Electro-mobility: Cleaning Mexico City's Air with Transformational Climate Policies Through Big Data Pattern Analysis in Traffic & Social Mobility

Mexico City is the most congested city in the world. With more than 40 million liters of daily fuel used for transportation, Mexico's population was exposed during 2016 to more than twice the pollution levels for ozone and fine particulate matter ($PM_{2.5}$) from those recommended by national air quality standards. Estimates show that cleaning Mexico City's air could avoid up to 10,856 annual deaths by meeting $PM_{2.5}$ and ozone exposure health standards.

Herein, we use big data to provide insights into specific issues in Mexico City's traffic congestion patterns. We elucidate regions for prioritized interventions, and propose and quantify the effect of solutions for climate change through transformational urban climate policies focused in electrifying the transportation fleet.

We first evaluate the entire metropolitan zone of Mexico City, the speed distributions of vehicle, and amount of traffic congestion events per regions. After spatially dissecting, we evaluate temporal distribution on the most affected regions. The diagnosis allows for a tailored analysis on vehicle-electrification policy measures. Our data approaches allow for identifying priority regions for infrastructure development, such as (*i*) the location of electric vehicle (EV) charging stations, (*ii*) the transportation routes that would have the highest impact if advanced charging-technologies are implemented, and (*iii*) the locations where the emissions reductions would be most significant.

Our data-driven tools aim to empower decision makers in Mexico City with systematic approaches to these issues, synthesizing recommendations based on large volumes of data, while allowing them to spatially identify where the biggest impacts can be made.

I. Introduction

Global GHG emissions from the transport sector account for about 23% of total energy related emissions; as countries develop, this sector's contribution to the climate problem is expected to exponentially grow (1). Deep decarbonization of our transportation options is needed if we are to meet the Paris Agreement goal of stabilizing greenhouse gas (GHG) emissions concentrations below a 2ºC warming scenario, and to increase our mitigation efforts for a safer 1.5ºC temperature target. This will only be possible if climate action is taken at the scale and pace that is needed to mitigate this change. New policy approaches, that leverage the power of innovative technologies are required to advance towards this goal.

Mexico has strongly committed towards helping to fight against climate change. Mexico's national determined contributions (NDC) has pledged to reduce GHG emissions by 22%, and reduce black carbon, a powerful short-lived climate pollutant (SLCP) by 51%.[1] Mexico also believes that it can reduce GHG emissions by 36% and black carbon output by 71% if international advancements are made towards improving climate finance, technology and capacity-building resources (2). It is important to underscore the fact that Mexico is the only country that has voluntarily committed to reducing both GHG and short-lived climate pollutants (SLCP), thus pioneering the SLCP policy agenda. The IPCC has just started its technical work to advance methods to measure these pollutants in the context of the UNFCCC reporting guidelines, and the Coalition for Climate and Clean Air[2] has been actively advocating for the need to link climate policies and efforts to reduce exposure to ambient air pollutants. Such pollutants degrade urban air quality, negatively impact the environment, and pose many health risks. In fact, transportation-derived pollutants have been linked to both chronic respiratory illness, and higher levels of infant mortality (3–5). It is only logical to think that countries will prioritize measures that achieve multiple benefits at the same time, in this case reducing health impacts related to both air pollution and the climate in general. Thus linking the UN Sustainable Development Goals (SDG) and real climate action is critical to the long-term sustainability of both Mexico and the world as a whole.

Electrifying the transportation sector has gained recent attention given its potential to significantly reduce GHG emissions (6–9). The *Paris Declaration on Electro-Mobility and Climate Change and Call to Action* is an example; backed by several agencies of the UN, the International Energy Agency and several car manufactures, the document calls for at least a 20% electrification of all transport by 2030 (10). Implementing policies to electrify vehicle fleets, however, requires tailored solutions to effectively address issues within a given city. Electrifying transportation is perhaps one of the most fascinating policies to analyze. From an engineering perspective, it calls for the integrated planning of two of the most complex systems ever created: the electric grid and the transport system. The co-optimization of these systems requires new computing approaches. Moreover, implementing electro-mobility solutions spans beyond technical challenges, as social behavior and economic sciences will play a critical role in low-carbon technology adoption.

It is within this context that the we aim to find policy solutions that will provide quantifiable benefit for both Mexico and other countries around the world. These benefits include CO_2 and SLCP reduction as well as environmental and traffic improvements. While we work using Mexico City's case, our intent is broader than advising one city government. We want to showcase the power of big data in advancing policy options, and in creating and visualizing solutions for experts and for the public. We aim to link the conversations of climate, air quality, and new transport technology deployment through big

[1] Short-lived climate pollutants (SLCPs) are powerful climate forcers that remain in the atmosphere for a much shorter period of time than longer-lived climate pollutants, such as carbon dioxide (CO_2). They include methane, fluorinated gases including hydrofluorocarbons (HFCs), and black carbon.

[2] CCAC is a coalition of 54 countries committed to SLCP mitigation and cooperation in this regard http://ccacoalition.org/en

data driven policy evaluation. It is our hope that we can help Mexico implement its NDC, through improved policy design, and that other countries can learn from the Mexican experience. Through this contribution, we aim to facilitate and support decision-making processes for urban developers and policymakers to optimize their technologies deployments, as well as policy evaluations.

The case of Mexico City

Mexico City is the most congested city in the world (11). In 2016, Mexico City's 20 million people were exposed to more than twice the pollution levels for ozone and fine particulate matters than those recommended by ($PM_{2.5}$) from those recommended by national air quality standards. Cleaning Mexico City's air could avoid up to 9,767 annual deaths by meeting $PM_{2.5}$ health standards, and 1,089 annual deaths by meeting ozone exposure standards (12). Also, people in the city spend a considerable amount of time in traffic, using over 66% more time for commuting than would be needed under normal traffic conditions (11). According to Waze driver satisfaction index, Mexico City's score is 5.2 (in a scale of 1-10), considering not only traffic but also safety, driver services, road quality, socioeconomic factors and consumer satisfaction. This placed Mexico in the 21 position of 38 cities evaluated with this metric (13).

With more than 20 million liters of daily fuel used for transportation, road traffic is the dominant source of air pollution and CO_2 emissions in Mexico (14). In Mexico City alone, 11 million tons of CO_2 and 1.2 thousand tons of black carbon could be related to transportation (15). If we consider the whole Metropolitan Area of Mexico City, with selected municipalities from State of Mexico and Hidalgo, CO_2 emissions increase to 23.7 million.[3] While CO_2 emissions are mainly driven by gasoline consumption from passenger vehicles, black carbon comes from an old diesel fleet for public transportation and road freight services. Thus, policy interventions targeting distinctive fleets will result in different environmental outcomes.

In addition to the NDC and Climate program, Mexico City has also launched a climate action plan (15). The National Institute of Ecology and Climate Change has put forward a Federal Program for Air Quality Management in Mexico City's Megalopolis (12), which includes actions for both Mexico City and neighboring states. A Metropolitan Environmental Commission manages coordinated action across states. We consider current policy approaches and institutional frameworks to fully reflect on the implementation challenges of our proposals.

As vehicle population in Mexico City increases, a severe challenge to mitigating GHG emissions arises. A sustainable approach to infrastructure development is required to provide reliable connectivity while minimizing environmental and health impact. An example of this type of approach is the current expansion of Mexico City's RTP system, in which buses run on diesel fuel. Due to the lack of the ultra low-sulfur diesel, required for efficient deployment of pollution control technologies, these buses end up having important PM_{10}, $PM_{2.5}$, and CO_2 emissions. Furthermore, the frameworks and tools to properly quantify and evaluate the priority transportation routes could be improved. Currently, policy makers rely on origin-destiny surveys that do not capture all city traffic patterns and are difficult to update. This can result, among other things, in a lack of understanding of new bottlenecks triggered by infrastructure projects.

We propose to use big data to improve transport infrastructure planning by providing a full picture of mobility patterns in Mexico City's Metropolitan Area. Our project evaluates Mexico City's options by considering current policies and proposing larger scale new low-carbon technology deployment. We do this using a big data approach, strongly and purposefully linking transportation and

---

[3] INECC's estimation using 2016 fuel consumption in the 16 districts of Mexico City and the municipalities of the State of Mexico and Hidalgo within the Metropolitan Area of Mexico City.

environmental planning for climate action. This paper is organized as follows. Section II describes data and methods to visualize and quantify traffic distribution, estimate emissions, identify charging locations and roads for electro-mobility solutions. Section III presents our findings, and Section IV discusses the policy implications. We conclude our work in Section V.

II. Materials and Methods

I. Acquiring and Visualizing Traffic Mobility Data

Traffic data, provided by Waze (16) through the REST application programming interface (API) is acquired every 2 min for a polygon covering Mexico City and its surrounding areas, spanning a total of 15,151 km^2. Entries are recorded from August 8th, 2017 to September 8th 2017, and only weekdays, Monday through Friday, are considered for this work. The Waze REST API returns every single traffic jam inside the polygon for the requested time interval. Each jam has an associated metadata length, number of segments, road type, intensity level, and average speed. Requests can contain anywhere from 0 to hundreds of jams, depending on the city congestion level at the sampled time.

A total of 583 M data points, encompassed in approximately 380 K individual lines, and more than 70 GBs of uncompressed data, are stored in a PostgreSQL database for easy access and retrieval.

To visualize the vast amount of collected data, an open-source python-based graphics pipeline system called Datashader is used (17). This pipeline aggregates the points (and their statistical descriptors) and makes a plane transformation to render a synthesized image.

Data manipulation is done in python and R languages. In python, packages such as pandas, numpy, dask, SciPy, scikit-learn, and geopandas, are used, and in R, dplyr and jsonlite packages are used. Two servers hosted on the cloud are used for data processing and visualization: (*a*) Microsoft Azure, with a Standard L8s machine with 8 vCPUs and 64 GBs RAM memory, and (*b*) Amazon Web Services with an EC2 instance with 32 vCPUs and 244 GBs RAM memory.

II. Impact of Public Policies on Emissions

a. Spatially-resolving Emissions

To model emissions, first an understanding of the vehicles emitting gases and airborne particles is required. A census of Mexico's automobile fleet containing volume, age, and distribution of automobiles across the relevant automobile types (*i.e.*, passenger cars, passenger trucks, single unit short haul trucks, single unit long haul trucks, motorcycles, and public transit) is used (18). Representative distribution of vehicles is shown in Table I.

Table I. Vehicle type and distribution in Mexico City

Type	Composition
Light Duty Vehicles	51.97%
Passenger Trucks	39.71%
Short Haul Trucks	0.47%
Long Haul Trucks	0.06%
Motorcycles	6.98%
Public Transit	0.81%

We use MOVES-Mexico to identify and quantify road transportation emissions (19). This tool, developed by the Environmental Protection Agency of the United States (20), runs simulations to predict emissions outputs based on the type of street, the car age and type, the car speed and travel length, as well as the atmospheric conditions of the region of interest. Through a cooperation project between the USEPA and INECC, the model is parameterized to Mexico's conditions and is used for policy analysis and for the GHG emissions inventory of Mexico (CITATION).

A breakdown of the mathematical methodology and variables used by MOVES-Mexico is required to project the road segments based on the acquired data. To estimate traffic volume per hour, an input required by MOVES-Mexico, we use a count of the street width (3 lanes average) and an estimate of space by an average car, since the Waze data does not have the traffic volume information. By doing this, we are able to obtain the volume of cars which fit on the line segment at any one moment. This value is scaled by time taken to traverse the segment of cars driving through the segment per hour. Afterwards, we construct functions for all recorded speed.

Emission outputs are obtained for carbon monoxide (CO), volatile organic compounds (VOC), nitrogen oxides (NO_x), sulfur dioxide (SO_2), ammonia (NH_3), carbon dioxide (CO_2), particulate matter with 2.5–10 µm diameter range (PM_{10}), and particulate matter with diameter below 2.5 µm ($PM_{2.5}$).

b. Proposed Public Policies

Three policies are proposed and evaluated in terms of their effects on $PM_{2.5}$ emissions, to analyze health impacts, as well as CO_2 emissions to analyze GHG mitigation potential. The first policy is a taxi intervention, in which Mexico City passes regulation electrifying all of its operating taxi fleet to impact high density urban centers of the city, an incremental first step towards more aggressive policies herein modeled. The second policy is focused on public transportation, specifically in an intervention in which Mexico City's public transit buses are electrified. The third policy involves a highly ambitious end-goal scenario in which all light duty vehicles (LDV) in Mexico City are electrified.

To reflect the differences in policies in our emission modeling, both input volumes and compositional distributions of different vehicles are varied. Emissions per road segment for each policy scenario are then calculated.

Emission outputs are aggregated to represent their spatial intensity and dispersion. The polygon enclosing Mexico City is divided into equidistant area regions, and emissions falling into these discretized areas are grouped and visualized through a Gaussian convolution method that both interpolates and estimates the spread between emission points.

III. Social mobility and traffic patterns for electro-mobility infrastructure deployment

We posit that larger capacity of electric vehicle (EV) stations should be placed in locations where there is a larger amount of traffic and a larger number of people, since these public stations are more likely to be used, and thus, must be scaled to meet such demand. In addition, we assume that the reduction in cost of EVs will continue rendering a ubiquitous adoption across income groups.

Relatively congested regions of Mexico City are filtered and labeled as broad zones of interest, in where a person who has not charged at home or at work, might suffer from range anxiety after driving his EV with not significant motion progress.

To model social interactions and their volumes at specific times of the day, we use Google's Places API and scrape the 'Popular Times' item of each desired location in Mexico City (21). This feature gives position and duration, on mobile phone GPS location signals and WiFi, to determine where users are.

A matrix with more than 1.6 M entries is acquired for all 16 different boroughs of Mexico City. The entries represent the relative volumes of people at different types of the day during different days of the week. The data includes parking lots, bars, gas stations, parks, schools, banks, and stores. Morning (7-9 AM), and evening (6-8 PM) times are filtered.

Congested zones are geospatially indexed and binned into equidistant latitude and longitude regions, and matched with regions where PopularTimes data also exists. A combined data set is created to get relative amounts of traffic and social interaction volumes in each bin at the studied hours. A k-means clustering algorithm with k=200 is run to obtain a spread of stations, and their density, across the city.

The visualization is done in Google Earth, which has the capacity for creating 3D projections using the KML file. The Python package Simplekml is used as a lightweight and efficient way to create various KML polygons. For each frequency data point, a KML bar is created with a height corresponding to the frequency value. A red-green color gradient is used to help visualize a relative comparison to the entire dataset. Shapefiles with Mexico City district border are converted into KML for Google Earth display, and to create a hexagonal grid stretching across the city borders.

IV. Using traffic flow data for electro-mobility infrastructure planning

Understanding traffic patterns in Mexico City is important to spatially identify areas for policy interventions, technology deployment, and air quality studies that can be translated into an efficient vehicle fleet deployment. We leverage the properties of the Waze data to this end and dividing the city into quadrants where traffic flow can be represented.

The jams dataset provided by Waze is used to represent the traffic flow. This dataset outlines the number of traffic jams in a given polygon (*i.e.*, street) consumer along with a description of the jam, its level, its geolocation, length, speed, among other important parameters. A representative point of each jam is chosen for each minute to allow flexibility in manipulation.

Flow direction is obtained by calculating the forward azimuth angles of the traffic flow by first ordering jam points from source to destination, and then applying Eq. 1.

$$\tan^{-1}\left(\frac{\sin\varphi_1 - \varphi_2 * \cos(\lambda_2)}{\cos(\lambda_1) * \sin(\lambda_2) - \sin(\lambda_1) * \cos(\lambda_2) * \cos(\varphi_1 - \varphi_2)}\right) mod\ 2\pi \tag{1}$$

The most dominant direction of that subset of points within the quadrant is taken as being representative of the traffic flow in the area. Assuming traffic is continuing in the same direction from one adjacent region to the next, we identify and plot patterns suggestive of complete traffic routes.

III. Results

Traffic jams are both spatially and temporally inhomogeneous, as seen in Fig. 1, where blue colors represent light traffic congestion, and red colors high congestion.

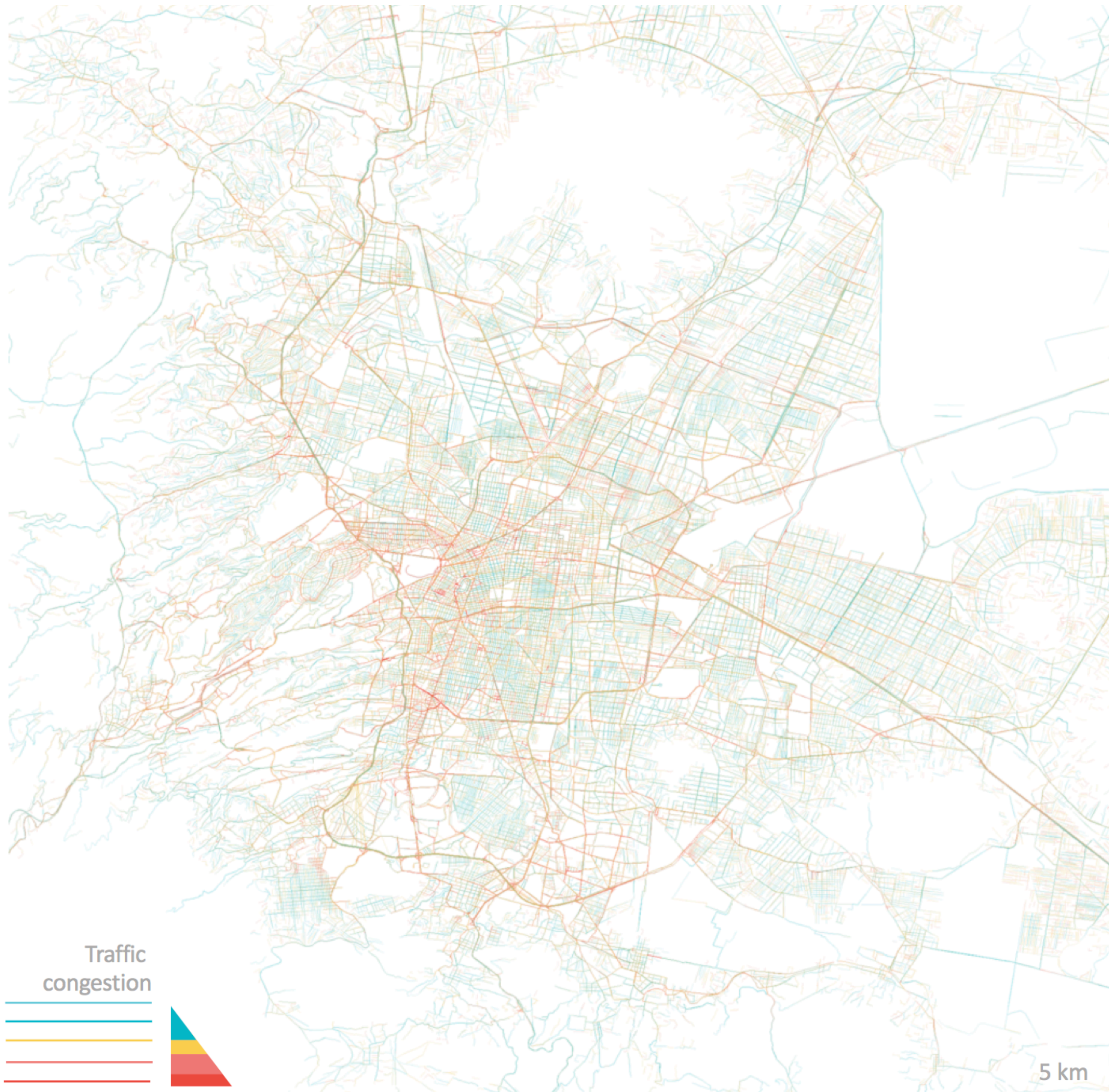

Figure 1 – Traffic jam intensity map of Mexico City for the studied month of Aug-Sept, 2017. Blue color represents low congestion and red color represents high congestion levels.

Traffic flow patterns shown in Fig. 2 elucidate a shift that goes towards the center-left part of the city in the morning time (7-9 AM), where major economic and business activities are located, and then outwards in the evening (6–8 PM).

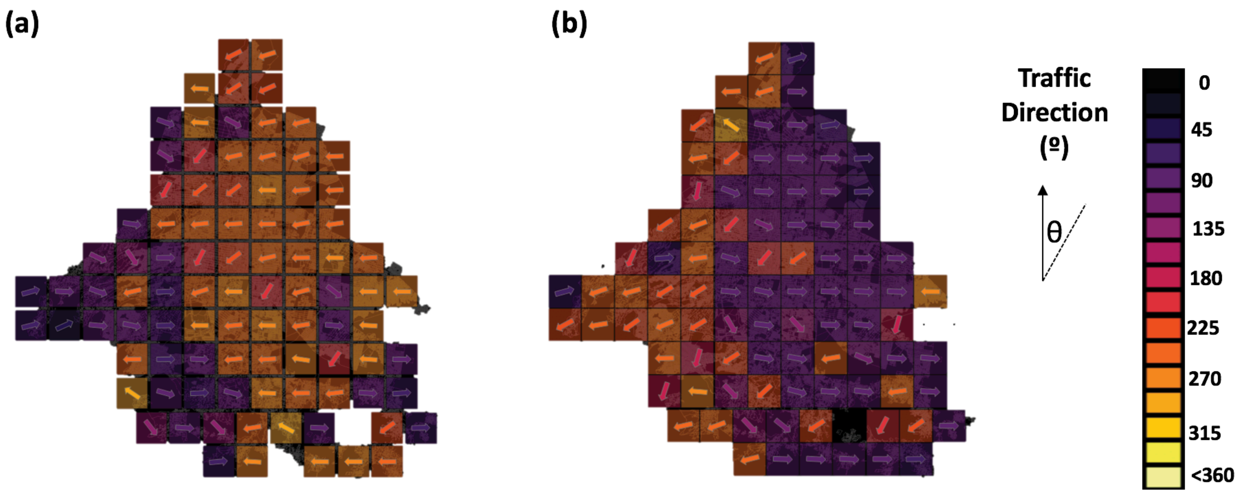

Figure 2 – Traffic flow patterns for Mexico City in the (a) morning time [7–9 AM], and (b) evening [6–8 PM]. Each square represents the spatial resolution for which traffic data was aggregated. The most dominant flow direction is shown by both an arrow inside the square, and the color of the box, as shown in the color scale. Degrees are measured clockwise from the north direction. Direction squares are overlaid on top of a Mexico City streets map.

Fig. 3 shows the cumulative amount of traffic jams per hour. Severe traffics events are significantly higher at business hours with peaks at 2 PM and 6-8 PM, higher than during the morning time (7-9 AM). Traffic significantly decreases from 10 PM to 5 AM.

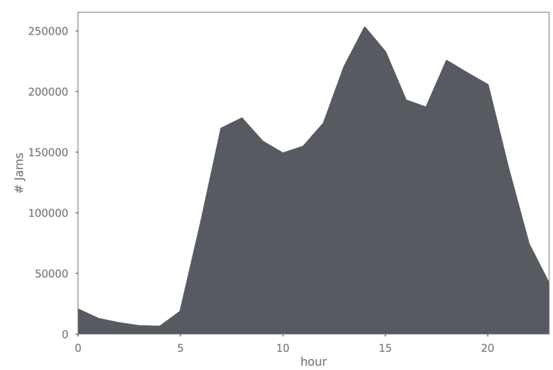

Figure 3 – Traffic jam intensity map of Mexico City for the studied month of Aug-Sept, 2017. Blue color represents low congestion and red color represents high congestion levels.

Results shown in Fig. 4 denote a 3.1% average reduction in $PM_{2.5}$ for the Taxi Cab electrification policy, with reductions of up to 4.1% in certain areas. CO_2 emission in this policy scenario are reduced on average 3.4%. The public transport policy achieved an average reduction in $PM_{2.5}$ of 25% and up to 26%. For CO_2 emissions, a reduction of 22.3% on average is observed. The Transformational policy, where all light duty vehicles are transformed into EVs, an average reduction in $PM_{2.5}$ of 44% is observed, with regions achieving reductions of up to 58%. CO_2 emissions obtained an average reduction of 49.4%.

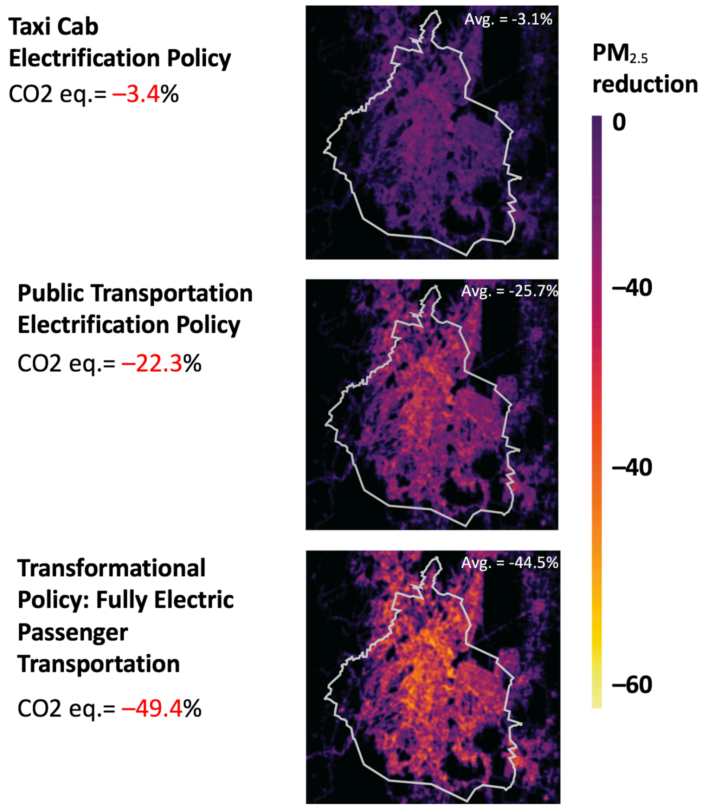

Figure 4 – Maps of Mexico City showing the impact of three different electrification policies in terms of $PM_{2.5}$ emissions percent reduction. Percent reduction in CO_2 equivalent emissions are also shown for each policy scenario. White contour lines denote Mexico City boundaries. $PM_{2.5}$ average reductions for Taxi Cab electrification policy is of 3.1%, 25.7% for Public Transportation electrification policy, and 44.5% for the Transformational policy (electrification of light-duty vehicles).

The distribution of 1.5 M points across 16 boroughs where social activities are recorded is shown in Fig. 5a. Fig. 5b shows a distribution of peaks of different heights and colors; the peaks' colors and heights represent where a large number of Mexico City inhabitants check into and where there are higher areas of road traffic, which is the criteria defined *a priori* for the proposal of potential EV charging stations. These are mostly located in the center of the city. In particular, the Cuauhtémoc and Benito Juarez districts see a higher concentration of data points. It is important to note that a recent substation with capacity to accommodate larger load demands was installed in the Cuauhtémoc borough.

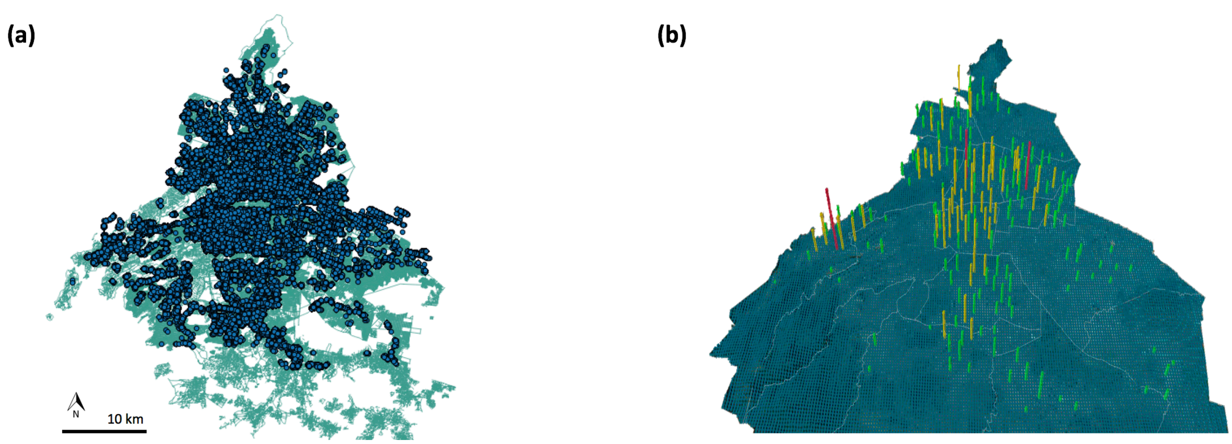

Figure 5 – (a) Map of Mexico with 1.5 M data points across 16 boroughs representing gas stations, parking lots, bars, parks, schools, banks, and stores. (b) Mexico region with proposed EV charging stations. Red peaks denote high density of EV charging stations required, yellow a moderate number, and green a lower density value.

To better understand the interplay between different boroughs, traffic congestion, and our proposed infrastructure framework, we contemplate different regions. These regions, as shown in Fig. 6, are meant to be considered when addressing the impact that covers the most populated regions (Fig. 6a), the regions with the most industrial development (Fig. 6b), and also the underserved and marginalized communities (Fig. 6c) that require environmental justice interventions upon the design of public policies.

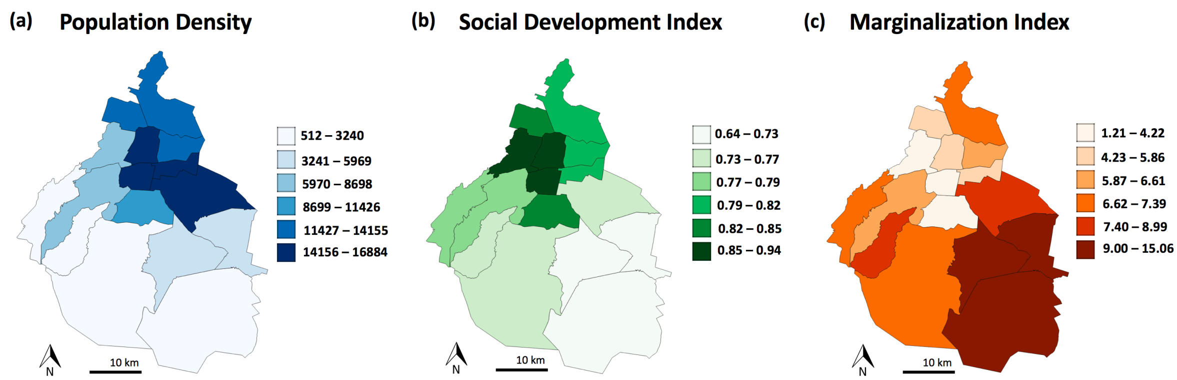

Figure 6 – Mexico City's (a) population density, (b) social development index, and (c) marginalization index regions. Darker shades of each color denote higher values.

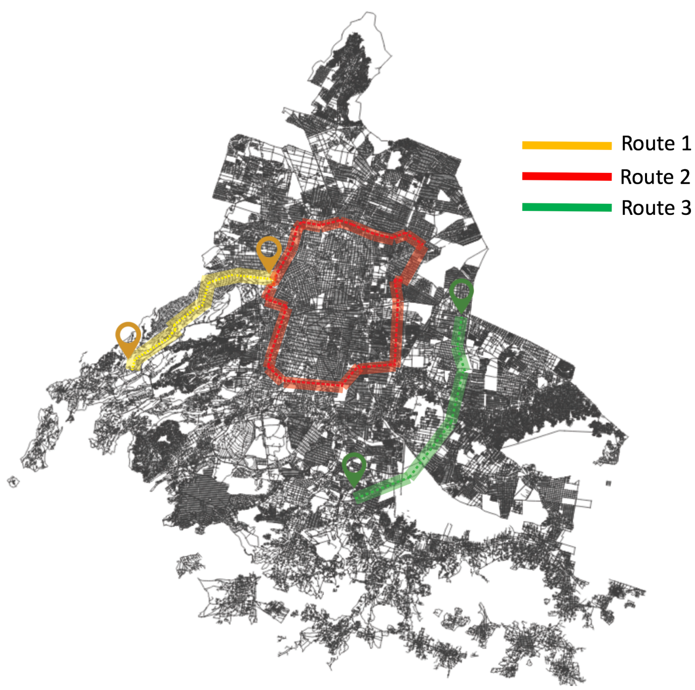

Figure 7 – Identified routes for continuous charging corridors complemented with stationary EV charging stations. The three proposed routes optimize for impact in emissions reductions, including the inclusion of highly developed areas (Route 1), high population densities (Route 2), and inclusion of communities with high marginalization index (Route 3). These regions also have potential EV charging stations identified, as shown in Fig. 5b.

Based on the traffic data (both congested regions and flow direction), EV station locations, and Mexico's demographics, we are able to propose transportation routes for electro-mobility interventions, as shown in Fig. 7. Each route optimizes for the minimization of emissions, while addressing different Mexico City population sectors and needs.

IV. Discussions

Waze data allow us to propose policy interventions based on congested roads, emission reduction potential, and potential EV charging stations. Based on our analysis, we are able to identify regions where electro-mobility interventions can be implemented. For one, stationary EV charging stations are proposed in regions across Mexico City. Route 1 alleviates congested regions (Fig. 1), and allows for the industrial sector (Fig. 6b) to minimize their emissions (Fig. 4); it also allows for planners to leverage proposed infrastructure development, either in the form of stationary EV charging stations or inductive-charging corridors for non-stop traffic flow. Similarly, Route 2 optimizes for high population density regions, and Route 3 serves marginalized communities and creates an inclusive urban design.

Any discussion about electro-mobility has to incorporate grid-capacity studies. In that regards, Mexico City has invested in modernizing its electricity distribution system. We have also considered routes taking into account the presence of advanced electric power distribution substations with new technologies such as protection and control units. Such advancements allow for increased power capacity in order to meet the demand of Mexico City's modern areas of Santa Fe (Fig. 7, Route 1) and Reforma (Fig. 7, Route 2). Thus, we consider future smart grid planning in the city; in future research, we will elaborate on the inter-linkage of this system with the transport network.

Based on the analysis developed for this challenge, we have identified two different regions of Mexico City for electro-mobility interventions.

1. An electrified ring road in Circuito Interior

Waze data captured Mexico's "Circuito Interior" congestion, a ring road that was designed as a high-speed highway, but that today suffers from severe bottlenecks during peak hours, as shown in Fig. 1. The ring road, shown in Fig 7 (Route 2), is a controlled access highway[4] with 6 lanes, 3 for each direction, and 4 side lanes. Electric buses (or elevated trains), can run in the inner lanes (or the outer side lane) in each direction along with modern charge-as-you-drive infrastructure. Congestion is particularly important in Ave. Benjamín Franklin to Ave. Rio Mixcoac, where the intersection of Ave. Revolución allows transit to the south and Ave. Patriotismo to the North. In more concrete terms, from the proposed electro-mobility route herein proposed, the introduction of stops at the intersection with main avenues, can allow for multimodal transit, including bike-parking options. Also, for electric passenger vehicles, we've down-selected and proposed the ideal location for charging stations based on Google's PopularTimes and Waze data.

2. Electrification of the outer ring road Periférico

This outer ring road of the city (given city growth it is no longer really surrounding the city, but it is still locally known as the *Periférico*) is a controlled access road, has three lanes and two side lanes in each direction. It also has an elevated toll highway in south and northeast directions. Transport options could exclusively run in the central lanes. Similar to the electrified ring road option, stop stations would

[4] Controlled access highways in Mexico City include: Circuito Interior; Anillo Periférico; Viaducto Miguel Alemán, Rio Becerra, Tlalpan y Carlos Lazo; Insurgentes; Zaragoza; Constituyentes; San Antonio Abad; Ejército Nacional; y Aquiles Serdán.

can be built in the main intersections, with a consideration for intermodal transit options. This intervention would reduce the congested regions shown in Fig. 1 attributable to this region, both by displacing vehicle use towards public transportation, and also by reducing the current inefficient bus routes that cross this long ring road with unpredictable stop-and-go behavior. Electric-grid interconnections would have to be reinforced to enable this massive transport option, but could start with the already available electric substations of Ave. San Antonio, exit to Querétaro´s highway, or Xochimilco.

We believe these changes could be impactful projects for both climate and air quality policy. While our analysis is based on traffic conditions, as described in Section 2, clearly we must refine and add a sensitivity analysis to changing conditions. Specially, we would like compare our traffic solutions with current subway and RTP expansion projects. The subway network is undergoing and important expansion of 43.5 km with 5 main projects.[5] In particular, Line B and Line 7 projects could be an interesting comparison to electrification proposal (d), since they consider potential connections to the airport. In the case of RTP expansion projects, the city has 3 main projects.[6] One project expects to add 90 Euro VI Diesel buses in Reforma, one of the main avenues. The second project tackles traffic to the south of the City, connecting San Lazaro to Vaqueritos, introducing 78 new buses (decision still pending on technology type Euro V or VI). Finally, the last project is still on planning stages but it would replace buses that cover the Periferico, with about 300 Euro VI Diesel buses. Further research would tackle the questions of how these options compare to new EV deployment strategies in terms of mobility, pollution control, and CO_2 emissions.

V. Conclusions

This work has explored electro-mobility options in Mexico City, using Waze data to identify and prioritize routes that report highest social benefit for Mexico's population, in terms of reduced traffic jams and pollution. We have used big data approaches to better understand CO_2 and other types of emissions in the city to improve our transport policy modeling tools with disaggregated data of city traffic. In addition, we used Google's Popular Times dataset to elucidate social mobility patterns, and used this information to recommend EV charging infrastructure and sites for potential intermodal transit planning.

Our results show that electro-mobility polices can bring substantial benefits in terms of pollution reduction and climate change mitigation. The three evaluated policies show reduced CO_2 as follows: (*a*) a 3.4% with the electrification of the taxi cab fleet, (*b*) a 22% with the electrification of the public transportation buses and, (*c*) a 49% reduction of electrification of the entire fleet of private passenger vehicles. In terms of $PM_{2.5}$, the reductions were 3.1, 24, and 44%, respectively. To our knowledge, this is the first analysis in the country to combine big data analytics with climate change policy evaluation and that integrates other important environmental benefits such as air pollution into the analysis. We believe that as a first step, the study provides valuable insights to further develop and fine-tune our data analytics for targeted interventions.

As a first approximation to this problem using these types of techniques, our study has several limitations, and should be consider only as a screening process towards more elaborated future work to finalize our policy recommendations. In particular, the combination of different fleet interventions, the modeling of mixes of current and new transport policies, and a rigorous cost-benefit analysis should follow to this first exercise. Nevertheless, our contribution is clear in signaling the future of urban

[5] Line 1, 1 km Observatorio-Pantitlan; Line 12 Observatorio-Mixcoac, 4.5 km; New Line A, 13 km, la Paz-Chalco; Line B, 5 km, Rio de los Remedios-airport; New Line 7, 20 km fast speed train to the airport.

[6] Line 7, Reforma (Fuente de Petroleos)-Indios Verdes. Line 5 expansion in Eje 3 Oriente from San Lazaro to Vaquerios; Line 8 in the Periferico (segment to be define).

planning using the power of data science.

Data-driven strategies for integrated mobility management is a game changer for environmental and urban planning. For decades, countries have tried to balance costs and benefits of transportation policies. On the one hand, increasing transportation demand responds to countries' economic growth; however, it has come with increased pollution, congestion and decreased quality of life in urban areas around the world. Even developed countries have not solved their traffic problems, and require new and innovative approaches for the design of modern transport empowered by IT solutions. In developing countries, new technologies can truly make a difference and leapfrog countries decades ahead in terms of mobility options.

Data-based approaches could also hold the key to one standing problem for the implementation of the Paris Agreement. Countries have pledged a variety of climate commitments, and our old methods to measure, report, and verify (MRV) emissions reductions are made even more challenging due to the diverse type of policies that will be emerging from the bottom-up. How would we decide among diverse transportation policies? How will we evaluate whether the policies worked? Are there ways to increase information flows of data in response to these questions or are we to wait a 5-year cycle for a global stock market crisis in order stake on critical issues rapidly shaping infrastructure decision making around the world? In this paper, we have used Waze data in the Mexico MOVES model to estimate emissions, significantly improving previous estimates of emissions in Mexico City's Metropolitan Area. Calibrated modeling tools matched with real-time data could provide new sources of policy evaluation. New technologies could play a substantial role in the design of MRV systems of mitigation action.

Cell phone data (*e.g.,* Waze, Popular Times) can also enable real-time managed transportation demand response. In a similar way that the electric sector has leveraged technology in order for consumers to respond to hourly electricity pricing changes, the transportation sector could potentially revolutionize congestion and pollution management using information flows and adequate incentives. Traditional economic instruments used in this field include gasoline taxes, levies on cars, payments for roads or parking, policies to discourage car use, and regulations that mandate certain technology changes. However, these policies do come at a social and political cost; due the political economy of their implementation, regulation is slow and often outpaced by traffic expansion. Incentives could be designed to discourage individuals' contribution to congestion and pollution by, for example, discouraging the ownership of an unnecessary extra vehicle. We envision the design of advanced pay-as-you-go economic instruments with real-time information as part a policy package that harnesses the power of big data for urban planning and real-time congestion and pollution management.

References

1. Sims R. RS F Creutzig, X Cruz-Núñez, M D'Agosto, D Dimitriu, MJ Figueroa Meza,, L Fulton, S Kobayashi, O.Lah, A McKinnon, P Newman, M Ouyang, JJ Schauer, D Sperling, and G Tiwari, I. Baum SB P Eickemeier, B Kriemann, J Savolainen, S Schlömer, C von Stechow, T Zwickel and JC Minx (2014) *Transport. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC, Cambridge, United Kingdom and New York, NY, USA.).
2. República G de la (2015) *Intended Nationally Determined Contribution* (http://www4.unfccc.int/submissions/INDC/Published%20Documents/Mexico/1/MEXICO%20INDC%2003.30.2015.pdf).
3. Evans J, et al. (2002) Health Benefits of Air Pollution Control. *Air Quality in the Mexico Megacity: An Integrated Assessment*, eds Molina LT, Molina MJ (Springer Netherlands, Dordrecht), pp 105–136.

4. Fann N, Risley D (2013) The public health context for PM2.5 and ozone air quality trends. *Air Qual Atmosphere Health* 6(1):1–11.
5. Loomis D, et al. (1999) Air Pollution and Infant Mortality in Mexico City. *Epidemiology* 10(2):118–123.
6. Altenburg T, Bhasin S, Fischer D (2012) Sustainability-oriented innovation in the automobile industry: advancing electromobility in China, France, Germany and India. *Innov Dev* 2(1):67–85.
7. Figenbaum E, Assum T, Kolbenstvedt M (2015) Electromobility in Norway: Experiences and Opportunities. *Res Transp Econ* 50(Supplement C):29–38.
8. Joller L, Varblane U (2016) Learning from an electromobility living lab: Experiences from the Estonian ELMO programme. *Case Stud Transp Policy* 4(2):57–67.
9. Auvinen H, et al. (2016) Electromobility Scenarios: Research Findings to Inform Policy. *Transp Res Procedia* 14(Supplement C):2564–2573.
10. UNFCCC (2015) *Paris Declaration on Electro-Mobility and Climate Change & Call to Action* Available at: http://newsroom.unfccc.int/media/521376/paris-electro-mobility-declaration.pdf.
11. TomTom (2017) TomTom Traffic Index. Measuring Congestion Worldwide. Available at: https://www.tomtom.com/en_gb/trafficindex/city/mexico-city.
12. INECC/SEMARNAT (2017) *Programa de Gestión Federal para Mejorar la Calidad del Aire de la Megalópolis. (Program for Air Quality Management in Mexico City's Metropolitan Area).* (Mexico City).
13. Waze (2017) Waze Driver Satisfaction Index. Available at: www.waze.com/driverindex.
14. INECC/SEMARNAT (2015) *Primer Informe Bienal de Actualización ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático*.
15. Mexico City Government (2014) *Programa de Acción Climática. Ciudad de México. 2014-2020 (Climate Action Plan for Mexico City 2014-2020)*.
16. Tránsito, Rotas, Mapas E GPS, E Estado De Las Carreteras -Waze Available at: https://www.waze.com/ [Accessed October 19, 2017].
17. datashader: Turns even the largest data into images, accurately (2017) (Bokeh) Available at: https://github.com/bokeh/datashader.
18. Instituto Nacional de Ecología y Cambio Climático | Gobierno | gob.mx Available at: https://www.gob.mx/inecc [Accessed October 19, 2017].
19. USAID (2016) *MOVES-Mexico User Guide* Available at: http://pdf.usaid.gov/pdf_docs/PA00MBG8.pdf.
20. US EPA *US EPA*. Available at: https://www.epa.gov/ [Accessed October 19, 2017].
21. Popular times and visit duration - Google My Business Help Available at: https://support.google.com/business/answer/6263531?hl=en [Accessed October 19, 2017].