) economically by optimizing on overall charging costs; (ii) environmentally by maximizing charging from RES; and (iii) socially, so it is financially and location-centric accessible.

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