Zero Emission Delivery Zones - *An Analysis on US Implementation*

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Executive Summary

Zero emission delivery zones (ZEDZs) are an innovative policy geared toward reducing greenhouse gas emissions by incentivizing the use of electric delivery vehicles and freight. In certain iterations, these zones mandate the use of EVs; however, some iterations are not mandated and instead rely on the use of incentives like priority parking. Through variations such as this, one benefit of a ZEDZ policy is that it can be tailored to fit the needs of a given municipality. Data from London, the Netherlands, and Shenzhen indicates these policies are indeed effective at reducing GHG emissions when paired with additional policies. London, for example, has implemented an ultra-low emission zone (ULEZ) that co-occurred with the implementation of congestion pricing at all times and a sulfur-free diesel policy. However, as seen with the London case, there is potential for GHG emissions to simply be offset to areas outside of the zone which is of particular concern when it comes to ensuring environmental policies are not disproportionately negatively impacting certain communities while benefiting others.

While zero emission zones (ZEZs) - zones that not only target delivery vehicles and freight, but passenger vehicles as well - have proliferated across Europe and China, little attention has been paid to their utility in the United States. However, currently three ZEDZ pilots are underway in Pittsburg, Los Angeles, and Santa Monica. Our report pays particular attention to the Santa Monica voluntary ZEDZ pilot with input from a variety of stakeholders, including government officials, partners on the pilot, advocates from community-based organizations, and multinational corporations. Throughout this project, we interviewed 11 organizations with interest in ZEDZs and discovered several challenges that municipalities in the United States must overcome, including, but not limited to: political feasibility, difficulties in generalizing the impact of these zones, stakeholder engagement, and equity concerns. The latter point is of particular interest, given that communities of color often bear the brunt of environmental injustice in the form of exposure to increased emissions and closer proximity to concentrated industrial manufacturing.

Given the historical trends we witnessed, we decided to center equity, political feasibility, and effectiveness in our qualitative and quantitative analyses not only to form recommendations that do the most good for the most people but also to take into account the possible negative externalities that might result from ZEDZs, particularly on populations that have a history of bearing the brunt of pollution. Furthermore, political feasibility poses a particular problem for municipalities in the United States and in California specifically, where jurisdictional limitations fostered by vehicle codes limit the amount of control a city government can exert over passenger and delivery vehicles. Nonetheless, the Cities of Los Angeles and Santa Monica have found ways to get around these limitations through novel curb management policies and legislative proposals in their City Councils.

Our findings from our original optimization model and qualitative analysis indicate that a combination of regulatory policies (e.g., mandatory ZEDZs) and incentive policies (e.g., priority parking and subsidies) is the most effective and equitable pathway to reduce greenhouse gas (GHG) and other emissions. ZEDZs can be used to increase EV uptake by businesses who employ freight and other delivery vehicles - each of which constitute a significant amount of global emissions - which reduces the environmental impact within a given municipality, and purchase subsidies can limit the burden of this policy shift on businesses - especially small businesses who may not have capital to move towards fleet electrification. Furthermore, our model can be used to determine how delivery vehicle flows will be impacted by the implementation of a ZEDZ and quantify the emission reductions that will result from it. Given the sparsity of the literature around ZEDZs, we expect our project and model to inform the budding last-mile logistics scholarly field and provide much needed support to municipalities who are interested in implementing this policy.

Glossary

Daily Vehicle Mile Traveled (DVMT):

The total miles traveled by a vehicle per day. In the optimization model in this report, we refer specifically to deliveries conducted by freight vehicles.

Delivery Company:

A delivery service is the pickup of goods from any location and the delivery of these goods to the location requested by the customer using a passenger car, bicycle, or other means of transportation. In this paper, we refer to a company that performs such delivery services based on customer requests as a delivery company. Examples include the United States Postal Service, FedEx, and Amazon.

Electric Vehicles (EVs):

This term refers to plug-in electric vehicles (PEVs) which encompass both battery electric vehicles and hybrid electric vehicles. For the sake of simplicity, we use the term EVs in this report to refer to all types of PEVs.

Fleet:

All vehicles owned or leased by a company or other entity. In this report, we refer specifically to freight vehicles.

Greenhouse Gas (GHG):

A gas that traps heat in the atmosphere. Major greenhouse gasses include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gasses.

Air Pollutants:

Substances that are harmful to the human body and the environment, such as carbon monoxide, nitrogen oxides, particulate matter (e.g. PM2.5 and PM10), and sulfur oxides.

Internal Combustion Engine Vehicles (ICEVs):

Vehicles powered by regular internal combustion engines (ICEs). ICEs are usually powered by fuels such as gasoline or diesel.

Last Mile Logistics:

The final part of the supply chain connecting the last distribution center to the destination point. This step of the delivery is often the most inefficient and challenging to optimize, and these challenges are referred to as the **last-mile delivery problem**.

Social Welfare:

A term in economics referring to the summed costs and benefits in society, including both those private and public. This also includes non-monetary costs and benefits, such as the cost of pollution. In conducting an economic or welfare analysis, a policy is usually deemed best if it increases social welfare (or increases it more than alternative policies). However, this type of analysis can mask distributional issues with a policy (for example, it is possible for a policy to increase total social welfare while also leaving many individual people worse off).

Zero Emission Delivery Zone (ZEDZ):

A Zero Emission Zone (ZEZ) that targets last mile deliveries (see ZEZ definition below).

Zero Emission Vehicles (ZEVs):

Vehicles that generate fewer GHG emissions than ICEVs. Based on the definition by The California Air Resources Board (CARB), ZEVs include Battery Electric Vehicles (BEVs), plug-in Hybrid Electric Vehicles (PHEV), and Hydrogen Fuel Cell Vehicles (HFCVs).

Zero Emission Zone (ZEZ) / Low Emission Zone (LEZ):

An area where only zero-emission vehicles (ZEVs) or vehicles that meet low emission zone requirements are allowed to access with no restrictions.

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Chapter 1

Introduction

Chapter 1: Introduction

Due to growing concerns about climate change and increased public awareness of environmental issues, many national and local governments are explicitly aiming to achieve "Carbon Neutrality" by 2050 in line with the United Nations Sustainable Development Goals (SDGs). For this to be achieved, a drastic reduction in greenhouse gas emissions is necessary. Though many policies are being proposed to combat the detrimental effects of climate change on communities across the world, few national governments are taking interest in the impacts of freight transport on the environment.Additionally, air pollution constitutes one of the biggest issues facing urban areas across the world and “there are clear indications that premature mortality due to air pollution exceeds significantly the number of traffic accident fatalities”.[1] Ranieri et al. (2018) states:

> “The impacts of transport air pollutant emissions are highly related to geographical position, and they are affected by many local factors, such as existing transport means and traffic. The impacts caused by the emissions are determined by evaluating human health diseases and environmental damages related to a unitary increase in the air pollution concentration. Epidemiological studies indicate that the most important air pollutants in urban area are: Particulate Matter (PM), Nitrogen Oxides (NOx), Carbon Monoxide (CO), aliphatic and aromatic hydrocarbons, Sulfur Dioxide (SO2) and heavy metal;

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[1] Jiang, Wei, Manfred Boltze, Stefan Groer, and Dirk Scheuvens. “Impacts of Low Emission Zones in Germany on Air Pollution Levels.” Transportation Research Procedia 25 (2017): 3370–82. https://doi.org/10.1016/j.trpro.2017.05.217.

the impacts on humans and the ecosystem are evaluated, and the related monetary costs are estimated."[2]

Thus, freight transport constitutes a "major contribution to air pollution," however, policy makers "rarely consider" the sector for regulation.[3] New innovations in technology and policy have occurred in the last two decades, allowing local governments to implement novel methods to curb pollutants and foster healthier environments for their constituents. Of particular interest is the impact of zero emission zones (ZEZ) and zero emission delivery zones (ZEDZ) in cities in Europe, Asia, and the United States on greenhouse gas (GHG) emission and other pollutant levels caused by internal combustion engine (ICE) vehicles.

Basics of Zero Emission Delivery Zones ("ZEDZ")

ZEDZs are a new policy that creates zones within cities tasked with the goal of reducing and ultimately eliminating greenhouse gas (GHG) and other emissions released by delivery vehicles.[4] These zones require the use of electric freight and delivery trucks, potentially limiting the amount of traffic congestion and pollution located within the established boundaries of the zone. According to C40 Cities et. al (2020), ZEDZs may have the added effect of helping countries and localities meet decarbonization targets, reducing noise and air pollution, facilitating the creation of green spaces, and stimulating demand for electric freight vehicles.[5] The latter point is of utmost concern as many firms are still reliant on diesel

[2] Ranieri, Luigi, Salvatore Digiesi, Bartolomeo Silvestri, and Michele Roccotelli. 2018. "A Review of Last Mile Logistics Innovations in an Externalities Cost Reduction Vision." Sustainability (Switzerland) 10 (3): 1–18. https://doi.org/10.3390/su10030782.
[3] Cruz, Cecilia, and Antoine Montenon. "Implementation and Impacts of Low Emission Zones on Freight Activities in Europe: Local Schemes Versus National Schemes." Transportation Research Procedia 12 (2016): 544–56. https://doi.org/10.1016/j.trpro.2016.02.010.
[4] C40 Cities, POLIS, and Transport Decarbonization Alliance. "How-to Guide Zero-Emission Zones." Accessed January 9, 2022. https://www.wbcsd.org/contentwbc/download/11039/162860/1.
[5] Ibid, 4.

trucks which consume more than 28% more energy and emit "38%" more GHGs than their electric counterparts.[6]

Current ZEDZs can be found in the following cities: Santa Monica, California; Amsterdam and Rotterdam, Netherlands; London, England; and Shenzhen, China[7]. The underlying premise in each of these zones is the same, namely, to reduce harmful emissions by requiring or incentivizing the use of electric vehicles. Even so, each city is different and thus requires the use of context-specific policy tools and incentives to garner or ensure compliance. In Santa Monica, for example, the first ever pilot of ZEDZ in the United States is underway in the form of a voluntary zero emission delivery zone where electric vehicle use is incentivized via priority curb areas.[8] London is incrementally moving toward a city-wide zero emission zone using different mechanisms such as the deployment of a city-wide low emission zone, congestion pricing at all times, and a 22 square kilometer ultra-low emission zone.[9]

All this is to say that each iteration of ZEDZ will look different in every context as the policy is ultimately shaped by what is politically and economically feasible for individual city governments. Because there is no current research on ZEDZ we can turn to Low Emission Zone results as a guide to understanding the effects of this type of and similar zoning policy. LEZs in the EU for example show incredible promise in reducing air pollution as Jiang et. al (2016) and Jones et. al (2012) show in their analyses. Comparing data from within and outside

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[6] Lee, Dong-Yeon, Valerie M. Thomas, and Marilyn A. Brown. "Electric Urban Delivery Trucks: Energy Use, Greenhouse Gas Emissions, and Cost-Effectiveness." Research-article. ACS Publications. American Chemical Society, July 5, 2013. World. https://doi.org/10.1021/es400179w.
[7] C40 Cities, POLIS, and Transport Decarbonization Alliance. "How-to Guide Zero-Emission Zones." Accessed January 9, 2022. https://www.wbcsd.org/contentwbc/download/11039/162860/1.
[8] LACI. "Santa Monica Zero Emissions Delivery Zone Pilot." Accessed January 4, 2022. https://laincubator.org/zedz/.
[9] C40 Cities, POLIS, and Transport Decarbonization Alliance. "How-to Guide Zero-Emission Zones." Accessed January 9, 2022. https://www.wbcsd.org/contentwbc/download/11039/162860/1; 45-47.

LEZs in Germany, Jiang et al. (2016) found that LEZs experienced a nearly 42% decrease in the average number of exceedance days - days in which air pollutant concentration exceeds the EU maximum - per year.[10] Jones et. al (2012) similarly finds a 33% to 65% reduction in ultrafine particulate matter and a 30% to 59% reduction in ambient particulate matter in London and Birmingham LEZs; however, it must be stated that the concurrent implementation of a "'sulfur free'" diesel policy may have contributed to these reductions.[11]

Finally, according to authors Nowlan and Usmani (2021), there is "significant unmet need" in terms of demand for zero-emissions last-mile delivery.[12] Some e-commerce platforms and shippers have already made commitments with specified dates to reach zero-emissions shipping, while others have made general pledges to combat climate change. Ikea, for example, "committed to 100% zero-emissions last-mile delivery and to become climate positive".[13] Etsy offsets 100% of their carbon emissions from shipping and Walmart announced zero-emissions shipping throughout their supply chain by 2040.[14] However, this can become difficult as most companies contract out shipping services rather than owning their own fleets. Carriers typically ship multiple items from different companies in the same truck.[15] Thus, for companies to request that their shipments be made with electric vehicles, this would often entail extreme operational complexity and cost burdens.

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[10] Jiang, Wei, Manfred Boltze, Stefan Groer, and Dirk Scheuvens. "Impacts of Low Emission Zones in Germany on Air Pollution Levels." Transportation Research Procedia 25 (2017): 3370–82. https://doi.org/10.1016/j.trpro.2017.05.217.
[11] Jones, Alan M., Roy M. Harrison, Benjamin Barratt, and Gary Fuller. "A Large Reduction in Airborne Particle Number Concentrations at the Time of the Introduction of 'Sulphur Free' Diesel and the London Low Emission Zone." Atmospheric Environment 50 (April 2012): 137. https://doi.org/10.1016/j.atmosenv.2011.12.050.
[12] Nowlan, Aileen, and Sabah Usmani. "Accelerating Zero- Emissions Delivery - Edf+Business," 2021. https://business.edf.org/files/EDF023_Zero-Emissions_v3.pdf: 9.
[13] Ibid.
[14] Ibid.
[15] Interview with IKEA

Client - World Resources Institute

Founded in 1982 and headquartered in Washington D.C., the World Resources Institute (WRI) operates globally in 12 countries and focuses on conducting research and developing practical solutions in 7 key areas "at the intersection of environment and human development: Cities, Climate, Energy, Food, Forests, the Ocean and Water".[16] To accomplish these goals, WRI operates four "Centers of Excellence" specializing in the fields of equity, finance, economics, and business. Specifically, we have partnered with World Resources Institute's Ross Center for Sustainable Cities. The Sustainable Cities program believes that decisions made today will determine whether we continue on a path of fractured, unsafe, polluting growth, or succeed in creating a sustainable, resilient, more inclusive future.

In response to Santa Monica's launching of the first ZEDZ in the United States in February 2021, WRI seeks to better understand the effectiveness of ZEDZs as a general pollution-reduction tool that cities can implement. Based on this need, this project seeks to answer the following policy question:

> **What are the best policies or combination of policies a city can use to reduce air pollution (GHG and other pollutants) from ICEVs? What are key considerations policymakers should keep in mind in the implementation process?**

[16] This overview is summarized from the "About Us" and "Our Work" sections of WRI's website: https://www.wri.org/.

Chapter 2

Problem Identification

Chapter 2: Problem Identification

Emissions in the Los Angeles Region

While the general level of air pollutants has decreased over the last 30 to 40 years, Los Angeles remains one of the "most polluted regions" in the United States.[17] In 2020, the City saw a decrease in smog fostered by stay-at-home orders that proliferated across the country, but this respite in air pollution was short-lived. By the end of the year, downtown Los Angeles was once again subject to heightened pollution with over 185 parts per billion (PPB) of ozone in the air - the "highest hourly reading in Southern California since 2003 and… in downtown L.A. in 26 years".[18] While total emissions - including all greenhouse gasses and particulate matter - decreased by 24% to 25.30 million metric tons (MMT) between 1990 and 2018, emission levels remain nearly 8 MMT greater than the City's stated goal of reaching roughly 17 MMT by 2025.[19] 90% of emissions within the City flow from stationary energy (e.g residential buildings, manufacturing, fugitive emissions from oil and gas systems, etc.) and transportation (including on- and off-road, railway, aviation, and water transportation).[20]

Of particular interest is the transportation sector. Nearly 30% of global emissions from the transport sector are related to trucks carrying freight, and these are often Internal Combustion Engine Vehicles (ICEVs) that rely on diesel fuel.[21] While total transportation

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[17] "Criteria Air Pollutants | Los Angeles County Department of Public Health - Environmental Health." Accessed January 25, 2022. http://publichealth.lacounty.gov/eh/safety/criteria-air-pollutants.htm.
[18] Barboza, Tony. "Los Angeles Suffers Worst Smog in Almost 30 Years." Los Angeles Times, September 10, 2020. https://www.latimes.com/california/story/2020-09-10/los-angeles-had-its-worst-smog-in-26-years-during-heat-wave.
[19] Huang, Anny, Cory Parmer, Larry Hunsaker, Donna Lee, Enrique Zaldivar, Daniel Meyers, Michelle Barton, et al. "City of Los Angeles Community Greenhouse Gas Emissions Inventory 2018," Apr. 2021. https://www.lacitysan.org/san/sandocview?docname=cnt058946
[20] Ibid, 10.
[21] Ritchie, Hannah. "Cars, Planes, Trains: Where Do CO2 Emissions from Transport Come From?" Our World in Data. Accessed January 28, 2022. https://ourworldindata.org/co2-emissions-from-transport.

emissions were last reported by the California Air Resources Board (CARB) to have decreased by 1.5 million metric tons between 2017 and 2018 in California, this sector remains one of the biggest culprits of air pollution, which may be a result of traffic congestion and the emissions generated by freight trucks.[22;23] Brown & Guffrida (2013) highlight how "CO2 generated by transport trucks burning carbon-based fuel represents a serious threat to the environment," while Cruz & Montenon (2016) emphasize how "environmental and sustainability issues are more severe in urban areas" like Los Angeles.[24;25] Accordingly, many authors have recommended policies that increase uptake of electric vehicles, especially in relation to the business sector which is economically impacted by last-mile logistics. Scholars have estimated that 28% to 75% of total logistical costs are incurred in the last mile, making it the most inefficient leg of delivery not only economically but also in terms of pollution.[26] Many freight vehicles used in last-mile logistics are light commercial vehicles, which constitute small, unoptimized loads.[27] Given that these vehicles are often diesel-powered, the emission of GHG is relatively higher in the last mile according to Allen et al. (2018).[28]

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[22] "Latest GHG Inventory shows California remains below 2020 emissions target," California Air Resources Board, accessed April 12, 2022, https://ww2.arb.ca.gov/news/latest-ghg-inventory-shows-california-remains-below-2020-emissions-target.
[23] Ibid, 18.
[24] Brown, Jay R., and Alfred L. Guiffrida. "Carbon Emissions Comparison of Last Mile Delivery versus Customer Pickup." *International Journal of Logistics Research and Applications* 17, no. 6 (November 2, 2014): 503–21. https://doi.org/10.1080/13675567.2014.907397.
[25] Cruz, Cecilia, and Antoine Montenon. "Implementation and Impacts of Low Emission Zones on Freight Activities in Europe: Local Schemes Versus National Schemes." *Transportation Research Procedia* 12 (2016): 544–56. https://doi.org/10.1016/j.trpro.2016.02.010.
[26] Gevaers, Roel, Eddy Van de Voorde, and Thierry Vanelslander. 2009. "Characterıstıcs Of Innovatıons In Last Mıle Logıstıcs-Usıng Best Practıces, Case Studıes And Makıng The Lınk Wıth Green And Sustaınable Logıstıcs." European Transport Conference, 1–21. http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=A0994C74D69269E4E869F48E76A18EFB?doi=10.1.1.676.5843&rep=rep1&type=pdf.
[27] Allen, J., M. Piecyk, M. Piotrowska, F. McLeod, T. Cherrett, K. Ghali, T. Nguyen, et al. 2018. "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 (April 2017): 325–38. https://doi.org/10.1016/j.trd.2017.07.020.
[28] Ibid.

The most common metric for evaluating air quality is the Air Quality Index developed by the Environmental Protection Agency which measures "the most common ambient air pollutants that are regulated under the Clean Air Act, including ozone and particle pollution".[29] The organization Plume Labs uses these EPA standards in conjunction with recommendations from the World Health Organization to develop a metric that can be used to evaluate the healthiness of a neighborhood's air quality in real time.[30] Using this Plume Lab data source, it is evident that the vast majority of the Los Angeles region suffers from unhealthy levels of air pollution.[31] On January 28th, cities from Inglewood to Newport Beach reached Plume AQI levels above 100 which is in the range of producing adverse health effects on individuals even without preexisting conditions (see **Figure 1** showing Plume AQI levels in the Greater Los Angeles area).[32] These measurements are likely an understatement due to the quarantining effects of Covid-19 and how air pollution tends to worsen during the summer.[33]

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[29] "Wildfire Smoke and Your Patients' Health: The Air Quality Index". United States Environmental Protection Agency. Accessed January 27 2022. https://www.epa.gov/wildfire-smoke-course/wildfire-smoke-and-your-patients-health-air-quality-index.

[30] "What is the Plume AQI". Plume Labs. Access January 27 2022. https://plumelabs.zendesk.com/hc/en-us/articles/360008268434-What-is-the-Plume-AQI-.

[31] "Air Quality Map of Los Angeles". *Plume Labs*. Accessed January 28 2022. https://air.plumelabs.com/Los_Angeles-air-quality-map-mwyt.

[32] "What are the Plume AQI pollution thresholds?" Plume Labs. Accessed January 28 2022. https://plumelabs.zendesk.com/hc/en-us/articles/360008409333.

[33] Mascarelli, Amanda. "Air pollution kicks into high gear during summer months". The Los Angeles Times. June 1 2011. https://www.latimes.com/health/la-xpm-2011-jun-01-la-he-summer-health-air-pollution-20110601-story.html.

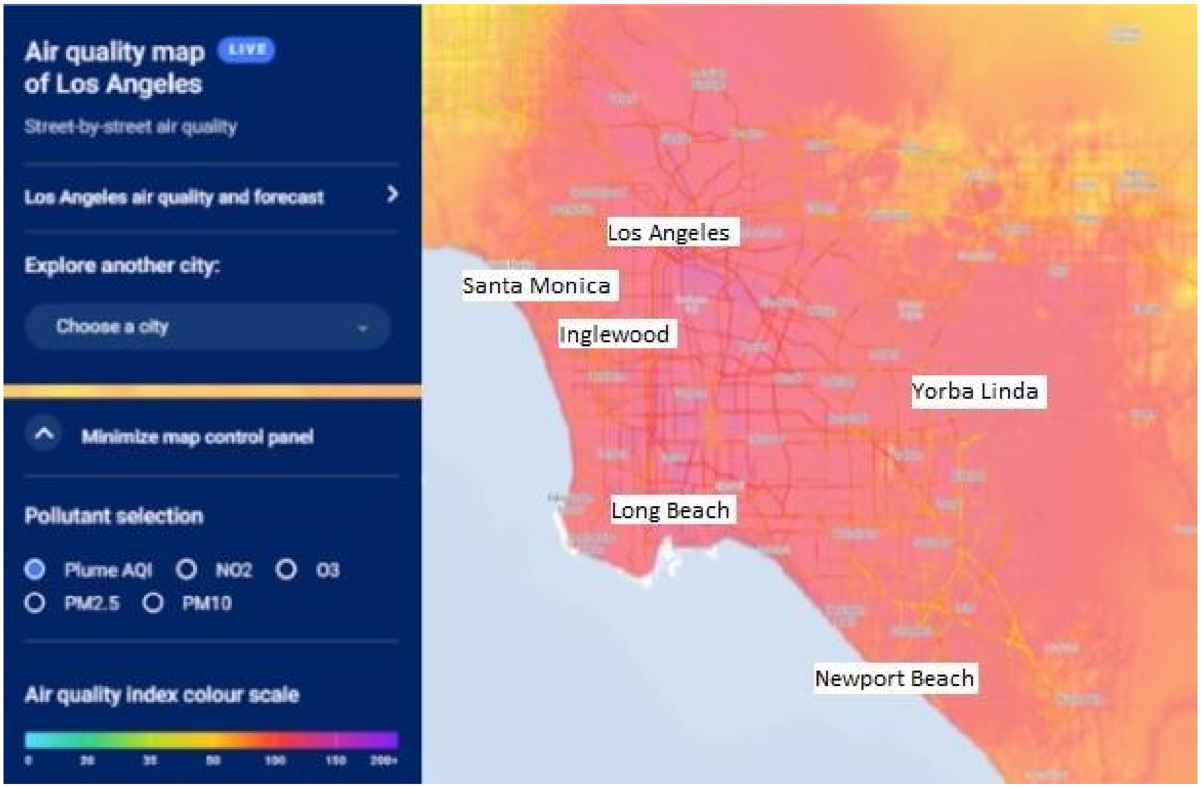

***Figure 1**: A map of Plume Lab AQI levels for the Los Angeles region on January 28th, 2022.*[34]

Santa Monica ZEDZ

The City of Santa Monica, in partnership with the Los Angeles Cleantech Incubator (LACI), began piloting a voluntary, one-square mile ZEDZ in 2021.[35] The area constitutes the first-ever ZEDZ in the United States and relies on public-private partnerships with organizations such as REEF Technology (an urban real estate and technology company), Nissan, and Automotus (a software company specializing in curb management).[36] While results of the pilot have yet to be seen, it has been established in the existing literature that ZEDZ in addition to other policies such as congestion pricing, urban consolidation centers, EV

[34] "World Air Map" Plume Labs. Accessed January 28th, 2022. https://air.plumelabs.com/en/.
[35] LACI. "Santa Monica Zero Emissions Delivery Zone Pilot." Accessed January 4, 2022. https://laincubator.org/zedz/.
[36] Jacobson, Barbara, Dan Welch, Lily Paul, and James Huang. "Going Beyond the Curb: Policies and Best Practices," n.d., 49.

subsidies, etc., can potentially contribute to decreased particulate matter in the air. With regards to the Santa Monica pilot, however, it must be noted that this ZEDZ is taking place under a resource rich municipality with the political will to experiment with innovative policies aimed at combating climate change - conditions which may not hold for all US cities with interest in these zones. For this reason, our team has put together a brief overview of the key considerations cities in the United States should include in their policymaking.

While individual case studies have shown that policies similar to ZEDZ can produce positive results, these results lead to additional questions such as: what are the key contributing factors to a ZEDZs' success or failure, and how do different city characteristics influence these factors? One goal of this report is to fill this gap and produce conclusions about ZEDZs that can be applicable across contexts. In addition, many cities implementing ZEDZs have concurrently implemented various policies to avoid excessive burdens on delivery companies, but this diversity of policies adds another layer of complication to any potential analysis. Furthermore, ZEDZs and similar policies such as ZEZs are often located in wealthy urban areas (e.g., London, and Santa Monica), and there are possible equity concerns regarding the implementation of ZEDZs. For example, ZEDZs may result in the relocation of ICEVs to outside of the zoning area, resulting in emissions simply being pushed to low income communities of color. These kinds of equity issues are also not addressed to any great extent in the literature.

Key Considerations

Our policy analysis aims to fill three major gaps in existing research on ZEDZ policies:

1. **Generalizability**: The diversity of city policies that exist in any given context (i.e., regulations, incentives, taxes, etc.) make side-by-side comparisons difficult.
2. **Stakeholder Engagement and Policy Implementation**: There is no shortage of parties involved in urban delivery, making it difficult to clearly analyze who benefits and who bears the burden of a ZEDZ.
3. **Equity and Unintended Consequences**: The literature on ZEDZ is largely silent on the issue of equity, which constitutes a major gap that overlooks the painful history of environmental racism and the opportunity that ZEDZs may provide in helping alleviate these injustices.

These gaps are explained further below:

Generalizability

The cities that are currently implementing ZEDZ pilot projects are very diverse in their methods and policies. While this constitutes a strength of ZEDZ - the ability to tailor the policy to specific contexts - it makes performing a generalizable analysis of the effectiveness and equitability of these zones difficult. For example, the City of Santa Monica is piloting a voluntary ZEDZ to "provide insights to other cities, regulators, and industry leaders on reducing long-term pollution exposure."[37] London, on the other hand, is using a phased-in approach to encourage the transition of a wider group of vehicles, including lorries, vans, buses, mini buses, coaches and specialist heavy vehicles, to zero-emission vehicles using Low

[37] LACI. "Santa Monica Zero Emissions Delivery Zone Pilot." Accessed January 4, 2022. https://laincubator.org/zedz/.

Emission Zones (LEZs) that were launched in February 2008 and subsequently the Ultra Low Emission Zones (ULEZs) that were launched in April 2019.[38] Unlike Santa Monica, London charges a driving fee for failure to meet zone requirements in addition to congestion pricing.

Shenzhen, the world's first city to introduce a zero-emission cargo policy, has established zero-emission cargo zones where electric cargo vehicles are free to enter the zones all day and fossil fuel cargo vehicles are prohibited.[39] Shenzhen is unique in that, in parallel with the introduction of zero-emission freight zones, it has also made significant investments in charging station infrastructure and provided complex incentives for logistics companies to optimize their vehicle usage patterns. Shenzhen is reported to be the most advanced globally towards the adoption of full logistics electrification.[40]

In addition to the above examples, there are several other types of transportation initiatives that cities can undertake in conjunction with a ZEDZ. In turn, the impacts of each of these initiatives will be influenced by factors such as the size of the city, the status of related policies, road congestion levels and times, and charging infrastructure.

Stakeholder Engagement and Policy Implementation

The relationship between those who bear the costs and benefits of a ZEDZ policy is likely to complicate this policy's adoption and implementation. Local governments who implement a ZEDZ with strict regulations and little stakeholder engagement may run the risk

[38] "Zero Emission Zones," Transport for London, accessed March 3, 2022, https://tfl.gov.uk/info-for/boroughs-and-communities/zero-emission-zones.
[39] Xue, Lulu, "Lessons from Shenzhen's Green Logistic Zones: Fast-Tracking Zero-Emissions Freight," *The City Fix*, March 11, 2021. Accessed January 9, 2022, https://thecityfix.com/blog/shenzhens-green-logistic-zones-fast-tracking-zero-emission-freight/.
[40] Liu, Qiyu, Ross McLane, Dave Mullaney, and Zhe Wang, "Putting Electric Logistics Vehicles to Work in Shenzhen." *RMI*. Accessed January 4, 2022. https://rmi.org/insight/putting-electric-logistics-vehicles-to-work-in-shenzhen/.

of losing political and public support of the policy. Many environmental policies such as ZEDZs are considered "cost-concentrated, benefit-distributed" policies and are consequently difficult to enact as described by American political scientist James Q. Wilson.[41] This is because the cost of these policies would be concentrated on businesses (in our case, delivery businesses especially if there are no subsidies) while the benefits of decreased pollution would be thinly-spread across the entire population in the zone (or even outside the zone in regards to GHGs). The political feasibility of this type of policymaking is suspect because businesses have a strong incentive to advocate against the policy while individuals who benefit lack strong incentives to advocate in favor. This would mean that public support and widespread stakeholder engagement is key to implementing this policy.

In addition, the effectiveness of incentives that are meant to encourage and ease the burden of transitioning to EVs in a ZEDZ, such as the priority loading curbs implemented by the City of Santa Monica, will vary from region to region depending on congestion, traffic rules, road capacity, and other factors. The strength of these incentives can be confounding factors that influence how likely delivery companies are to support a ZEDZ policy.

Equity Concerns and Unintended Consequences of ZEDZs

To create the most effective policies possible and to address long-standing environmental injustices, it is crucial that policymakers seriously consider any equity concerns before implementing ZEDZ policies. In particular, it is becoming increasingly apparent that substantive interventions and the implementation of sustainable initiatives in communities of

[41] Pal, Leslie A. and Weaver, R. Kent, *The Government Taketh Away: The Politics of Pain in the United States and Canada*, (Georgetown University Press, 2003), 13. https://books.google.com/books?id=wfta6JKAlJMC&pg=PA1&lr=&source=gbs_selected_pages&cad=3#v=onepage&q&f=false.

color in the United States - which are often the most affected by pollution based on geographical factors such as redlining and historical segregation - are urgently needed. Historically speaking, communities of color often bear the brunt of environmentally harmful practices and people of color are more likely to experience "exposure to environmental and health risks" spawned by uneven environmental regulation enforcement in the United States.[42] For example, Starbuck & White (2016) found that "children of color make up almost two-thirds of the 5.7 million children who live within one mile of a high-risk chemical facility" and make up an increasing proportion of those who attend school near one.[43] Tubert (2020) asserts that "environmental burdens… disproportionately affect communities of color" and lists examples such as increased exposure to toxic waste, shortened expected lifespans, and a myriad of health issues.[44]

Another important equity concern of ZEDZs involves their impact on home prices and the process of gentrification. While ZEDZs will likely improve air quality, walkability, and other quality-of-life measures, they may also raise the price of rent, properties, and amenities, leading to the displacement of populations presently living in these communities.[45] In Seattle, Washington, the construction of new public light-rail facilities was found to increase the share of non-Hispanic whites in surrounding neighborhoods.[46] However, a systematic review of 35

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[42] Bullard, Robert D, "Confronting Environmental Racism," *Race, Gender & Class* 5 *(1993):* 17, accessed February 18, 2022, https://www.jstor.org/stable/41674849.

[43] Starbuck, A., and R. White, "Living in the Shadow of Danger: Poverty, Race, and Unequal Chemical Facility Hazards," *Center for Effective Government (2016)*:1, accessed February 20, 2022, https://doi.org/10.13140/RG.2.1.2202.7284.

[44] Tubert, Ariela, "Environmental Racism: A Causal and Historical Account," *Journal of Social Philosophy (2021):*1-3*,* accessed January 6, 2022, https://doi.org/10.1111/josp.12407.

[45] Cheng Keat Tang, "The Cost of Traffic: Evidence from the London Congestion Charge," *Journal of Urban Economics* 121 (2021), https://doi.org/10.1016/j.jue.2020.103302.

[46] Hess, Chris L., "Light-Rail Investment in Seattle: Gentrification Pressures and Trends in Neighborhood Ethnoracial Composition". *Urban Affairs Review* 56 (2021): 181. https://journals.sagepub.com/doi/pdf/10.1177/1078087418758959.

quantitative-based studies on the "gentrification outcomes resulting from transit-based interventions" found that gentrification is more closely associated with "local dynamics, built environment attributes, and accompanying policies than transit-oriented development".[47]

Encouragingly, evidence suggests there are specific policies and strategies that cities can undertake to mitigate or prevent displacement. Research from the Brookings Institution recommends three broad categories of policies.[48] The first, "Taxation Tools" recommends allowing long time residents to defer potential tax increases that may result from rising home values; additionally, proportions of any increased tax revenue resulting from gentrification can be ear-marked to be devoted towards building more affordable housing. The second section, "Affordable Housing Preservation and Production", recommends requiring housing developers to set aside specific proportions of new developments to be devoted to affordable housing, and existing affordable housing stock can be preserved via lower-interest loans and grants offered by the city government. Thirdly, "Economic Development and Income-Raising Tools" can be exercised by city governments to help ensure the "great economic resources that generally accompany a gentrifying community" are widely dispersed to its present population. These tools include small business loans to help allow existing businesses to take advantage of new market opportunities and the guaranteeing of employment of local residents in newly-built facilities.

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[47] Padeiro, Miguel, Ana Louro, and Nuno Marques da Costa, "Transit-oriented development and gentrification: a systematic review". *Transport Reviews* 39 (2019): 749. https://www.tandfonline.com/doi/pdf/10.1080/01441647.2019.1649316?needAccess=true.
[48] Kennedy, Maureen and Paul Leonard. "Dealing With Neighborhood Change: A Primer On Gentrification And Policy Choices," Brookings Institution Center on Urban and Metropolitan Policy (2016), https://www.brookings.edu/wp-content/uploads/2016/06/gentrification.pdf.

A strong policy of equitable access to the benefits of ZEDZ is necessary not only to reduce the disproportionate harm that communities of color experience but to increase the overall quality of life for communities. As **Figure 2** demonstrates, a large portion of LA County is in need of interventions that help reduce pollutants. While ZEDZs are a relatively new phenomena, the potential for their spread across the state and world constitutes an opportunity for policymakers to address equity concerns that are well-documented by the environmental justice literature.

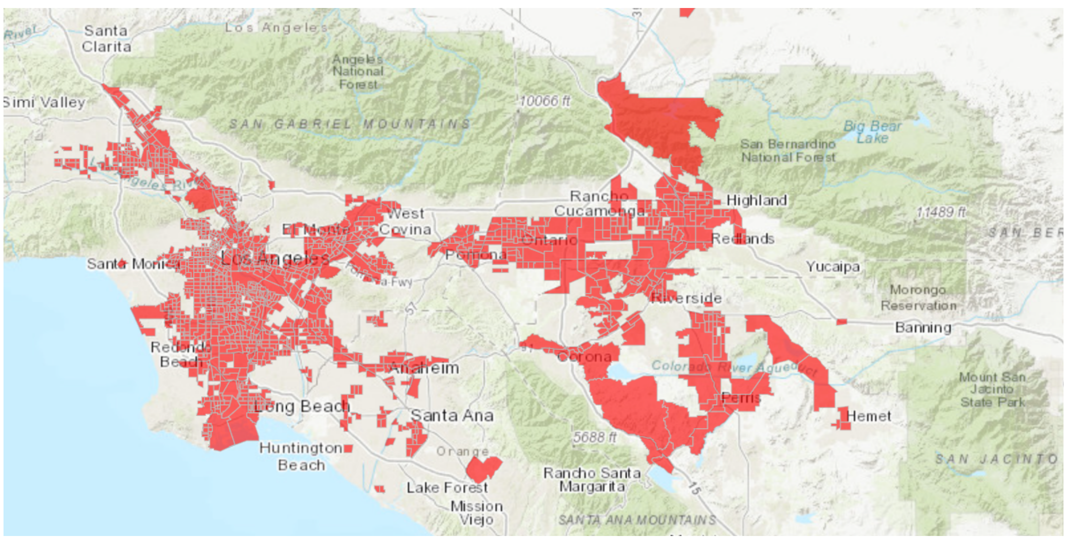
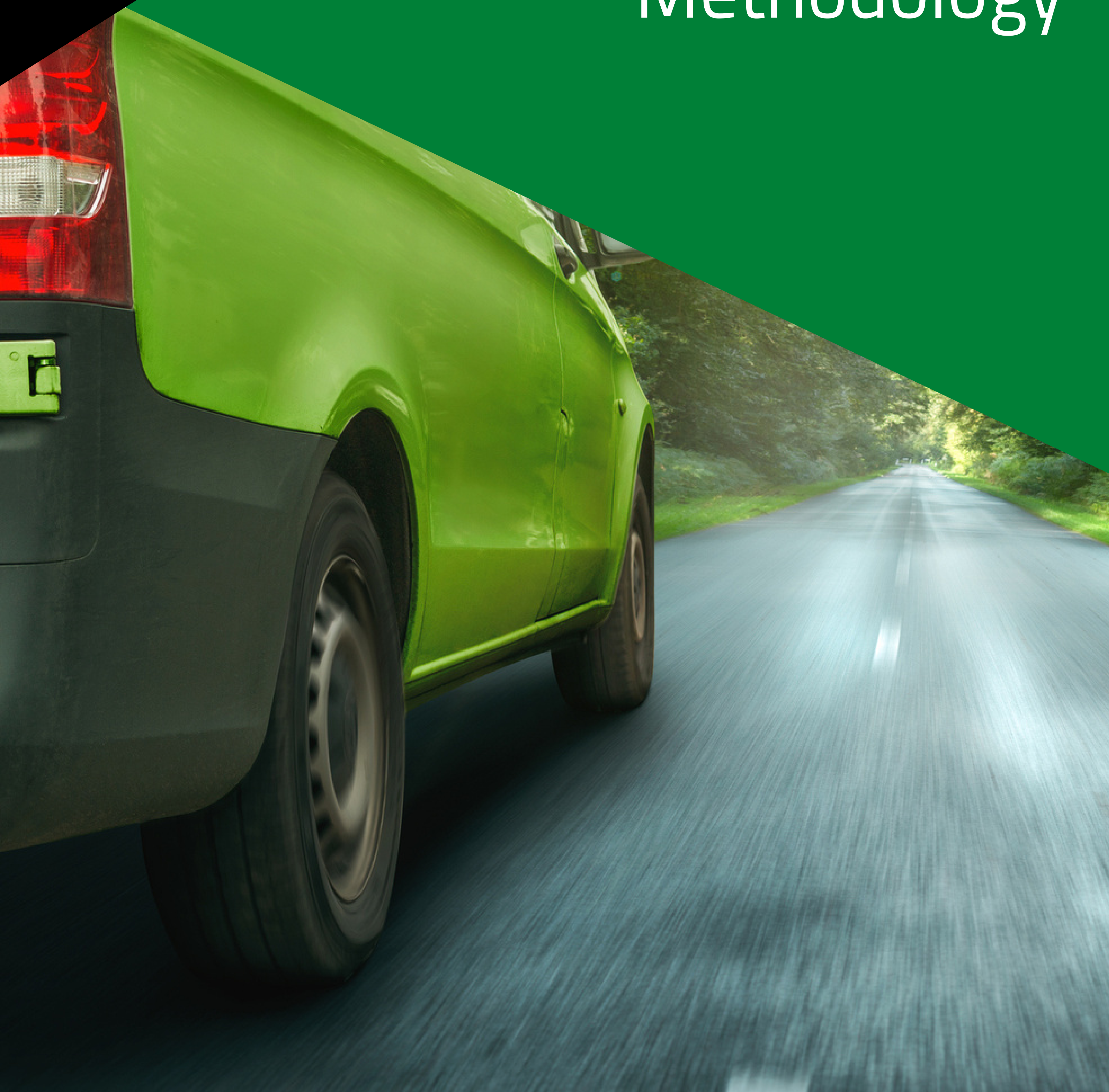


***Figure 2**: Disadvantaged Communities Map as designated by CalEPA (red areas are the top 25% scoring census tracts in terms of pollution)*[49]

[49] "SB 535 Disadvantaged Communities," *California Office of Environmental Health Hazard Assessment* (June 2017), https://oehha.ca.gov/calenviroscreen/sb535.

Chapter 3

Methodology



Chapter 3: Methodology

Method Overview

Quantitative analysis is one potent method to evaluate the effectiveness of various policies in reducing the environmental impact of last-mile deliveries. In particular, quantifying a policy's impacts can allow easier side-by-side evaluations with other policies. On the other hand, qualitative research involving appropriate stakeholders is highly beneficial because of the complexity of ZEDZ policy implementation, such as overcoming the hurdles of last-mile delivery, the wide range of stakeholders, and the rapidly changing EV market. Therefore, we utilize a combination of qualitative research and quantitative analysis.

In our qualitative research, we conducted a series of interviews with key stakeholders such as policy makers and their technical advisors, experts in the relative fields, business participants, and an environmental justice organization. Our main focus was on stakeholders in Santa Monica City, which implemented the pilot ZEDZ. However, several interviews have also been conducted outside of the City of Santa Monica for the purpose of gaining additional insight and making our results more generalizable.

Our quantitative approach is used to uncover how effective several policies, including ZEDZs, would likely be in reducing emissions and how much they would likely burden business stakeholders and governments. We accomplish this by combining an optimization model with an economic analysis to determine the social cost and benefit of each policy.

Based on the results of the qualitative and quantitative studies, we will also compare ZEDZs to other policies with a criteria-alternative matrix. This will assist in providing a well-rounded analysis of each policy alternative by displaying the strengths and weaknesses of each alternative.

A literature review was conducted as a preliminary step to our study. The literature review helped us understand the issues found in last-mile delivery, how previous studies addressed these issues and potential solutions, and what gaps exist in the research.

Understanding Background Context Through a Literature Review

In order to prepare ourselves to assess the potential of ZEDZ policies, we conducted a literature review in advance of this project. This review is broken down into several sections:

1. The background and importance of last mile logistics.
2. Policy alternatives that policy makers will likely be faced with.
3. An in-depth definition and characterization of ZEDZs.
4. Current iterations of ZEDZs.
5. Possible obstacles faced by ZEDZs.
6. Equity concerns.
7. Possible models that can be used to evaluate ZEDZ policies.

From our literature review, we uncovered issues in the last-mile portion of the supply chain that form the basis for policy, identified policy alternatives, gained greater understanding of how existing research addresses these issues, and explored current ZEDZs. These findings are used as foundational knowledge for each of the following methods. We include the literature review in **Appendix A**.

Assessing the Impacts and Process of ZEDZ Implementation through Interviews

Interviews with various stakeholders are used to determine policy effectiveness in ways that quantifiable data would be unable to detect. Interviewing is a research method that helps to uncover unknowns, reveal processes, weave narratives, and opens up conflicting perspectives.[50] Using this method and conducting interviews with policymakers will uncover the circumstances behind their policy making. Specifically, the following are key questions asked through our interviews with policymakers that are working to implement ZEDZ policies;

- what they considered in establishing the zone coverage;
- how they assessed the impact on the local community;
- whether and what kind of resistance they encountered from businesses; and
- if and how equity considerations factored into the decision to enact a ZEDZ.

The interviews we conducted is what is known as an elite interview, in which interviewees are selected based on their roles in their respective organizations.[51] Interviewees are selected primarily from two perspectives (i) deep diving into the ZEDZ pilot project in the City of Santa Monica, and (ii) case studies in other regions. For (i), these include the City of Santa Monica and ZEDZ project implementation supporters, participating businesses, and local communities as well as government officials and researchers from the Netherlands- a country which is leading zero-emission zone policy. We have interviewed 10 organizations in total. **Appendix B** shows the list of interviewees and **Appendix C** shows an interview guide used with the various interviewees.

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[50] Aaron Panofsky, "Class Summary." PP291A: Qualitative Methods for Policy Analysis. Class lecture at University of California, Los Angeles, CA, December 3, 2021.
[51] Jennifer Hochschild, "Conducting Intensive Interviews and Elite Interviews," *Workshop on Interdisciplinary Standards for Systematic Qualitative Research*, 2009.

Most interviews lasted about an hour and were conducted online. If the interviewees allowed it, the interviews were recorded and transcribed. We also confirmed that the sole purpose of the interviews was for this study and that special attention was paid to confidentiality.

Quantitatively Measuring the Efficiency of ZEDZ

Our report also makes use of quantitative methods to evaluate the effectiveness of ZEDZs compared to other policies. This process entails several difficulties unique to the context of ZEDZs, including:

- Since ZEDZs are relatively new, there are few governments that are implementing this policy, even when looking globally. This issue of small sample-size makes a traditional econometric approach to exploring the impacts of ZEDZs unfeasible.
- Obtaining data is challenging due to the complexity of the logistics field (such as the intermix of public and private entities) and the need to protect trade secrets and personal information.
- The diversity of ZEDZ policies themselves, as exemplified by the voluntary rather than mandatory ZEDZ in the City of Santa Monica, makes direct comparisons difficult.

To overcome these difficulties and verify the effectiveness of a ZEDZ policy in the context of Santa Monica, we will conduct a quantitative analysis of ZEDZ policies using the following three steps:

1.) Assemble as much demographic and logistic data as we can from our literature review and interviews to construct baseline data on what shipping looks like in the City of Santa Monica in the absence of any emission-related policies.

2.) Input this baseline data into an optimization model to generate a plausible dataset of current shipping traffic, including the types of vehicles used. Then, add constraints to this model to predict how traffic would change as a result of different ZEDZ policies.

3.) Calculate the changes in social welfare through economic analysis based on the optimization model results.

Step 1) Constructing Baseline Data

Our first task with our quantitative approach is collecting necessary data. De Bok et al., from whom much of our optimization model is based on, conducted their analysis using an extensive database of freight transportation in the Netherlands.[52] However, it does not appear that a similar dataset is currently available in the US, at least for the City of Santa Monica or the Greater Los Angeles area. In the interviews we conducted, we asked each organization or individual if they would be able to provide any relevant data, but they were not for the following reasons:

- The ZEDZ project in Santa Monica is in a pilot phase and the city government has not been able to collect comprehensive data
- The complexities of the delivery industry make it impossible to collect data that we would need (e.g., some delivery companies rarely actually own the vehicles and outsource the actual transportation of the trucks to small businesses).[53]
- The organization is a private company and is unwilling to share potentially sensitive information

[52] Michiel de Bok, Lóránt Tavasszy, and Sebastiaan Thoen, "Application of an Empirical Multi-Agent Model for Urban Goods Transport to Analyze Impacts of Zero Emission Zones in The Netherlands," *Transport Policy*, no. September 2019 (2020), https://doi.org/10.1016/j.tranpol.2020.07.010.
[53] Interview with IKEA.

To overcome this challenge of a lack of data, we reconstructed a shipping dataset using a variety of sources. To accomplish this, data was assembled on population distributions, information on each intersection in the city, average freight demand across the United States, and general freight vehicle operating characteristics.

For our model, we chose to focus on parcel delivery (rather than other delivery types such as construction materials) for the following reasons:

- A lack of data on other delivery types;
- Parcel delivery is one of the targets in the ZEDZ pilot project in Santa Monica;[54]
- The geographic use of Santa Monica is mainly residential;
- As the major industries in Santa Monica are tourism and finance, it is not expected that there are many deliveries associated with manufacturing;[55]
- The transportation characteristics of parcel delivery as indicated by FleetDNA are relatively similar to the overall total compared to other types of businesses[56]
- Further justification of this assumption can be found in **Appendix D**.

Additionally, datasets were collected consisting of depots and delivery locations, the optimal route connecting each location, the vehicle set consisting of EVs and ICEVs (internal-combustion electric vehicles), the load capacity of each vehicle, the demand at each delivery location, emission of GHG and air pollutant by vehicle type, and cost factors for our economic analysis. See **Appendix D** for information on the emissions per vehicle type and

[54] Interview with Electric Vehicle Program Coordinator from the City of Santa Monica.
[55] "Data USA: Santa Monica, CA," Census Place, n.d., https://datausa.io/profile/geo/santa-monica-ca/#:~:text=The largest industries in Santa,Fishing %26 Hunting (%24138%2C011)%2C.
[56] National Renewable Energy Laboratory, "Fleet DNA: Commercial Fleet Vehicle Operating Data | Transportation Research: Fleet DNA Project Data.," 2019. https://www.nrel.gov/transportation/fleettest-fleet-dna.html.

their associated social costs, which is used in our economic analysis. See **Appendix E** for more details on how the baseline traffic data was generated and how we obtained the data used for consumer nodes, depots, and traveling distances.

Step 2) Optimization Model

Our next step was the construction of an optimization model, into which we input our baseline data to estimate current shipping traffic and then add constraints to predict how shipping would change as a result of different ZEDZ and other policies. To generate these predictions, this method minimizes each shipping company's total costs, such as total ownership and transportation costs under the limitation of time and vehicle capacity. In fact, this modeling method is used in the majority of research papers on last mile logistics.[57] Once the daily driving route of each vehicle is calculated by this method, GHG and air pollutant emissions can be calculated by using existing documents or developed tools.[58;59]

In our literature review, we confirmed that there are many variations of optimization models that address the last-mile delivery problem.[60; 61; 62] Among them, researchers like de

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[57] Olsson, John, Daniel Hellström, and Henrik Pålsson, "Framework of Last Mile Logistics Research: A Systematic Review of the Literature," Sustainability (Switzerland) 11, no. 24 (2019): 1–25, https://doi.org/10.3390/su11247131. . 2019.

[58] "Manufacturer-Run In-Use Testing Program Data for Light-Duty Vehicles, Light-Duty Trucks, and Heavy-Duty Vehicles Class 2b and 3," *U.S. Environmental Protection Agency*, 2022, https://www.epa.gov/compliance-and-fuel-economy-data/manufacturer-run-use-testing-program-data-light-duty-vehicles.

[59] "Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool," *Argonne National Laboratory (2021*,) https://greet.es.anl.gov/afleet.

[60] Alho et al, "A multi-scale agent-based modeling framework for urban freight distribution," *Transportation Research Procedia* 27 (2017), accessed February 8, 2022, https://doi.org/10.1016/j.trpro.2017.12.138.

[61] Anand Nilesh, "An Agent Based Modelling Approach for Multi-Stakeholder Analysis of City Logistics Solutions," *Delft University of Technology* (2015), https://www.researchgate.net/profile/Nilesh-Anand/publication/281203877_An_Agent_Based_Modelling_Approach_for_Multi-Stakeholder_Analysis_of_City_Logistics_Solutions/links/55dafe6508aeb38e8a8a3680/An-Agent-Based-Modelling-Approach-for-Multi-Stakeholder-Analysis-of-City-Logistics-Solutions.pdf.

[62] Agostino Nuzzolo, Luca Persia, and Antonio Polimeni, "Agent-Based Simulation of Urban Goods Distribution: a Literature Review", *Transportation Research Procedia* 30 (2018): 33-42, https://doi.org/10.1016/j.trpro.2018.09.005.

Bok et al. propose a multi-agent model using empirical data.[63] A multi-agent model "consists of multiple decision-making agents which interact in a shared environment to achieve common or conflicting goals".[64] As the stakeholders behind urban freight transportation are so diverse and have heterogeneous preferences, a multi-agent model that can take into account a variety of stakeholders is appropriate for this situation.[65]

Given these factors, our model is based on de Bok et al.'s model which predicts the impact on logistic traffic in the Netherlands as a result of ZEZ policies.[66] Their model is divided into three sections: shipment synthesizer, tour formation, and network assignment, and our model will likewise be divided into these three sections.

The first section, shipment synthesizer, is tasked with generating a dataframe of possible shipments that could plausibly occur on an average day. This dataframe contains the following for each generated shipment:

- The name and location of the sender;
- The name and location of the receiver;
- The company that is conducting this shipment

The second section, tour formation, is concerned with estimating the number of shipments contained in a single shipment route and then grouping these shipments together (i.e.

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63 De Bok, Tavasszy, and Thoen, "Application of an Empirical Multi-Agent Model for Urban Goods Transport to Analyze Impacts of Zero Emission Zones in The Netherlands", 1.
64 "Multi-Agent Systems", The Alan Turing Institute, accessed December 27, 2021, https://www.turing.ac.uk/research/interest-groups/multi-agent-systems.
65 Edoardo Marcucci et al., "Simulating Participatory Urban Freight Transport Policy-Making: Accounting for heterogeneous Stakeholders' Preferences and Interaction Effects", *Transportation Research Part E: Logistics and Transportation Review* 103 (2017): 69-86, https://doi.org/10.1016/j.tre.2017.04.006.
66 De Bok, Tavasszy, and Thoen, "Application of an Empirical Multi-Agent Model for Urban Goods Transport to Analyze Impacts of Zero Emission Zones in The Netherlands", 1-8.

can multiple shipments be completed in a single tour of a shipment vehicle, and if so which shipments are likely to be grouped together).

The third section, network assignment, attempts to predict the potential routes that vehicles will take to complete these tours. These estimates are derived simply by mapping the shortest path from the sender location that connects all recipient locations. For more details on the calculations for the optimization model, see **Appendix F**.

The result is a plausible list of shipments and shipping routes that could occur in a single day in Santa Monica in the absence of any emission policies. We then produce estimates based on differing assumptions from a range of possible scenarios resulting from the implementation of three different policies: mandatory ZEDZ, voluntary ZEDZ (including incentives such as priority parking), and vehicle subsidies. The following are the different scenarios:

- **Baseline**: No policies (all vehicles owned are ICEVs)
- **Scenario 1**: Implementation of mandatory ZEDZ
    - All delivery vehicles within the designated delivery zone must be EVs
- **Scenario 2**: Implementation of voluntary ZEDZ
    - EV use is encouraged by priority parking spaces and loading zones
- **Scenario 3**: Implementation of purchase subsidies for EVs
    - A one-time $2000 subsidy for EV purchases, which is currently the policy in California[67].

[67] "Tax Guide for Motor Fuel Taxes," California Department of Tax and Fee Administration, https://www.cdtfa.ca.gov/industry/motor-fuel-taxes.htm#Started.

- **Scenario 4**: Combining the implementation of mandatory ZEDZ and purchase subsidies
- **Scenario 5**: Combining the implementation of voluntary ZEDZ and purchase subsidies
- **Scenario 6**: Combining the implementation of mandatory ZEDZ, incentives for voluntary ZEDZ, and purchase subsidy

Step 3) Economic Analysis

To measure how effectively ZEDZ and other policies reduce GHG and air pollutant emissions, we conduct an economic analysis on these optimization model results. Mirhedayatian and Yan (2018) provides a framework to assess the social impacts (e.g. externalities and welfare) of policies intended to support EVs that we use for this step.[68]

According to Mirhedayatian and Yan, by assuming that willingness to pay does not change in the short run, willingness to pay drops out of our welfare-analysis equation and does not need to be calculated. The only variables left to calculate are the change in total delivery cost, the change in government revenue, and the change in total external cost (i.e. the value of reduced emissions). All these changes will be derived from the optimization model. See **Appendix G** for details on the calculation methodology.

The value of emission reductions can be derived from a calculation tool called Afleet, provided by Argonne, which utilizes the externality costs of various emissions provided by the

[68] Seyed Mostafa Mirhedayatian and Shiyu Yan, "A Framework to Evaluate Policy Options for Supporting Electric Vehicles in Urban Freight Transport," *Transportation Research Part D: Transport and Environment* 58 (2018): 22-38, https://doi.org/10.1016/j.trd.2017.11.007.

U.S. Environmental Protection Agency (EPA). The key metrics that will be used as criteria for comparison are the following:[69; 70]

- GHG emissions - Greenhouse gas emissions, mainly carbon dioxide and methane
- CO - Carbon monoxide,
- NOX - The nitrogen oxides (nitric oxide (NO) and nitrogen dioxide (NO_2))
- PM10 - Particles with diameters that are 10 micrometers and smaller
- PM2.5 - Particles with diameters that are 2.5 micrometers and smaller
- VOC - Volatile organic compounds

Comparing Policy Alternatives

In addition to using the optimization model, we will compare different policies aimed at reducing delivery emissions using insights gained from the following tools:

- Interviews with local and global policymakers, business, community groups, ZEDZ researchers, and other stakeholders. **(See Appendix B for a list of all interviewees)**
- Policy evaluation (Cost Benefit Analysis (CBA)) using a Criteria Alternative Matrix
- Literature Review

Criteria Alternative Matrix

In addition to our welfare analysis of a ZEDZ policy, we will also compare this to other policies with a criteria-alternative matrix (CAM), a tool used in policymaking that assigns weights to various criteria and compares policy alternatives based on resulting scores. The

[69] "Pollutants and Health: Alternative Fuels Data Center," U.S. Department of Energy, https://afdc.energy.gov/vehicles/emissions_pollutants.html.
[70] "Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool", Argonne National Laboratory, April 9, 2021, https://greet.es.anl.gov/afleet_tool.

reason we are adding a CAM is because our welfare analysis described in the previous section can potentially mask important caveats to any potential policy. For example, it is possible that a policy can increase overall welfare while simultaneously creating large disparities amongst those who bear the costs and benefits of this policy. Additionally, policymakers may prioritize certain criteria over others, such as equity over efficiency. A criteria alternative matrix will assist in providing a well-rounded analysis of each policy alternative by showing us which criteria each alternative excels in the most. **A summary of our chosen criteria and alternatives are provided below.**

Policy Evaluation Criteria

Political Feasibility

This criteria measures how easily a policy can be implemented and sustained through the political process and if there is public support for the policy. Including this criteria is important because so far in our analysis there is no tool to measure political feasibility. We know based on interviews as well as through the Los Angeles Cleantech Incubator's (LACI) Santa Monica pilot partner information that stakeholder involvement played a large role in implementing the Santa Monica ZEDZ.[71] Therefore to continue measuring the effectiveness of ZEDZ in LA County, we must include this criteria in our policy alternative analysis because of the large role stakeholders are expected to play. The stakeholders we decided upon in determining levels of political feasibility include local city officials (such as city council members and transportation agency members), businesses who would be required to comply

[71] "What Others Are Saying About the Zero Emissions Delivery Zone in Santa Monica", LA Incubator. February 25, 2021, https://laincubator.org/sm-zedz-partners/.

with ZEDZ policy changes, and local special interest groups (such as neighborhood councils and environmental justice groups.)

Efficiency

Measured in terms of emissions reduced per dollar spent. Policies should ideally reduce large quantities of emissions at a relatively low price. Zero emission zones and zero emission delivery zones require some form of financial investment in the implementation process, especially with regards to infrastructure. For example, in the Los Angeles pilot program, each ZEDZ location was budgeted $2,000 to pay for upfront costs.[72] Additionally, ZEDZ policies will likely create ongoing, indirect costs such as prompting businesses to purchase more-expensive EVs. For this reason, measuring the relationship between emissions reduced and the costs of the policy is key in helping policymakers evaluate policy alternatives. Metrics for this criteria can be pulled from the optimization model as well as other external sources.

Equity

We will define equity as a measure of how much harm is reduced or avoided in implementing the policy. Minority and low-income communities continue to bear the brunt of environmentally harmful practices and people of color are more likely to experience "exposure to environmental and health risks" spawned by uneven environmental regulation enforcement in the United States.[73] Policies will receive high marks in terms of this metric if they do not create additional burdens on disadvantaged communities or low-income individuals. Examples of such unintended harmful impacts on marginalized communities include encouraging

[72] "LA City Council Authorizes Loading Zones for Zero-Emission Vehicles Only", *NBC Los Angeles*, last modified June 29, 2021, https://www.nbclosangeles.com/news/local/la-city-council-authorizes-loading-zones-for-zero-emission-vehicles-only/2627666/.
[73] Ibid., 42.

gentrification, diverting traffic to these communities, or creating fees for low-income individuals.

Policy Alternatives

The following are four policy alternatives that will be included in the criteria alternative matrix. Congestion Pricing, Purchase Subsidies, Mandated ZEDZ, and Voluntary ZEDZ are all options policymakers can pursue to solve the problem of high levels of pollutants in LA County. **Appendix H** also outlines policies LA County has in place currently to give more context on the policy playing field we are working off of. Some other alternatives, like off hour deliveries or low emission zones, may be added at a later time if rough data can be found to measure policy effectiveness, equity, and political feasibility.

Congestion Pricing (Table 1) - By attaching a toll to certain vehicles during peak traffic hours, this policy is meant to change the behavior of individuals by incentivizing them to avoid driving during peak hours. The implementation of congestion pricing varies from city to city by the number of enforcement hours, location where the policy is implemented, and the type of vehicles included in the pricing models. In a 2021 study, Washington State University researchers found congestion pricing could "reduce the vehicle fatality rate, generating $25 billion in annual benefits and could improve vehicle fleet fuel efficiency, generating roughly $10 billion in annual operating cost savings".[74] The I-15 corridor in San Diego is an example of this policy which contains high-occupancy vehicle lanes with tolls that vary dynamically based on the current level of traffic congestion.[75]

[74] Clifford Winston and Jia Yan, "Vehicle Size Choice and Automobile Externalities: A Dynamic Analysis", *Journal of Econometrics* 222, no. 1 part A (2021): 196-218, https://doi.org/10.1016/j.jeconom.2020.07.032.
[75] "Congestion Pricing: Examples Around the U.S.", U.S. Department of Transportation Federal Highway Administration, last modified February 11, 2022, https://ops.fhwa.dot.gov/congestionpricing/resources/examples_us.htm.

Table 1: *Costs and Benefits of Congestion Pricing*

Costs	Benefits
Infrastructure to collect fees	Decreased pollution associated with internal combustion engines
Determination of areas that would be subject to pricing	Controls congestion at peak times
Opposition from the public	Encourages use of public transport
	Generates revenue via fees

Purchase Subsidies (Table 2) - Targeting electric vehicles (EVs) and infrastructure for subsidies can potentially offset the greater upfront cost that EVs experience over traditional diesel and internal combustion engine (ICE) vehicles. Slow EV uptake may be, in part, related to elevated costs. Nonetheless, switching to electric freight can potentially offset the "28%" of total delivery costs incurred in the "last leg of the supply chain" and create upwards of "$1 million in health benefits from reduced air pollution" for every fifteen electric freight trucks.[76; 77] As of July 2021, 47 states plus the District of Columbia have implemented some form of EV subsidies, such as in the form of tax credits, rebates, or registration fee reductions.[78]

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[76] Yuan Wang et al, "Towards Enhancing the Last-Mile Delivery: An Effective Crowd-Tasking Model with Scalable Solutions." *Transportation Research Part E: Logistics and Transportation Review* 93 (2016): 279–93, https://doi.org/10.1016/j.tre.2016.06.002.
[77] Aileen Nowlan and Sabah Usmani, "Accelerating Zero- Emissions Delivery", Environmental Defense Fund, 2021, https://business.edf.org/files/EDF023_Zero-Emissions_v3.pdf.
[78] Hartman, Kristy and Laura Shields. 20 August 2021. "State Policies Promoting Hybrid and Electric Vehicles". National Conference of State Legislatures. https://www.ncsl.org/research/energy/state-electric-vehicle-incentives-state-chart.aspx.

Table 2: *Costs and Benefits of Purchase Subsidies*

Costs	Benefits
Monetary costs to fund the subsidies	Decreased pollution associated with internal combustion engines
Garnering widespread support	Increased EV uptake by consumers and businesses
May reducing revenue for any given Department of Transportation (DOT)	May primarily benefit individuals who can afford EV vehicles

Mandatory ZEDZ (Table 3) - Zero Emission Delivery Zones ("ZEDZ") are areas created with the explicit goal of reducing and ultimately eliminating greenhouse gas (GHG) emissions and other pollutants released by delivery vehicles and can thus be seen as a combination of innovative policies and vehicles.[79] These zones require the use of electric freight and delivery trucks, thus limiting the amount of traffic congestion and pollution located within established boundaries. According to C40 Cities et. al (2020), ZEDZ may have the added effect of helping countries and localities meet decarbonization targets, reducing noise and air pollution, facilitating the creation of green spaces, and stimulating demand for electric freight vehicles.[80]

[79] C40 Knowledge Hub. May 2020. "Zero Emission Zones for Freight: Lessons from Beijing." Accessed January 9, 2022. https://www.c40knowledgehub.org/s/article/Zero-Emission-Zones-for-Freight-Lessons-from-Beijing?language=en_US.
[80] Ibid, 4.

Table 3: *Costs and Benefits of Mandatory ZEDZ*

Costs	Benefits
Increased costs for businesses that will need to electrify delivery vehicles	Potential for green spaces to be developed
Potential fees associated with zoning ZEDZ	Stimulating demand for electric freight vehicles
Resources will be needed to garner widespread support	Decreases in traffic congestion
Enforcement of zoning area costs	Decreased pollution associated with internal combustion engines

Status Quo - Voluntary ZEDZ (Table 4) - Currently, the City of Santa Monica is piloting a voluntary ZEDZ that electric freight vehicles can make use of located in a one-square mile area near the Third Street Promenade. Voluntary ZEDZ require similar implementation methods as their mandatory counterparts, however we expect that GHG and PM emissions for the former would be decreased at a rate that is somewhat less than the latter. This is not only due to the decreased infrastructure requirements that are delegated to the City of Santa Monica, but also due to slow EV uptake not only by businesses, but also by consumers throughout the United States.[81] However, there is promise that voluntary ZEDZ pilots will act as proof of concept for the development of mandatory ZEDZ across the United States.

[81]https://www.pewresearch.org/fact-tank/2021/06/07/todays-electric-vehicle-market-slow-growth-in-u-s-faster-in-china-europe/

Table 4: *Costs and Benefits of Voluntary ZEDZ*

Costs	Benefits
Might be too lax to be effective	Potential for decreases in traffic congestion
Resources will be needed to garner widespread support	Potential for green spaces to be developed
Increased costs associated with electric freight vehicles for participating businesses	Stimulating demand for EVs
	Decreased pollution associated with internal combustion engines

Chapter 4

Policy Evaluation

Chapter 4: Policy Evaluation

Assessing the Impacts and Process of ZEDZ Implementation through Interviews

Our team has conducted interviews with many individuals who have shed light on the impacts and process of ZEDZ implementation. Some have offered advice on the development of our model, while others have direct experience with policy implementation in different municipalities. Ultimately, our interviewees highlighted what exactly makes ZEDZ an attractive policy option over alternatives. Furthermore, they addressed characteristics a municipality should have to demonstrate that it is willing and able to implement these zones in their jurisdictions.

Our interviewees have highlighted the fact that municipalities in the United States - and in California in particular - are bound by statutory limitations on the policies they can develop within their jurisdictions. A subject-matter expert at CALSTART stated that cities themselves are not empowered to create and implement ZEDZ due to jurisdictional bounds around what is feasible and unfeasible. Santa Monica was able to circumnavigate this restriction by forming a voluntary ZEDZ. In order to create a mandatory version, it would require the State of California to implement policies similar to AB 617, which amended and added provisions to the Health and Safety Code relating to non-vehicular air pollution.[82] The bill requires the monitoring and implementation of a statewide policy on tracking air pollution metrics, with particular emphasis on high-impact communities who are disproportionately impacted by air pollution. The expert offered the insight that many of the hardest hit communities in Los

[82] Nonvehicular air pollution: criteria air pollutants and toxic air contaminants, A.B. 617 (2017). https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB617

Angeles have been vocal about their support for ZEDZ - a reality that is counter to what we initially assumed was the case. Instead of emphasizing the political feasibility of ZEDZ as it relates to stakeholders, we plan to emphasize the sustainability of the policy in the realm of policymakers and political processes that might be beyond community intervention.

Corroborating what the expert from CALSTART pointed out in terms of political feasibility, an official at the City of Santa Monica, stated there is movement at the state level on changing California vehicle codes to allow municipalities to exert such power but, for now, they are bound by jurisdictional limitations. The ZEDZ pilot being voluntary had the added effect of limiting the burden placed on businesses to comply and many of the benefits of the zone are targeted towards small businesses in the form of ensuring that a third party is not cutting into their profits. However, one characteristic of the Santa Monica zone that should be noted is that the city enjoys a level of community support that is unlikely to be replicated across a wide range of cities. Though we've learned that many of the hardest hit communities indeed support ZEDZ, partnerships with community based organizations could offset potential shortfalls in stakeholder engagement.

In our site visit, we were able to see several designated zero emission loading curbs that were located near businesses in Downtown Santa Monica. While the lack of enforcement capabilities makes it difficult to police these curbs, the infrastructure for a mandatory ZEDZ is in place. Several private partners are contributing to this effort in tandem with the City of Santa Monica such as LACI, Automotus, Coco, and REEF to name a few. In addition to having monitoring infrastructure and designated loading curbs for zero emission vehicles, the City of Santa Monica is also offering remotely-piloted delivery services, zero emission transportation within Santa Monica, and rentable three-wheeler vehicles that are highway approved. While awareness and use of these goods may not be at the level the City of Santa Monica would like (as illustrated by the fact that an ICEV was parked in the first designated zero emission curb we visited), the groundwork has been laid for a successful pilot in a city already dedicated to sustainability.

In our interview with one of Santa Monica's partners on the ZEDZ pilot, the Los Angeles Cleantech Incubator (LACI), we uncovered the reasons behind the adoption of ZEDZ by Santa Monica. According to LACI these include, but are not limited to: the spread and inability to manage electric scooters, curb management, the establishment of a microhub, and personal delivery devices among other things. When it came to implementing the ZEDZ pilot, the City of Santa Monica and LACI partnered with a variety of different organizations not only to collect and analyze data, but also to utilize the zone to determine whether it was feasible to make it permanent. Beyond the partnerships that have been established, community based organizations play a role in offering feedback on the pilot while also attending ZEDZ Advisory Committee meetings - a fact apparently characteristic of LACI pilots. Furthermore, our interviewees were more than willing to share their experiences and data (at least data that is not subject to a memorandum of understanding between LACI and the City of Santa Monica) with us, helping us gain more information on the pilot.

In addition to meeting with LACI, our team met with an additional partner on the ZEDZ pilot: Automotus. The company has worked closely with the City of Santa Monica to site cameras for the ZEDZ and currently monitors them by recording what vehicles are using the curb, the length of time that is spent in the loading zone, and what type of engine the vehicle has. In our interview with two individuals at Automotus we discovered that cities without the data and technology necessary to determine camera and curb placements require longer to begin a pilot. However, this data can be brought together quickly as was seen with the City of Santa Monica whose initial siting took nearly six months to complete, while all subsequent cameras installed following this initial time period were expedited. This suggests that with a small amount of experience, municipalities across the country might be able to implement ZEDZ swiftly. Finally, our interviewees from Automotus highlighted the fact that this is the first time that the federal government has ever funded a curb management project of this magnitude, making our project and Santa Monica's ZEDZ pilot incredibly consequential.

In addition, an individual working with the Los Angeles Mayor's Office of Sustainability on zero emission policies, shared both CALSTART and the City of Santa Monica's sentiments on jurisdictional limitations. In order to get around these limitations, however, our interviewee suggested that cities rely on curb management practices like the City of Los Angeles has. Currently there are five zero emission curbs in the Downtown Los Angeles area, and this number is expected to increase to at least 100 over the next six years. The basic premise behind this is: while it is currently not possible for cities to restrict or prohibit entry into a geographic area on the basis of emissions, a high amount of curb spaces dedicated to zero emission vehicles will *de facto* create a zero emission zone even without *de jure* authorization. Furthermore, in our interviewee's discussions with various stakeholders, they found support among businesses who requested the development of policies to facilitate transitions toward fleet electrification. Taken along with our other interviews, it appears that

ZEZs generally enjoy widespread support across a variety of stakeholders including communities, businesses, and policymakers.

The latter point became even clearer in our discussion with East Yard Communities for Environmental Justice (EYECJ). An organizer with EYECJ stated that many of the communities they work with have specifically asked for ZEZs, whether in the form of zero emission lanes on the 710 corridor or actual designated zones within their communities. While ZEDZ specifically has not been a topic of discussion among EYECJ communities, the need for policies that target emissions is clear given that many of the worst effects of climate change are often centered around low-income communities and communities of color. On the topic of the City of Los Angeles' curb management proposal, our interviewee stated that the focus should not be on curbs, but rather on the entire life cycle of an internal combustion engine (ICE) vehicle because they impact hardest hit communities for that entire duration. Finally, our interviewee suggested that policymakers should prioritize the consideration of several topics which include: accessibility to hardest hit communities, centering communities that are impacted the most by goods movement, being diligent in understanding who will benefit the most from ZEDZ and why, helping small businesses electrify their fleets, and ensuring that there is no displacement as a result of ZEDZ.

We additionally conducted an interview with an employee with the Dutch government who is currently working with cities across the Netherlands to determine how best to implement their ZEZs. Sharing their experience thus far, this individual highlighted the fact that implementation is a difficult process, especially when it comes to tracking zone violations and enforcing the policy. They stated the most important aspect for the Dutch government has been incentivizing the use of these zones by cities, given the pattern and practice of early stakeholder involvement. Thus, as the expert from CALSTART noted previously, it is clear that cities within the Netherlands and the United States lack robust incentives to adopt ZEZs - a gap that we may be able to fill with our analysis. The Dutch government is currently tackling their own goals of attaining net-zero by 2030 with between 29-32 cities announcing zones that will start in either 2025 or 2030 and 30 to 40 freight zones, however, the results of their own LEZs, ZEZs, and ZEDZs have not been released as of yet. For this reason we may not be able to receive robust data from this source.

A related interview on the status of implementation of these zones in the Netherlands was conducted with a Professor from the University of Amsterdam. Tracking the history of the development of LEZs, ZEZs, and ZEDZs within the country, the Professor stated that the government's Climate Agreement led to agreements between national and local authorities and sectors leading to the creation of ZEZs in nearly all 40 municipalities of the Netherlands. With a national legislative framework in place, these zones have proliferated. This could constitute an option for the State of California to open the way for municipalities to create and implement their own zones. Nonetheless, the Netherlands does experience a very different political, economic, and cultural environment (such as in the form of its smaller, more urbanized and homogenous population) than that of the United States so it would be difficult to superimpose the Dutch government's experience on the United States.

Ultimately, it has become even more clear that ZEDZs and ZEZs are context-specific policies that can be shaped by the needs and desires of the communities that contain them. In several cities across the world these zones are far bigger than the one square mile pilot currently underway in Santa Monica. The benefit of this is that ZEDZs and ZEZs can be narrowly tailored to serve the interests of a given municipality, however, regardless of size our goal is to determine whether this policy is politically feasible in the context of the Greater Los Angeles area and potentially the United States.

The Quantitative Analysis Results

Our quantitative analysis breaks down total costs into the following four categories (see **Table 5**):

Table 5: *Cost Categories*

Type of Cost	Definition in our report
Total Ownership Cost (TOC)	The private cost of owning and operating a vehicle. Includes the cost for fuel (either gasoline or electricity), maintenance, and the original purchase price. We assume that the vehicles are in operation for five years, so this original purchase price is divided by 5 to create a yearly cost.
Externality Costs	The total cost of the emissions produced, as defined by the Afleet database.
Government Revenue	The total taxes and fees collected by the government, minus the cost of any constructed infrastructure or subsidies paid out.
Total Social Cost	Total Ownership Cost plus Externality Costs, minus Government Revenue

Before comparing the different policy scenarios with our model, we first compare the fundamental characteristics produced by an ICEV and an EV based on the data we collected. Note that, in the descriptions that follow, we will focus on Class-2 commercial vehicles, the most commonly used category in the Los Angeles area.[83] While we only address Class-2

[83] City of Santa Monica, "Environmental Impact Report 6th Cycle 2021-2029 Housing Element Update: Appendix G – Transportation Study" Accessed February 13, 2022. https://www.santamonica.gov/media/Housing-Element-Update-2021-to-2029/APPENDIX%20G-TRANSPORTATION%20STUDY.pdf

vehicles here for simplicity, the trends are the same for all vehicle classes which can be found in **Appendix C**.

Figure 3 compares the yearly total social cost for Class-2 ICEVs and EVs, assuming a daily vehicle miles traveled (DVMT) of 40, which is the average value obtained from actual parcel transport data[84]. The figure shows that TOC is the dominant contributor to the total social cost, and that the social cost of EVs exceeds that of ICEVs. This indicates that: 1) adopting EVs without additional support would place substantial additional costs on private freight companies, 2) government intervention would likely be required to encourage these companies to adopt EVs, and 3) the value of the reduction in externalities would have to be increased to overcome this higher cost, either by placing a higher price tag on emissions or due to the unique circumstances of where this driving is taking place.

[84] National Renewable Energy Laboratory, "Fleet DNA: Commercial Fleet Vehicle Operating Data | Transportation Research | NREL."

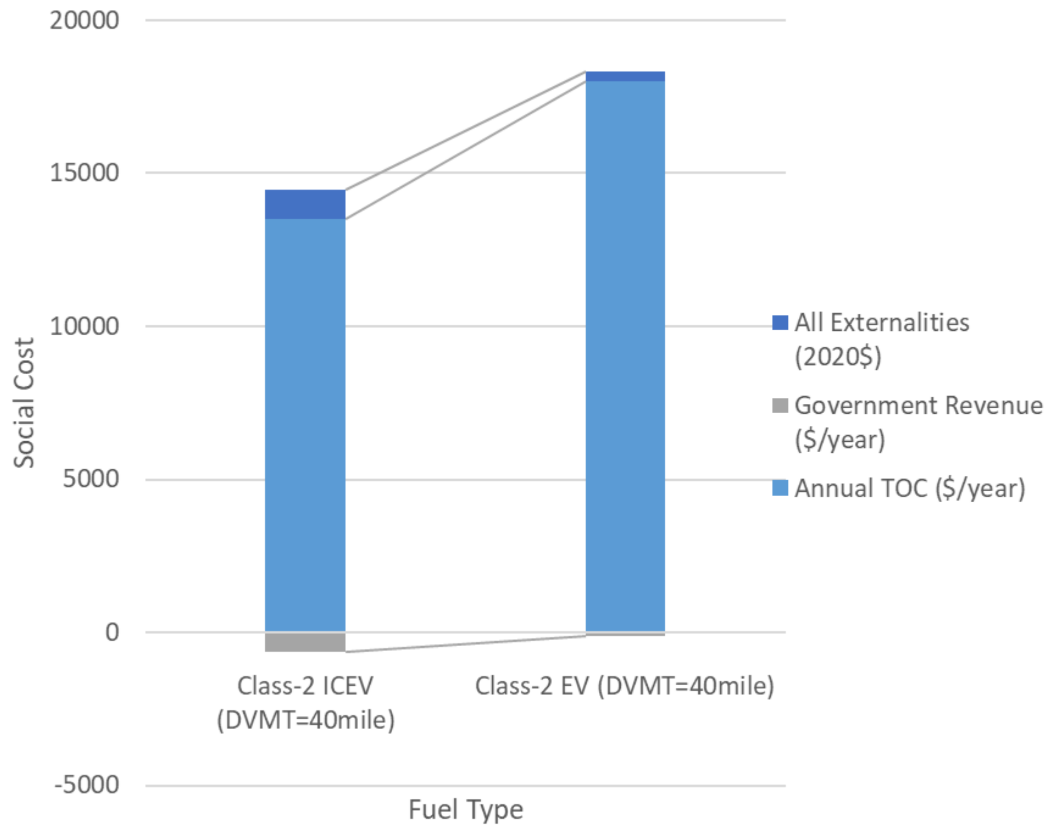

Figure 3: *Total Social Cost by Fuel Type*

To expand on these points further, **Figure 4(a)** shows a comparison of the total ownership cost (TOC) that private companies must incur to purchase and operate each different type of vehicle. This chart shows the annualized purchase cost (assuming a fixed 5-year depreciation period), annual fuel cost (proportional to mileage), maintenance cost, and other costs (insurance and license fees) that make up the TOC by fuel type. As shown, purchase cost of EVs is so high that they are not compensated by fuel savings for last-mile deliveries with short driving range. Because of this, ICEVs are a better option for freight companies than EVs when only considering cost. Thus, our baseline model assumes all deliveries are conducted with ICEVs. Since EVs have an advantage in terms of longer driving distances, **Figure 4(b)** shows the relationship between DVMT and TOC. From this figure, it is clear that the cost of EVs is never lower than that of ICEVs below 100 miles. Based on the vehicle driving characteristics shown in Appendix C, EVs are almost always more expensive than ICEVs, since last-mile DVMT is rarely more than 100 miles.

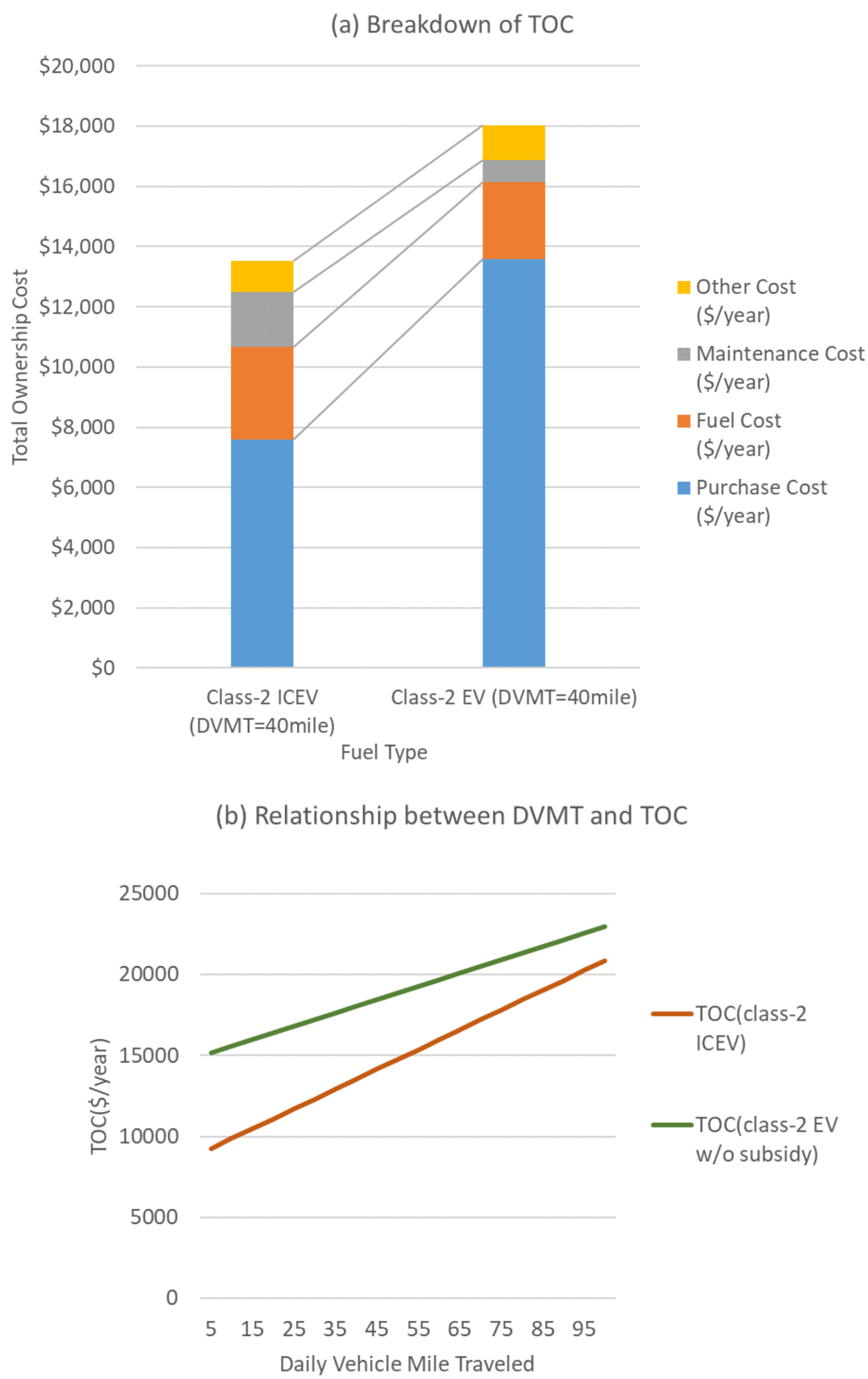

Figure 4: *Characteristics of Total Ownership Cost by Fuel Type*

GHG and air pollutant emissions are shown in **Figure 5**, and it is clear that EVs have a strong advantage over ICEVs in terms of their respective environmental effects. So while ICEVs may be beneficial for companies in reducing their private costs, EVs are beneficial to the communities in which they are driven and society at large due to their greatly reduced emissions.

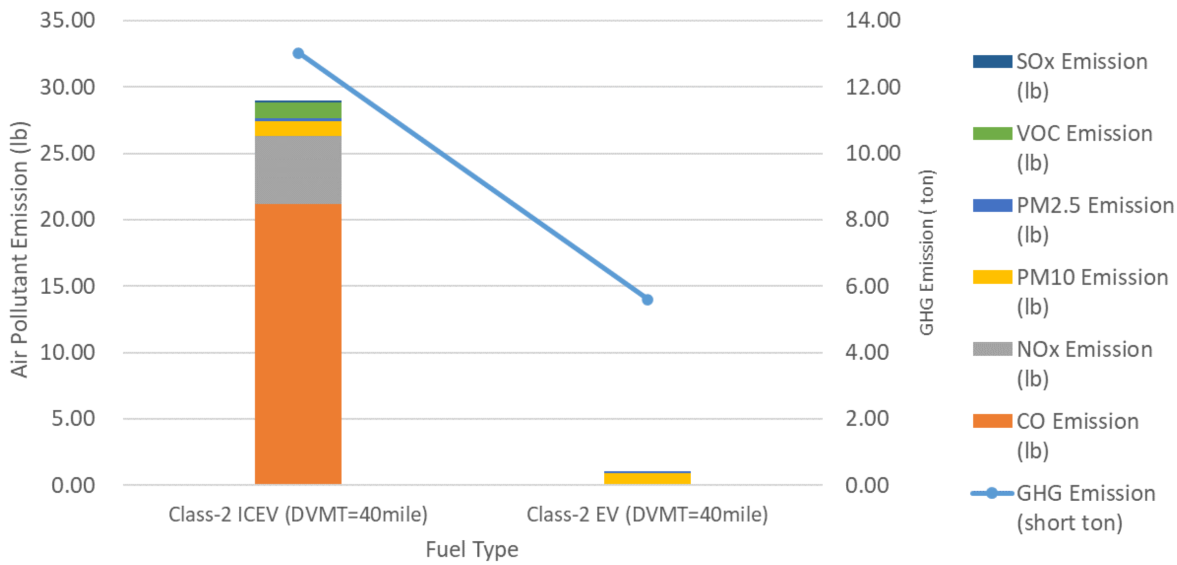

Figure 5: *Characteristics of GHG and Air Pollutant Emission by Fuel Type. GHG is measured in tons, while other pollutants are measured in pounds.*

We now turn to presenting the results of our model which analyzes the case of Santa Monica. Based on the sources and methods stated in **Appendix D (Table D-8) and Appendix E (Table E-1)** we created pseudo-empirical data. A summary of the pseudo-empirical input data we generated is shown in **Table 6** and **Table 7**.

Table 6: Input data for Optimization Model (City of Santa Monica)

Items	Value
Number of all nodes	367
Number of depot nodes	16
Number of consumer nodes	351
Number of consumer nodes inside ZEDZ	75
Freight Vehicles	
Target vehicle class	Class-2
Target fuel type	Diesel / Electricity
Average payload capacity	3739.4 lbs
Driving duration	4.81 h/day
Non-driving delivery duration	7.87 h/day
Estimated maximum parking lot waiting time	0.46 h/day

Table 7: Input data for Economic Analysis (City of Santa Monica)

Items	Value	
	ICEV	EV
Cost parameters		
Purchase cost of freight vehicles	$38,000	$68,000
Fuel Price	$3.16/mile	$6.30/mile
Average Fuel Economy	12.0	29.1
Maintenance and Repairs Cost	$0.155/mile	$0.064/mile
Insurance Cost	$904.0	$904.0
License and Registration	$133.0	$233.0
Fuel Tax	$0.67	$0.28
Purchase Subsidy	$0	$2,000
Hazardous Substance Emissions		
GHG (ton/mile)	0.00111	0.00048
CO (lb/mile)	0.00181	0.00000
NOx (lb/mile)	0.00044	0.00000
PM10 (lb/mile)	0.00009	0.00008
PM2.5 (lb/mile)	0.00002	0.00001
VOC (lb/mile)	0.00010	0.00000
SOx (lb/mile)	0.00001	0.00000
Externality Costs		
GHG (ton/mile)	$40.76	$40.76
CO (lb/mile)	$0.00	$0.00
NOx (lb/mile)	$23.15	$23.15
PM10 (lb/mile)	$33.85	$33.85
PM2.5 (lb/mile)	$305.27	$305.27
VOC (lb/mile)	$56.82	$56.82
SOx (lb/mile)	$648.43	$648.43

We obtained the following results (see **Table 8**) for our baseline and 6 different scenarios mentioned in the Methodology section.

***Table 8**: The Result of the Quantitative Analysis*

(a) *Total Results*

Scenario	Vehicle Numbers		Total Routing Distance (miles/day)	Social Cost ($/year)	Annual TOC ($/year)	Government Revenue ($/year)	Externalities ($/year)
	EV	ICEV					
Baseline	0	24	770.4	$306,555	$301,439	$12,581	$17,697
Scenario 1 (ZEDZ-M)	9	15	776.3	$351,892	$346,846	$8,986	$14,031
Scenario 2 (ZEDZ-V)	0	24	770.4	$306,555	$301,439	$12,581	$17,697
Scenario 3 (Subsidy)	0	24	770.4	$306,555	$301,439	$12,581	$17,697
Scenario 4 (ZEDZ-M + Subsidy)	9	15	776.3	$351,892	$343,246	$5,386	$14,031
Scenario 5 (ZEDZ-M + ZEDZ-V)	9	15	749.6	$348,518	$344,046	$8,970	$13,442
Scenario 6 (ZEDZ-M + ZEDZ-V + Subsidy)	9	15	749.6	$348,518	$340,446	$5,370	$13,442

(b) *Comparison to Baseline*

Scenario	Δ(Distance) (miles/day)	Δ(Total Social Cost) ($/year)	Δ(TOC) ($/year)	Δ(Revenue) ($/year)	Δ(External-ity) ($/year)
Baseline	-	-	-	-	-
Scenario 1 (ZEDZ-M)	6	$45,336.80	$45,407	-$3,596	-$3,666
Scenario 2 (ZEDZ-V)	0	0	$0	$0	$0
Scenario 3 (Subsidy)	0	0	$0	$0	$0
Scenario 4 (ZEDZ-M + Subsidy)	6	$45,336.80	$41,807	-$7,196	-$3,666
Scenario 5 (ZEDZ-M + ZEDZ-V)	-21	$41,963.10	$42,607	-$3,611	-$4,255
Scenario 6 (ZEDZ-M + ZEDZ-V + Subsidy)	-21	$41,963.10	$39,007	-$7,211	-$4,255

The implementation of mandatory ZEDZ (Scenario 1) increases the number of EVs and total routing distance. This indicates that EV-only zones impose new constraints on companies, forcing them to purchase EVs and change their routes. As a result, the cost of externalities goes down, but the TOC of logistics firms also increases. This confirms what we assessed several times in our interviews (such as from the Professor in Amsterdam and our IKEA interview): that EV policies can place financial burdens on logistic companies. In contrast, under the voluntary ZEDZ and the purchase subsidy policies (Scenarios 2 and 3), we found no difference from the baseline scenario. This is due to the dominant high purchase cost of EVs. California's purchase subsidy of $2,000 (which was used in our Scenario 3) or a parking incentive to slightly increase the actual delivering time (which was used in our Scenario 2), by themselves, are not strong enough to compensate for the additional cost of EVs. Indeed, from the previous **Figure 4b**, it can be inferred that the value of subsidies or priority parking spots must exceed about $5,000 per vehicle *yearly* for companies to make a profit switching from ICEVs to EVs under these policies, given a DVMT of 40.

However, another perspective emerges when we consider the combination of policies. For example, the combination of mandatory ZEDZ and subsidies (Scenario 4) would reduce the TOC, which would reduce the burden on logistics companies. In other words, when these policies are combined, subsidies function as a way for governments to shoulder some of the burden placed on logistics companies. When the voluntary ZEDZ incentive is added to the mandated ZEDZ (Scenario 5), the total routing distance is reduced due to efficient delivery, reducing both TOC and externality costs. The combination of all the policies (Scenario 6) shows both characteristics we can see in Scenarios 4 and 5.

How should the reduction in externalities be compared to the higher TOC? Our defined methods would indicate that, in all scenarios, the externality reductions are matched or outweighed by the TOC increases, leading to an overall stagnation or increase in total social cost. This would seem to indicate that none of the policy scenarios are worth taking. However, there are strong caveats to this conclusion. For starters, many logistic companies such as Amazon are incredibly wealthy, and it may very well be worth reducing their profits to better protect the environment, even if the dollar amount of the profits reduction is greater than the estimated dollar value of the emissions reduction.[85]

Secondly, to quantify the value of emission reductions, this analysis relied on a concept in economics known as "the social cost of carbon", which is the "estimate of the economic costs, or damages, of emitting one additional ton of carbon dioxide into the atmosphere, and thus the benefits of reducing emissions" (this concept can also be applied to other forms of emissions as well).[86] The difficulty in estimating the social cost of carbon (and certain other emissions) is that the effects of global warming are highly uncertain, and there is new research indicating that previous estimates have been too low.[87] It is also a highly politicized value; under the Obama administration, the social cost of carbon was estimated at $45 per ton, while

[85] "Amazon.com Announces Fourth Quarter Results." Amazon Investor Relations, last modified Feb 2022. https://ir.aboutamazon.com/news-release/news-release-details/2022/Amazon.com-Announces-Fourth-Quarter-Results/.
[86] Rennert, Kevin et al. "The Social Cost of Carbon". *Brookings Institution*. September 9, 2021. https://www.brookings.edu/bpea-articles/the-social-cost-of-carbon/#:~:text=The%20social%20cost%20of%20carbon%20is%20an%20estimate%20of%20the,the%20United%20States%20and%20abroad.
[87] Ibid.

the Trump administration placed this estimate “somewhere between $1 and $6”.[88] This is all to say that placing an exact dollar value on emission reductions is more alchemy than science.

Thirdly, for communities that are highly interested in protecting local and global environments, the above policy options may represent some of the only strategies available to help achieve these goals. These communities may be willing to pay a premium in order to reduce their carbon and other footprints.

Fourthly, corporate brand strategy considerations are not included in our financial calculations. There may be cases where a logistics company is interested in a clean image, or where such a shipper may request the use of Zero Emission Vehicles to their freight companies, in which case the company may choose EVs even with their expensive cost. In those cases, policies such as voluntary ZEDZ or subsidies must be beneficial. One such example is Amazon’s pledge to convert its fleet to electric vehicles.[89]

Finally, many governments advocate carbon neutrality. In California, in particular, SB 100 and the action plan based on it have determined that all vehicle sales will be limited to Zero Emission Vehicles by 2035, in order to make all vehicles Zero Emission by 2045 (see Appendix H). In light of these social demands, policies that reduce the burden of EVs are highly effective.

With these considerations in mind, a more appropriate interpretation of the results is to compare the policies relatively: of these policies, combining mandatory ZEDZs with the parking and loading incentives found in voluntary ZEDZs (with and without subsidies) was

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[88] “Trump vs. Obama on the Social Cost of Carbon–and Why It Matters”. Columbia Center on Global Energy Policy. November 15, 2017. https://www.energypolicy.columbia.edu/research/op-ed/trump-vs-obama-social-cost-carbon-and-why-it-matters.

[89] Weise, Karen and Neal E. Boudette. “Can Anyone Satisfy Amazon’s Craving for Electric Vehicles?” The New York Times. January 18, 2022. https://www.nytimes.com/2022/01/18/technology/amazon-electric-vans.html.

found to reduce emissions the most. This combination was also found to achieve emission reductions at a lower total social cost than mandatory ZEDZs alone. Adding subsidy policies transfers some of the burden of EV adoption from companies to the government.

Criteria Alternative Matrix Results

Table 9 shows a criteria alternative matrix (CAM) that ranks each policy in order from most likely (4) to achieve our chosen criteria to least likely (1). It's important to note that this CAM does not include combinations of policies and only includes an analysis of policies as they stand alone. The weights for each criterion are determined through learnings from our interviews. For example, almost every interviewee across the city and community levels emphasized the importance of political feasibility for a policy that established zoning regulations. If a policy can not be enacted or sustained politically, then its other positive attributes do not matter as the policy will never take effect. Therefore we chose to weigh the political feasibility criteria as the most important with a 40% weight. Efficiency, measured in emissions reduced per year/costs per year, and equity, framed as a policy that does not cause additional harm on historically marginalized communities or small businesses, are both weighted equally at 30% weight each. Both efficiency and equity remain important criteria based on our interviews which is why the difference in weight between efficiency and equity in comparison to political feasibility is only placed at 10%. Efficiency remains a moderately high criteria because the ultimate goal of the policymaker is to reduce pollution levels from ICE at a reasonable cost and equity remains just as important to policymakers in Southern California because of the history of environmental policies excluding communities of color highly impacted by pollution as well as the risk of overburdening small businesses with high costs from fleet electrification.

Table 9: *Criteria Alternative Matrix*

		Policy 1		Policy 2		Policy 3		Policy 4	
		Congestion Pricing		Purchase Subsidies		Mandatory ZEDZ		Voluntary ZEDZ	
Criterion	**Weight**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**
Political Feasibility	4	1	4	2	8	3	12	4	16
Efficiency (emissions reduced per year /cost per year)	3	3	9	2	6	4	12	1	3
Equity (in terms of least burdens placed on historically marginalized communities, or small businesses)	3	2	6	3	9	1	3	4	12
Total	**10**		**19**		**23**		**27**		**31**

Political Feasibility Results

Out of the four policies we are comparing it is clear that voluntary ZEDZ are the most politically feasible. Because there is little enforcement for businesses to participate in the program and low implementation costs there is likely to be very little pushback. This has been demonstrated through the Santa Monica pilot where residents, businesses, and lawmakers were all in favor of the policy. The enforcement level of Santa Monica's program specifically does not involve law enforcement either so accountability for non electric vehicles who use up curb space designated for electric delivery vehicles is nonexistent. In addition, the cost to set up curb space in a voluntary zone is low including small changes such as curb paint and signage.

In comparison to the voluntary ZEDZ, a mandatory ZEDZ has a much higher level of costs and requirements for compliance within the policy. Despite higher costs, there is still a large amount of public support coming from locally impacted communities as demonstrated through interviews with East Yard Communities for Environmental Justice and CalStart. There is potential for this local momentum to provide the necessary push to make this policy more likely to be supported by lawmakers. For these reasons, we ranked this policy as the second most likely to meet the political feasibility criteria across lawmakers, residents, businesses, and community special interest groups.

The other two policies, congestion pricing and purchase subsidies are ranked much lower in the political feasibility criteria because they both incur direct costs on communities. Although versions of both these policies are implemented in LA County, they are much more watered down indicating there is political support but only to an extent. Congestion pricing, in particular, faces a significant amount of opposition, making it ranked the lowest (1) on political feasibility.

Efficiency Results

Efficiency can be seen as the amount of emissions reduced in relation to the amount of dollars spent. The ideal policy will cost the least while creating the largest positive impact; however, this isn't always the case. The most efficient individual result we studied is the mandatory ZEDZ policy, while the least efficient individual result is a voluntary ZEDZ and subsidy. The results from our model indicate a high likelihood of success in reducing emissions via a mandatory ZEDZ policy. Not only is this due to the constraint on vehicle type in specific zones, but it's also because of enforcement mechanisms which disincentivize the use of ICEVs.

The opposite is true for voluntary ZEDZ which are neither enforced nor create any constraints on the types of vehicles that can enter a given zone, making it much more difficult to see any substantive effect on GHG emissions. Current EV subsidy levels are too low to financially incentivize companies to EVs.

Congestion pricing is considered the second most efficient. According to the International Council on Clean Transportation, congestion pricing has the potential to reduce GHG emissions and particulate by "15-20%" based on data from London, Singapore, and Stockholm.[90] In other words, if GHG emissions and particulate matter constitute 100 parts per million (ppm), congestion pricing can reduce that to between 80 and 85 ppm. Given that modern camera technology is required to implement this policy, we can logically assume that a municipality would need at least ten to twenty automatic license plate readers (ALPRs). At $15,000 to $20,000 per ALPR, this would cost a given municipality between $100,000 to $400,000 for installation alone. However, the costs of implementation are offset by the revenue generated by the policy; the City of New York is expected to earn nearly $1.1 billion per year from this policy alone.[91] Given that Manhattan - where congestion pricing is being implemented - only constitutes 22.8 square miles, we can expect revenue earned to be nearly 22 times greater in Los Angeles (roughly 503 square miles). These factors together allowed us to give congestion pricing the second most efficient policy.

We found subsidies by themselves to be completely ineffective. Due to the higher cost of EVs, our model indicates that the value of subsidies must exceed $5,000 per vehicle *yearly*

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[90] Ed Pike, P.E.. "Congestion Charging: Challenges and Opportunities," The International Council on Clean Transportation, Published April, 2010. https://theicct.org/sites/default/files/publications/congestion_apr10.pdf.
[91] Gribbin,D.J.. "Congestion pricing is all around us. Why is it taboo on our roads?" Blookings, October 16, 2019. https://www.brookings.edu/blog/the-avenue/2019/10/16/congestion-pricing-is-all-around-us-why-is-it-taboo-on-our-roads/.

for companies to voluntarily switch from ICEVs to EVs given a DVMT of 40 and if we assume that delivery companies are profit maximizers. A subsidy amount below that value will have no impact on emissions, as the composition of fleets and miles driven will remain the same as if there were no subsidy. A vehicle owned by a delivery company would have to reach a DVMT of about 85 for the cost difference between the two types of vehicles to be within $2000, which is the current California subsidy.

Equity Results

The most equitable result, based on our definition of equity, is the voluntary ZEDZ. Other policy solutions do not impact all residents equally, creating large disproportionate effects. For example, purchase subsidies and congestion pricing can be seen as being ultimately beneficial to those who are more well-off. The proportion of money spent on the congestion price versus income will be less for those with higher incomes than those with lower incomes. Similarly, purchase subsidies that are non-means tested benefit the well-off at a rate that is somewhat larger than for those with lower incomes.

Our overall results from the CAM conclude that a voluntary ZEDZ policy is the best option for cities to undertake to meet this criteria. While it is less successful in terms of reducing actual pollutants, other policy options create additional burdens on small businesses and marginalized communities. A voluntary ZEDZ policy in comparison to other stand alone policies can still achieve these reduction successes in ways that are palatable to the voting public.

Chapter 5

Recommendations for Policymakers

Chapter 5: Recommendations for Policymakers

How to Use this Report in the Future

As cities consider options to meet emission and pollutant reduction goals, we recommend utilizing the model designed in this report to estimate costs and pollutant level reductions from alternative policies to best identify the ideal policy plan for each city. In addition, since no one pollutant reducing policy can meet all criteria effectively we recommend packaging various policies together. Our model demonstrates that a combination of policies produce the highest results in decreasing costs and pollutant levels. Based on our criteria alternatives matrix, both voluntary ZEDZ and mandatory ZEDZ provide the best policy options to address GHG emissions and similar pollutants emitted from ICE vehicles. To better improve the political feasibility and equity aspects of these policies we recommend the following additions to these policies:

1. First, we recommend cities consider adding purchase subsidies of freight electric vehicles to a ZEDZ program. The primary reason is to offset costs businesses would incur, particularly small businesses from transition to electric vehicle fleets. Mandated ZEDZ in particular would add additional burdens on small businesses since these companies don't have the capital to transform fleets. If a city plans on establishing a mandated ZEDZ, then they should also aim to accommodate this additional cost. This subsidy program can help both in increasing the equity score and the political feasibility score for this policy. **Furthermore, as our model demonstrates, the best policy is to couple subsidies with mandated ZEDZ. Voluntary ZEDZ and purchase subsidies**

combinations don’t result in high enough incentives for companies to switch between ICE vehicles and EV’s.

2. Second, we recommend establishing a phased process for ZEDZ. Because the United States has a much different cultural context than European cities that already have mandated ZEDZ and ZEZ, there is a higher political barrier to face when considering mandated ZEDZ as a policy. Instead, following Santa Monica’s model, a voluntary ZEDZ will provide an onboarding process introducing the features of a ZEDZ to businesses and communities, warming up stakeholders to the concept of a regulated electric vehicle zone. Once cities are able to experiment with the voluntary ZEDZ, they can begin establishing goals for electrification, like the Netherlands cities have done, before finally instating a mandatory ZEDZ.
3. Third, we recommend cities pursue an extensive exploratory process when considering implementing a ZEDZ. The Santa Monica pilot prioritized stakeholder involvement and our report also includes interviews from a wide variety of stakeholders. Because there is no one size fits all policy for ZEDZ, it is critical that cities engage with all stakeholders when designing the policy. Stakeholders we recommend starting with include businesses in areas where there are high last mile deliveries, communities located near last mile delivery zones and shipment hubs, and private businesses who can provide data and implementation support. The two most important stakeholders we identified through studying Santa Monica’s model are community members both within and near the zone as well as small businesses. We recommend cities prioritize including these stakeholders as early as possible in the policy creation process.

4. Finally, a barrier to mandated ZEDZ across states and across the country still remains in the form of limitations to rulemaking on mandating electric vehicles. State legislation would need to pass to overcome this obstacle. This is one of the reasons why Santa Monica's ZEDZ is voluntary, as a voluntary requirement produces less legal hurdles. However, cities interested in gaining political traction can begin with a smaller scale pilot program or voluntary ZEDZ to help demonstrate to their constituents that such a policy would not be overly burdensome. Additionally, increased united local demands for policies like mandatory ZEDZs will likely increase in tempo, given that new laws have recently been passed that are requiring automakers to sell greater and greater proportions of electric trucks.[92] Other similar California laws are listed in **Appendix H**.

How to Use The Pollutant Estimating Model

Our multi-agent model approach was chosen due to its usefulness in contexts that face a wide array of different stakeholders and conditions, which thus made it well-suited for analyzing transportation and logistic policies. While models can always be improved with more data, we were able to overcome data-deficiency challenges by creating probable estimates for missing variables based on demographics and available freight and logistics data. Organizations that face similar data challenges can similarly apply these methods and utilize the sources that we have identified.

[92] Profita, Cassandra. "California's Landmark Electric Truck Rule Targets 'Diesel Death Zone'". *National Public Radio*. June 16, 2020. https://www.npr.org/2020/06/26/883634480/californias-landmark-electric-truck-rule-targets-diesel-death-zone

Care has been taken to ensure that the code, spreadsheets, and equations used in the creation of our model are well documented and intuitive to apply to other contexts. New users of the model need only replace our data with new data specific to their own contexts.

Municipalities that are deciding among varied transportation emission policies would likely benefit from use of our model. The main benefit of quantifying a policy's impacts is that it allows easy comparison to other policies. A key insight that can be gained from the application of our model is the change in vehicle-routings that would occur in the presence of ZEDZ policies. These new routings, in addition to providing emission results, could also be used to help assess how overall traffic would change from these policies, and this information would be useful in subject matters outside of climate mitigation. Municipalities, which likely have access to a greater wealth of data, would be able to finetune the parameters of our model further.

Research institutions, including our client The World Resources Institute, may be interested in adding additional complexity to our model to further enrich the results. For example, the types of deliveries examined can be expanded to include types other than parcel deliveries.

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Appendix A - Literature Review

Literature Review: Zero Emission Delivery Zones

Introduction

Due to growing concerns about climate change and skyrocketing demand for sustainable energy, many national and local governments are explicitly aiming to achieve "Carbon Neutrality" by 2050 in line with the United Nations Sustainable Development Goals (SDGs). For this to be achieved, a drastic reduction in greenhouse gas emissions is necessary. Though many policies are being proposed to combat the detrimental effects of climate change on communities across the world, few national governments are taking interest in the impacts of freight transport on the environment. For example, air pollution constitutes one of the biggest issues facing urban areas across the world and “there are clear indications that premature mortality due to air pollution exceeds significantly the number of traffic accident fatalities” (Jiang et al. 2016, 3370). Ranieri et al. (2018) states:

> “The impacts of transport air pollutant emissions are highly related to geographical position, and they are affected by many local factors, such as existing transport means and traffic. The impacts caused by the emissions are determined by evaluating human health diseases and environmental damages related to a unitary increase in the air pollution concentration. Epidemiological studies indicate that the most important air pollutants in urban area are: Particulate Matter (PM), Nitrogen Oxides (NOx), Carbon Monoxide (CO), aliphatic and aromatic hydrocarbons, Sulfur Dioxide (SO2) and heavy metal; the impacts on humans and the ecosystem are evaluated, and the related monetary costs are estimated.” (2)

Thus, freight transport constitutes a “major contribution to air pollution,” however, policy makers “rarely consider” the sector for regulation (Cruz & Montenon 2016, 555).

New innovations in technology and policy have occurred in the last two decades, allowing local governments to implement novel methods to curb pollutants and foster healthier environments for their constituents. Of particular interest is the impact of zero emission delivery zones (ZEDZ) on cities in Europe, Asia, and the United States in terms of greenhouse gas (GHG) emissions, local air pollution and equity. The current literature surrounding these zones is relatively sparse, with more emphasis on existing low emission zones (LEZs) rather than ZEDZ. However, several pilots are underway that may offer insight into political and economic feasibility as well as positive effects on communities and the environment. In order to capture the potential of ZEDZ, this review will be broken down into several sections. The first section will discuss the background and importance of the last mile logistics; the second will briefly explore policy alternatives policy makers will likely be faced with; the third will cover case examples of current ZEDZ and similar pilots, the fourth will highlight the possible obstacles faced by ZEDZ; the fifth will be centered around current iterations of ZEDZ; the sixth section will discuss equity concerns, and the final section will present possible models that can be used to evaluate ZEDZ policies.

Background: The Importance of Last Mile Logistics

Last-mile logistics - the final part of the supply chain from the last distribution center to the consumer - is an emerging area of study that is attracting academic and professional attention due to transport externalities (Ranieri et al. 2018; Lim, Jin, and Srai 2018). Ranieri et al. (2018) concludes that the major externalities are "air pollution, climate change, noise pollution, congestion, accidents and infrastructure wear and tear in the transport sector" (2). Last-mile logistics are alleged to be the most inefficient stage of delivery, and the cost of last-mile delivery accounts for a substantial part of the overall supply chain with scholars estimating that 28% to 75% of total costs are incurred in this distance (Gevaers et al. 2009; Wang et al. 2016). Furthermore, the transportation industry accounts for 17% of the world's total greenhouse gas emissions and is an important area of discussion when considering global warming (Ritchie 2020).

Several factors explain the rapid growth of the importance of the last leg of delivery: the emerging e-commerce market (Lim, Jin, and Srai 2018), urbanization and population growth (Cárdenas, Beckers, and Vanelslander 2017), innovation (Ranieri et al. 2018), and sustainability concerns (Aljohani and Thompson 2019). The growth in e-commerce specifically has caused several vital issues, especially during the last mile (Gevaers, Van de Voorde, and Vanelslander 2009). Many freight vehicles used in last-mile logistics are light commercial vehicles, which constitute small and unoptimized loads (Allen et al. 2018). As most of these light-duty vehicles are diesel-powered, the emission of GHG is thus relatively higher in the last mile (Allen et al. 2018). According to the Rocky Mountain Institute, light and medium-duty freight trucks “account for nearly half of overall road freight CO2 emissions and around 4% of global CO2 emissions” (Liu et al. 2020). The use of diesel-fueled freight trucks not only contributes to overall GHG emissions, but also places significant costs on firms who pay at least “35%” more in maintenance costs compared to electric freight owners (Lee et al. 2013). Therefore, mitigating the externalities of last-mile logistics is essential.

The need to deal with these externalities has led to a significant increase in academic interest in this area. In fact, 75% of the last mile research has been published within the last five years (Olsson et al. 2019). However, due to the complexity of urban logistics, it’s possible that the research into last mile logistics is not mature. Olsson et al. (2019) conducted a systematic literature review and categorized the methodologies used in last mile logistics research into six major parts: modeling and simulation, case studies and interviews, surveys, theoretical and conceptual papers, multi-methodology, and systematic literature reviews. The authors argue that the diversity seen in those multiple categories exemplifies that there are no unified theories in this field. Therefore, according to Olsson et al., there is still room for research to contribute to theory building, elaboration, and testing.

Innovation in both vehicles and policymaking are two of the cardinal options to reduce externalities created by urban delivery. Electric vehicles (EVs) are an essential part of reducing GHG emissions and air pollution caused by last mile logistics. For example, Menga et al. (2013) show the effect of introducing electrification of vehicles, including two-wheelers, into last mile delivery to reduce externalities. The authors studied the impact of replacing current delivery vans with EVs in the city of Milan, Italy and found that the daily driving distance is within the vehicles' driving range, so it is possible to charge them at night. Therefore, there is no need to install a large-scale public charging infrastructure in the city center, and EVs can be introduced without changing the current logistics system significantly.

Policy Alternatives

There are several different policy alternatives being tested across the world to incentivize sustainable transportation both for delivery and passenger vehicles including, but not limited to: urban consolidation centers (UCCs), congestion pricing, electric vehicle subsidies, night time deliveries, green loading zones, and rail transport. These alternatives can be grouped into two categories: Policies to promote zero emission vehicles and policies to improve the efficiency of delivery.

Promoting Zero Emission Vehicles

Electric Vehicle (EV) Subsidies

Battery electric vehicles generally have a high purchase price but are known to have low operating costs, suggesting that subsidies can have a significant impact on EV uptake by consumers and freight vehicle owners. In regards to the latter, however, a study by Lebeau et al. (2016) found that delivery companies often do not fully evaluate the environmental performance or operating costs of their vehicles, leading the authors to suggest that subsidies should be used in conjunction with other policies. Ultimately, the main cost incurred by logistical companies will be the conversion of their gasoline vehicles into electric vehicles. Some of this direct cost will be inherently compensated by how EVs save money on fuel. However, the fact that businesses are not making this transition voluntarily suggests that the costs outweigh the savings for these companies. Additional costs will come in the form of the logistical cost of charging these vehicles and finding charging stations along their routes. These costs will thus largely depend on the price of EVs, the price of fuel and electricity, and the availability of charging stations, all of which are extremely context specific. This complexity adds uncertainty and risk to businesses looking to make investments to transition their fleet.

Nonetheless, in a comparison of electric and diesel trucks, Lee et al. (2013) found that the former uses between “14% and 34%” less energy overall than the former at the lowest and highest electric freight efficiency, respectively (8028). While electric trucks have an upfront cost that is about 1% greater than their diesel counterparts, the literature establishes that “CO2 generated by transport trucks burning carbon-based fuel represents a serious threat to the environment” (Lee et al. 2013, 8022; Brown & Guiffrida 2013, 504). By switching to electric delivery vehicles, firms can potentially offset the “28%” of total delivery costs incurred in the “last leg of the supply chain” and create upwards of “$1 million in health benefits from reduced air pollution” for every fifteen electric freight trucks (Wang et al. 2016, 279; Nowlan & Usmani 2021, 2). Therefore, robust EV subsidies paired with novel sustainability policies may catalyze an industry shift toward electric freight vehicles.

Congestion Pricing

Congestion Pricing is a policy designed under the premise that reducing traffic congestion could reduce greenhouse gas emissions and other externalities resulting from a high number of polluting vehicles on the road. By attaching a toll to certain vehicles during peak traffic hours, the policy is meant to change behavior of individuals by incentivizing avoiding driving during peak hours. The implementation of congestion pricing varies from city to city by the number of enforcement hours, location where the policy is implemented, and the type of vehicles included in the pricing models.

Congestion pricing is a policy that has the potential to improve urban freight logistics. While most congestion pricing is aimed at reducing non-logistical transportation, some have aimed to assess the effect of congestion pricing on last mile logistics (Börjesson & Kristoffersson 2014; Liu, Zhang, & Yang 2017). Chen et al. (2019), for example, investigated how the congestion charging mechanism affects the behavior of couriers and e-commerce consumers, ultimately finding that the policy influences the behavior of freight companies and consumers in regards to early and late deliveries, freight volume, and consumer preferences around delivery times. The authors go on to propose a pricing model that incorporates e-commerce logistics practices into a theoretical bottleneck model.

Other behavior changes from congestion pricing can also include decisions consumers make on the type of vehicles they are purchasing. For example, in a 2021 study Washington

State University researchers found congestion pricing could "reduce the vehicle fatality rate, generating $25 billion in annual benefits and could improve vehicle fleet fuel efficiency, generating roughly $10 billion in annual operating cost savings" (Winston 2021).

Improving Delivery Efficiency

Urban Consolidation Centres (UCCs)

One of the policies that has emerged to address issues caused by last mile delivery is freight consolidation at Urban Consolidation Centers (UCCs) (Ranieri et al. 2018; Janjevic and Ndiaye 2017). UCC policy facilitates the use of logistics facilities located in peripheral areas of cities to consolidate deliveries to the consignees (Browne et al. 2005). These centres are expected to reduce the number of urban freight vehicles needed, improve the reliability of deliveries, and increase the efficiency of freight forwarders. Antwerp, Belgium, for example, introduced a UCC policy and the total distance traveled was reduced by 22% and fuel consumption by 36% compared to conventional direct delivery without consolidation (Kin et al. 2016). However, as many UCCs depend highly on government subsidies, it is reported that the financial sustainability of the policy is a critical issue (Janjevic and Ndiaye 2017).

Off Hour Deliveries (OHD)

Shifting urban freight deliveries to off-peak hours has the potential not only to increase the efficiency of freight deliveries, but also to reduce externalities. Fu & Jenelius (2018) evaluated a pilot project implemented by the City of Stockholm between 2014 and 2016 which allowed large trucks to deliver goods in the city during the night. The authors found that by shifting deliveries from peak daytime hours to nighttime, better transport efficiency could be achieved in terms of operational efficiency, delivery reliability, and energy efficiency.

A 2011 study of off hour delivery programs in New York also found the switch of truck traffic to off hours brought about substantial economic benefits with travel speeds increasing from 11.8 miles/hour during peak traffic hours to 20.2 miles/hour during off hours. There were also huge reductions in service times during off hours from a maximum of 1.8 hours per customer to 0.5 hours in the evening hours as well as travel time reductions amounting to a 6% decrease in Manhattan (Holguín-Veras 2011). Economic benefits of a full implementation OHD program ranged from $147 to $193 million per year. These savings correspond to travel time and environmental pollution savings.

Zero Emission Delivery Zones ("ZEDZ")

Zero Emission Delivery Zones ("ZEDZ") are areas created with the explicit goal of reducing and ultimately eliminating greenhouse gas (GHG) emissions released by delivery vehicles and can thus be seen as a combination of innovative policies and vehicles (C40 cities et. al 2020, 4). These zones require the use of electric freight and delivery trucks, thus limiting the amount of traffic congestion and pollution located within established boundaries. According to C40 Cities et. al (2020), ZEDZ may have the added effect of helping countries and localities meet decarbonization targets, reducing noise and air pollution, facilitating the creation of green spaces, and stimulating demand for electric freight vehicles (4). The latter point is of utmost concern as many firms are still reliant on diesel trucks which consume more than "28%" more energy and emit "38%" more GHGs than their electric counterparts (Lee et. al 2013, 8028).

Current ZEDZ include, but are not limited to: Santa Monica, CA; Amsterdam and Rotterdam in the Netherlands; London, England; and Shenzhen, China (C40 Cities et al. 2020). The underlying premise in each of these countries is the same, namely, to reduce harmful emissions by requiring the use of electric vehicles. Even so, each city is quite different and thus requires the use of context-specific policy tools and incentives to garner or ensure compliance. In Santa Monica, for example, the first ever pilot of ZEDZ is underway in the form of a last-mile delivery zone that is currently voluntary (LACI 2020), whereas London is incrementally moving toward a city-wide zero emission zone using different mechanisms such as the deployment of a city-wide low emission zone, congestion pricing at all times, and a 22 square kilometer ultra-low emission zone (C40 Cities et al. 2020, 45-47).

All this is to say that each iteration of ZEDZ will look different in every context and are ultimately shaped by what is politically and economically feasible for city governments. Even so, Low Emission Zones (LEZs) in the EU show incredible promise in reducing air pollution as Jiang et. al (2016) and Jones et. al (2012) show in their analyses. Comparing data from within and outside LEZs in Germany, Jiang et al. (2016) found that LEZs experienced a nearly 42% decrease in the average number of exceedance days - days in which air pollutant concentration exceeds the EU maximum - per year (Jiang et. al 2016). Jones et. al (2012) similarly finds a 33% to 65% reduction in ultrafine particulate matter and a 30% to 59% reduction in ambient particulate matter in London and Birmingham LEZs, however, it must be stated that the concurrent implementation of a "'sulphur free'" diesel policy may have contributed to these reductions (137). A more detailed discussion of current iterations of ZEDZ will occur in the next section.

Finally, according to authors Nowlan and Usmani (2021), there is a "significant unmet need" in terms of demand for zero-emissions last-mile delivery (9). Some e-commerce platforms and shippers have already made commitments from zero-emissions shipping by a date to general pledges to combat climate change. These commitments cannot be reached without zero-emissions shipping (Nowlan 2021, 9). Companies have set transportation-specific targets. Ikea, for example, "committed to 100% zero-emissions last-mile delivery and to become climate positive" (Nowlan 2021, 5). Etsy offsets 100% of their carbon emissions from shipping and Walmart announced zero-emissions shipping throughout their supply chain by 2040 (Nowlan 2021, 5). However, this can become difficult as most companies contract out shipping services rather than owning their own fleets. Carriers typically ship multiple items from different companies in the same truck. It can become an extreme operational complexity and cost burden that could prohibit shippers from requesting specific vehicles to make their deliveries. (Nowlan 2021, 5). In a ZEDZ model, a shipper or group of shippers, will "sponsor" zero-emission vehicles (Nowlan 2021, 6). This will allow companies to ensure their deliveries are not contributing to air pollution, greenhouse gas emissions, and adverse health effects.

Current Iterations of Zero Emission Zones

The following are currently known zero emission zoning programs being implemented. In some cities more stringent policies such as zero emission zone (ZEZ) are used where policies targeting freight and delivery vehicles are included under the wider goal of zero emissions across cities. In others there is more of a focus on ZEDZ. More cities are expected to adopt ZEDZ or similar policies in the near future. The C40's Zero Emission Vehicles Network for example includes the following cities: Amsterdam, Auckland, Austin, Copenhagen, Dar es Salaam, London, Los Angeles, Houston, Madrid, Mexico City, Nanjing, New York City, Oslo, Salvador, San Francisco, Seattle, Shenzhen, Toronto, and Warsaw. This network includes cities that are pursuing a transition to zero emission vehicles and serves as a platform for cities to share best practices and policies (C40 Cities 2022). In addition 35 cities have signed the C40 Green and Healthy Streets GHS Declaration and committed to achieving zero emission zones by 2030 (C40 Knowledge Hub 2020).

Santa Monica, United States

In conjunction with the Los Angeles Cleantech Incubator (LACI), a private non profit working to accelerate the commercialization of clean technologies, the City of Santa Monica launched the first ZEDZ in the US in February 2021. The zone is a pilot zone composed of a one square mile voluntary zone involving 15 partners. The partners are composed of participating delivery companies (including Ikea, Axlehire, Guayaki, Alsco Uniforms, Foodcycle, Shopify, and REEF Technologies) who will voluntarily deploy and test zero emission modes of last mile delivery, and tech providers who will help monitor implement, and evaluate the zone.

The zone is located in the commercial activity core of Santa Monica with up to 20 zero emission loading priority curb areas. The ZEDZ is designed to provide priority curb access to participating zero emission delivery vehicles completing last mile deliveries. The technology used to monitor the program comes from Automotus, a private tech start up specializing in curb management. Automotus monitors and analyzes vehicle activity in each curb zone, collects anonymized data for impact evaluation of "delivery efficiency, safety, congestion, and emissions," and provides real-time parking availability data for ZEDZ participating drivers (City of Santa Monica 2021). Other tech partners include Maxwell Vehicles, Circuit, and Freewire, but based on public records it is unclear what their role is in the program. The City of Santa Monica also reports additional collaborations with the following tech providers: Coco, Kiwibot, Tortoise, Rollo, Blue Systems, Fluid Truck, Motiv Power Systems, Nissan, ROUSH CleanTech, and Lighting eMotors.

One of the stated goals of this pilot program is to provide insights for other cities, regulators, and industry leaders around ZEDZ and the reduction of long term exposure to pollution. The program's other goals also include using metrics around zero emission delivery use, congestion, safety, dwell time to inform future deployments of ZEDZ in Los Angeles and other urban areas, as well as to demonstrate the technology needed to implement ZEDZ. The technology innovations the program seeks to pursue include "electric micro mobility solutions for food and parcel delivery, medium-duty and light-duty electric delivery vehicles for goods, and first-in-the-nation commercial medium-duty electric truck-sharing and charging available for local small businesses,"(City of Santa Monica 2021).

The ZEDZ in Santa Monica is part of a larger multi year initiative LACI launched in 2018, called the Transportation Electrification Partnership (TEP), that brought together local government officials, utilities, state regulators, industry leaders, and start ups with the goal of reducing GHG emissions and air pollution in the greater Los Angeles area. The TEP launched the Zero Emissions Roadmap 2.0 in 2019 with the goal of accelerating the electrification of vehicles and "zero emission goods movement" by 2028 in time for the Olympic and Paralympic Games (LACI 2019). Other policies included in the TEP include congestion pricing and reducing vehicle miles traveled.

One of the calls to action the Zero Emission Roadmap 2.0 proposes is investing in goods movement, freight vehicles, and related infrastructure that will advance zero emission solutions. They specifically target the I-710 freeway in their proposal with the goal of creating a zero emissions freight corridor along the I-710 freeway by 2028. Last-mile innovation is also included in this proposal with a recommendation to create voluntary ZEDZ in congested areas.

London, United Kingdom

London currently has boroughs that are implementing UltraLow Emission Zones (ULEZ) and Low Emission Zones (LEZ). ULEZ launched in April 2019 and was originally in place in central London with the zone being operational 24 hours a day throughout the year, except on Christmas Day. (Transport for London "Low Emission Zone"). On October 25, 2021, London expanded the ULEZ zone to cover more area, resulting in a zone that is 18 times larger than the original central London zone and covering 3.8 million people. Vehicles driving in ULEZ must meet ULEZ emission standards or are charged a 12.50 pounds fee to drive in the zone. Certain vehicles are exempt from ULEZ standards, such as vans or specialist heavy vehicles, but they must still meet LEZ emission standards to avoid facing charges.

LEZs on the other hand first came into operation in February 2008 and are located in Greater London with the zones operating 24 hours a day throughout the year (Logistics UK). The LEZ applies to buses, heavy goods vehicles (HGVs), and coaches (a bus used for longer distance travel) with a requirement to meet the Euro IV standard for particulate matter emissions. Vans and minibuses began being included in LEV's in 2012 with the requirement of meeting the Euro 3 standard for particulate matter emissions. The daily charges for violating LEZ emission standards are much higher than ULEZ, with the charge for vans or HGVs weighing less than 3.5 tonnes totalling 100 pounds per day and a 300 pounds per day charge for HGVs or vans weighing over 3.5 tonnes (Transport for London "How to pay a LEZ charge").

Zero Emission Zones (ZEZ) were first stated as a policy goal in 2018 as highlighted in the London Mayor's 2018 Transport Strategy in Proposal 35. Proposal 35 states the following, "The Mayor, through TfL and the boroughs, and working with Government, will seek to implement zero emission zones in town centres from 2020 and aim to deliver a zero emission zone in central London from 2025, as well as broader congestion reduction measures to facilitate the implementation of larger zero emission zones in inner London by 2040 and London-wide by 2050 at the latest," (Greater London Authority 2018). In September 2019, a guidance for local zero emission zones was published by the Transport for London (TfL) authority. Boroughs who wish to participate in ZEZ programs are able to request funding support through various city funding programs and entities including the Mayor's Air Quality Fund and the Liveable Neighborhoods Program.

ZEZ is a policy that is part of the Mayor's larger goal of having a zero carbon London by 2050. The Mayor's Transport Strategy states that a Central London ZEZ will be delivered by 2025. By 2040 TfL aims to begin implementing larger ZEZs in inner London and then expand ZEZ across London by 2050. The appeal of the policy comes from the fact that the current LEZ and ULEZ still do not meet target levels of particulate matter (PM). The World Health Organization for example has a PM target of 2.5 by 2030 that London is including in its 2050 goal. ZEZs offer a pathway to improve air quality by incentivizing the shift towards zero emission vehicles.

ZEZ in London provides a model that targets emissions beyond delivery zones with its inclusion of all vehicles in the city. Two approaches for local boroughs to adopt are provided in the Tfl guidance. The first approach aims to integrate ZEZ into existing Healthy Streets projects that focus on prioritizing walking, cycling, and public transport. The second approach focuses on targeting local air pollution hotspots where ZEZs are used as an "intervention to improve air quality and protect sensitive receptors and user groups, such as schools or hospitals," (Transport for London 2019). This approach also recommends applying ZEZs in a "tightly defined local area for a specific time period", as well as introducing micro-consolidation facilities so freight and servicing can be conducted with zero emission last mile modes and vehicles," (Transport for London 2019).

The boroughs in London that currently have ZEZ include Islington and Hackney (boroughs of Greater London) with ZEZ that started in 2018. Petrol and diesel vehicles are banned from these zones between Monday and Friday from 7-10 am and 4-7 pm. Automatic Number Plate Recognition (ANPR) cameras are used for enforcement, and the penalty for violation can go up to 130 pounds ("London - Zero Emission Zone Islington and Hackney"). The City of London (the historic city and financial district) also has a ZEZ that began in June 2020 which involved removing permissions for vehicles during certain times of the day that had large pedestrian usage ("London ZEZ - Islington and Hackney").

China

As of 2020, 14 cities in China, such as Shenzhen, Chengdu, and Beijing, have implemented some form of a zero or low emission freight zone, with Shenzhen being the only city with a strict zero emission delivery zone.

Shenzhen

Shenzhen has had a zero emission freight zone since 2018 and was the first city in the world to introduce a zero emission freight policy. The policy included 10 "green logistic zones", where all day free access is available to electric freight vehicles weighing under 4.5 tonnes, while fossil fuel freight vehicles were banned from these zones (Xue 2021). The city began implementing the policy with multiple small zones rather than having simply one large zone. The zones covered 1.1% of Shenzhen's land area with each zone spanning 0.4 to 5.4 square kilometers. Zone locations were determined by hot spot modeling where high levels of pollutants and CO_2 were identified. Shenzhen utilized financial incentives and a vehicle leasing scheme to incentivize the transition to zero emission freight vehicles. This allowed small logistic providers specifically to be able to meet policy requirements, when they otherwise would not have the capital to do so. Another factor allowing Shenzhen to more easily adopt a zero emission freight zone is its high investment in freight vehicle electrification and charging station infrastructure through the use of subsidies and a complex incentive structure for logistics companies to optimize vehicle use patterns. Shenzhen is reported to have more than 70,000 vehicles in its ELV fleet putting it the furthest along in adopting full logistics electrification (Zhe 2020).

In 2020, the Rocky Mountain Institute (RMI) in conjunction with the city of Shenzhen, published a report summarizing the utilization rate of electric logistics vehicles (ELV) in Shenzhen as well as opportunities to improve ELV utilization. The report highlights two challenges Shenzhen faced once ELVs became widely expected to replace ICE vehicles. The first is the ability of ELV's to perform on long distances and with heavy loads. ELVs in Shenzhen are advertised to achieve an average of 250 km for best case range and an average of 135 km for worst case range. The worst case range and variability in range is what disincentivizes operators from completely getting rid of ICE vehicles. The second issue is vehicle performance specifically with regards to battery degradation. This performance issue leads operators choosing to lease ELVs rather than purchase them.

Beijing and Chengdu

Beijing has had an off hour delivery policy in place since 1984 with freight deliveries done at night and a limited number of freight deliveries allowed to be done during the day. By 2018, the city implemented the Blue Sky Defense War plan that required all freight vehicles less than 4.5 tonnes to be zero emission by 2020. In 2019, access permits were being experimented with to see if the permit could help meet zero emission fleet targets. Similarly, Chengdu's zero emission zone limits access for deliveries between 7 - 10 am and between 5 - 9 pm with only the window of 10 - 5 pm allowed for freight vehicles to enter zones (C40 Knowledge Hub 2020).

Oslo, Norway

Oslo has had a low emission zone (LEZ) in operation since October 2017. The LEZ is active Monday to Friday between 6 am and 6 pm. The LEZ is combined with congestion pricing with reduced tariffs available to electric cars depending on what area of the zone you're driving in. The city is currently in the process of also implementing a zero emission zone with the goal of making designated areas completely car free ("Oslo - LEZ - CS"). In 2017, the city launched the Car-free Livability Program with the goal of decreasing cars in the city centre. By 2018, 760 parking spaces had been removed and in 2019 the city was working to make the streets more bicycle and pedestrian friendly (Oslo kommune 2019).

Oslo aims to reach zero emissions by 2030 and is progressing in developing ways to deliver freight through zero emission technology. DB Schenker, a global logistics company, has already built a logistics center for non compliant vehicles to deliver goods that can then be transferred to zero emission vehicles including trucks and electric cargo bikes entering the city. (“Oslo’s Zero-Emission City Center” 2020).

Netherlands

The Netherlands has a national framework for low emission zones called “milieuzones”. In these zones passenger vehicles and vans are subject to emission standards based on zone type. Yellow zones (no yellow zones are in operation currently) allow vehicles meeting the Euro 3 emissions standard and the green zones (currently used in Amsterdam, Arnhem, Den Haag, and Utrecht) allow vehicles that meet Euro 4 emission standards into the zones. Heavy duty vehicles and coaches are also subject to zone requirements but only green zones apply to trucks (“Netherlands”). Only Amsterdam is reported to have a green zone that applies to coaches. Rotterdam is also an exception with a zone for trucks that has higher standards (the Euro 6 standard).

Low Emission Zones currently exist in 15 cities and 30 Zero Emission Zones currently exist across the country (“Netherlands”). It is also reported that 30 cities in the Netherlands have set timelines for introducing zero emissions freight zones by 2025 (Broom 2021). This initiative is part of the “Urban Logistics Implementation Agenda” signed by the Dutch Environment Minister Stientje Van Veldhoven, transport companies, and municipalities.

Implementation Obstacles Faced by ZEDZ

Political will

The political impetus for ZEDZs are largely derived from agreements to reach certain GHG targets. In the Netherlands, the implementation of ZEDZs is part of a larger strategy to meet the “National Climate Agreement”, which aims to reduce carbon emissions by 49% compared to 1990 levels (Climate Agreement 2019, 5). The same agreement that specified this goal also designated the implementation of zero-emission zones in a minimum of 30 cities, directly framing these zones within the context of larger climate initiatives (Climate Agreement 2019, 68). Santa Monica has also made such goals part of official city policy, with the city pledging to decrease carbon emissions to 80% below 1990 levels by 2030 (Climate, Action & Adoption Plan, 6). Political support for ZEDZs will likely reflect general views on global warming and climate mitigation policies. According to a report by the Brookings Institution, “about a third to almost half of the public believes that the seriousness of global warming is generally exaggerated”, and this belief is very partisan with Republicans being much less likely than Democrats to rate global warming as a serious threat (Kamarck, 2019).

Additionally, implementation of ZEDZs will likely suffer from a “concentrated costs, dispersed benefits” problem. The cost of implementing ZEDZs will fall on relatively few businesses, while the benefits will be thinly spread across a large number of people. These individual businesses will have a large incentive to strongly advocate against ZEDZs, while individual citizens that benefit have a much smaller incentive to advocate in favor. This will likely lead to strong resistance against ZEDZs from these negatively-affected companies and a comparatively weak showing of support from benefitting citizens. James Q. Wilson describes policy-making with concentrated costs and dispersed benefits as “entrepreneurial politics”, and notes that “legislation of this type is inherently difficult to pass and requires skilled political entrepreneurs to mobilize the public and politicians” (Pal and Weaver 2003, 13)

Cities often have significant to complete leeway in determining the exact implementation strategy of ZEDZs, which cities can leverage to implement ZEDZs in the most politically-acceptable ways possible. While Netherlands’ zero-emission zones are part of the larger Climate Agreement, “municipalities will be responsible for the decisions and choices surrounding the introduction and enforcement of a zone” (Climate Agreement 2019, 69). Los Angeles has agreed to conduct a “ZEDZ pilot program” to test the feasibility of these zones within the context of the city and county and this pilot program is stated to “encourage clean renewable energy use” by creating “commercial loading zones exclusively available for zero-emission commercial delivery vehicles” in five locations around the city (Reynolds 2021, 1; City News Service 2021). Pilot programs such as this can potentially be used to address problems before they arise and ease public anxieties about the program

Cost

The main cost to logistical companies will be the cost of converting their gasoline vehicles into electric vehicles. Some of this direct cost will be inherently compensated by how EVs save money on fuel. However, the fact that businesses are not making this transition voluntarily suggests that the costs outweigh the savings for these companies. Additional costs will come in the form of the logistical cost of charging these vehicles and finding charging stations along their routes. These costs will thus depend largely on the price of EVs, the price of fuel and electricity, and the availability of charging stations, all of which are extremely context specific. Additionally, these costs will be influenced by specific policies undertaken by the city, such as subsidies.

ZEDZs can be implemented in phases in order to reduce the transition burdens on logistics companies. When the Netherlands implemented its “Climate Agreement” in 2019, it was agreed that at least 30 cities would implement zero emission zones by 2020, but with the caveat that logistical companies would be exempt from these restrictions until 2025 in order to allow these businesses to “make preparations in good time” (Climate Agreement 2019, 68-69).

City governments, too, will face costs to enforce adherence to regulations inside the ZEDZs, costs to put up signage and other markings denoting the area of a ZEDZ, and the cost of constructing supporting infrastructure, such as EV charging stations. These costs are also extremely context specific and will depend on the exact policies that cities wish to implement. For its ZEDZ pilot program, Los Angeles spent only $2000 per ZEDZ location, however this only involved the construction of “loading zones for the ‘exclusive use and access by zero-emission commercial delivery vehicles’” (City News Service 2021).

Equity Concerns

An important metric policymakers of all stripes must consider when crafting ZEDZ is equity. Historically speaking, communities of color often bear the brunt of environmentally harmful practices and people of color are more likely to experience “exposure to environmental and health risks” spawned by uneven environmental regulation enforcement in the United States (Bullard 1993, 17). For example, Starbuck & White (2016) find that “children of color make up almost two-thirds of the 5.7 million children who live within one mile of a high-risk chemical facility” and make up an increasing proportion of those who attend school near one (1). Tubert (2020) asserts “environmental burdens… disproportionately affect communities of color” and lists increased exposure to toxic waste, shortened expected lifespans, a myriad of health issues, and cites how “efforts to rebuild communities of color [after severe weather connected to climate change] are often inadequate compared to efforts to rebuild white communities” (1-3). Thus, it is becoming increasingly apparent that substantive interventions and the implementation of sustainable initiatives in communities of color - which are often the poorest communities - are urgently needed. ZEDZ, therefore, can be seen as an environmental good that brings with it several benefits including, but not limited to: decreased air pollution, sustainable infrastructure, and decreased GHG emissions. While these zones currently exist in wealthy urban areas (e.g London, Santa Monica), the potential for their spread across countries constitutes an area where positive change and equity can be fostered - especially in communities of color. Several recommendations have appeared across the literature on last-mile logistics in terms of equity, especially as it relates to air pollution and home prices.

According to the authors Nowlan and Usmani (2021), air pollution causes and aggravates medical conditions including heart disease, diabetes, lung disease, asthma, and puts people at an increased risk of COVID-19 complications or death (2). These warehouses and distribution centers that manage last-mile deliveries are mostly in low-income communities and communities of color. This indicates that low-income communities and communities of color are disproportionately impacted by the negative effects of shipping (Nowlan 2021, 2).

ZEDZ aims to diminish this inequity by electrifying last-mile delivery. Local leaders, when determining ZEDZ, can issue maps of at-risk neighborhoods where the zones should be prioritized by private actors. Nowlan and Usmani (2021) also argue that “local and regional policymakers can also create enabling policies such as utility make-ready funding, access preferences in central business districts for ZEVs [zero-emission vehicles] that are launched from depots in at-risk communities” (7). State and local leaders play a critical role in facilitating the acceleration of ZEDZ in high-risk communities to improve health and reduce disproportionate health burdens.

One important equity concern of ZEDZs involves their impact on home prices and the process of gentrification. While ZEDZs will likely improve air quality, walkability, and other quality-of-life measures, in doing so they may also raise the price of rent, properties, and amenities and lead to displacement of populations presently living in these communities. In Seattle, Washington, the construction of new public light-rail facilities was found to increase the share of non-Hispanic whites in surrounding neighborhoods (Hess 2020, 181). However, a systematic review of 35 quantitative-based studies on the “gentrification outcomes resulting from transit-based interventions" found that gentrification is more closely associated with “local dynamics, built environment attributes, and accompanying policies than transit-oriented development” (Paderiro et. al 2019, 749).

Encouragingly, evidence suggests that there exist specific policies and strategies that cities can undertake to mitigate or prevent displacement. Research from the Brookings Institution recommends three broad categories of policies (Brookings 33-36). The first, “Taxation Tools” recommends allowing long time residents to defer potential tax increases that may result from rising home values; additionally, proportions of any increased tax revenue resulting from gentrification can be ear-marked to be devoted towards building more affordable housing. The second section, “Affordable Housing Preservation and Production”, recommends requiring housing developers to set aside specific proportions of new developments to be devoted to affordable housing, and existing affordable housing stock can be preserved via lower-interest loans and grants offered by the city government. Thirdly, “Economic Development and Income-Raising Tools” can be exercised by city governments to help ensure the “great economic resources that generally accompany a gentrifying community” are widely dispersed to its present population. These tools include small business loans to help allow existing businesses to take advantage of new market opportunities and guarantee employment of local residents in newly-built facilities.

A movement toward equitable access to the benefits of ZEDZ is thus necessary not only to reduce the disproportionate harm that communities of color experience but to increase overall quality of life for the many. In order to do so, at the broadest level, Heynen & Ybarra

(2020) comment on the necessity of learning from “environmental justice literature as it moves from localised neighborhood struggles against toxics towards a structural critique of the ways that exposures to environmental harms and access to environmental goods are unequally distributed by race, class, and empire” (2). While ZEDZ are a relatively new phenomena, the potential for their spread across the world constitutes an opportunity for policymakers to center equity concerns that are well-documented by the literature around environmental justice. Moving toward a more equitable distribution of the costs of climate change and the benefits of sustainability mechanisms like ZEDZ has the potential to offset the existing harms caused by environmental injustice.

Models

Various studies have attempted to model the impacts of zero-emission zones or similar policies. These models can broadly be categorized by the amount of data that they require, with some models being almost entirely theoretical and other models being data-intensive.

One theoretical model from an article in “Mathematical Problems in Engineering” attempts to determine which among three different types of last-mile delivery methods is optimal given certain circumstances such as the number of orders being delivered and distances between communities (Wang et. al 2014, 6). Their model consists largely of an objective function for each delivery method which represents the total delivery time per item delivered; this objective function is then minimized subject to a series of constraints, such as how each location should only be visited once or the carrying capacity of each vehicle (Wang et. al 2014, 3-4). Most of these constraints are generalizable and can be used in settings outside of China where the paper focuses. This optimization equation is graphed to produce zones that show under which circumstances each delivery method is best (Wang et. al 2014, 6). A similar approach can be used to compare delivery methods in an American city such as Santa Monica, and the only data needed would be the location of population clusters and the efficiency of different vehicle types.

Google OR-Tools provides a useful framework for coding and developing models for “capacitated vehicle routing problems”, which are delivery problems in which “vehicles with limited carrying capacity need to pick up or deliver items at various locations. The items have a quantity, such as weight or volume, and the vehicles have a maximum capacity that they can carry. The problem is to pick up or deliver the items for the least cost, while never exceeding the capacity of the vehicles” (“Carrying Constraints”). To create this model, the only data needed are the number of vehicles, location of destinations, location of return depot where the routes start and end, the demand of goods for each destination, and the carrying capacity of each vehicle (“Carrying Constraints”). This model produces an optimal route per vehicle in order to meet all the demand. In our analysis, we can add constraints to this model to represent the limitations imposed by a ZEDZ, and the resulting routes might suggest how traffic would change as a result of the ZEDZ.

One data-intensive approach attempts to assess the impact of zero-emission zones in the Netherlands (de Bok et. al 2020, 1). In their analysis, truck shipment data is the main data source utilized, and this data set contains information on “over 200 thousand observed truck trips”, detailing “the vehicle, the route, and shipments that were carried” from before the implementation of ZEDZs (de Bok et. al 2020, 2-3). The authors are able to use this data to fine tune a model that predicts shipment paths across Rotterdam (de Bok et. al 2020, 4-6). Once it has been verified that the model accurately predicts shipments, the authors then apply the constraint of the ZEDZ, finding that the ZEDZ reduced emissions within the zone but also increased total vehicle miles driven, mostly from outside the zone (de Bok et. al 2020, 7-8).

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Appendix B - Interviewee List

Communities		
Role	**Interview Goal**	**Org**
Community Organizer	-Understand local organizing landscape around similar zoning policies to ZEDZ	East Yard Communities for Environmental Justice
Alternative Fuels Program Manager	- Interviewee has been working on a project with several organizations which was funded by folks called the "Zero Now" initiative - goal was to create ZEZs - Utilize expertise to ask feasibility questions around ZEDZ	CalStart
Santa Monica, US based ZEDZ		
Role	**Interview Goal**	**Org**
Pilots Manager	-Understand LACI implementation process -Acquire data sets needed for model or data analysis	LACI (the org that implemented Santa Monica program)
Electric Vehicle Program Coordinator	-Understand the role the office played in partnering with LACI	City of Santa Monica Office of Sustainability and the Environment
Chief of Staff	-Identify any useful data sets for purposes of answering our policy question -Understand enforcement strategy and data collection processes	Automotus
Climate Advisor	- Discuss City of LA's plans of zero emissions curbs and compare them to the ZEDZ pilot in Santa Monica	City of Los Angeles
Chief of Staff	- Discuss the private sector, technology aspect of ZEDZ camera implementation	Automotus
Project Manager	-To better understand challenges and opportunities for businesses to transition to electric fleets	IKEA
Amsterdam, Netherlands based ZEDZ		
Role	**Interview Goal**	**Org**
Professor in City Logistics	- To understand structure of ZEDZ in Amsterdam - To identify any comparable data sources we can use	Amsterdam University of Applied Sciences
Utrecht, Netherlands based ZEDZ		
Role	**Interview Goal**	**Org**
Advisor International		Netherlands Enterprise Agency

Sustainable Logistics	- Obtain a government perspective in the Netherlands on their ZEZ's	(RVO)

Appendix C - Interview Guide

Topic	Question
Background	How did [insert organization name] become involved in ZEDZ?
	What was the process of choosing [insert city] as a pilot for ZEDZ?
	Who are the key players in ZEDZ both internationally and domestically in your opinion?
	How were different stakeholders brought into the process of formulating this ZEDZ?
	Why did you choose ZEDZ when there are other alternatives with regards to reducing GHG and hazardous substances?
Businesses	Was there resistance from businesses in the community?
	What do you anticipate to be the impact on businesses? Has there been any impact on businesses already?
	Did freight/logistic companies adapt well to the ZEDZ policies? Were any subsidies or other policies in place to make transitioning to EVs easier?
	Did you consult with the logistics company before policymaking? What did you discuss with them?
Processes and Results	Going into it, what were your primary hypotheses about ZEDZ and how have they changed over time?
	What results have you seen thus far?
	What was the community response to the development of such zones?
	What are you doing, or planning to do, for monitoring and policy evaluation?
	What are some of the possible direct or indirect costs of implementing this policy?
Data	Did you rely on any data to formulate your initial hypotheses about ZEDZ?
	Is there any data that you can potentially share with us?

	(Especially for the City of Santa Monica,) Could you give us some data on population by region, average daily freight volume, location of depots, Share of logistics companies etc.?
	What models were used to forecast the impacts of this ZEDZ? Were these models developed using real data?
Equity	Were there any equity concerns during the implementation of this ZEDZ?
	Was there any resistance from community members or residents in implementing these zones?
	Is there a risk that this ZEDZ would push traffic to less wealthy areas or contribute to gentrification?
	What was your approach to selecting the zone? Did you have any difficulties in deciding how far to include in the zone?
Ethics	The information obtained in this interview will be shared only between our UCLA team and our client, WRI. It will not be used for commercial purposes. It is possible that parts of the study may be made public, but in that case, due consideration will be given to confidentiality and anonymity. Do you have any concerns in this regard beforehand?
	Is it okay for us to record this conversation?

Appendix D - Details for the Pseudo-Empirical Data of Vehicles used for Parcel Delivery

Justifying Parcel Delivery Assumption

In our model, we made the simplifying assumption to only examine parcel deliveries. To justify this assumption, we examine if and how deliveries may change based on the type of good being delivered. To do this, we checked the driving characteristics of all last-mile delivery types using empirical vehicle driving data obtained from Fleet DNA[93]. **Table D-1** shows the summary statistics from this research, such as the daily vehicle mile traveled (DVMT). Characteristics other than DVMT are as follows.

- driving duration: driving time that does not include time spent with the car stopped,
- zero speed duration: the hours when the speed is recorded as zero (such as when the vehicle is idling or at a delivery),
- total average speed: the average speed for the day (excluding delivery and parking times but including times at stop lights),
- average stop duration: the average seconds per delivery stop,
- total stops: the total number of delivery stops for the day, and
- total stop duration: the total hours for the day spent at delivery stops.

The types of goods investigated include telecom, warehouse delivery, parcel delivery, linen delivery, food delivery, and utility.

***Table D-1**: Summary Statistics of Last-Mile Delivery by Type*

Vocation	Freqency	DVMT (mile)	Driving Duration (h)	Zero Speed Duration (h)	Total Avg Speed (mile/h)	Avg Stop Duration (sec)	Total Stops	Total Stop Duration (h)
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Telecom	185	27.50 (16.74)	1.11 (.56)	1.87 (1.76)	11.37 (5.11)	932.44 (1003.17)	47.26 (22.72)	11.26 (8.25)
Warehouse Delivery	60	93.16 (35.68)	2.80 (.69)	1.54 (.79)	21.85 (7.44)	613.44 (204.78)	83.32 (19.96)	13.73 (4.33)
Parcel Delivery	687	44.89 (23.51)	2.26 (.96)	2.55 (1.78)	10.31 (4.54)	299.99 (402.28)	143.84 (61.84)	7.87 (6.14)
Linen Delivery	423	68.14 (30.79)	2.22 (.77)	2.88 (1.86)	14.52 (6.3)	506.22 (407.48)	77.70 (32.59)	9.08 (4.02)
Food Delivery	357	38.86 (14.71)	1.16 (.33)	1.38 (2.42)	19.69 (8.27)	1777.07 (804.44)	30.51 (9.66)	13.65 (3.6)
Utility	127	27.54 (19.2)	0.91 (.55)	2.33 (2.01)	11.27 (8.17)	706.21 (674.64)	20.78 (13.08)	4.18 (4.11)
Total	1,839	47.69 (28.48)	1.85 (.95)	2.28 (2.01)	13.65 (7.32)	736.07 (809.51)	86.44 (63.83)	9.55 (6.01)

Source: Own with information from Fleet DNA, https://www.nrel.gov/transportation/fleettest-fleet-dna.html

[93] "Fleet DNA Project Data." (2020). National Renewable Energy Laboratory. Accessed February 28th, 2022: www.nrel.gov/fleetdna

It can be seen that each commercial type has different delivery characteristics. As our team lacked data on the specific delivery demands of Santa Monica, we chose to focus on parcel delivery for the following reasons:

- parcel delivery is one of the targets in the ZEDZ pilot project in Santa Monica[94]
- the geographic use of Santa Monica is mainly residential
- as the major industry of Santa Monica is tourism and finance[95], it is not expected that there are many deliveries associated with manufacturing
- the transportation characteristics of parcel delivery as indicated by FleetDNA are relatively similar to the overall total compared to other types of businesses

To support this last bullet point, **Figure D-1** is a histogram comparing parcel deliveries to the average of all delivery types combined based on the data gained by Fleet DNA. "All delivery" includes all the vocations listed in **Table 2.1:** telecom, warehouse, parcel, linen, food, and utility deliveries. From the figure, it can be seen that the distribution shape of parcel delivery is similar to that of total delivery for DVMT. As our model mainly focuses on total vehicle miles driven, this metric of DVMT is the most important. Because parcel deliveries are so similar to the average, only focusing on parcel deliveries makes sense in this context.

[94] Interview with Santa Monica official
[95] Data USA "Santa Monica, CA Census Place."
https://datausa.io/profile/geo/santa-monica-ca/#:~:text=The%20largest%20industries%20in%20Santa,Fishing%20%26%20Hunting%20(%24138%2C011)%2C

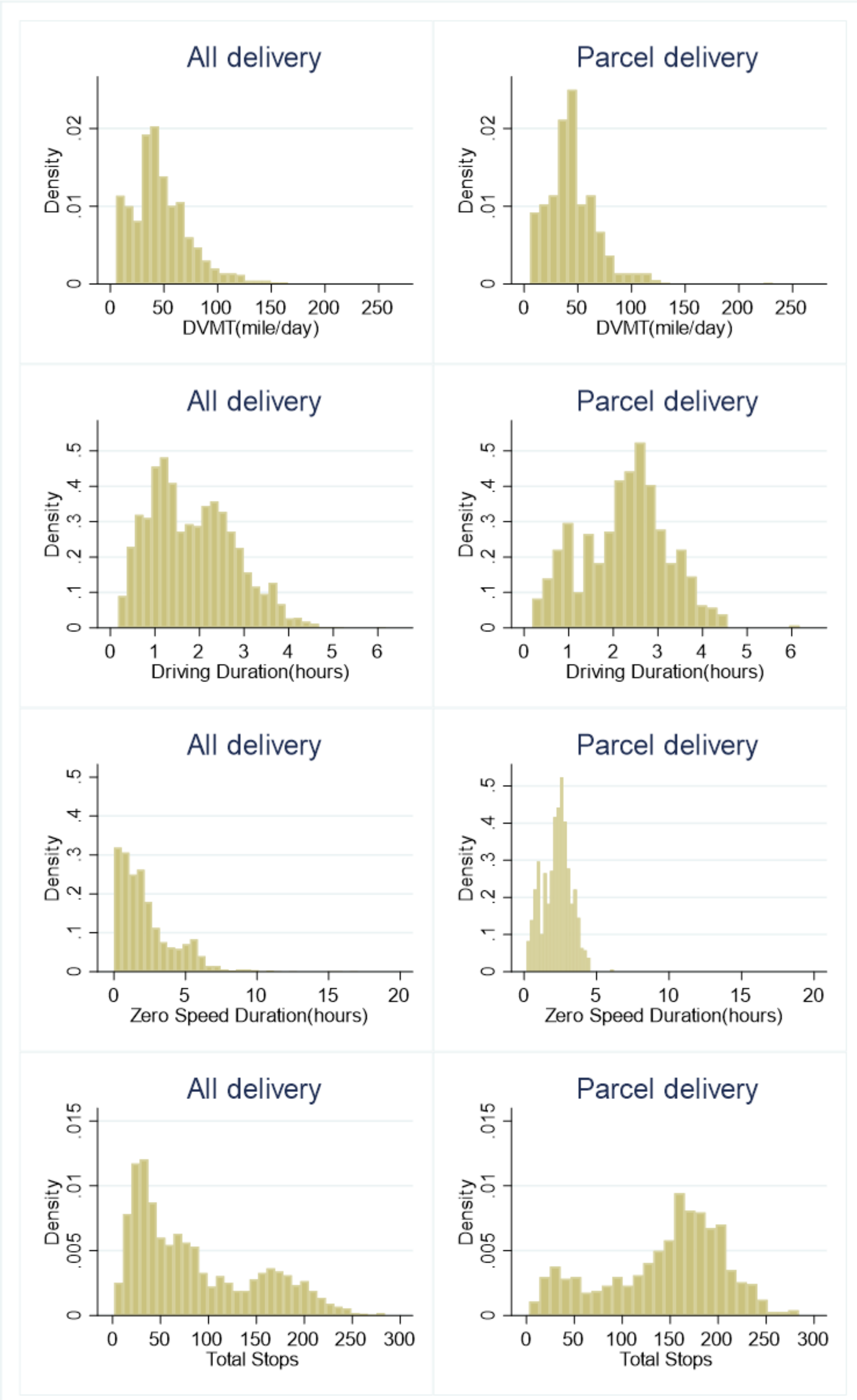
All delivery
Parcel delivery
Density
DVMT(mile/day)
Driving Duration(hours)
Zero Speed Duration(hours)
Total Stops

***Figure D-1**: Comparison of Parcel and All Last-Mile Delivery Characteristics*

Calculating the Incentive to Adopt EVs in the Voluntary ZEDZ

To further optimize our model, we take into consideration changes in idling time. Using values from **Table D-1** on parcel deliveries, driving time calculated from DVMT and Total Average Speed (4.35h/day) does not exactly match the sum of Driving Duration and Zero-Speed Duration (4.81h/day). The reason for this is that Zero-Speed Duration, in addition to including the times that are factored into the Average Speed calculation such as time spent waiting at traffic lights, also includes additional waiting times, such as time spent waiting for parking. Therefore, the difference (0.46h/day) can be assumed to be an upper bound for the amount of time spent waiting for parking and delivering goods. The driving time calculated from DVMT and Total Average Speed (4.35h/day) can be interpreted as a delivery hours lower bound. The incentive for using EVs in a voluntary ZEDZ is priority for certain loading and parking spaces. The reduction in time spent on securing parking locations (and thus the money saved on fuel) will be used as the incentive for companies to switch to EVs in the voluntary-ZEDZ scenario.

Characteristics of Delivery Vehicle Types

Here, we describe the characteristics of different delivery vehicles. **Table D-2** shows the vehicle class categories presented by the US Department of Energy (DOE)[96]. Since the Santa Monica ZEDZ pilot project targets up to Medium Duty Vehicles according to the classification by the Federal Highway Administration, we set the target vehicle classes as Class-1 to 6.

***Table D-2:** Classification of Vehicle Classes and Examples*

[96] DOE "Vehicle Weight Classes & Categories.", https://afdc.energy.gov/data/

Gross Vehicle Weight Rating (lbs)*1	Federal Highway Administration*1		Types of Vehicles*2	Examples*3*4			
				Name	Price ($)	Capacity (cf)	Payload (lb)
<6000	Class 1: <6,000lbs	Light Duty: <10,000lbs	Cargo Van / Mini Van	Nissan NV200	$22,300	122.7	1,480.0
10,000	Class 2: 6,001-10,000lbs		Cargo Van / Mini Van / Step Van	Mercedes Metris Van	$31,200	199.0	2,500.0
14,000	Class 3: 10,001-14,000lbs	Medium Duty: 10,001-26,000lbs	Walk-In / City Delivery	Chevrolet Express 3500	$47,180	239.7	4,113.0
16,000	Class 4: 14,001-16,000lbs		Large Walk-In / City Delivery	Ford E450	$57,777	743.1	8,980.0
19,500	Class 5: 16,001-19,500lbs		Large Walk-In / City Delivery	Ford F550	$79,734	825.0	10,680.0
26,000	Class 6: 19,501-26,000lbs		Bevarage Truck	Chevrolet LCF 5500HD	$95,189	1,189.0	11,461.0
33,000	Class 7: 26,001-33,000lbs	Heavy Duty: >26,001lbs	Truck Tractor	-	-	-	-
>33,000	Class 8: >33,001lbs		Truck Tractor	-	-	-	-

*1 DOE "Vehicle Weight Classes & Categories.", https://afdc.energy.gov/data/
*2 TCS "A Guide to Truck Weight, Classification, and Uses." https://www.tcsfuel.com/blog/truck-weight-classification/
*3 Anderson Vans "Cargo Van Weight Limits." https://andersonvans.com/cargo-van-weight-limit/
*4 Comvoy "Package Delivery Trucks for Sale." https://www.comvoy.com/vehicles/Package-Delivery-trucks-for-sale-12l6?page=5

Justifying Class-2 Vehicle Assumption and Calculating the Number of Tours Conducted per Vehicle

We were not able to obtain data on the exact fleet compositions of each carrier in Santa Monica. Instead, real-world examples of ICEVs and EVs were examined to establish vehicle loading capacities in the optimization model. From the websites of automakers and other sources, we extracted the gross vehicle weight rating (GVWR), payload capacity, and cargo volume capacity for each of freight vehicles used for last-mile delivery. **Table D-3** shows the mean and standard deviation of GVWR and payload capacity for each vehicle class. **Table D-4** also shows the sample data collected.From this research, we assume that all deliveries are conducted by the most common type of delivery vehicle, which is a class-2 cargo van. These vans are on average able to carry 3,739.4lbs and operate with a load factor of 40%[97], meaning each tour would carry 1,495.76lbs. Based on our research on loading times, we estimate each vehicle would be able to conduct two tours in a single day[98].

Table D-3: *Cargo Loading Capacities*

[97] Aljohani and Thompson, "An Examination of Last Mile Delivery Practices of Freight Carriers Servicing Business Receivers in Inner-City Areas." 2020.
[98] Aljohani and Thompson, "An Examination of Last Mile Delivery Practices of Freight Carriers Servicing Business Receivers in Inner-City Areas." 2020.

	samples	GVWR(lbs)		Payload(lbs)	
		Mean	SE	Mean	SE
Class-1	4	4994.7	96.2	1507.4	26.2
Class-2	17	9142.5	211.1	3739.4	166.5
Class-3	11	11220.3	280.5	5636.3	367.5
Class-4	9	14392.2	103.0	7876.7	343.7
Class-5	5	16800.0	406.2	10442.0	283.2
Class-6	9	21438.9	733.8	12860.3	1543.3

Table D-4: *Real Example of Freight Vehicle Model*

Type	Name	Engine Type	GVWR (lbs)	Payload (lbs)
Cargo Van	Mercedes-Benz Metris Cargo Van 2022	ICEV	6,393	2,502
Cargo Van	Nissan NV Cargo 2022	ICEV	9,100	2,920
Cargo Van	Nissan NV Cargo 2021	ICEV	9,900	3,540
Cargo Van	Ford Transit Cargo Van 2022	ICEV	9,500	4,460
Cargo Van	Ford Transit Connect Van 2022	ICEV	5,240	1,510
Cargo Van	Mercedes-Benz Sprinter Cargo Van 144" regular 2021	ICEV	8,550	4,134
Cargo Van	Ram ProMaster Cargo Van 2022	ICEV	8,550	3,770
Cargo Van	Nissan NV200 Compact Cargo 2021	ICEV	4,772	1,492
Cargo Van	Chevrolet Express Cargo Van 2022	ICEV	9,600	4,311
Cargo Van	GMC Savana Cargo Van 2022	ICEV	8,600	3,280
Cargo Van	GMC Savana Van 159 2020	ICEV	14,200	9,265
Light Duty Box Truck	Ford E350 2019	ICEV	12,500	7,640
Light Duty Box Truck	Ford F-350 SRW 4x2 Regular Cab 145.0"	ICEV	9,800	4,370
Light Duty Box Truck	Ford F-350 SRW 4x2 Regular Cab 145.0"	ICEV	11,100	4,730
Light Duty Box Truck	GMC Savana G33903 2018	ICEV	12,300	4,333
Medium Duty Box Truck	Ford F-350 DRW 4x2 Regular Cab 145.0"	ICEV	14,000	7,940
Medium Duty Box Truck	Ford F-450 DRW 4x2 Regular Cab 145.0"	ICEV	15,000	8,350
Medium Duty Box Truck	Ford F-450 DRW 4x2 Regular Cab 145.0"	ICEV	16,500	9,850
Medium Duty Box Truck	Ford F-550 DRW 4x2 Regular Cab 145.0"	ICEV	17,500	10,850
Medium Duty Box Truck	Ford F-550 DRW 4x2 Regular Cab 145.0"	ICEV	18,000	11,350

Medium Duty Box Truck	Ford F-550 DRW 4x2 Regular Cab 145.0"	ICEV	19,500	12,070
Medium Duty Box Truck	Ford F-600 DRW 4x2 Regular Cab 145.0"	ICEV	22,000	15,090
Medium Duty Box Truck	Hino 155 2017	ICEV	14,500	6,495
Step Van	Ford F-59 2021	ICEV	16,000	10,080
Step Van	Ford F-59 2021	ICEV	19,500	13,470
Step Van	Ford F-59 2021	ICEV	22,000	15,750
Step Van	Ford E-350 (SRW) 138" Wheelbase	ICEV	10,050	5,100
Step Van	Ford E-350 (DRW) 138" Wheelbase	ICEV	11,500	6,270
Step Van	Ford E-350 (DRW) 158" Wheelbase	ICEV	11,500	6,210
Step Van	Ford E-350 (DRW) 176" Wheelbase	ICEV	12,500	7,210
Step Van	Ford E-450 (DRW) 158" Wheelbase	ICEV	14,000	8,480
Step Van	Ford E-450(DRW) 176" Wheelbase	ICEV	14,500	8,980
Step Van	Freightliner MT45 P1000 Stepvan 2022	ICEV	19,500	993
Step Van	Freightliner MT55 P1200 Stepvan 2022	ICEV	23,000	15,500
Cargo Van	Ford E-Transit Cargo Van 2022 (Regular-length Low-roof)	EV	9,500	3,880
Cargo Van	Ford E-Transit Cargo Van 2022 (Regular-length Medium-roof)	EV	9,500	3,750
Cargo Van	Ford E-Transit Cargo Van 2022 (Regular-length Medium-roof)	EV	9,500	3,533
Cargo Van	Nissan e-NV200 Evalia	EV	4,961	1,451
Cargo Van	Renault Kangoo Maxi ZE 33	EV	5,005	1,577
Cargo Van	BrightDrop EV600	EV	9,990	2,200
Cargo Van	Lightning eMotors Transit 350HD Cargo Van	EV	10,360	3,498
Cargo Van	Maxwell Vehicles ePro Electric Van	EV	9,350	4,100
Cargo Van	Mercedes-Benz eSprinter Cargo Van 1500	EV	8,550	3,953
Cargo Van	Mercedes-Benz eSprinter Cargo Van 2500	EV	9,050	4,189
Cargo Van	Mercedes-Benz eSprinter Cargo Van 3500	EV	9,990	4,677
Cargo Van	Mercedes-Benz eSprinter Cargo Van 3500XD	EV	11,030	5,717
Light Duty Box Truck	CityFreighter CF1	EV	10,582	5,291
Medium Duty Box Truck	Endera Motors L	EV	14,500	6,900

Medium Duty Box Truck	GreenPower EV Star Cargo	EV	14,330	6,500
Medium Duty Box Truck	Lightning Electric Isuzu FTR / Chevrolet 6500XD	EV	25,950	13,650
Medium Duty Box Truck	Lightning Electric Zero Emission E-450 Box Truck	EV	14,500	7,980
Step Van	Ford F-59 2022	EV	16,000	10,080
Step Van	Ford F-59 2022	EV	19,500	13,470
Step Van	Ford F-59 2022	EV	22,000	15,750
Step Van	NGEN-1000	EV	10,001	6,000

Sample Sources;
TrueCar, https://www.truecar.com/best-cars-trucks/cargo-vans/
Penske, https://m.penskeusedtrucks.com/ut/#/search-inventory
Electric Vehicle Database,
https://ev-database.org/#sort:path~type~order=.rank~number~desc|range-slider-range:prev~next=0~1200|range-slider-acceleration:prev~next=2~23|range-slider-topspeed:prev~next=110~450|range-slider-battery:prev~next=10~200|range-slider-towweight:prev~next=0~2500|range-slider-fastcharge:prev~next=0~1500|paging:currentPage=0|paging:number=9
SCE,
https://www.pge.com/pge_global/common/pdfs/solar-and-vehicles/clean-vehicles/ev-fleet-program/PGE_EV-Fleet_Vehicle-Availability_Distribution-Delivery.pdf
Ford, https://www.ford.com/commercial-trucks/e-series-cutaway/models/e350-cutaway-srw/

Testing for Carrying Capacity Differences Between EVs and ICEVs

One factor that would impact our model is if electric vehicles have a different carrying capacity than diesel vehicles, perhaps because of the heavier battery. To determine if this is true, we tested whether there is a significant difference in cargo payload capacity for vehicles with similar GVWRs. For EVs and ICEVs, we performed two regressions (one for EVs and one for ICEVs) with payload capacity as the outcome variable and GVWR as the independent variable. We then tested by using the coefficients for each as two samples. The resulting t-value was -0.685, with no statistically significant difference at the 5% significance level. Therefore, we assume that EVs and ICEVs have similar payload capacities. For simplicity, we assume that the same vehicles are used for each vehicle class and set these averages as the cargo capacity limits.

Emission Characteristics of Different Vehicle Types

We will describe the data used to evaluate the total ownership cost (TOC), GHG/Air Pollutant emissions, and these externality costs for each vehicle. The Argonne International Institute provides tools called "Afleet" for these calculations[99]. Of these, the Excel spreadsheet tool has a "background" cell that shows the data on which the calculations are based, using data from the US Environmental Protection Agency (EPA) and other sources. These are used to calculate TOC, gas and other emissions, and externality costs as shown in **Tables D-5** to **D-7**. Note that only on-road emissions (such as from driving) will be calculated for the various types of emissions, and off-road emissions (such as from

[99] Argonne National Laboratory, AFLEET Tool, https://greet.es.anl.gov/afleet

idling) will be ignored for simplicity. The reason why GHG emissions from EVs are not zero is that the carbon footprint including power generation is calculated. The calculation assumes the energy mix in California as of 2020. See **Table D-8** and **D-9** for details on data sources.

Table D-5: *Cost-related Characteristics of Freight Vehicles by Vehicle Class*

Class_id	Class	Fuel_id	Fuel	Purchase Cost ($)	Purchase Cost ($/year)*1	MPGGE(mile/gallon)	Maintenance and Repair ($/mile)	Fuel Cost DGE ($/mile)	LDV Insurance ($/year)	LDV License and Registration ($/year)
1	Class-1	1	Diesel	$22,300	$4,460	12.0	0.1550	$3.16	$904.0	$133.0
1	Class-1	2	Electric	$44,600	$8,920	29.1	0.0643	$6.30	$904.0	$233.0
2	Class-2	1	Diesel	$38,000	$7,600	12.0	0.1550	$3.16	$904.0	$133.0
2	Class-2	2	Electric	$68,000	$13,600	29.1	0.0643	$6.30	$904.0	$233.0
3	Class-3	1	Diesel	$44,000	$8,800	22.4	0.1155	$3.16	$904.0	$133.0
3	Class-3	2	Electric	$77,000	$15,400	57.3	0.0479	$6.30	$904.0	$233.0
4	Class-4	1	Diesel	$53,000	$10,600	15.6	0.1656	$3.16	$904.0	$133.0
4	Class-4	2	Electric	$93,000	$18,600	37.8	0.0687	$6.30	$904.0	$233.0
5	Class-5	1	Diesel	$70,000	$14,000	6.3	0.1048	$3.16	$904.0	$133.0
5	Class-5	2	Electric	$150,000	$30,000	22.0	0.0709	$6.30	$904.0	$233.0
6	Class-6	1	Diesel	$75,000	$15,000	5.6	0.1064	$3.16	$904.0	$133.0
6	Class-6	2	Electric	$185,000	$37,000	19.5	0.0841	$6.30	$904.0	$233.0

*1 Assume 5 years of declining balance as depreciation

Source: Own with information from AFLEET Tool 2020 - Spreadsheet: https://greet.es.anl.gov/index.php?content=afleet

Table D-6*: Emission Factors by Vehicle Class*

Onroad Emissions

Class_id	Class	Fuel_id	Fuel	GHG short tons / mile	CO lb / mile	NOx lb / mile	PM10 lb / mile	PM2.5 lb / mile	VOC lb / mile	SOx lb / mile
1	Class-1	1	Diesel	0.0011143	0.0018114	0.0004377	0.0000992	0.0000174	0.0001024	0.0000126
1	Class-1	2	Electric	0.0004796	0.0000000	0.0000000	0.0000818	0.0000099	0.0000000	0.0000000
2	Class-2	1	Diesel	0.0011143	0.0018114	0.0004377	0.0000992	0.0000174	0.0001024	0.0000126
2	Class-2	2	Electric	0.0004796	0.0000000	0.0000000	0.0000818	0.0000099	0.0000000	0.0000000
3	Class-3	1	Diesel	0.0008539	0.0020127	0.0004863	0.0001102	0.0000193	0.0001138	0.0000097
3	Class-3	2	Electric	0.0004567	0.0000000	0.0000000	0.0000779	0.0000094	0.0000000	0.0000000
4	Class-4	1	Diesel	0.0008112	0.0019121	0.0004620	0.0001047	0.0000183	0.0001081	0.0000092
4	Class-4	2	Electric	0.0004339	0.0000000	0.0000000	0.0000741	0.0000090	0.0000000	0.0000000
5	Class-5	1	Diesel	0.0007706	0.0018165	0.0004389	0.0000995	0.0000174	0.0001027	0.0000087
5	Class-5	2	Electric	0.0004122	0.0000000	0.0000000	0.0000703	0.0000085	0.0000000	0.0000000
6	Class-6	1	Diesel	0.0006935	0.0016102	0.0003890	0.0000882	0.0000154	0.0000910	0.0000086
6	Class-6	2	Electric	0.0003279	0.0000000	0.0000000	0.0000728	0.0000088	0.0000000	0.0000000

Source: Own with information from AFLEET Tool 2020 - Spreadsheet: https://greet.es.anl.gov/index.php?content=afleet

Table D-7*: Externality Cost by GHG/Air Pollutant*

Emissions	Value	Unit
GHG	$40.76	2020$ per short ton
CO	$0.00	2020$ per pound
NOx	$23.15	2020$ per pound
PM10 (PM2.5-10)	$33.85	2020$ per pound
PM2.5	$305.27	2020$ per pound
VOC	$56.82	2020$ per pound
SOx	$684.43	2020$ per pound

Source: AFLEET Tool 2020 - Spreadsheet:
https://greet.es.anl.gov/index.php?content=afleet

Table D-8*: List of Required Datasets related to vehicles for Optimization Model*

Input Data	Sources and Method of Data Creation
Sets and parameters used in the optimization model	
Set of all vehicles	
Fleet Component (EVs/ICEVs)	
Vehicle Class & Types	*- Organize Vehicle Class and Vehicle Type based on information from the Alternative Fuels Data Center provided by DOE[1]*
Payload Capacity of each vehicle	*- Extract information such as Vehicle Model, Engine Type, Gross Weight, Payload Capacity, etc. from the website and organize it by Vehicle Class[2]*
Driving Characteristics	*- All driving characteristics were calculated from average vehicle operation information, such as daily vehicle mile traveled in parcel delivery, from FleetDNA information[3]*
Daily vehicle mile traveled	
Driving/non-driving duration	
Total stops	

1 U.S. Department of Energy, Vehicle Weight Classes & Categories, https://afdc.energy.gov/data/10380

2 See Appendix C

3 NREL Transforming Energy, Fleet DNA: Commercial Fleet Vehicle Operating Data, https://www.nrel.gov/transportation/fleettest-fleet-dna.html

Table D-8*: List of Required Datasets for Economic Analysis*

Input Data	Sources and Method of Data Creation
Parameters used in the economic analysis	
Cost Parameters	*- The following information was extracted from the "Background Information" sheet of the Afleet Database spreadsheet[4]*
Parameters used to calculate TOC	
Purchase cost of freight vehicles	*- Utilize data for each Vehicle Class's new purchase price provided by Afleet Database.[4] This is then divided by 5 to create a yearly cost.* *- Also used for model validity checks*
Fuel Price (diesel/electricity)	*- Electricity or Diesel prices in California as provided by Afleet Database[4] (Original Source: AEO 2021 Table A3 (Years 2020 - 2050))*

Average Fuel Economy	*- Average fuel economy (miles per gasoline gallon equivalent) provided by the AFREET database[4] for vehicle type (e.g., utility cargo van) that matches each vehicle class.*
Maintenance and Repairs	*-Average maintenance and repair cost for LDV by state as provided by Afleet Database[4]*
Insurance Cost	*-Average insurance for LDV by state as provided by Afleet Database[4]*
Parameters used to calculate Government Revenue	
Fuel Tax (diesel/electricity)	*- Diesel and electricity taxes in California provided by CA Department of Tax and Fee Administration[5]* **they are already included in the fuel price above*
License and Registration	*- EV and ICEV licensing and registration fees for LDVs in California, provided by Afleet Database*
Hazardous Substance Emissions	*- Emission factors per state (per mile) provided by Afleet Database (Original source: EPA MOVES3 - https://www.epa.gov/moves)*
GHG	
Other Air Pollutants	
Externality Costs	*- All externality costs provided by Afleet Database*
GHG	
Other Air Pollutants	

4 Argonne National Laboratory, AFLEET Tool, https://greet.es.anl.gov/afleet

5 CA Department of Tax and Fee Administration, Tax Guide for Motor Fuel Taxes, https://www.cdtfa.ca.gov/industry/motor-fuel-taxes.htm#Overview

Appendix E - Details for the Pseudo-Empirical Data of Santa Monica Nodes and Arcs

For several reasons, e.g., the City of Santa Monica does not have detailed data, most of the actual data needed for input was not available. We, therefore, managed this challenge by creating pseudo-empirical data on delivery demand in the City of Santa Monica. The input data required for the optimization model, such as nodes and fleet compositions, have just been outlined in the main text. However, as details were omitted in the main for the sake of readability described in detail here. **Table E-1** shows the Input data components and the sources and method to gain or estimate them. Note that all sources are listed in the table and omitted in the text, for the sake of simplicity.

Table E-1*: List of Required Datasets related to nodes for Optimization Model*

Sets and parameters used in the optimization model	
Input Data	**Sources and Method of Data Creation**
Set of all nodes	
Set of depots and their share of deliveries	- *Information on Freight Company Homepages*[1] - *Carrier market share*[2]
Set of customers and their demand	-*List of Streets in Santa Monica*[3] - *Demographics by census tract obtained from data.census.gov website*[4] - *Average per capita parcel demand in US provided by Briest et al.*[5] - *Weight per parcel provided by Mazareanu*[6]
Subset of nodes located outside the ZEDZ	- *Census tract polygon data obtained from Santa Monica Open Data*[7]
Set of traveling distance between all possible pairs of nodes and depots	- *Calculate latitude and longitude information from zip address using Google Maps Geocoding API*[8] - *Calculate travel time and distance between each node using Google Maps Distance Matrix API*[9]
Subset of arcs that connect two nodes without crossing the limited zone	- *Self-calculations via code that determined whether the delivery enters a ZEDZ area by using ZEDZ polygon data and latitude/longitude information of each node.*

1 Electric Vehicle Database (https://ev-database.org), SCE (https://www.pge.com/pge_global/common/pdfs/solar-and-vehicles/clean-vehicles/ev-fleet-program/PGE_EV-Fleet_Vehicle-Availability_Distribution-Delivery.pdf), Ford(https://www.ford.com/commercial-trucks/e-series-cutaway/models/e350-cutaway-srw/), etc.

2 businesswire, "Pitney Bowes Parcel Shipping Index Reveals 37 Percent Parcel Volume Growth in US for 2020." https://www.businesswire.com/news/home/20210914005274/en/Pitney-Bowes-Parcel-Shipping-Index-Reveals-37-Percent-Parcel-Volume-Growth-in-US-for-2020

3 List of Streets in Santa Monica, https://geographic.org/streetview/usa/ca/los_angeles/santa_monica.html

4 U.S. Census Bureau, data.census.gov website, https://data.census.gov/cedsci/

5 Patrick Briest, Julian Dragendorf, Tim Ecker, Detlev Mohr, and Florian Neuhaus, "The endgame for postal networks: How to win in the age of e-commerce." McKinsey&Company, May 24, 2019. https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/the-endgame-for-postal-networks-how-to-win-in-the-age-of-e-commerce

6 E. Mazareanu, "What was the approximate weight of this particular purchase?" statista, Feb 28, 2022. https://www.statista.com/statistics/974065/cross-border-delivery-package-weight-worldwide/

7 Santa Monica Open Data, https://data.smgov.net/dataset/Census-Tracts/diw8-bjw6

8 Google Maps Platform, Geocoding API, https://developers.google.com/maps/documentation/geocoding/overview

9 Google Maps Platform, Google Maps Distance Matrix API, https://developers.google.com/maps/documentation/distance-matrix/overview

To begin with, the following assumptions were made to estimate the amount of demand at each node for parcels in the City of Santa Monica.

1) Demand in a particular area is proportional to the population of that area.
2) Deliveries to each household can be aggregated to neighboring intersections and the intersections can represent the demand of neighboring households.

Based on this assumption, we first utilized demographics for each census tract from census information. In addition, we used the information provided by the City of Santa Monica for each intersection. Intersection information was converted to latitude and longitude information using the Google Maps Geocoding API and determined by programming created in python if each intersection exists within each tract. The population represented by each intersection was then calculated by dividing the tract's population by the number of intersections within each tract. This was multiplied by the per capita parcel demand for the U.S. as a whole to calculate the consumer nodes and their respective demands.

For depot nodes, we identified depot locations from each company's website for the four major delivery companies (USPS, UPS, Amazon, and FedEx), the sum of which account for nearly 100% of the total market share. As with the consumer nodes, this information was converted to latitude and longitude information using the Google Maps Geocoding API. For each of the consumer nodes, the distance to each depot was calculated from the latitude and longitude information, and by delivery companies, the closest depot was allocated as the responsible one.

For each responsible depot, the distance and time traveled between the depot and all consumer nodes to be delivered were calculated by utilizing the Google Maps Distance Matrix API and python programming.

Location information for all consumer- and depot- nodes is shown in **Figure E-1**.

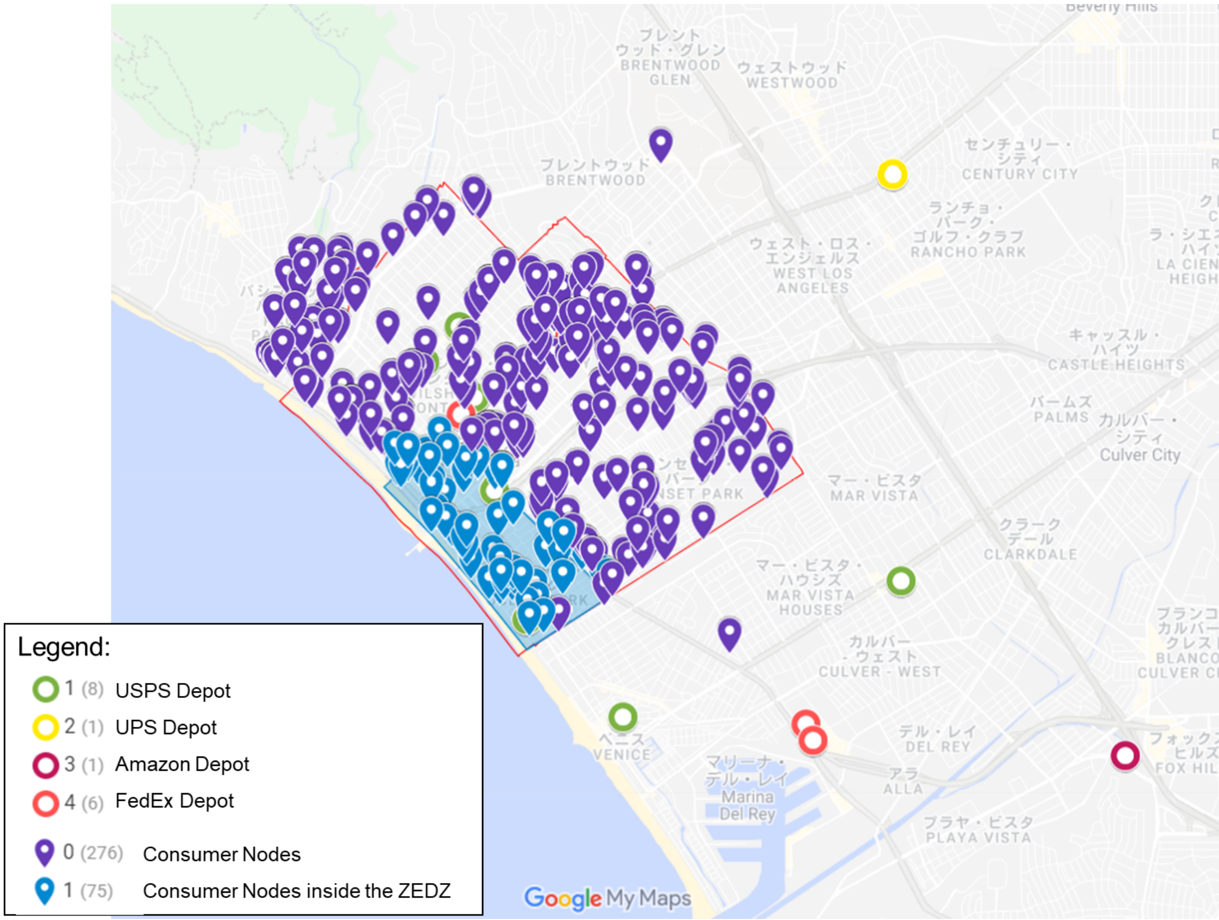

***Figure E-1**: Location for all nodes*

Appendix F - Details for the Optimization Model

Shipment Synthesizer
We begin by first assembling data from Google Maps containing the coordinates of all depot and consumer nodes throughout Santa Monica, as well as the street distance between these locations. A consumer node is a street corner of a residential neighborhood. Through our interviews, research, and contacts, we were unable to find delivery or parcel demand data. Instead, we estimate this demand through population density by dividing the population of each census tract to each consumer node within that tract[100]. Based on our delivery research, we also assume 70-80% of parcels are delivered via postal networks[101], and that the average weight of a parcel is 1.1kg/parcel[102].

We then assign each parcel-demanded a carrier. We know the proportions of freight shipments that are conducted by UPS, Amazon, USPS (including Amazon deliveries conducted through the postal service), and FedEx[103], and each assignment is based on these proportions. Once assigned a carrier, the model detects the closest depot owned by that carrier. **Figure E-1** is a dataframe representing this portion of the model:

[100] U.S. Census Bureau, data.census.gov website, https://data.census.gov/cedsci/
[101] McKinsey&Company, "The endgame for postal networks: How to win in the age of e-commerce." https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/the-endgame-for-postal-networks-how-to-win-in-the-age-of-e-commerce
[102] E. Mazareanu "What was the approximate weight of this particular purchase?." https://www.statista.com/statistics/974065/cross-border-delivery-package-weight-worldwide/
[103] Businesswire, "Pitney Bowes Parcel Shipping Index Reveals 37 Percent Parcel Volume Growth in US for 2020." https://www.businesswire.com/news/home/20210914005274/en/Pitney-Bowes-Parcel-Shipping-Index-Reveals-37-Percent-Parcel-Volume-Growth-in-US-for-2020

	Receiver	Receiver_ID	Receiver Lat	Receiver Lon	Receiver_ZEDZ	Sender	Sender_ID	Sender Lat	Sender Lon	Sender_ZEDZ
0	10th Court, Santa Monica, CA90403	1	34.019890	-118.488409	0	UPS	9	34.051950	-118.431388	0
1	10th Court, Santa Monica, CA90405	2	34.019897	-118.487261	0	FedEx	12	34.023789	-118.492240	0
2	10th Street, Santa Monica, CA90401	3	34.019890	-118.488409	0	Amazon Logistics	10	33.984066	-118.398651	0
3	10th Street, Santa Monica, CA90402	4	34.019890	-118.488409	0	USPS	5	34.015040	-118.487514	1
4	10th Street, Santa Monica, CA90403	5	34.019890	-118.488409	0	Amazon Logistics	10	33.984066	-118.398651	0
...	...	...	...	...	...	...	...	...	...	...
346	Winnett Place, Santa Monica, CA90402	347	34.031853	-118.502660	0	USPS	1	34.030044	-118.497416	0
347	Woodacres Road, Santa Monica, CA90402	348	34.039950	-118.505475	0	USPS	1	34.030044	-118.497416	0
348	Yale Street, Santa Monica, CA90403	349	34.038366	-118.475060	0	USPS	2	34.034159	-118.492490	0
349	Yale Street, Santa Monica, CA90404	350	34.034314	-118.470567	0	UPS	9	34.051950	-118.431388	0
350	Yorkshire Avenue, Santa Monica, CA90404	351	34.026252	-118.461364	0	USPS	5	34.015040	-118.487514	1

***"Receiver_ZEDZ" and "Sender_ZEDZ" are equal to 1 if the receiver or sender is located inside the ZEDZ.

Figure E-1*: Initial list of shipments.*

Tour Formation

We then group these shipments into tours that can be conducted by a single vehicle's route. To do this, we first divide these shipments by carrier. For each tour, we randomly select a shipment to act as the initial starting point. Then, using the Google Maps API, we create a table containing the travel distance between every possible pair of nodes and depots in our data. We then conduct a "nearest neighbor" algorithm that detects which shipment conducted by the same carrier is closest to the starting shipment. Once that shipment is added to the tour, we look for the shipment that is closest to the previous shipment's node . We continue grouping shipments in this way until the vehicle for the tour is at its capacity limit. **Figure E-2** displays the start of one such grouping:

	Receiver	Receiver_ID	Receiver Lat	Receiver Lon	Receiver_ZEDZ	Sender	Sender_ID	Sender Lat	Sender Lon	Sender_ZEDZ
0	10th Street, Santa Monica, CA90402	4	34.019890	-118.488409	0	USPS	5	34.01504	-118.487514	1
1	7th Street, Santa Monica, CA90401	106	34.015040	-118.487514	1	USPS	5	34.01504	-118.487514	1
2	State Route 1, Santa Monica, CA90401	315	34.015152	-118.486527	1	USPS	5	34.01504	-118.487514	1
3	State Route 1, Santa Monica, CA90402	316	34.015152	-118.486527	1	USPS	5	34.01504	-118.487514	1
4	State Route 1, Santa Monica, CA90405	319	34.015152	-118.486527	1	USPS	5	34.01504	-118.487514	1

Figure E-2: *An example of the some of the shipments carried out by one vehicle in the USPS fleet.*

Network Assignment

The above algorithm for grouping tours also conveniently groups them in such a way that already produces an optimal route. To generate total distance, we simply sum the distances along the route.

Mandated ZEDZ Constraints

We now begin implementing the likely constraints of a ZEDZ policy. Under a “mandated” ZEDZ, all vehicles within the zone must be electric. We can rerun the above process with this constraint in place, meaning that tours in the ZEDZ must be conducted by an electrical vehicle and shipments should be grouped accordingly. This produces a different grouping of tours.

	Receiver	Receiver_ID	Receiver Lat	Receiver Lon	Receiver_ZEDZ	Sender	Sender_ID	Sender Lat	Sender Lon	Sender_ZEDZ
0	3rd Street, Santa Monica, CA90401	85	34.016409	-118.496789	1	UPS	9	34.05195	-118.431388	0
1	State Route 1, Santa Monica, CA90403	317	34.015152	-118.486527	1	UPS	9	34.05195	-118.431388	0
2	State Route 1, Santa Monica, CA90404	318	34.015152	-118.486527	1	UPS	9	34.05195	-118.431388	0

Figure E-3: *An example of a tour being completed within the ZEDZ. (All shipments within this zone must be completed by an electric vehicle.)*

The end results are two sets of shipments, one for a mandated ZEDZ and the other for a baseline in which no policy exists. Using these results, we can further apply our other policies such as subsidies and voluntary ZEDZs (explained in Appendix C)

Whilst producing realistic results, this model would benefit from some comprehensive real traffic dataset that we can compare the results of our baseline estimates to. Access to such a dataset will allow us to adjust certain parameters of the model to be more realistic and verify that we are on the right track.

Appendix G - Details for the Economic Analysis

In the following, we show how to calculate the change in social welfare in the economic evaluation method presented by Mirhedayatian and Yan[104].

The amount of change in social welfare is expressed by the following equation;

$$\Delta W = \Delta S + \Delta R - \Delta EC,$$

where ΔW: the change in social welfare, ΔS: sum of changes in the total surplus, ΔR: change in government revenue, and ΔEC: change in the total external cost.

Total surplus is the sum of consumer surplus and producer surplus.

$$\Delta S = \Delta CS + \Delta PS,$$

where ΔCS: the consumer surplus, and ΔPS: the producer surplus

The change in consumer surplus is represented by the sum of the ch ange in willingness to pay and the change in service charges;

$$\Delta CS = \Delta WP - \Delta P_c,$$

where ΔWP: the change in the willingness to pay, and ΔP_c: service price for all customers

$$\Delta PS = \Delta P_p - \Delta TC,$$

where ΔP_p :service price for producer, and ΔTC: total delivery cost for the logistics company.

The producer's surplus is expressed as the change in the price offered by the producer minus the change in the total delivery cost.

Under the assumption that $P_c = P_p$ and the willingness to pay does not change in the short run, we can achieve

$$\Delta CS = -\Delta P_c,$$

$$\Delta PS = \Delta P_p - \Delta TC = \Delta P_c - \Delta TC,$$

$$\Delta S = \Delta CS + \Delta PS = -\Delta P_c + \Delta P_c - \Delta TC$$

The change in government revenue is represented by the amount of change in EV purchase subsidies, vehicle taxes, fuel taxes, and zone fees (if any). The formulas are omitted here as they are simply calculated based on the number of vehicles, driving distance, etc.

The change in the total external cost is also calculated from the result of the optimization model, by using marginal external cost of each emissions proposed by several papers.

[104] Mirhedayatian and Yan (2018), https://www.sciencedirect.com/science/article/pii/S1361920917305576?via%3Dihub#t0005

Appendix H - California State Regulations

The following is a summary of the legal framework, regulations, and incentives in the State of California, which influence this paper, particularly the qualitative and quantitative analysis in the City of Santa Monica.

Table H-1: *Legal Framework for Carbon Neutrality in California State*

Legislation and Publications	Contents
Senate Bill No.100[105]	Requires California electricity generation to transition to 100% carbon neutral by 2045.
Executive Order N-79-20[106]	Banning the sale of new gasoline vehicles and mandating that all new vehicles (passenger cars and trucks) sold in the state be zero-emission vehicles in the state by 2035.
Governor's Office of Business and Economic Development (Go-Biz)[107]	Based on the executive order, Go-Biz, in collaboration with 29 other state agencies, released the " California Zero-Emission Vehicle Market Development Strategy.
Action Plan by California Air Resources Board[108]	See the tables of regulations and incentives below.

Table H-2: *Regulations based on the Action Plan*

Title	Target	Target Year
Advanced Clean Fleets	100% zero-emission drayage, last-mile delivery and public fleets	2035
	100% zero-emission refuse, utility fleets and buses	2040
	100% zero emissions for other truck and bus fleets, where feasible	2045
Advanced Clean Trucks	Ensuring manufacturers to sell zero-emission medium- and heavy-duty trucks as an increasing portion of their sales from 2024 to 2035 to achieve; - 100,000 zero-emission trucks - 300,000 by 2035.	2030 / 2035
Transport	All truck TRUs to be zero emissions	2030

105 https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100
106 https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf
107 https://static.business.ca.gov/wp-content/uploads/2021/02/ZEV_Strategy_Feb2021.pdf
108 https://static.business.ca.gov/wp-content/uploads/2021/03/CARB_ZEV-Action-Plan.pdf

Refrigeration Units (TRU)		

Table H-3: Incentives based on the Action Plan

Incentives	Contents
Clean Mobility Options	provides funding for various community clean transportation projects (other than vehicle ownership), including zero-emission and plug-in hybrid car sharing, vanpools, electric and regular bicycle sharing, scooter sharing, innovative transit, micro-and on-demand services
Hybrid and Zero-emission Truck and Bus Voucher Incentive Program (HVIP)	incentives for long-term transition to ZEVs in the heavy-duty market and supporting investments in other emerging technology areas to achieve greenhouse gas emission reductions and ambient air quality standards
Truck Loan Assistance Program	help small business truck owners that fall below conventional lending criteria and are unable to qualify for traditional financing attain financing for cleaner trucks

Appendix I - Site Visit Photos

Two of Coco's remotely piloted robot delivery vehicles. Coco, in addition to REEF, LACI, Automotus, Nissan, and several other companies, offers this service within the Zero Emission Delivery Zone pilot located in Downtown Santa Monica.

One of the many signs that the City of Santa Monica has erected to incentivize the use of zero emission loading zones. These zones are located near businesses for easy access by delivery companies.

A camera aimed at a zero emission loading zone within the City of Santa Monica's pilot area. These cameras were sited and installed by Automotus for monitoring purposes rather than for enforcement.

The back of a three-wheeler zero emission vehicle offered to rent by REEF, another partner in the ZEDZ pilot in Downtown Santa Monica.