The Chicken and the Egg Dilemma for Charging Infrastructure and Electric Vehicle Diffusion: A Developing World Case Study

BY JESSICA ARIAS-GAVIRIA, VERONICA VALENCIA-HERNANDEZ, SANTIAGO ARANGO-ARAMBURO, YRIS OLAYA M, ERIK R. LARSEN, RICARDO SMITH

Introduction

The sustainable development goals (SDGs) were established as a guide which exhort societies to look at their 2030 horizon (UN, 2015). Although synergies exist between several goals, there are also a number of trade-offs between SDGs that makes sustainable development an even harder challenge (Nerini et al., 2018). Reaching the SGDs requires a broad and multidisciplinary vision, as well as carefully planned actions to minimize these trade-offs. The transport sector is a fundamental driver of economic development and is necessary for human wellbeing, but it consumes 65% of oil products (IEA, 2019a), is responsible for 14% of global CO_2 emissions (EPA, 2020) and for 10 % of total anthropogenic PM10 and PM2.5 emissions (IEA, 2018), and accounts for up to 25 % of black carbon (Klimont et al., 2017).

There are several problems associated with the transport sector and urban mobility that emphasize the need to think about sustainable mobility. The concept of sustainable mobility encompasses safe, affordable, accessible, and efficient services and infrastructure while minimizing GHG emissions and environmental impacts (UN, 2016). Although the sustainable mobility scheme covers a wide spectrum of alternatives, this document focuses on one of the alternatives aimed at mitigating the problem of air quality, extensive use of fossil fuels and GHG emissions: electromobility. In this paper we discuss measures that can facilitate the adoption of electric vehicles and the development of supporting infrastructure such as charging stations.

To fully achieve the environmental benefits of electromobility, societies need to simultaneously develop renewable energy generation and distribution and charging infrastructure. Additionally, societies focused on this solution need to develop new business models and consider the beliefs and choices of individuals. This coevolution is represented in Figure 1 as a reinforcing loop between electric vehicles (EV) and charging infrastructure. In this phenomenon, the adoption of EV depends on the population's preference of EV over fossil-fueled vehicles (FFV). With more EV circulating, the demand for charging infrastructure increases, creating the opportunity for new business models focused on the EV service. However, the construction of charging points may take time, and the increase in charging point availability could be delayed. This availability is necessary, not only for increasing the preference of EV over FFV, but is also needed to provide confidence to consumers about the reliability of the system.

As Figure 1 shows, providing incentives to the EV demand only, is not enough to increase the use of EV. This "chicken and egg" causal dilemma requires action from all fronts within a system's thinking perspective to guarantee that the growth of both EV and charging points are balanced.

In developing countries such as Colombia, the transport sector accounts for 40% of the total fossil fuel demand of the country, and 11% of the total GHG emissions (DNP & enersinc, 2017; IDEAM & PNUD, 2016). The rapid growth of Colombian cities has brought another challenge regarding air quality. Cities like Bogota and Medellin must deal with several environmental contingency strategies during the year as a result of high concentrations of particulate material and other pollutants. Although these episodes are strongly correlated to meteorological conditions, the direct causes come from the large quantity of emissions from transport and industry (Isaza, Hoyos, & Herrera, 2019; Zapata, Cano, Ramírez, Rubiano, & Jiménez, 2015). Electromobility is an innovative solution to both GHG emissions and air quality problems. In this vein, the Colombian government started to promote electric

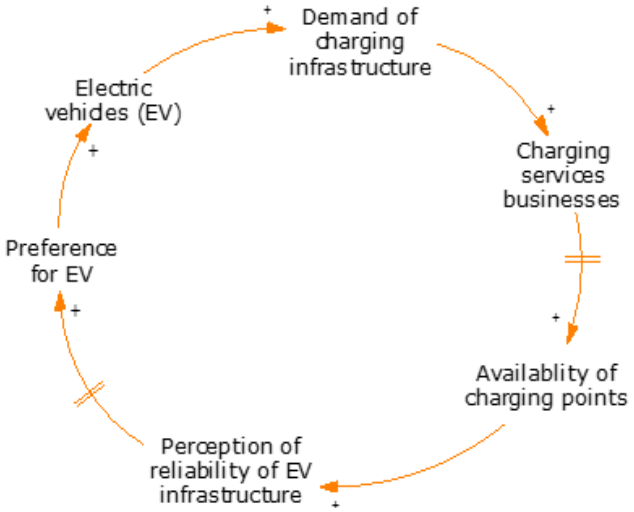


Figure 1 - Reinforcing loop between demand for electric vehicles and electromobility infrastructure.

Jessica Arias-Gaviria, Veronica Valencia-Hernandez, Santiago Arango-Aramburo, Yris Olaya M, and Ricardo Smith are with the Decision Sciences Group, Facultad de Minas, Universidad Nacional de Colombia, Medellin, Colombia. **Erik R. Larsen** is with the School of Business and Social Sciences, Aarhus University, Denmark. Santiago Arango-Aramburo can be reached at saarango@unal.edu.co

and hybrid vehicles in 2010, as shown in Figure 2. With the coalition of several of its institutions such as the Mining and Energy Planning Unit (UPME), the Ministry of Environment and Sustainable Development (MinAmbiente), and the National Planning Department (DNP), the Colombian government has established goals regarding EV such as 17500 hybrids and EV by 2021 (UPME, 2016), and 600000 for 2030 (CONPES 3934, 2018). However, Colombian cities still have major barriers to a massive electrification of transport. To this end, the national government has authorized territorial entities to promote electric mobility through government incentives and tools. Cities such as Bogotá, Medellín and Cali have implemented policies engaging public transport and private incentives that promote the electrification of the transport sector (ANDI, 2019; FENALCO & ANDI, 2020).

Despite breakthroughs regarding electric mobility, Colombia is lagging behind other countries in the Latin American and Caribbean region, particularly in terms of standardization and operability (BID, 2019). Efforts have been insufficient, the targets are far from being met (today, the country has achieved only 37% of the goal for 2021) and many barriers are yet to be overcome. In addition to common barriers (financial, regulatory and legal, technical and technological barriers of public acceptance and market availability), developing countries such as Colombia have additional problems. Some examples of these national issues include: the fact that the initial investment for an electric car is not viable for the majority of the population, the lack of specific legislation, incentives, planning restrictions, standards, and R&D, cultural barriers such as a resistance to change and risk aversion to new technologies, and above all, barriers at the infrastructural level such as limited charging stations (Ardila, 2014).

In Medellin and its surrounding metropolitan area (The Aburra Valley Metropolitan Area - AMVA), mobile sources are responsible for more than 86% of NOx and 91% of PM2.5 emissions (UPB & AMVA, 2019). Local authorities are rather strict, and have been working in recent years to formulate and implement action plans for both air quality and sustainable transport, along with several citizen initiatives which monitor air pollution in the Valley and demand further governmental actions. These governmental plans and social demands seek to promote cycling, walking and public transport, as well as introducing electromobility to replace fossil-fueled private vehicles and buses. Although Medellin is the Colombian city with the largest progress in sustainable transport and many action plans are already in place, (an electric metro system among them) there is still a lot of work to be done. The main pending piece of these initiatives is the development of an electromobility infrastructure and the design of effective incentives. As an example, from the 64 buses bought in 2019, only 22 are currently operating because, in the words of the 2020 Secretary of Mobility, "there is nowhere to charge them" (Caracol Radio, 2020). In this vein, in this paper we intend to review the status of EV in Medellin, discuss the main opportunities and barriers for the transport sector, as well as the electricity sector, and recommend some actions to accelerate the adoption of EV in the city.

The case of Medellin Metropolitan Area

Medellín is the second largest city in Colombia (after the country capital, Bogota), the main city in the AMVA valley along with other nine municipalities, and the

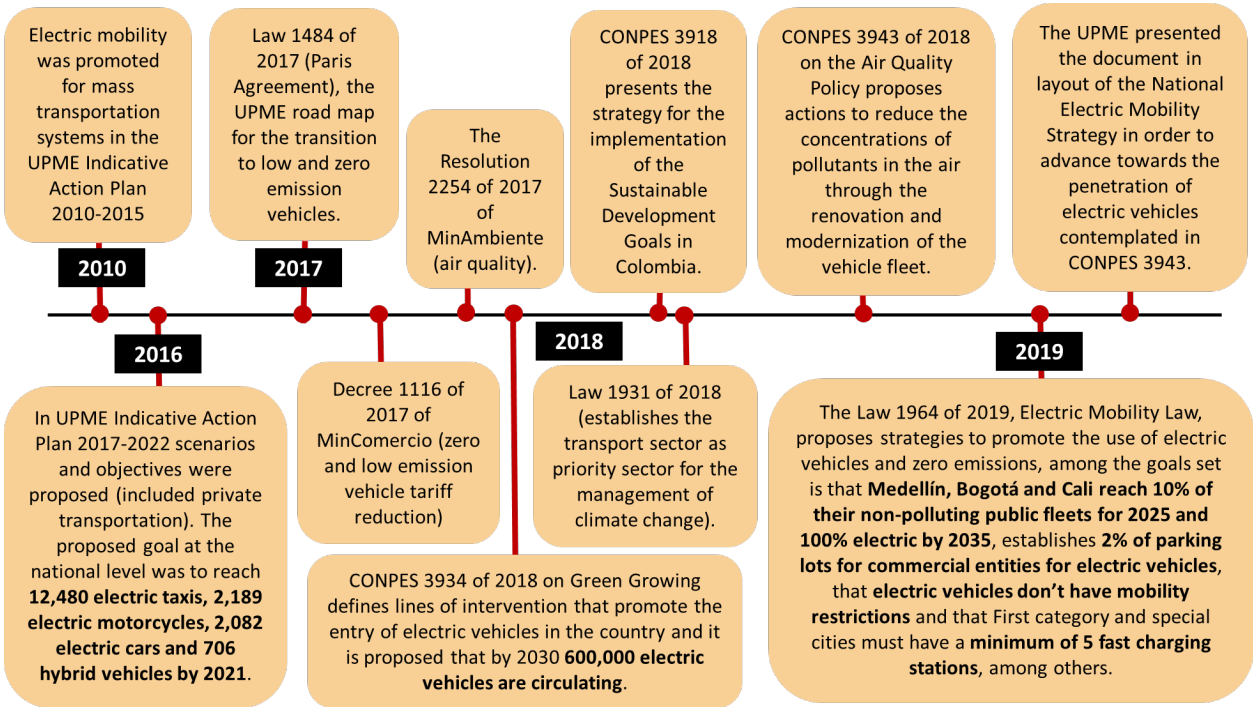


Figure 2 - Timeline of Colombian electromobility policies and incentives.

largest urban area and economic center of the Antioquia region. The valley is located in the central Andes mountain range, has an average altitude of 1495 meters above sea level (Alcaldía de Medellín, 2006), and is characterized by being a narrow, semi-closed, deep depression surrounded by high mountains. This characteristic prevents normal air circulation under certain weather conditions, which causes a trapping of particulate matter and pollution through a phenomenon of thermal inversion and atmospheric stability (Gómez, 2017).

The shape of the valley, the meteorological conditions, and anthropogenic emissions, where the protagonists are mobile sources, cause two environmental emergency episodes every year. One of these emergencies arises in April and another in November. Each episode can last up to more than one month. In these episodes, the concentration of PM2.5 and PM10 particulate matter exceeds the guideline values recommended by WHO (MinAmbiente & Fundación Cardiovascular de Colombia, 2012; UPB & AMVA, 2019; WHO, 2005). In fact, around 4500 people die each year in the city from Acute Respiratory Diseases (ARD), mainly in areas of increased vehicular traffic (Contraloría de Medellín, 2019).

In 2016, 74% of the emissions of the land transport in the Antioquia region were due to cargo transport and public passenger services (IDEAM & PNUD, 2016). In the AMVA, the transport sector emits more than 4.4 Mt/year of equivalent CO_2 (including CH_4 and N_2O), and most of the NO_x and PM2.5 emissions come from trucks and private vehicles, as shown in Figure 3 (UPB & AMVA, 2019). Since mobile sources are a main contributor to air quality problems in the metropolitan areas, some measures have been implemented to promote electric vehicles. The Colombian EV fleet has grown consistently in the past 10 years (see Figure 4), but EV still have a minor share, with only 0.04% of the country's total fleet (MinTransporte & RUNT, 2019). More than half of these EV are two wheelers (33% mopeds and 25% motorcycles), 26% are large vehicles such as trucks, buses and vans, and the remaining 16% are automobiles (MinTransporte & RUNT, 2019).

Antioquia is the region with the most registered electric vehicles in the country with approximately 24% (concentrated in Medellin and its metropolitan area), followed by Bogota with 21%, Cundinamarca with 20%, Valle del Cauca with 14% and Bolívar with 4%(FENALCO & ANDI, 2020; MinTransporte & RUNT, 2019). In 2018 the AMVA had more than 1.5 million private vehicles in circulation: 54.6% two-wheelers and 38.3% automobiles (DANE, 2019; UPB & AMVA, 2019). There are currently only a total of 25 electric vehicle charging points in the AMVA (See Figure 5), for an approximate

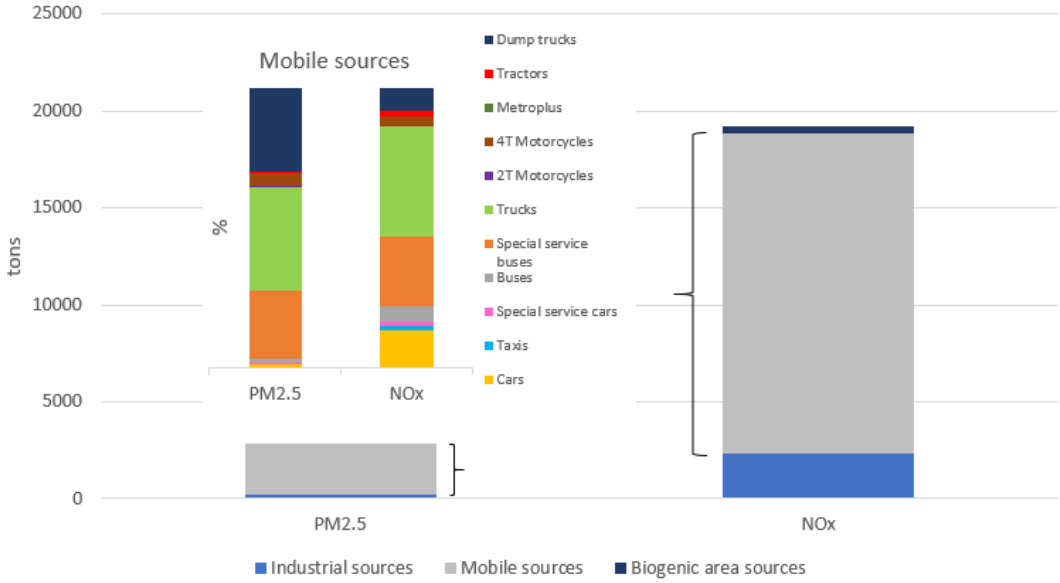
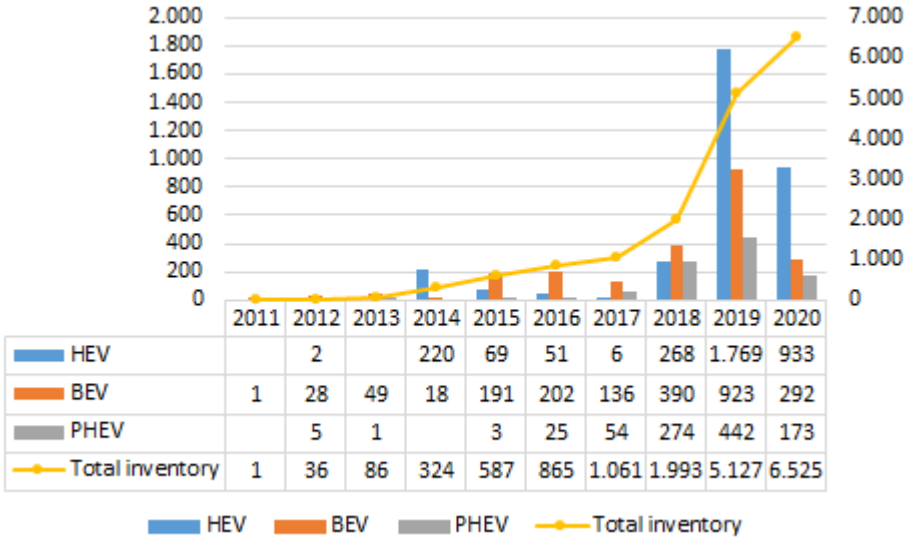


Figure 3 - Particulate matter emissions by type of source. Data from UPB & AMVA (2019).



	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
HEV		2		220	69	51	6	268	1.769	933
BEV	1	28	49	18	191	202	136	390	923	292
PHEV		5	1		3	25	54	274	442	173
Total inventory	1	36	86	324	587	865	1.061	1.993	5.127	6.525

Figure 4 - Evolution of annual sales (bars, graphed in left axis) and total inventory of electric vehicles by April 2020 (graphed in right axis) in Colombia. Data from ANDEMOS (2020). HEV: Hybrid Electric Vehicles, PHEV: Plug-in Hybrid Electric Vehicles, BEV: Battery Electric Vehicles

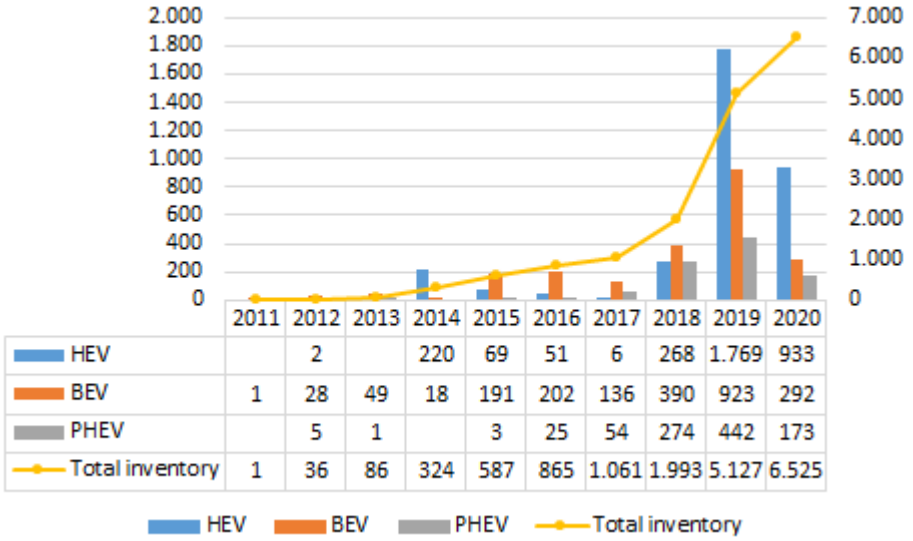


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Figure 5 - Charging points in AMVA (Revista vec, 2020).
Green indicates normal stations and orange indicates high powered stations.

ratio of 1 charging point for every 60 electric vehicles (Revista vec, 2020). This is a very low rate compared to the recommendation of the European Union Alternative Fuels Infrastructure Directive ratio of 1 charging point for every 10 electric vehicles (EC, 2014; IEA, 2019b).

Recent efforts made by the Medellin Municipality to keep increasing the number of EV, include the introduction in 2018 of seven 100% electric vehicles for traffic police (Secretaría de Movilidad de Medellín, 2018), the acquisition in 2019 of 64 Padron-type buses for the public transport fleet, with a capacity of 80 passengers per bus (of which only 22 are circulating today), and the introduction in 2019 of a subsidy for the replacement of fossil-fuel taxis, which grants beneficiaries around 4900 USD per taxi. This last incentive has the target of replacing 1500 taxis by 2022 (7,5% of the taxis fleet) (Secretaría de Movilidad de Medellín, 2019b, 2019a).

To achieve a net decrease in emissions, it is also important to align decisions such as the introduction of new electric buses with the renovation of the internal combustion bus fleet. In the case of private transport, the factors that influence the individual purchase decision and cultural barriers such as the idea of the lack of autonomy and the higher cost of electric vehicles must be addressed. Additionally, there is an enormous opportunity to be found in electric motorcycles, as this type of vehicle represents almost 60% of the total number of vehicles in the national inventory (55% in AMVA) and are an accessible investment option for low and middle-income people, in a country where 47% of the population earns less than minimum wage (235,7 USD per month) (DANE, 2020; RUNT, 2020).

Policy recommendations

Despite the opportunities for EV, the high costs of electric vehicles and the lack of charging infrastructure are a barrier for adoption, particularly within the private sector. Table 1 compares measures adopted in different regions to promote electromobility. The most successful countries have developed incentives not only for EV, but also for charge infrastructure, local industries, and accurate standards for hardware (i.e., charger geometry) and buildings (EIA, 2019).

Although Colombia has progressed in its definition of targets and fiscal incentives for vehicles, there are many barriers yet to be overcome. The main obstacles include adopting standards, incentivizing electric infrastructure, and promoting local industry. Government incentives have been insufficient. Tax exemptions and having no barriers with regard to mobility, among other incentives implemented, do not generate a preference for electric vehicles because the acquisition costs are still much higher than combustion vehicles. Another important factor is the limited grid capacity in households for charging an electric vehicle,

Table 1 - Promotion policies for EV in different countries. Data from IEA (2019).

		Canada	China	European Union	India	Japan	United States	Colombia
Regulations (vehicles)	ZEV mandate	x*	x				x*	
	Fuel economy standards	x	x	x	x	x	x	x*
Incentives (vehicles)	Fiscal incentives	x	x	x	x		x	x
Targets (vehicles)		x	x	x	x	x	x*	x
Industrial policies	Subsidy	x	x			x		
Regulation (chargers)	Hardware standards	x	x	x	x	x	x	
	Building regulations	x*	x*	x	x		x*	x**
Incentives (chargers)	Fiscal incentives	x	x	x		x	x*	
Targets (chargers)		x	x	x	x	x	x*	x*

* Indicates that the policy has only been implemented at a state/province/local level.
** Indicates partial implementation.

where adapting the electrical network is very costly for a single owner. Moreover, existing chargers in the market have different geometries which could make it difficult to find the right charging point for a particular type of vehicle in public places.

Figure 6 presents a roadmap of policy recommendations to tackle the chicken-egg dilemma discussed in the introduction from different perspectives, and accelerate the adoption of electromobility in Colombia, and particularly in Medellin. These policy recommendations are made considering the potential health benefits for urban centers, such as lower emissions, more efficient public transport, and less noise. However, a rigorous cost-benefit analysis is needed to be able to complement the design and be able to prioritize these policies. We have classified these recommendations as: short-term (those that could be addressed with the existing knowledge and information of the transport sector), and mid-term and long-term (that need further analysis and detailed studies to inform them). At a national level, Colombia has several fiscal incentives such as VAT reduction from 19% to 5%, however, additional incentives and regulations are needed to equal the ownership costs of EV to the costs of combustion vehicles (Decreto 1116 de 2017).

Safety and emissions standards for vehicles in Colombia are below the best available technologies, and while all vehicles are required to pass emission tests, there are difficulties in enforcing this regulation. In this vein, an upgrade of vehicle standards could support the adoption of technologies with lower emissions, including EV (IEA, 2019b). The deployment of electromobility must be accompanied by the evolution of the charging infrastructure. This entails that it is also crucial to establish clear targets for charging stations and evaluate the pertinence of fiscal incentives to reduce the costs of electrical infrastructure. Moreover, the country needs to enforce the adoption of a unified standard for EV chargers, and to align building standards with electricity standards to ease charging in residential buildings. To remove perception barriers regarding the performance of electric vehicles, it is important to continue with the demonstration pilots in the public transport sector (i.e., buses and taxis). More sustainable transportation models can be achieved by involving stakeholders in the planning processes and policy design.

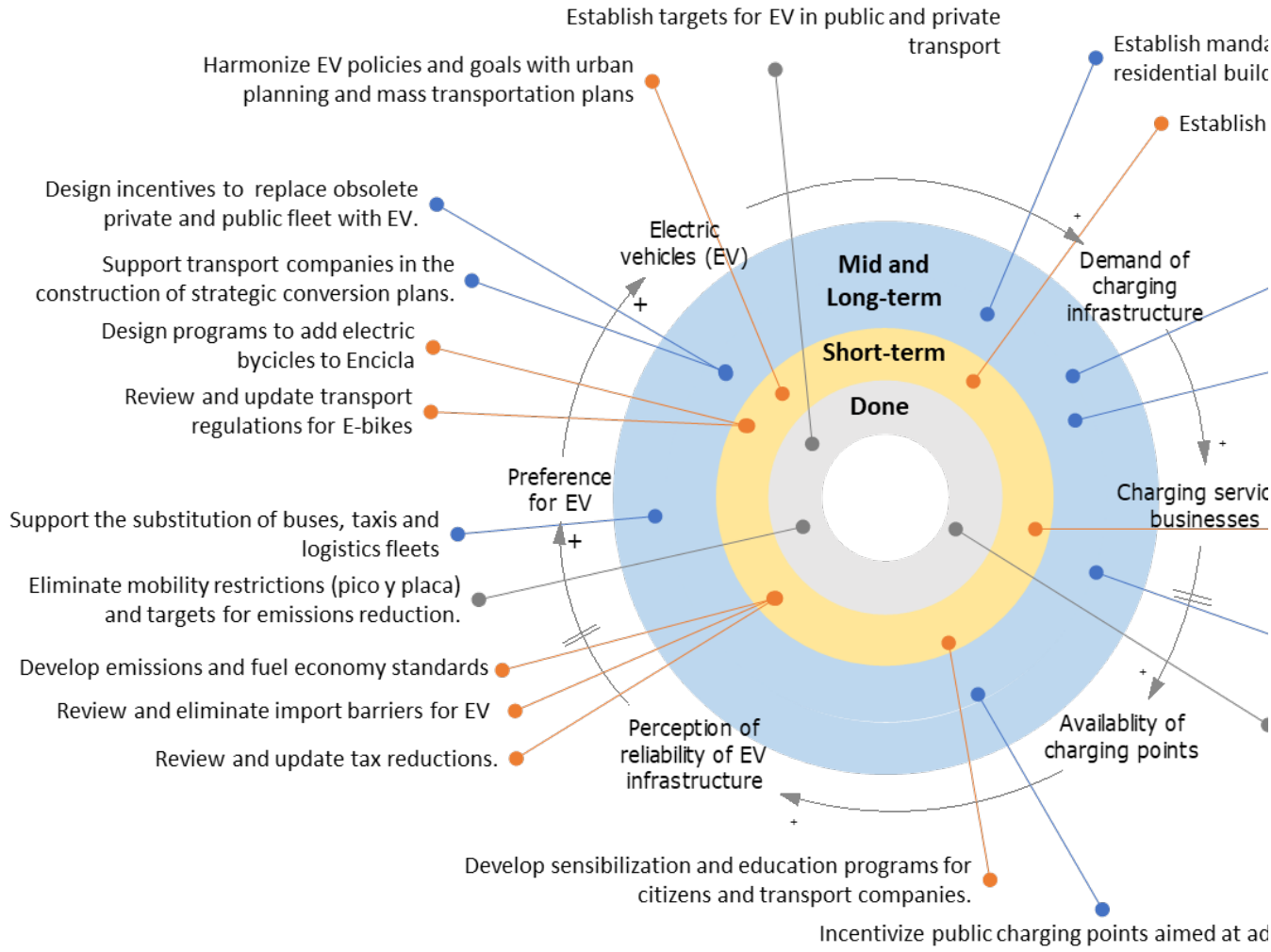

Figure 6 - Roadmap of policy actions for promoting EV in Medellin

Given that the infrastructure requires immediate attention, in the short term the government and companies can continue promoting charging points in existing parking lots in public places such as shopping centers and universities. In addition to this measure, in the mid-term the local authorities should evaluate the pertinence of including mandatory requirements for charging points in new buildings and address the limited grid capacity that prevents charging in households and older buildings.

Medellín needs to continue developing a sustainable, integrated public transportation system, supported by electric buses, taxis and bicycles, rather than just introducing more cars to the already congested city. There are opportunities to adopt EV in sectors such as last-mile delivery (movement of goods from a transportation center to the final destination) and school transportation, renewing an ageing fleet. Lessons from fast motorcycle adoption in the past suggest that this is a segment of private transportation with high growth potential for EV and that this sector needs to be given the attention it is due in order to ensure the safety of drivers and pedestrians. In the private vehicles sector, motorcycles are strategic; we cannot ignore that motorbikes provide a cheap and efficient alternative to transportation, especially for the low-income population that lives on the hillside neighborhoods of Medellin. The most strategic vehicles in the commercial sector are buses, trucks, and cargo and logistics vehicles (significant contributors in emissions from mobile sources, see Figure 3). It is also paramount for the local authorities to support transport companies in the construction of their own strategic plans for conversion towards sustainable fleets.

Medellín also has a free public bicycle sharing program called “Encicla”. A discussion that could take place in the mid-term is the design of a tariff program for including electric bikes to the “Encicla” fleet. Electromobility, beyond encouraging the use of EV, should be part of a sustainable mobility program. In this regard, schemes for shared EV and alternative models that do not include vehicle ownership (renting) must be integrated into the sustainable mobility scheme, and could even be an important part of the task of breaking down cost and cultural barriers regarding electric vehicles, that is, as part of the promotion or marketing of electromobility.

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