Systemic Analysis of the Electrification of Last-Mile Freight Transport

Julieth Stefany García Collazos
Facultad de Minas
Universidad Nacional de Colombia
Medellín, Colombia
jugarciaco@unal.edu.co

Laura Milena Cárdenas
Facultad de Ingeniería
Universidad de Antioquia
Medellín, Colombia
lauram.cardenas@udea.edu.co

Carlos Jaime Franco
Facultad de Minas
Universidad Nacional de Colombia
Medellín, Colombia
cjfranco@unal.edu.co

Abstract

The growth of the urban population has permanently increased the demand for products. Likewise, the maturation of electronic commerce has increased urban freight transport, which has brought negative externalities such as emissions, pollution, noise, congestion, and loss of habitat. There is a visible effort to make urban last-mile deliveries more sustainable, mainly in environmental aspects. This is the reason for an interest in replacing conventional vehicles with electric vehicles, but this replacement has a series of conditions. The objective of this document is to systematically analyze the electrification of last-mile freight transport. From the review of the state of the art, affirmations were identified that allowed to establish cause and effect relationships between different attributes of the system that is represented, in such a way that, a causal diagram was obtained that systemically expresses the studied situation. As a result, we identify that social dissatisfaction because of particulate matter emissions generates social pressure that promotes incentives for the electrification of last-mile transportation and generates an increase in the sales of electric vehicles, thus reducing the sales of conventional vehicles.

Keywords
Electrification, last mile, electric vehicles, freight, transport.

1. Introduction
The rapid growth of e-commerce and package deliveries around the world demands new solutions to satisfy the desire of customers; this means a challenge for last-mile transport (Allen et al., 2018;

Figliozzi, 2020). Freight transport represents a lifesaver for commerce and industry, but it causes significant negative impacts on the quality of life in urban areas in terms of congestion, emissions, and consumption of space (Cleophas et al., 2019). The city's logistics initiatives have long suggested the need for environmentally friendly urban transport, but it faces organizational and technological challenges. Given technological advancements and innovative business models, clean urban transport concepts could contribute to more sustainable and customer-friendly urban transport (Cassiano et al., 2019).

More and more cities are striving to provide acceptable air quality and noise levels for their inhabitants (Ehrler et al., 2021). The growth in purchases has led to an increase in transport demand due to deliveries and returns. Therefore, an approach is needed to decouple demand for last-mile transportation from increased emissions. However, this is only possible if transport efficiency is improved and zero- and low-emission technologies such as electric vehicles are incentivized. One problem identified is limited access to data on urban commercial transport, as well as on electric mobility, which makes it difficult for both logistics providers and decision-makers to prepare for these developments and understand their implications (Ehrler et al., 2021).

Likewise, the environmental impact of the last-mile transportation sector has significant repercussions on global warming, health, and the economy. The need to reduce emissions caused by dependence on fossil fuels and to encourage the use of renewable energy sources has driven the development of zero-emission propulsion systems (Arvidsson & Pazirandeh, 2017; Castillo et al., 2020). The energy transition of last-mile transportation is shown as an alternative both for mitigating environmental impact and for improving people's quality of life.

This document aims to carry out a systemic analysis of the electrification of last-mile freight transport to know the relevant variables and the conditions that would make it possible. In section
(2) a literature review will be presented, in section (3) the methodology used, in section (4) the results and in section (5) a series of conclusions will be made.

2. Literature Review

Transportation is causing problems in urban areas, particularly freight transport, considering that most of the goods delivered end up in city centers. Modern cities need solutions to reduce the costs of externalities such as congestion, pollution, and others, which have increased in recent years; due to the growth of freight delivery (Mucowska, 2021; Ranieri et al., 2018). Last-mile logistics is the least efficient stage of the supply chain and comprises up to 28% of the total cost of delivery. Therefore, improving last-mile logistics and significantly reducing externalities are important challenges. New technologies and means of transport, innovative techniques, and organizational strategies allow more efficient handling of last-mile delivery in urban areas (Ranieri et al., 2018).

Before the COVID-19 pandemic there had already been an increase in the transportation of individual shipments, including the downtown areas. During the pandemic, in the implementation of the preventive measures adopted, it has increased by more than 100% in some cities. This was reflected in unsustainable development, particularly in terms of the urban environment (Settey et al., 2021). Likewise, the characteristics of these operations are in direct conflict with the urban.

infrastructure that is increasingly being redesigned in favor of walking, cycling, and public transport, which reduces the accessibility of the sidewalk for last-mile operations. Other pressures on last-mile operators are associated with managing seasonal peaks in demand, shortened delivery times between ordering customers and making deliveries, meeting delivery deadlines, failure rates in first-time deliveries, and the need to manage high levels of product returns (Allen et al., 2018).

New laws and regulations on greenhouse gas emissions have led shippers to become interested in using electric vehicles for last-mile deliveries. Since the mid-2000s, EVs have gained popularity in several countries even though their market share remains relatively low. However, most of the advances have been made in passenger cars and most of the technical and scientific studies have been the focus of this segment. By contrast, the potential of electric vehicle technology for freight distribution has received less attention (Pelletier et al., 2016; Quak et al., 2016).

For entrepreneurs, electric charging vehicles appear as a viable option, although considerable efforts have still been required at the government level, through the promotion of public measures in the form of support for purchase costs or rental rates and offering services of technical experts (Østli et al., 2017). However, they are conditioned by a series of gaps such as the limited capacities of the battery of these vehicles require visits to the charging stations during the delivery routes, which must be taken into account in the planning of the route to avoid itineraries inefficient with long detours (Arias-Londoño, et al., 2021; Boccia et al., 2021; Schneider et al., 2014). Other related economic attributes are the vehicle's purchase price and operating costs, which are currently very high. On the other hand, autonomy, environmental efficiency, recharging infrastructure, recharging time, fuel cost, fuel production, the intensity of use, and route planning are other attributes considered concerning electric vehicles in the last mile transportations (Castillo et al., 2020). In general, collaborative methods should be considered that contribute to a shared vision of urban mobility that takes into account all actors in the supply chain such as charging point operators, the automotive industry, car rental services, farmers, and local authorities, to ensure that the system works more efficiently (Galati et al., 2021).

Another relevant issue identified in the literature review is the energy costs of commercial electric vehicles, there are almost four times less expensive than conventional diesel trucks, per mile, at current market values. However, although EVs are simpler and cheaper to maintain, there are more uncertainties associated with the lifespan and long-term costs of batteries. In addition, there are limitations in terms of miles traveled per day without recharging (Feng & Figliozzi, 2013). According to (Feng & Figliozzi, 2013) only in scenarios with high utilization, that is more than 16,000 miles per year per truck, electric vehicles are competitive.

The progressive electrification of urban distribution fleets, motivated by the consolidation of EVs technology and by the mobility advantages that cities grant to non-polluting vehicles, poses future challenges that affect electricity distribution networks (Martínez et al., 2021). The integration of electric vehicles with the energy grid has become a relevant area of research due to the increasing penetration of EVs in current transport systems. With proper management of electric vehicle charging and discharging, the grid can now meet the energy requirements of a considerable number of electric vehicles. In addition, EV's can help improve the reliability and stability of the energy network through ancillary services such as energy storage (Lin et al., 2021). However, the source of electricity generation must be considered, because in case the use of coal or fossil fuels is necessary, the adoption of EVs increases the emissions of particulate matter, compared to diesel vehicles due to the carbon intensity of the electricity system, while reducing them when at least 50% of the electricity comes from renewable sources (Croci et al., 2021).

Identifying new operating models and vehicles that can be applied for last-mile deliveries in urban areas becomes crucial. An alternative evidenced in the literature review process is to implement electric bicycles, according to (Bieliński & Ważna, 2020), electric bicycles are used mainly as first and last mile transport and to travel directly to various places of interest. Another trend is the implementation of smaller and lighter vehicles for last-mile deliveries in urban areas. (de Oliveira et al., 2017).

3. Methods

To analyze the electrification of last-mile freight transport, given its complexity, we used Checkland's systems thinking methodology. The Checkland Systemic Soft Methodology (MSB), also known as SSM for its acronym in English, is a form of rational systems thinking appropriate to deal with complex human situations, particularly the so-called soft situations (Checkland & Scholes, 1990). Checkland comments regarding the rudimentary elements of systems thinking that: “A systems thinking starts from an observer who describes the world that is outside of us and who, for some personal reason, wishes to describe it “holistically”.

From the review of the state of the art, affirmations were identified that allowed to establish cause and effect relationships between different attributes of the system that is represented, in such a way that, a causal diagram was obtained that systemically expresses the studied situation. Afterward, the feedback structures that emerged from the relationship between the attributes of the system were analyzed, seeking coherence between the arguments and the representation.

4. Results and Discussion

In this section, we will present the results of the exercise developed from the review of the state of the art. In Figure (1) the causal loop diagram developed to capture the causal relationships that systemically express the situation studied is presented. The figure below explains each of the six feedback loops obtained.

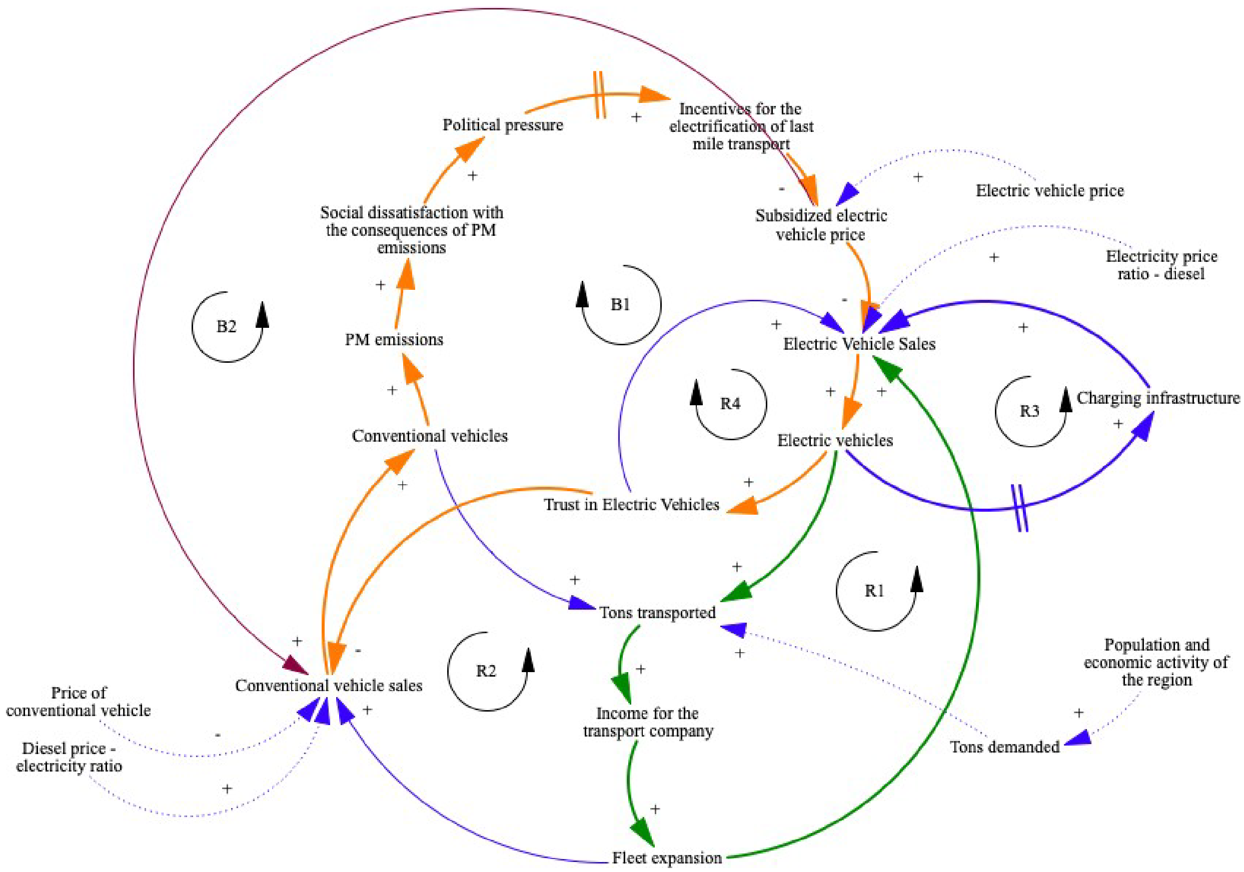

Figure 1. Causal diagram of the electrification of last mile freight transport.

4.1 Reinforcement loops

R1: The variables that contain this loop are sales of electric vehicles, electric vehicles, tons transported, income for the transport company and fleet expansion. The increase in the population worldwide, access to technology and information, electronic commerce, and the activity of cities have increased the demand for tons transported, which at the same time benefits national economies and the income of transport companies. By having greater cash flow, transport companies can invest in the acquisition of a new fleet for the transport of last-mile goods; in this case, companies can choose which fleet they want to buy. Interest in electric vehicles has increased in recent years, particularly due to the benefits in reducing emissions that are related, that is the reason to transport companies could have an interest in acquiring an electric fleet for their last-mile transport, additionally due to the short distances that this vehicle category must travel. That decision by the company could benefit sustainable transportation in cities. In this loop, the sales of electric vehicles are reinforced.

R2: The variables that contain this loop are conventional vehicles sales, conventional vehicles, tons transported income for the transport company and fleet expansion. While in R1 the company decides to acquire electric vehicles, in R2 the transport company could continue to buy conventional vehicles (diesel and gasoline) that can bring a series of externalities that must be evaluated in detail. In this loop, the sales of conventional vehicles are reinforced.

R3: The variables that contain this feedback loop are charging infrastructure, electric vehicles sales and electric vehicles. The charging infrastructure is a condition for the promotion of EVs sales. This is relevant because it creates security for electric vehicle buyers; Having a robust electricity distribution network that guarantees the proper functioning of the fleet and, above all, the operation of freight transport can significantly influence the electrification of last-mile freight transport. In this loop, it aims to show that by having more charging points the sales of electric vehicles are promoted; this, in turn, increases the participation of the electric fleet in the transport of last-mile cargo, which triggers the considerable installation of charging infrastructure. It is relevant to highlight the delay between electric vehicles and charging infrastructure, considered because this process is not immediate; to the contrary, it could take a long time given the number of resources that it requires in addition to the public policy and land-use decisions. In this loop, the charging infrastructure is necessary to reinforce the growth of electric vehicles.

R4: The variables that contain this feedback loop are electric vehicles sales, electric vehicles, and trust in electric vehicles. Confidence in electric vehicles is relevant in promoting them. For this variable, several points must be considered, for example, the price of the vehicle may be high and that generates insecurity for the buyer because, since there is not enough information about it, it is questioned whether it is worth investing that money. Likewise, there are not enough points of sale for spare parts or specialized maintenance centers in this vehicle segment. On the other hand, not all countries have a professional or technical academic training program that allows training on issues of maintenance or assembly of electric vehicles. All these factors increase or decrease the trust or confidence in EVs that undoubtedly promote the sale of the same, which makes the participation of EVs in last-mile transport significant.

4.2 Balance loops

B1: The variables that contain this loop are political pressure, incentives for the electrification of last mile transport, subsidized electric vehicle price, electric vehicles sales, electric vehicles, trust in electric vehicles, conventional vehicles sales, conventional vehicles, particulate matter emissions, and social dissatisfaction with the consequences of particulate matter emissions. The use of conventional vehicles over time has contributed to the climate change that currently has us in extreme conditions because they are vehicles that emit particulate material in the combustion process of traditional energy sources (diesel and gasoline). This increase in PM emissions has generated social dissatisfaction, given the consequences for health, contamination of resources, and the increase in natural disasters caused by climate change. This social dissatisfaction is reflected in protests, requests from younger generations about sustainable development that allows future generations to have a planet, in addition to alerts from government entities and specialized institutes on the subject that generate anxiety and concern in populations, this generates political pressure on decision-makers who want to take appropriate actions in favor of all actors.

Based on this pressure, a series of incentives have been generated for the buy of EVs, since they are considered zero emissions, depending on the source of electricity generation with which they operate. Some of these incentives can be a reduction in taxes for the acquisition of vehicles, financial support in the importation or the vehicle tariff, cheap rates in energy, lanes, or exclusive areas for the circulation of EVs, and others. The development and promotion of incentives reduce the cost that each EV purchased must assume; this increases the interest and the opportunity to acquire this vehicle segment, which increases its participation in the national fleet, which reinforces the contribution of vehicles in the transport of last-mile cargo.

The incentives not only increase the participation of EVs, but they also increase confidence in them, which decreases the sales of conventional vehicles, because the transport company seeing the benefits in economic, logistical, and environmental terms of the electric technology will not have resources in the conventional technology. This would benefit nations in reducing PM emissions and mitigating climate change, considering the international commitments acquired on this issue. In this feedback loop, the acquisition of EVs is reinforced, whenever incentives are considered.

B2: The variables that contain this loop are political pressure, incentives for the electrification of last mile transport, subsidized electric vehicle price, conventional vehicle sales, conventional vehicles, particulate matter emissions, and social dissatisfaction with the consequences of particulate matter emissions. In this loop in case there are no incentives that promote the electrification of last-mile freight transport and reduce the cost of EVs, the total price will be assumed by the buyer. However, since the prices of the vehicles are so high concerning a conventional one, without the incentives, buyers will prefer to buy a conventional vehicle to increase their participation in the total fleet. This increases PM emissions, which starts again the social disagreements that generate social pressures and that encourage the creation of incentives that benefit the energy transition in transport. In any case, it is evident which incentives are a determining variable for the promotion of EVs or the increase in sales of conventional vehicles.

Worldwide, countries are incorporating electric vehicles to meet the demand for last-mile cargo transport, in the literature review process we were able to evidence the following (Allen et al., 2018; Croci et al., 2021; Ehrler et al., 2021; Feng & Figliozzi, 2013; Settey et al., 2021), the experiences reflected in these were taken to validate the variables and conditioning factors reflected in the causal diagram.

5. Conclusion

Transport is causing problems in urban areas, particularly freight transport, because online sales and globalization have increased because of the dynamism of societies. This, in turn, leads to new trends in freight transport and it is expected that more goods will be delivered shortly. Most of the goods delivered end up in city centers, considering that last-mile logistics is the least efficient stage of the supply chain, improving last-mile logistics and a significant reduction in externalities are issues of great relevance.

Driven by commitments, interests, new laws, and regulations on greenhouse gas emissions, transporters are starting to use electric vehicles for last-mile deliveries. However, this migration to EVs has a series of challenges and difficulties, such as the cost of vehicles, the absence of recharging infrastructure, the storage capacity of batteries, the lack of incentives to promote the importation and purchase of EVs. EVs, among others.

For the development of this document, from the review of literature, statements were identified that allowed the constitution of causal relationships, which were included in a causal diagram that systemically expresses the situation studied. When conducting the analysis, we identified that tax incentives condition the increase in sales of both electric and conventional vehicles, given that the existence of incentives that reduce the cost of EVs promotes their sale because it decreases the value to be financed by the buyer, while that if there are no incentives for EVs, transport companies will prefer to purchase conventional vehicles. Given that last mile transportation will continue to increase significantly, governments must promote the necessary incentives, both tax, and non-tax, to indirectly reduce emissions and diversify the basket of the transportation sector.

As future work, we intended to bring the causal diagram built to a System Dynamics model with simulations that allows evaluating different scenarios.

References

Allen, J., Piecyk, M., Piotrowska, M., McLeod, F., Cherrett, T., Ghali, K., … Austwick, M. Understanding the impact of e-commerce on last-mile light goods vehicle activity in urban areas: The case of London. *Transportation Research Part D: Transport and Environment*, *61*, 325–338, 2017.

Arias-Londoño, A., Gil-González, W., & Montoya, O. D. A linearized approach for the electric light commercial vehicle routing problem combined with charging station siting and power distribution network assessment. *Applied Sciences (Switzerland)*, *11*(11), 2021.

Arvidsson, N., & Pazirandeh, A. An ex ante evaluation of mobile depots in cities: A sustainability perspective. *International Journal of Sustainable Transportation*, *11*(8), 623–632, 2017.

Bieliński, T., & Ważna, A. Electric scooter sharing and bike sharing user behaviour and characteristics. *Sustainability (Switzerland)*, *12*(22), 1–13, 2020.

Boccia, M., Masone, A., Sforza, A., & Sterle, C. A column-and-row generation approach for the flying sidekick travelling salesman problem. *Transportation Research Part C: Emerging Technologies*, *124*(January), 102913., 2021

Cassiano, D. R., Bertoncini, B. V., & de Oliveira, L. K. A conceptual model based on the activity system and transportation system for sustainable urban freight transport. *Sustainability (Switzerland)*, *13*(10), 2021

Castillo, O., Álvarez, R., & Domingo, R. Opportunities and Barriers of Hydrogen – Electric. *Processes*. Checkland, P., & Scholes, J. (1990). The Developed Form of Soft Systems Methodology. *Soft Systems Methodology in Action*, 2020.

Cleophas, C., Cottrill, C., Ehmke, J. F., & Tierney, K. Collaborative urban transportation: Recent advances in theory and practice. *European Journal of Operational Research*, *273*(3), 801–816, 2019.

Croci, E., Donelli, M., & Colelli, F. An LCA comparison of last-mile distribution logistics scenarios in Milan and Turin municipalities. *Case Studies on Transport Policy*, *9*(1), 181–190, 2021.

De Oliveira, C. M., De Mello Bandeira, R. A., Goes, G. V., Gonçalves, D. N. S., & De Almeida D'Agosto, M. Sustainable vehicles-based alternatives in last mile distribution of urban freight transport: A Systematic literature review. *Sustainability (Switzerland)*, *9*(8), 2017.

Ehrler, V. C., Schöder, D., & Seidel, S. Challenges and perspectives for the use of electric vehicles for last mile logistics of grocery e-commerce – Findings from case studies in Germany. *Research in Transportation Economics*, *87*(December 2018), 2021.

Feng, W., & Figliozzi, M. An economic and technological analysis of the key factors affecting the competitiveness of electric commercial vehicles: A case study from the USA market. *Transportation Research Part C: Emerging Technologies*, *26*, 135–145, 2013.

Figliozzi, M. A. Carbon emissions reductions in last mile and grocery deliveries utilizing air and ground autonomous vehicles. *Transportation Research Part D: Transport and Environment*, *85*, 102443, 2020.

Galati, A., Giacomarra, M., Concialdi, P., & Crescimanno, M. Exploring the feasibility of introducing electric freight vehicles in the short food supply chain: A multi-stakeholder approach. *Case Studies on Transport Policy*, *9*(2), 950–957, 2021.

He, Z., & Haasis, H. D. Integration of urban freight innovations: Sustainable inner-urban intermodal transportation in the retail/postal industry. *Sustainability (Switzerland)*, *11*(6), 2019.

Lin, B., Ghaddar, B., & Nathwani, J. Electric vehicle routing with charging/discharging under time-variant electricity prices. *Transportation Research Part C: Emerging Technologies*, *130*(July), 103285, 2021.

Martínez, M., Moreno, A., Angulo, I., Mateo, C., Masegosa, A. D., Perallos, A., & Frías, P. Assessment of the impact of a fully electrified postal fleet for urban freight transportation. *International Journal of Electrical Power and Energy Systems*, *129*, 2021.

Mucowska, M. Trends of environmentally sustainable solutions of urban last-mile deliveries on the e- commerce market—a literature review. *Sustainability (Switzerland)*, *13*(11), 2021.

Østli, V., Fridstrøm, L., Johansen, K. W., & Tseng, Y. Y. A generic discrete choice model of automobile purchase. *European Transport Research Review*, *9*(2), 2017.

Pelletier, S., Jabali, O., & Laporte, G. Goods distribution with electric vehicles: Review and research perspectives. *Transportation Science*, *50*(1), 3–22, 2016

Quak, H., Nesterova, N., Van Rooijen, T., & Dong, Y. Zero Emission City Logistics: Current Practices in Freight Electromobility and Feasibility in the Near Future. *Transportation Research Procedia*, *14*, 1506– 1515, 2016.

Ranieri, L., Digiesi, S., Silvestri, B., & Roccotelli, M. A review of last mile logistics innovations in an externalities cost reduction vision. *Sustainability (Switzerland)*, *10*(3), 1–18, 2018.

Schneider, M., Stenger, A., & Goeke, D. The electric vehicle-routing problem with time windows and recharging stations. *Transportation Science*, *48*(4), 500–520, 2014.

Settey, T., Gnap, J., Beňová, D., Pavličko, M., & Blažeková, O. The growth of e-commerce due to COVID- 19 and the need for urban logistics centers using electric vehicles: Bratislava case study. *Sustainability (Switzerland)*, *13*(10), 2021.

Biography

Julieth Stefany Garcia Master in Sustainable Energy Management and Environmental Engineering. Sustainable transport leader in the National Planning Unit of Mining and Energy. Modeler on energy issues and demand projections. Supervision and management of transportation projects. Experience in prevention, mitigation, and control of environmental risks. Teacher of graduate courses. Research experience.

Laura Milena Cárdenas Doctor in Engineering – Systems and Informatics from the National University of Colombia - Medellín headquarters, Master's in System Engineering. Currently, she works as an Assistant professor in the Industrial Department at the Universidad de Antioquia. Her research areas include system dynamics, renewable energy modeling and simulation. Her recent work includes analysis of Colombian electricity markets, electric vehicles, among others.

Carlos Jaime Franco Doctor in Engineering - Energy Systems from the National University of Colombia - Medellín headquarters, Master in Use of Water Resources and Civil Engineer. Currently, he works as a tenured professor in the Department of Computer Science and Decision at the National University of Colombia - Medellín headquarters. His research areas include complex systems, energy market modeling and simulation, and policy evaluation and strategy formulation for the electricity sector. His recent work includes analysis of low-carbon economies, demand response, integration of electricity and biofuel markets, among others.