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The role of alternative combustion vehicles and the modal changes on the path to decarbonizing road transport

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Extended abstract:

Although the transportation sector has mediated the economic development of nations and the exchange of goods and services, it is directly responsible for problems such as pollution by particulate matter and emissions. The transportation sector consumes 65% of petroleum products worldwide (IEA, 2019) and is responsible for 24% of direct emissions of CO_2 from fuel combustion (IEA, 2020) and 10% of the total anthropogenic emissions of PM_{10} and $PM_{2.5}$ (IEA, 2018). The environmental pressure due to pollution in cities made it essential to think of new ways of conceiving transportation systems around the world. In Colombia, the transportation sector consumes 43% of the country's energy (UPME, 2019) and represents 10% of greenhouse gas emissions (IDEAM & PNUD, 2016).

Colombia has taken steps to lead the transition to low-carbon transport and consolidate a comprehensive sustainable transport strategy. The political goal of decarbonization of transport was defined by CONPES 3934 of 2018, where it is proposed that by the year 2030 there will be 600,000 electric vehicles circulating between taxis, passenger vehicles, light vehicles, light trucks, and official vehicles (CONPES 3934, 2018). The panorama is such that electric vehicles in Colombia went from less than 200 in 2011 to more than 38,000 vehicles among electric motorcycles, hybrid vehicles, plug-in hybrid vehicles, and battery electric vehicles at the end of 2021 (ANDEMOS, 2021). Antioquia, and in particular the Area Metropolitana del Valle de Aburrá, is the region with the most private electric vehicles registered in the country with approximately 24%, followed by Bogotá with 21%, Cundinamarca with 20% and Valle del Cauca with 14% (MinTransporte & RUNT, 2019).

The recent literature that studies issues related to the decarbonization of the transport sector has focused on the change of fuels and the transition towards electric mobility (Anandarajah et al., 2013; Babar et al., 2021; Bellocchi et al., 2018; Biresselioglu et al., 2018; Danielis et al., 2021; Govindarasu & Venkatesh, 2019; R. R. Kumar & Alok, 2020; Rajper & Albrecht, 2020). However, the decarbonization of the sector does not depend only on changing combustion sources, it also depends on the interaction of several factors and agents, including the share types of alternative fuel vehicles (Requia et al., 2018), as well as the development of infrastructure and modal changes (IEA, 2021). An integrative framework is needed to consider these interactions in the context of developing countries and modeling is a useful tool that provides a qualitative understanding of the system,

quantifies possible benefits, intervenes of the system without causing harm, and allows to warn decision-makers about the possibilities of action (Bellocchi et al., 2018). And, system dynamics is an appropriate methodology for developing an integrative framework, already used to model problems related to sustainability, including transport dynamics (Honti et al., 2019) because of using accumulating variables and flows, feedbacks, non-linearities, and time delays.

This research aims to diagnose the possible decarbonization trajectories of a Colombian metropolitan area and its effects in terms of GHG emissions avoided and additional electricity demand. The study is carried out at the metropolitan area level given that the diffusion of alternative energy source vehicles has advanced quite asymmetrically in the different territories of the country, and it has been identified that the importance of purchasing attributes differs between cities (Soto et al., 2018). The proposed model studies the private vehicle fleet of two categories: motorcycles and automobiles in the Area Metropolitana del Valle de Aburrá (AMVA) in Colombia. Each vehicle category has different vehicle propulsion options, either using traditional fossil fuels or using alternative combustion sources. Alternative combustion source vehicles are those that run on at least one alternative other than fossil fuels and include biofuel vehicles, fuel cell vehicles, and natural gas vehicles (Martos et al., 2016). The model has four interconnected modules: 1) vehicle/motorcycle stock, 2) use of transport, 4) fueling points infrastructure, 5) electricity consumption, and 6) emissions.

The stock dynamics contemplates the purchase process. An individual will choose the technological alternative that maximizes his utility according to five characteristics, three negatives: initial investment, the operating costs, and the environmental factor (emissions); and two positives in utility: range and the new availability of infrastructure (fueling stations). Fueling stations will be required depending on the number of vehicles per technology and the time it takes to refuel it. And depending on the percentage share of combustion technologies in the vehicle fleet, the emissions and electricity use of the vehicle fleet will be obtained. Stock dynamics also include the process of familiarization or social influence in the adoption of alternative combustion technologies. According to F. M. Bass (1969) the diffusion of new technologies is a process that occurs gradually, tracing what is known as an S-shaped curve that accelerates as more people adopt the new technology and it becomes more familiar to the social system. And once the potential market begins to run out because most people have decided to adopt the innovation, market saturation occurs, and the speed of adoption slows down.

People also make decisions regarding the use of transport, which in the model corresponds to the module of travel demand and modal split. Individuals will choose the transportation option that maximizes their utility, in this case, the individual will choose to use private, public, or non-motorized transportation, and then they choose whether to use a car, motorcycle, taxi, bus, metro, or a non-motorized mode (this category includes walking and cycling). The choice will depend on four attributes, two positives: access to the transport mode and the speed of the transport mode; and two negatives: waiting time and travel cost.

The results suggest that the modal split will follow a similar trend under a business-as-usual scenario (**Figure *1***), however, the reduction in operating costs of private modes such as motorcycles would make motorcycle trips exceed bus trips, for example. Therefore, the decarbonization of public transport systems should be parallel to the decarbonization of private transport. In this way, although the operating costs of private transport decrease, public transport could maintain competitive tariffs.

Regarding the car fleet, we found that the protagonists by 2050 will be hybrid vehicles (HEV), with a percentage share of 48% (**Figure *2***). BEVs would have a 16% share and gasoline vehicles 32%. In the model, natural gas maintains a slow growth in the medium term but is picked up by electric vehicles, and hydrogen fuel cell vehicles are not competitive with electric vehicles under the scenario business-as-usual. The advancement of one technology over another depends on the attributes that influence the consumer's decision; therefore, political decision-makers must study which are the most important attributes for consumers in the area studied and how these attributes can be improved through public policies and financial and non-financial incentives.

The simulation allows observing that it is possible to avoid 36.4 Mt of CO_2 (**Figure *3***) equivalent even in the business-as-usual scenario where incentives are still lacking and there are technical, financial, and cultural barriers towards alternative combustion vehicles in Colombia. This fact shows that the definition of adequate policies could increase the speed of the transition to sustainable mobility by intervening in the modal distribution of trips and the diffusion of vehicles with alternative propulsion sources. In addition, despite the results on the advancement of the mobility of alternative combustion sources, the structure of the model allows us to identify that the vehicles that are already in circulation have an inertial effect on the market, and replacement policies should be considered to accelerate the transition. Finally, alternative combustion vehicle diffusion, mainly electric vehicles, will bring about an increase in electricity demand of approximately 1,530 GWh per year (**Figure *3***), which shows the need to prepare the electricity sector for the entry of electric vehicles.

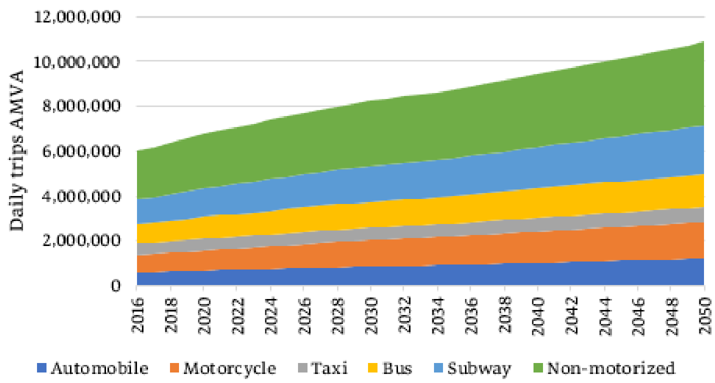

Figure 1. Modal distribution, AMVA.

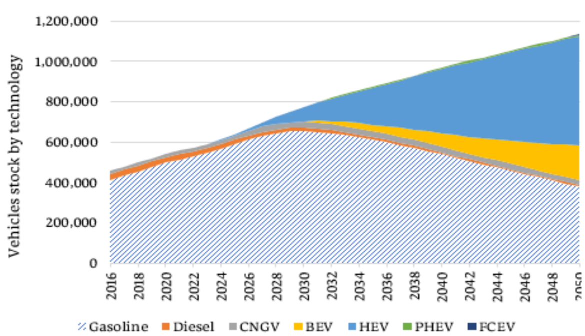

Figure 2. Vehicles stock evolution.

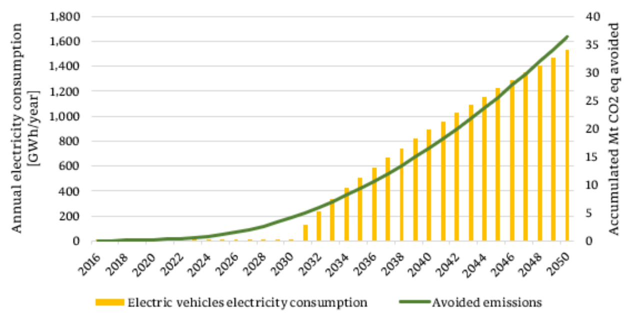

Figure 3. Changes in electricity consumption and avoided emissions because of electric vehicles diffusion.

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