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Research Report

April 2025

Investigating Transportation Decarbonization through Transit and Rideshare Electrification: A Scenario Analysis with Large-Scale Models

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16. Abstract

This study evaluates the energy consumption and emission characteristics associated with rideshare and transit electrification in the Houston metropolitan region using the U.S. Department of Energy's Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility workflow. An integrated modeling framework combining POLARIS, stochastic vehicle trip prediction (SVTrip), and Autonomie was used to examine travel demand, vehicle operations, energy consumption, and emissions under multiple passenger vehicle electrification scenarios. Scenarios included a baseline condition, electrification of a 20,000-vehicle Transportation Network Company (TNC) fleet, full passenger vehicle fleet electrification, expansion of the electrified TNC fleet to 40,000 vehicles, and a separate transit bus electrification assessment. Results indicate that battery electric vehicles generally exhibited lower energy consumption and modeled greenhouse gas emission rates than conventional internal combustion engine vehicles, with average energy consumption of approximately 0.214 kilowatt-hours per kilometer. The transit bus assessment, based on simulated service mileage and published emission factors, estimated approximately 67% lower operational greenhouse gas emissions for battery electric buses compared with conventional diesel buses under equivalent service mileage assumptions. The findings provide insights into vehicle-level energy consumption and emission characteristics under alternative electrification assumptions and illustrate the potential operational emissions advantages of electric transit buses.

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Investigating Transportation Decarbonization through Transit and Rideshare Electrification: A Scenario Analysis with Large-Scale Models

A National Center for Sustainable Transportation Research Report

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Investigating Transportation Decarbonization through Transit and Rideshare Electrification: A Scenario Analysis with Large-Scale Models

Executive Summary

Transportation electrification is an important strategy for improving vehicle energy efficiency and reducing transportation-related emissions. Electrification of shared mobility services and public transit fleets is of particular interest because these vehicles can accumulate substantial mileage and operate under a wide range of traffic conditions. Evaluating these technologies using detailed transportation and vehicle modeling can provide insight into how vehicle use, operating conditions, and powertrain characteristics influence energy consumption and emissions.

This study applies the U.S. Department of Energy's Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility workflow to examine transportation electrification in the Houston metropolitan region. The analysis integrates Planning and Operations Language for Agent-based Regional Integrated Simulation (POLARIS), an agent-based transportation system model; stochastic vehicle trip prediction (SVTrip), a vehicle speed-profile generation tool; and Autonomie, a high-fidelity vehicle energy simulation platform. POLARIS represents regional travel activity and vehicle operations, SVTrips generate detailed speed profiles from simulated trips, and Autonomie uses those operating profiles to estimate vehicle energy consumption and emissions for different powertrain technologies. Vehicle technologies evaluated include internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel cell electric vehicles (FCEVs).

The study examines a baseline condition and alternative fleet electrification cases involving a 20,000-vehicle electric Transportation Network Company (TNC) fleet, full passenger-vehicle fleet electrification, and an expanded 40,000-vehicle electric TNC fleet. The 40,000-vehicle case represents an expansion of the assumed electric TNC fleet from 20,000 to 40,000 vehicles and provides an additional comparison of vehicle energy consumption and emission characteristics under a larger fleet-size assumption. Transit bus electrification is assessed separately using transit activity generated through POLARIS together with literature-based energy and emission factors.

The analysis demonstrates substantial differences in energy consumption across vehicle powertrain technologies. Among the technologies evaluated, BEVs exhibited the lowest average energy consumption, approximately 0.214 kWh/km, compared with higher energy requirements for conventional and hybrid powertrains. The TNC analysis also characterizes occupied and unoccupied vehicle activity, including vehicle miles traveled (VMT) and vehicle hours traveled (VHT), providing information on operational characteristics such as passenger service and deadheading. The alternative fleet cases illustrate how the integrated modeling workflow can be used to examine vehicle energy

and emission characteristics under different electrification assumptions. The separate transit bus assessment, based on simulated service mileage and published energy consumption and emission factors, estimated approximately 67% lower operational greenhouse gas emissions for battery electric buses compared with conventional diesel buses under equivalent service mileage assumptions.

Overall, the study demonstrates an application of an integrated metropolitan transportation and vehicle-energy modeling workflow for examining transportation electrification. Rather than estimating total regional greenhouse gas impacts, the analysis focuses on travel and vehicle operations, energy consumption, and vehicle-level emission characteristics associated with alternative powertrain and fleet assumptions. The modeling framework provides a foundation for future analyses that could incorporate additional fleet, technology, infrastructure, and policy assumptions to evaluate systemwide effects of transportation electrification.

Introduction

Overview

Transportation is a major component of energy use in the United States, and increasing the efficiency of transportation systems remains an important objective for improving their environmental performance. Vehicle electrification has emerged as a major technological pathway for reducing petroleum dependence and improving energy efficiency. Advances in battery technology, electric powertrains, and charging infrastructure have accelerated the adoption of electric vehicles (EVs) across private, shared-mobility, and public transportation applications.

Transportation Network Companies (TNCs), such as rideshare services, represent an important application for vehicle electrification because their vehicles can accumulate substantial mileage and include both passenger-carrying and unoccupied vehicle movements. Electrification of public transit fleets similarly provides an opportunity to replace conventional diesel-powered buses with battery electric technologies. Understanding the energy and emission characteristics of these applications requires consideration not only of vehicle technology but also of how vehicles are used and operated within the transportation system.

Houston, Texas, serves as an important case study for examining these issues. As one of the largest metropolitan regions in the United States, Houston is characterized by high automobile dependency, extensive roadway infrastructure, significant travel demand, and a large and diverse transportation system. These characteristics make the region well suited for applying large-scale transportation and vehicle simulation tools to examine travel activity, vehicle operations, and the energy and emission characteristics associated with transportation electrification.

Although vehicle electrification has been extensively studied, relatively few studies have applied an integrated metropolitan-scale modeling workflow that connects regional travel activity and vehicle operations with detailed vehicle energy simulation. This study applies the U.S. Department of Energy's Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility workflow to examine rideshare and passenger-vehicle electrification in the Houston metropolitan region. The analysis integrates regional transportation simulation, detailed vehicle speed-profile generation, and vehicle energy modeling to characterize energy consumption and vehicle-level emissions under alternative fleet and powertrain assumptions. Transit bus electrification is assessed separately using simulated transit activity together with literature-based energy and emission factors.

Study Objectives

The primary objective of this study is to examine transportation electrification in the Houston metropolitan region using an integrated transportation and vehicle-energy modeling framework that accounts for regional travel activity, vehicle operating conditions, and differences among vehicle powertrain technologies. Specifically, the study seeks to:

1) characterize travel activity and vehicle operations in the Houston metropolitan region using the POLARIS agent-based transportation system model;
2) evaluate vehicle energy consumption and emission characteristics across multiple powertrain technologies using detailed vehicle operating profiles generated through SVTrip and simulated in Autonomie;
3) examine vehicle energy and emission characteristics under alternative fleet electrification assumptions, including electric TNC fleet deployment and broader passenger-vehicle electrification; and
4) assess transit bus electrification separately using simulated transit activity and literature-based energy and emission factors.

To accomplish these objectives, the study applies the U.S. Department of Energy's SMART Mobility modeling workflow integrating POLARIS, SVTrip, and Autonomie. POLARIS provides information on regional travel activity and vehicle operations, SVTrip translates simulated trips into detailed vehicle speed profiles, and Autonomie estimates vehicle-level energy consumption and emissions for alternative powertrain technologies. This integrated approach enables the study to examine how travel activity, operating conditions, and vehicle technology interact in determining transportation energy use and emission characteristics. The analysis does not estimate or compare total regional greenhouse gas impacts across the electrification cases.

Report Organization

The remainder of this report is organized as follows. The Background summarizes previous research related to transportation decarbonization, vehicle electrification, rideshare systems, transit electrification, lifecycle assessment, and activity-based travel demand modeling. The Research Methodology section describes the integrated modeling approach used in this study, including the POLARIS, SVTrip, and Autonomie platforms, study area characteristics, scenario development, and model calibration procedures.

The Results and Discussion section presents the findings of the scenario analyses, including the impacts of rideshare fleet electrification, full fleet electrification, expanded rideshare fleet deployment, and transit bus electrification on transportation energy consumption and emissions. Finally, the Conclusions and Future Research section summarizes the major findings, discusses study limitations, and identifies opportunities for future research related to transportation electrification and decarbonization.

Background

Transportation Decarbonization and the Need for Electrification

The transportation sector plays an important role in supporting economic activity, mobility, and quality of life. However, it is also one of the largest contributors to greenhouse gas (GHG) emissions worldwide. Increasing population, urbanization, economic growth, and travel demand have led to substantial increases in transportation-related energy consumption over the past several decades. In the United States, transportation has become the largest source of GHG emissions, driven largely by the continued growth in vehicle ownership and VMT.

Transportation decarbonization has therefore emerged as a major policy objective at the federal, state, and local levels. Strategies for reducing transportation-sector emissions include improvements in vehicle fuel economy, expansion of public transportation, promotion of active transportation modes, adoption of alternative fuels, and widespread electrification of vehicle fleets. Among these approaches, electrification has received significant attention because of its potential to substantially reduce GHG emissions and criteria pollutants while maintaining mobility and accessibility.

BEVs, PHEVs, and FCEVs have emerged as key technologies supporting this transition. Research consistently demonstrates that electric vehicles produce significantly lower emissions than conventional ICEVs, particularly when electricity is generated from renewable or low-carbon sources (García-Olivares et al., 2018; Massoli, 2020). Lifecycle analyses further indicate that BEVs can reduce overall emissions by more than 70 percent compared with conventional vehicles when powered by clean electricity sources (Shafique and Luo, 2022; Union of Concerned Scientists, 2019).

Electrified vehicles also offer significant energy-efficiency advantages. Dominković et al. (2018) compared multiple transportation fuel pathways, including hydrogen, biofuels, electrofuels, and electricity, and concluded that electrification provides some of the greatest opportunities for reducing transportation-sector emissions. Similarly, Pan et al. (2018) projected that electricity could account for nearly 60 percent of transportation energy demand by 2100 in China, while Haasz et al. (2018) found that transportation electrification could contribute substantially toward achieving long-term GHG reduction targets in Europe.

Global Strategies for Transportation Decarbonization

Transportation decarbonization strategies extend beyond vehicle technology and include modal shifts, public transit improvements, shared mobility, land-use strategies, and other measures intended to reduce automobile dependence and improve transportation system efficiency. Studies conducted across multiple countries identify electrification as an important component of transportation-sector decarbonization while emphasizing that its effectiveness depends on interactions with travel behavior, transportation infrastructure, energy systems, and broader transportation policies (Dominković et al., 2018; Pan et al., 2018).

The literature therefore supports a systems-level perspective in which vehicle technology, travel behavior, infrastructure deployment, energy generation, and transportation operations jointly influence energy use and environmental outcomes. This perspective also motivates the use of modeling approaches capable of connecting transportation-system activity with vehicle-level energy performance.

Shared Mobility, Ridesharing, and Transportation Network Companies

The emergence of Transportation Network Companies (TNCs), such as Uber and Lyft, has significantly transformed urban mobility by providing travelers with flexible, on-demand transportation options. Shared mobility services can increase vehicle utilization and provide alternative to private vehicle ownership; however, their effects on transportation energy use and emissions depend strongly on how the services are operated and how they influence travel behavior (Yin et al., 2018).

The environmental implications of TNC services are particularly sensitive to vehicle miles traveled (VMT), vehicle occupancy, and unoccupied vehicle movements. Although shared rides can increase vehicle occupancy by serving multiple passengers during a trip, TNC operations can also generate additional VMT when vehicles travel without passengers to reach pickup locations, reposition between trips, or wait for new requests. Consequently, the environmental effects of TNC services cannot be inferred Soley from passenger occupancy and depend on the balance between passenger-serving and unoccupied vehicle activity (Ward et al., 2019).

Electrification can substantially change the energy and emission characteristics of TNC operations because TNC vehicles may accumulate considerably more mileage than typical privately owned vehicles. Evaluating electrified TNC fleets therefore benefits from considering both vehicle technology and operational characteristics, including occupied and unoccupied travel. Agent-based transportation models provide a means of representing these operational characteristics and examining TNC vehicle activity within the broader transportation network.

Public Transit Electrification

Public transit electrification has become an important component of efforts to improve the energy and environmental performance of urban transportation systems. Diesel buses have traditionally dominated transit fleets, but battery electric buses (BEBs) are increasingly being deployed as battery technology, charging infrastructure, and vehicle performance improve.

Previous studies have found that battery electric buses can reduce operational energy use and emissions relative to conventional diesel buses (Griswold et al., 2017; Guerrero, 2017; Lim Lek Keng et al., 2021), although the magnitude of these benefits depends on vehicle efficiency, route characteristics, operating conditions, and the electricity generation mix. Transit bus performance can also vary with passenger loads, congestion, climate, auxiliary energy requirements, and charging strategies (Yoo Nakyoung et al., 2021; He et al., 2023; Cabral and Sun, 2023). These factors make the operational context important when comparing conventional and electric transit technologies.

Because transit vehicles typically operate repeatedly along established routes and accumulate substantial annual mileage, fleet electrification can produce meaningful changes in transit-system energy use and emission characteristics. Evaluating bus electrification therefore requires consideration of both transit activity and vehicle-specific energy requirements.

Life Cycle Assessment of Electric Vehicles

Although electric vehicles produce little or no tailpipe emissions, a comprehensive assessment of their environmental impacts requires consideration of the entire vehicle lifecycle. Life Cycle Assessment (LCA) provides a framework for evaluating emissions associated with raw material extraction, manufacturing, operation, maintenance, and end-of-life disposal (Curran, 2013).

Numerous studies have shown that electric vehicles outperform conventional vehicles on a lifecycle basis despite higher manufacturing emissions. Battery production represents a significant source of upstream emissions, yet these impacts are generally offset by lower operational emissions over the vehicle's lifespan (Qiao et al., 2019; Shafique and Luo, 2022).

Massoli (2020) reported that electric vehicles emit approximately 73 percent less carbon dioxide per mile than gasoline vehicles on a lifecycle basis. Similar benefits have been documented for public transit fleets. According to the Union of Concerned Scientists (2019), electric transit buses produce substantially lower lifecycle GHG emissions than diesel and natural gas buses.

The environmental performance of electric vehicles depends strongly on the electricity generation mix. Shen et al. (2019) demonstrated that transitions toward renewable and nuclear electricity generation significantly improve the lifecycle performance of electric vehicles. Consequently, transportation electrification and power-sector decarbonization should be viewed as complementary strategies rather than independent initiatives.

Although lifecycle considerations provide important context for transportation electrification, the analytical components of this study use different system boundaries. Vehicle-level passenger and TNC analyses are based primarily on the outputs of the POLARIS-SVTrip-Autonomie workflow, while the transit bus assessment includes a separate literature-based lifecycle component. These results are therefore interpreted within their respective analytical boundaries rather than as directly comparable lifecycle estimates.

Evolution of Travel Demand Modeling

Evaluating transportation electrification strategies requires analytical tools capable of representing traveler behavior and transportation system dynamics. For many decades, transportation planners relied on the traditional four-step travel demand model. While widely used, this framework treats trips as independent events and often fails to capture the complex relationships among daily activities, travel decisions, and household behavior.

To overcome these limitations, researchers increasingly adopted activity-based and tour-based modeling approaches (Bhat et al., 2004a). These models recognize that travel is derived from individuals' participation in activities and therefore represent travel decisions within the broader context of daily schedules and behavioral constraints.

Comparative studies have demonstrated the advantages of activity-based approaches. Ferdous et al. (2011) found that tour-based models outperformed traditional trip-based models in forecasting travel demand. Similarly, Hajinasab et al. (2015) demonstrated the value of multi-agent simulation approaches for evaluating transportation planning scenarios.

Researchers have also highlighted the limitations of traditional four-step models in emissions analysis. Because these models often focus on average conditions, they may not adequately capture the temporal and spatial variations necessary for detailed energy and emissions estimation (Páez and Scott, 2007; Mladenovic and Trifunovic, 2014).

Agent-Based Models for Emission and Energy Analysis

Agent-Based Models (ABMs) have emerged as powerful tools for representing transportation systems at a disaggregate level. These models simulate the decisions and interactions of individual travelers, households, and vehicles, allowing researchers to

capture behavioral heterogeneity and dynamic system interactions. Several agent-based frameworks have been developed for transportation planning applications. The Comprehensive Econometric Micro-simulator for Daily Activity-travel Patterns (CEMDAP) has been used extensively in Texas to generate detailed activity-travel patterns for individuals and households (Pinjari et al., 2006). A Learning-Based Transportation Oriented Simulation System (ALBATROSS) was applied in the Netherlands to evaluate travel behavior and associated emissions (Beckx et al., 2009), while Travel Activity Scheduler for Household Agents (TASHA) was developed for the Greater Toronto Area to improve regional emissions inventories (Hatzopoulou et al., 2007).

Additional advances have been made through models such as Agent-based Dynamic Activity Planning and Travel Scheduling (ADAPTS) (Auld et al., 2009; Shabanpour et al., 2018), which dynamically integrates activity planning with transportation network simulation. These approaches provide detailed vehicle trajectories and travel patterns that can be linked to emissions models such as MOtor Vehicle Emission Simulator (MOVES) and Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) to estimate environmental impacts at the individual vehicle level.

POLARIS represents one of the most advanced agent-based transportation modeling platforms currently available. Zuniga-Garcia et al. applied POLARIS to simulate travel behavior in the Atlanta-Chattanooga region and integrated the results with the GREET model to estimate emissions based on detailed vehicle trajectories and speed profiles.

Agent-based transportation simulation can also support vehicle energy analysis by providing detailed information on trip characteristics and vehicle operating conditions. When these outputs are linked with vehicle-level simulation tools, energy consumption and emissions can be evaluated under operating profiles that reflect variation in trip distance, speed, and network conditions rather than relying exclusively on fixed average-per-mile factors. This linkage provides the methodological basis for integrating POLARIS, SVTrip, and Autonomie in the present study.

Houston as a Strategic Case Study for Transportation Electrification

Houston provides a particularly valuable setting for evaluating transportation electrification strategies. As one of the largest metropolitan regions in the United States, Houston is characterized by high automobile dependence, substantial freight activity, extensive roadway infrastructure, and rapidly growing travel demand.

These characteristics create both challenges and opportunities for transportation decarbonization. High levels of VMT contribute to significant transportation-related emissions, while the region's economic importance and transportation infrastructure make it an ideal environment for evaluating emerging technologies and policies.

Houston's extensive roadway network, transit system, and rideshare activity provide an appropriate setting for examining the interaction between regional travel activity, vehicle operations, and alternative vehicle technologies. Applying the modeling framework to Houston also demonstrates its use in a large automobile-oriented metropolitan region characterized by substantial variation in trip distances, network conditions, and transportation services. The case study therefore provides an opportunity to examine vehicle energy and emission characteristics under realistic metropolitan travel and operating conditions.

Research Gap and Study Motivation

Although substantial research has been conducted on transportation electrification, important methodological gaps remain in connecting regional travel activity and vehicle operations with detailed vehicle-level energy analysis. Many studies focus primarily on vehicle technologies or rely on aggregate energy and emission factors, while transportation system models provide detailed information on travel activity and network operations but may not capture the vehicle-level effects of different powertrain technologies and operating conditions.

Previous research has examined electric vehicle charging behavior (Kavianipour et al.), electric bus operations (Lee et al., 2021; Zhang et al., 2024), and shared and automated mobility systems (Gurumurthy et al., 2020; Gurumurthy et al., 2021). These studies demonstrate the importance of considering both transportation-system characteristics and vehicle technology when evaluating emerging mobility applications. However, opportunities remain to connect metropolitan-scale travel simulation with detailed vehicle operating profiles and vehicle energy modeling in order to characterize how energy use and emissions vary across powertrain technologies and operating conditions.

This study addresses this methodological need by applying an integrated POLARIS-SVTrip-Autonomie workflow to the Houston metropolitan region. POLARIS provides detailed information on regional travel activity and vehicle operations, SVTrip translates simulated vehicle trips into detailed speed profiles, and Autonomie uses these profiles to estimate energy consumption and vehicle-level emissions for different powertrain technologies. This linkage enables energy and emission characteristics to be examined using simulated vehicle operating conditions rather than relying solely on fixed average-per-mile assumptions.

This study applies this framework to a baseline condition and alternative passenger-vehicle and TNC fleet electrification assumptions. Transit bus electrification is examined separately using transit activity from POLARIS and literature-based energy and emission factors. Together, these analyses demonstrate how large-scale transportation modeling and vehicle-energy analysis can be used to characterize transportation electrification while also identifying areas where additional data and analysis would be required to estimate systemwide or regional impacts.

Research Methodology

Integrated Modeling Framework

This study employed an integrated modeling framework that combines regional transportation simulation, vehicle speed-profile generation, and vehicle energy simulation to characterize travel activity, vehicle operations, energy consumption, and vehicle-level emissions under alternative fleet and powertrain assumptions in the Houston metropolitan region. The framework integrates three complementary tools developed and maintained by Argonne National Laboratory: POLARIS, SVTrip, and Autonomie.

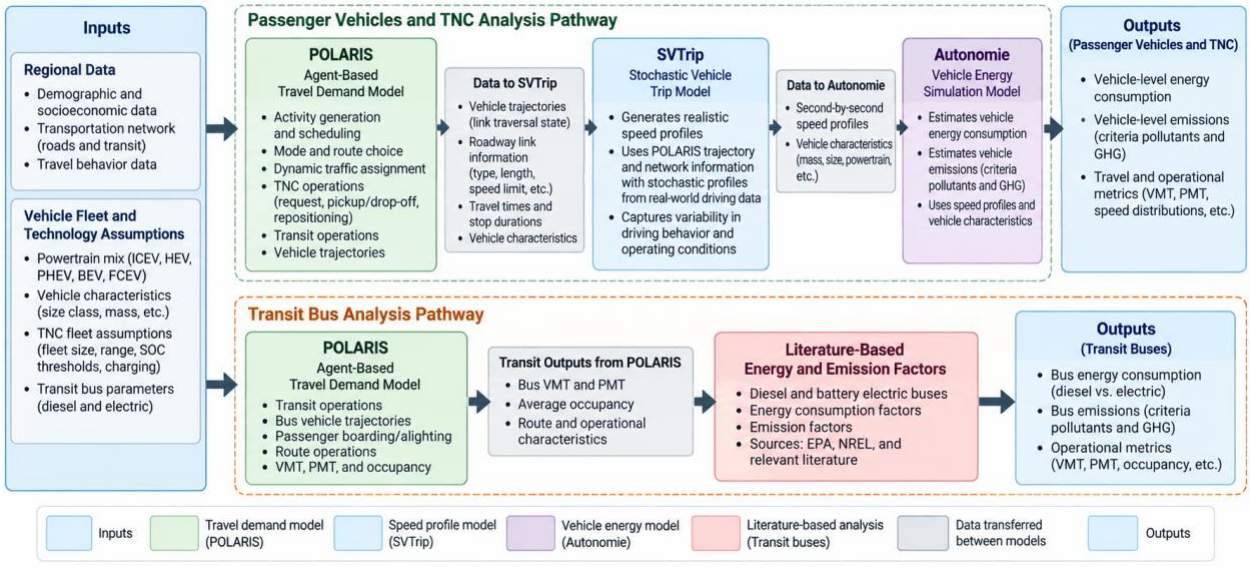


Figure 1. Integrated Modeling Framework and Data Flow for Vehicle Energy and Emission Analysis.

The integration of these tools enables vehicle energy consumption and emissions to be evaluated using operating profiles derived from simulated regional travel rather than relying solely on fixed average-per-mile assumptions. POLARIS represents regional travel activity and vehicle operations, SVTrip translates vehicle trips into detailed speed profiles, and Autonomie uses those operating profiles to estimate energy consumption and emissions for different vehicle powertrain technologies. This linkage is particularly useful for examining how differences in trip distance and vehicle operating conditions influence the energy and emission characteristics of alternative powertrains.

POLARIS Activity-Based Travel Demand Model

The Planning and Operations Language for Agent-based Regional Integrated Simulation (POLARIS) is an advanced agent-based travel demand modeling platform developed by

Argonne National Laboratory (Auld et al., 2016). POLARIS simulates the travel behavior of individual travelers and households while simultaneously representing transportation network operations throughout a metropolitan region.

Unlike traditional four-step travel demand models, which treat trips as independent events, POLARIS employs an activity-based framework that recognizes travel as a consequence of participation in daily activities. Individual travelers are represented as agents who make decisions regarding activity participation, departure time, destination choice, mode selection, and route choice. These decisions are influenced by socioeconomic characteristics, household structure, transportation system conditions, and travel preferences.

POLARIS incorporates multiple behavioral and operational components, including activity generation, activity scheduling, mode choice, dynamic traffic assignment, transit operations, and shared mobility services. The model is capable of representing multimodal transportation systems and capturing interactions among private vehicles, transit services, rideshare operations, and freight movements. For TNC services, POLARIS represents passenger travel requests and fleet vehicles and models the assignment of vehicles to requests, passenger pickup and drop-off operations, and vehicle routing. The shared mobility framework also supports fleet management strategies, including vehicle repositioning and charging operations (Argonne National Laboratory, 2026)

For this study, POLARIS served as the foundation of the analytical framework. Inputs included demographic and socioeconomic data, transportation network characteristics, vehicle ownership information, and travel behavior data. The model generated detailed outputs describing individual travel patterns, vehicle trajectories, travel times, travel distances, and network performance. These outputs characterized regional travel and vehicle activity and provided inputs for the subsequent vehicle energy analysis.

SVTrip Speed Profile Generation

While travel demand models provide information regarding trip origins, destinations, distances, and travel times, vehicle energy consumption depends heavily on second-by-second vehicle operating conditions. To bridge this gap, this study employed the Stochastic Vehicle Trip (SVTrip) model developed by Argonne National Laboratory.

SVTrip generates naturalistic speed profiles using information obtained from travel demand simulations. Inputs to SVTrip include vehicle trajectories, roadway classifications, speed limits, travel times, stop durations, and other trip characteristics produced by POLARIS. These POLARIS outputs reflect the characteristics of the Houston roadway network, including link type, length, speed limits, capacity, and traffic conditions influenced by the number of vehicles operating on each link. SVTrip uses these network-informed outputs together with stochastic speed profiles derived from previously collected real-world vehicle driving data to generate detailed speed traces..

A major advantage of SVTrip is its ability to capture the variability and randomness inherent in vehicle operation. Even when two vehicles travel along the same route, differences in acceleration patterns, deceleration rates, traffic conditions, and driver behavior can produce substantially different energy consumption outcomes. SVTrip incorporates these effects by generating realistic speed trajectories rather than relying on average travel speeds.

The resulting speed profiles provide a more detailed representation of vehicle operating conditions, including stop-and-go traffic, freeway operations, arterial travel, and intersection delays. These detailed speed traces serve as critical inputs for vehicle energy simulation and emissions estimation.

Previous studies have successfully applied the POLARIS-SVTrip framework to estimate vehicle energy consumption and evaluate transportation electrification scenarios. For example, Zuniga-Garcia et al. (2023) used this integrated approach to analyze freight electrification within the Atlanta-Chattanooga region.

Autonomie Vehicle Energy and Emissions Simulation

Autonomie is a high-fidelity vehicle simulation platform developed by Argonne National Laboratory for evaluating vehicle energy use, performance, emissions, and operating costs across a wide range of vehicle technologies. The platform supports simulation of conventional internal combustion engine vehicles, HEVs, PHEVs, BEVs, and FCEVs.

Autonomie utilizes detailed vehicle specifications together with vehicle operating conditions to estimate energy consumption and emissions. Inputs include vehicle characteristics, powertrain configurations, roadway conditions, and speed profiles generated by SVTrip. Using these inputs, the model simulates vehicle performance at a high level of detail and calculates energy use and emissions for individual trips and vehicle types.

In this study, Autonomie was used to evaluate six vehicle powertrain technologies under the fleet electrification cases considered. The model estimated trip-level energy consumption and emissions based on the speed traces generated through the POLARIS-SVTrip workflow. These outputs were used to characterize and compare energy consumption and vehicle-level emission characteristics across the powertrain technologies evaluated.

Autonomie has been widely applied in transportation energy research. Previous studies have used the platform to evaluate energy consumption across multiple vehicle classes and future transportation scenarios (Cokyasar et al., 2020; Freyermuth et al., 2020). The model's ability to represent detailed vehicle dynamics makes it particularly suitable for evaluating transportation electrification strategies and comparing alternative powertrain technologies.

Framework Integration

For passenger vehicles and TNC fleets, the modeling workflow begins with the activity-based simulation conducted in POLARIS. Vehicle trajectories, travel times, and trip characteristics generated by POLARIS are processed through SVTrip to create detailed speed profiles. These speed profiles are subsequently used as inputs to Autonomie, which estimates vehicle-level energy consumption and emissions for the powertrain technologies evaluated. This sequential workflow links regional travel and vehicle operating conditions with vehicle-level energy simulation.

Transit bus operations were also represented within the POLARIS simulation framework. The model generated transit performance measures including VMT, passenger miles traveled (PMT), vehicle occupancy, and passenger boarding and alighting activity. However, because detailed transit vehicle emissions modeling was not fully supported within the Autonomie framework at the time of this study, transit bus electrification was evaluated using a separate, complementary methodology.

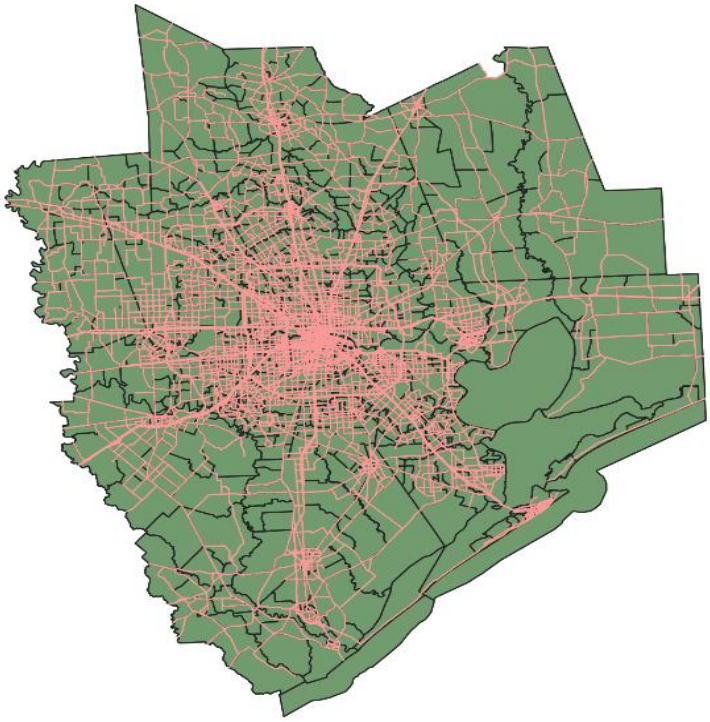
The transit bus assessment combined POLARIS-generated transit activity measures with emission factors, fuel economy assumptions, electricity consumption rates, and lifecycle assessment parameters obtained from the U.S. Environmental Protection Agency (EPA), the National Renewable Energy Laboratory (NREL), and published literature. This approach enabled estimation of GHG emissions for both diesel and electric bus operations under equivalent service conditions and provided insight into the potential environmental benefits of transit fleet electrification.

The combined framework allows researchers to evaluate how changes in travel behavior, vehicle technology, rideshare operations, and transit fleet characteristics influence regional energy consumption and environmental performance. By linking traveler decisions with vehicle operations and emissions outcomes, the framework provides a robust basis for assessing transportation decarbonization strategies and supporting data-driven planning decisions. The resulting methodology supports evaluation of both rideshare electrification and transit bus electrification within a consistent regional modeling environment.

Study Area and Simulation Environment

Study Area

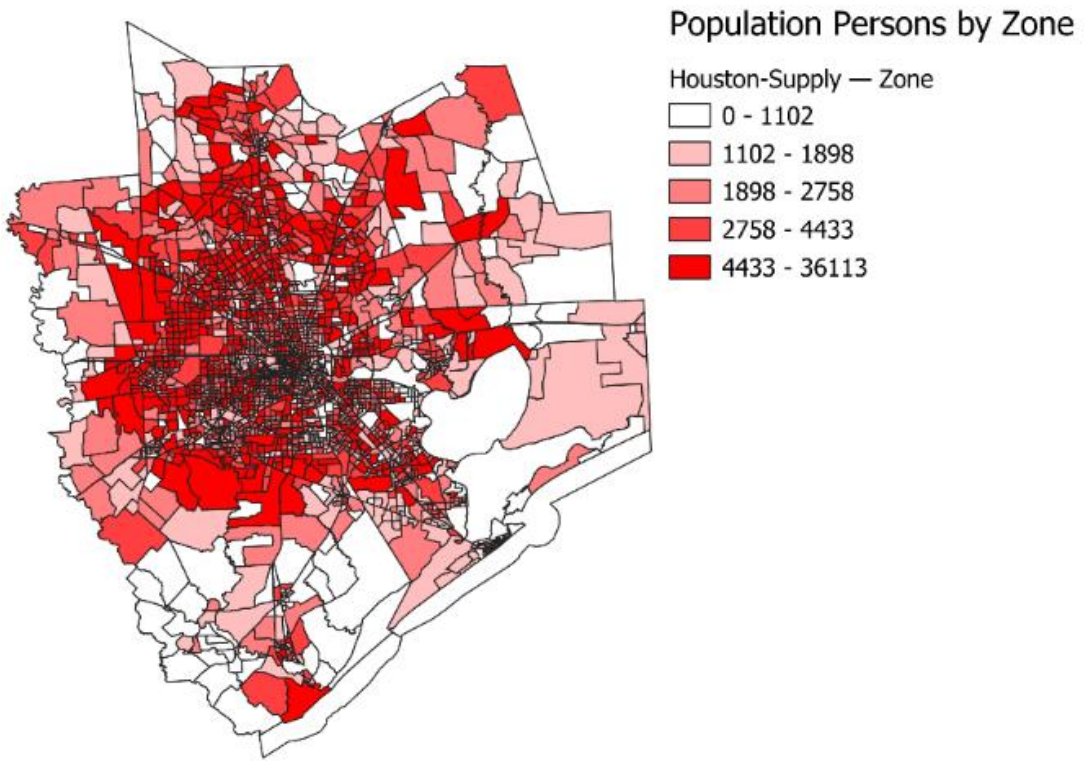
The Houston metropolitan region was selected as the study area because of its size, economic significance, transportation activity, and growing interest in transportation decarbonization strategies. As one of the largest metropolitan areas in the United States, Houston is characterized by high levels of automobile dependency, extensive roadway infrastructure, substantial freight activity, and rapidly increasing travel demand. These characteristics make the region an appropriate case study for examining vehicle electrification and shared mobility applications (Figure 2).



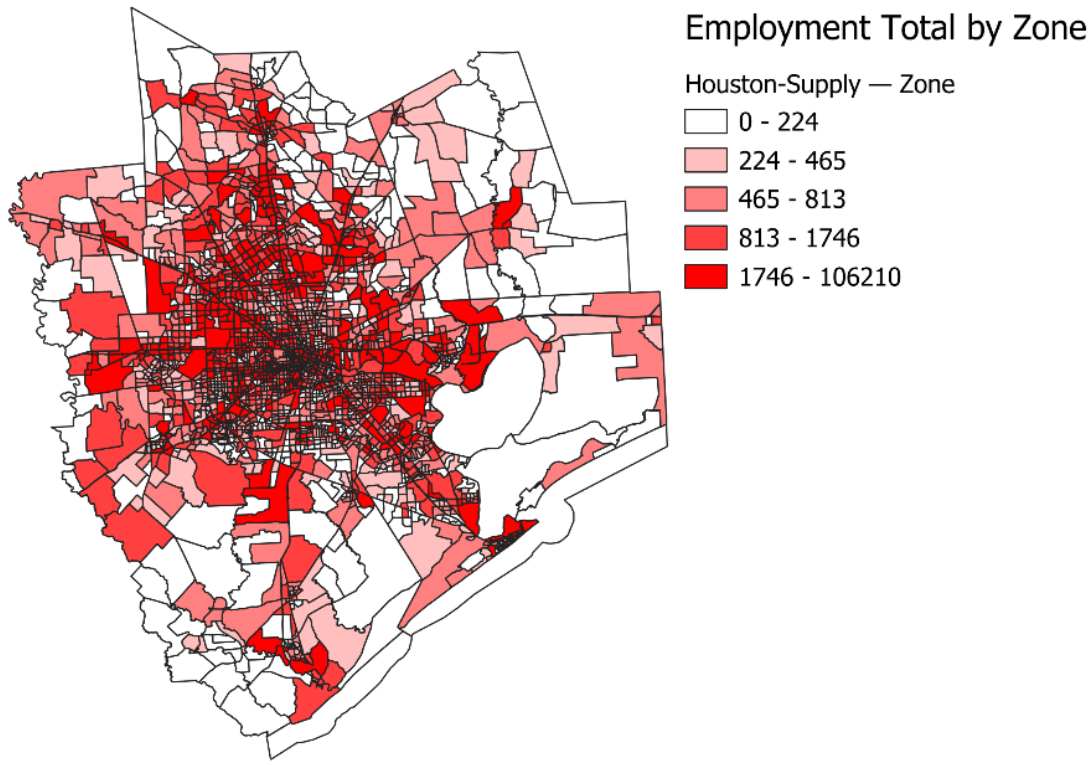
2a. Houston TAZs by links



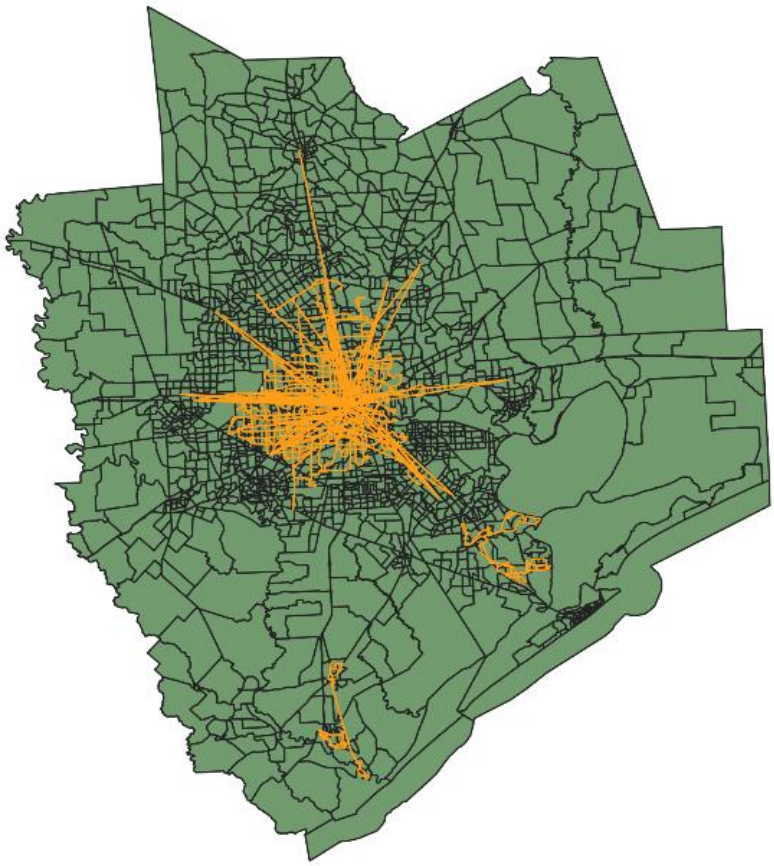
2b. Houston TAZs by nodes



2c. Population persons by zone



2d. Employment total by zone



2e. Houston transit links

Figure 2. Study area.

The study area encompasses the 11-county Houston-Galveston metropolitan region and covers approximately 10,062 square miles. The region includes a diverse mix of urban, suburban, and rural areas and serves as a major transportation hub for both passenger and freight movement. The extensive transportation network, combined with significant rideshare activity and transit operations, provides an appropriate environment for examining transportation electrification.

Within the POLARIS modeling framework, the regional transportation network is represented using 5,217 traffic analysis zones (TAZs), 26,672 roadway links, and 20,261 nodes. This detailed network representation enables simulation of travel behavior and traffic operations at a high spatial resolution while maintaining computational efficiency for large-scale regional analyses. The network includes major freeways, arterial roadways, collector streets, and local roadway connections necessary to represent daily travel patterns throughout the metropolitan area.

Data Sources

The Houston POLARIS model used in this study was developed using regional transportation and travel demand data obtained primarily from the Houston-Galveston Area Council (H-GAC). The present study applied this Houston POLARIS model as part of the integrated modeling framework described above. The underlying model inputs include data from H-GAC, the U.S. Census Bureau, and regional transportation planning sources.

The roadway network utilized in this study was derived from the 2015 regional travel demand model maintained by H-GAC, the Metropolitan Planning Organization (MPO) responsible for transportation planning in the Houston region. The network dataset includes roadway geometry, functional classifications, capacities, speed limits, and traffic assignment information required for activity-based simulation.

Population and household characteristics were derived from the 2018 American Community Survey (ACS) Public Use Microdata Sample (PUMS). These data were used to create a synthetic population representing the demographic and socioeconomic characteristics of households residing within the study region. The synthetic population includes information related to household size, income, employment status, vehicle ownership, and other attributes that influence travel behavior.

Travel behavior inputs were obtained from the 2018 Houston Household Travel Survey. These data provided information regarding trip-making behavior, activity participation, mode choice preferences, trip timing, and travel patterns. The survey data were incorporated into the activity-based demand modeling framework and used to calibrate behavioral components of the simulation.

Mode choice decisions within the model were represented using a nested multinomial logit structure. This approach captures the hierarchical nature of travel decisions and allows travelers to choose among competing transportation alternatives based on travel time, travel cost, accessibility, and service characteristics.

Activity-Based Simulation Environment

The simulation environment was developed within the POLARIS platform using the Agent-based Dynamic Activity Planning and Travel Scheduling (ADAPTS) framework (Auld et al., 2009; Auld et al., 2016). The model represents daily travel behavior through the simulation of individual travelers and households whose decisions collectively determine regional travel patterns.

The activity-based framework simulates both long-term and short-term travel decisions. Long-term decisions include household characteristics, vehicle ownership, workplace location, and residential location. Short-term decisions include daily activity participation, departure time choice, destination selection, mode choice, and route choice. By representing travel as a consequence of activity participation, the framework provides a more realistic representation of travel demand than conventional trip-based models.

Within the simulation, population characteristics remain fixed while travel behavior is allowed to respond dynamically to transportation system conditions. This approach enables travelers to adjust departure times, travel modes, route choices, and trip-making decisions in response to changing network conditions and transportation service availability.

Traffic operations are simulated using a Dynamic Traffic Assignment (DTA) framework integrated within POLARIS. Vehicle routing is based on experienced travel times generated by a mesoscopic traffic simulation model. The mesoscopic representation captures congestion formation, traffic flow dynamics, and network performance while remaining computationally feasible for large metropolitan regions.

The DTA component utilizes a Link Transmission Model (LTM)-based traffic flow representation that allows travel conditions to evolve throughout the day. Compared with traditional static assignment procedures, this approach provides a more realistic representation of congestion patterns and traveler responses to changing traffic conditions.

Electrification Scenario Configuration

To evaluate the impacts of transportation electrification, multiple scenarios were developed within the simulation environment. The baseline scenario represents existing travel patterns and vehicle fleet composition within the Houston metropolitan region. Alternative scenarios were designed to examine the effects of rideshare fleet electrification and broader vehicle fleet electrification strategies.

Scenario Development

A scenario-based analysis was conducted to evaluate the impacts of vehicle electrification on regional energy consumption and emissions within the Houston metropolitan area. Scenario analysis provides a systematic approach for comparing alternative transportation futures and assessing the environmental benefits associated with different levels of electrification. By modifying vehicle fleet characteristics while maintaining a consistent travel demand framework, the analysis isolates the effects of electrification on transportation system performance.

The scenarios developed in this study represent progressively higher levels of transportation electrification. Beginning with existing travel and vehicle ownership conditions, subsequent scenarios examine the impacts of electrifying TNC fleets and ultimately the broader regional vehicle fleet. An additional scenario evaluates the effects of increased rideshare fleet deployment on energy consumption and emissions outcomes.

All scenarios were simulated using the same regional travel demand model, roadway network, and synthetic population. This approach ensured that observed differences in

performance measures were attributable primarily to changes in vehicle technology and fleet composition rather than variations in demographic or network characteristics.

Baseline Scenario

The baseline scenario represents existing travel demand, transportation system operations, and vehicle fleet characteristics within the Houston POLARIS model. It serves as the reference condition for examining the alternative fleet electrification cases considered in this study. The baseline reflects the transportation network, demographic, travel behavior, and vehicle characteristics embodied in the model and its underlying data sources; it should therefore be interpreted as the model's reference condition rather than as a representation of current-year conditions..

Under the baseline scenario, the existing vehicle fleet includes multiple powertrain technologies, including internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel cell electric vehicles (FCEVs). Vehicle travel activity and operating conditions generated through POLARIS were processed through SVTrip to generate detailed speed profiles, which were subsequently used in Autonomie to estimate vehicle-level energy consumption and emissions for the powertrain technologies evaluated.

The baseline scenario provides the reference travel and vehicle operating conditions used in the subsequent analyses and enables characterization of differences in energy consumption and vehicle-level emission characteristics across alternative powertrain and fleet assumptions.

Electrified Transportation Network Company Fleet Scenario

The first electrification case examines an electric Transportation Network Company (TNC) fleet consisting of 20,000 vehicles operating within the Houston metropolitan region. The TNC vehicles are assumed to operate as battery electric vehicles (BEVs), allowing the analysis to examine the travel, operational, and vehicle-energy characteristics associated with an electrified rideshare fleet.

Each electric TNC vehicle is assumed to have a driving range of approximately 300 miles. Operational assumptions include a minimum state-of-charge (SOC) threshold of 15 percent and a charging cutoff threshold of 95 percent. These parameters define the vehicle range and charging constraints applied to the electric TNC fleet in the simulation.

The 20,000-vehicle electric TNC fleet is treated as an analytical modeling case for examining electrified rideshare operations rather than as a forecast of future TNC deployment in the Houston region. The case provides a basis for characterizing TNC vehicle activity, including occupied and unoccupied travel, and for examining the energy and vehicle-level emission characteristics associated with the modeled electric TNC fleet.

Full Fleet Electrification Scenario

The second electrification scenario examines widespread adoption of electric vehicles throughout the modeled passenger-vehicle fleet. Under this scenario, all private and shared-use vehicles are assumed to operate using electric powertrains.

This case was used to examine vehicle energy and emission characteristics under an assumption of complete passenger-vehicle fleet electrification and to provide a contrast with the more targeted TNC electrification case. It represents an analytical electrification case rather than a forecast of a specific future year or regional vehicle-adoption pathway.

Expanded Electrified TNC Fleet Scenario

The final TNC case examines a larger electrified rideshare fleet. In this case, the modeled electric TNC fleet is expanded from 20,000 vehicles to 40,000 vehicles. The electric TNC vehicles are subject to the same vehicle and charging assumptions used in the 20,000-vehicle electrified TNC case.

This case was used to examine differences in TNC vehicle activity and operations associated with a larger modeled electric rideshare fleet, including occupied and unoccupied vehicle travel. Comparison with the 20,000-vehicle TNC case provides information on how TNC operational characteristics change when a larger electric TNC fleet is represented in the simulation.

Transit Bus Electrification Assessment

In addition to the passenger-vehicle and TNC analyses, this study included a separate assessment of transit bus electrification in the Houston metropolitan region. The assessment used transit activity generated through POLARIS together with literature-based energy consumption and emission factors to compare diesel and battery electric bus operations.

The agent-based simulation framework implemented in POLARIS explicitly represents transit operations within the regional transportation network. Transit vehicles, passenger boarding and alighting activities, route operations, vehicle miles traveled (VMT), passenger miles traveled (PMT), and vehicle occupancy levels were simulated as part of the regional travel demand model. These outputs provide information on transit system utilization and operational characteristics under the modeled travel conditions. Unlike passenger vehicles and TNC vehicles, transit buses were not directly simulated within the Autonomie vehicle energy modeling platform. At the time of this research, Autonomie's transit vehicle capabilities were limited and did not fully support the detailed emissions estimation required for large-scale transit fleet analysis. Therefore, a separate analytical approach was used for the transit bus assessment. Transit operational outputs generated by POLARIS, including VMT, PMT, and average occupancy were combined with literature-based energy consumption and emission factors for conventional diesel and battery electric buses. The energy consumption and emission parameters used in this assessment

were obtained from the U.S. Environmental Protection Agency (EPA), the National Renewable Energy Laboratory (NREL), and relevant published literature.

This approach provides a comparison of the operational energy and emission characteristics of diesel and battery electric bus technologies under the same modeled transit activity. Because the transit bus assessment uses literature-based factors rather than the POLARIS–SVTrip–Autonomie workflow applied to passenger vehicles and TNCs, its results are interpreted separately and are not used for direct comparison of regional emissions impacts across the electrification cases.

Model Convergence

Prior to evaluating electrification scenarios, the activity-based travel demand model was examined to assess the stability of simulated travel behavior and network performance across successive iterations. This convergence assessment was conducted to determine whether key simulation outputs had stabilized sufficiently for use in the subsequent vehicle energy and emissions analysis.

The Houston regional model implemented in POLARIS was developed using demographic, socioeconomic, and travel behavior data obtained from the H-GAC, the ACS, and the Houston Household Travel Survey. The present assessment examined the convergence of travel demand and network performance measures generated by the model. Although these measures provide information on simulation stability, they do not constitute an independent validation of model outputs against observed regional travel conditions.

Convergence Assessment

POLARIS utilizes an iterative simulation framework in which travelers continuously adjust their decisions regarding route choice, departure time, destination selection, and mode choice in response to experienced travel conditions. As a result, multiple iterations are required before system-level performance measures stabilize.

To evaluate convergence, several key indicators were monitored across successive simulation iterations, including:

- Zone-to-zone travel time and distance skim matrices
- Vehicle Miles Traveled (VMT)
- Total number of trips
- Average travel speed by mode

These indicators were examined for simulation iterations 14 through 17, representing the final stages of the model execution process.

Skim Matrix Stability

Travel time and distance skim matrices provide a summary of accessibility and travel conditions throughout the transportation network. Stability of these matrices across iterations suggests that travelers' route and destination choices have largely stabilized.

Figure 3 presents hourly travel time and travel distance skim values for iterations 14 through 17. The results demonstrate consistent temporal patterns across all iterations, with only minor variations observed between successive runs. The similarity of the curves suggests that the model had achieved convergence and was producing stable estimates of interzonal travel conditions.

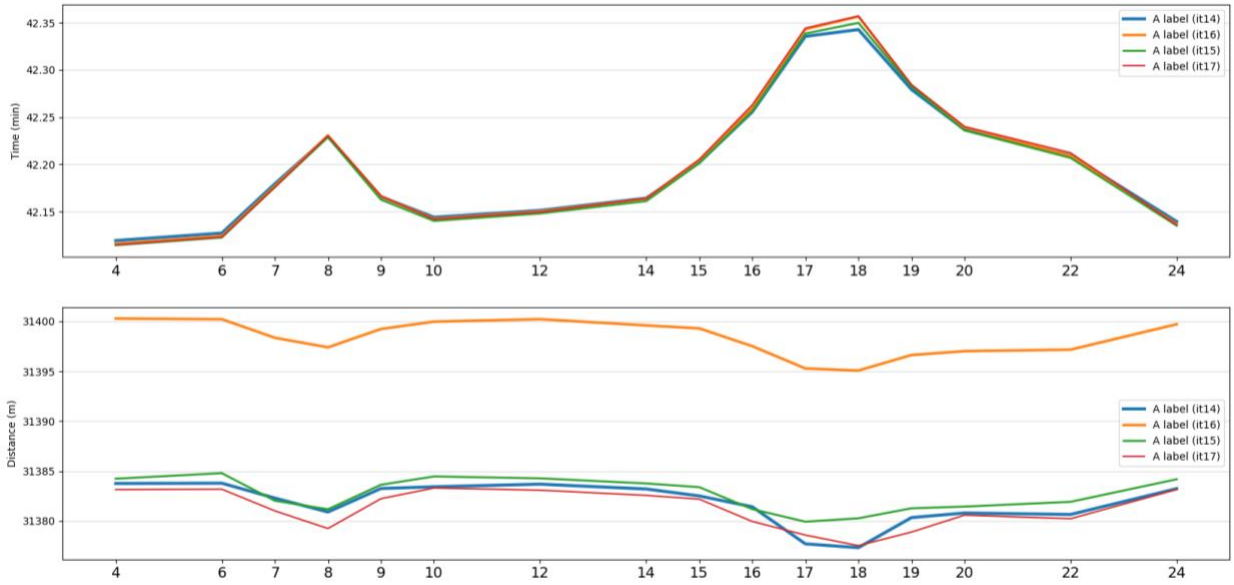


Figure 3. Hourly travel time and travel distance skim values across iterations 14 to 17.

The convergence of skim matrices is particularly important because these values influence subsequent traveler decisions within the activity-based modeling framework. Stable skim values suggest that the feedback process between travel demand and network performance is approaching consistency.

Vehicle Miles Traveled and Trip Generation

VMT and total trip production represent two of the most important indicators of travel demand model performance. Significant fluctuations in either measure across iterations may indicate instability in traveler behavior or network conditions.

Figure 4 illustrates regional VMT and total trip counts across the final simulation iterations. Results show that both measures remained highly consistent between iterations 14 and 17. Variations were relatively small across the final iterations, suggesting that these measures were approaching stable values.

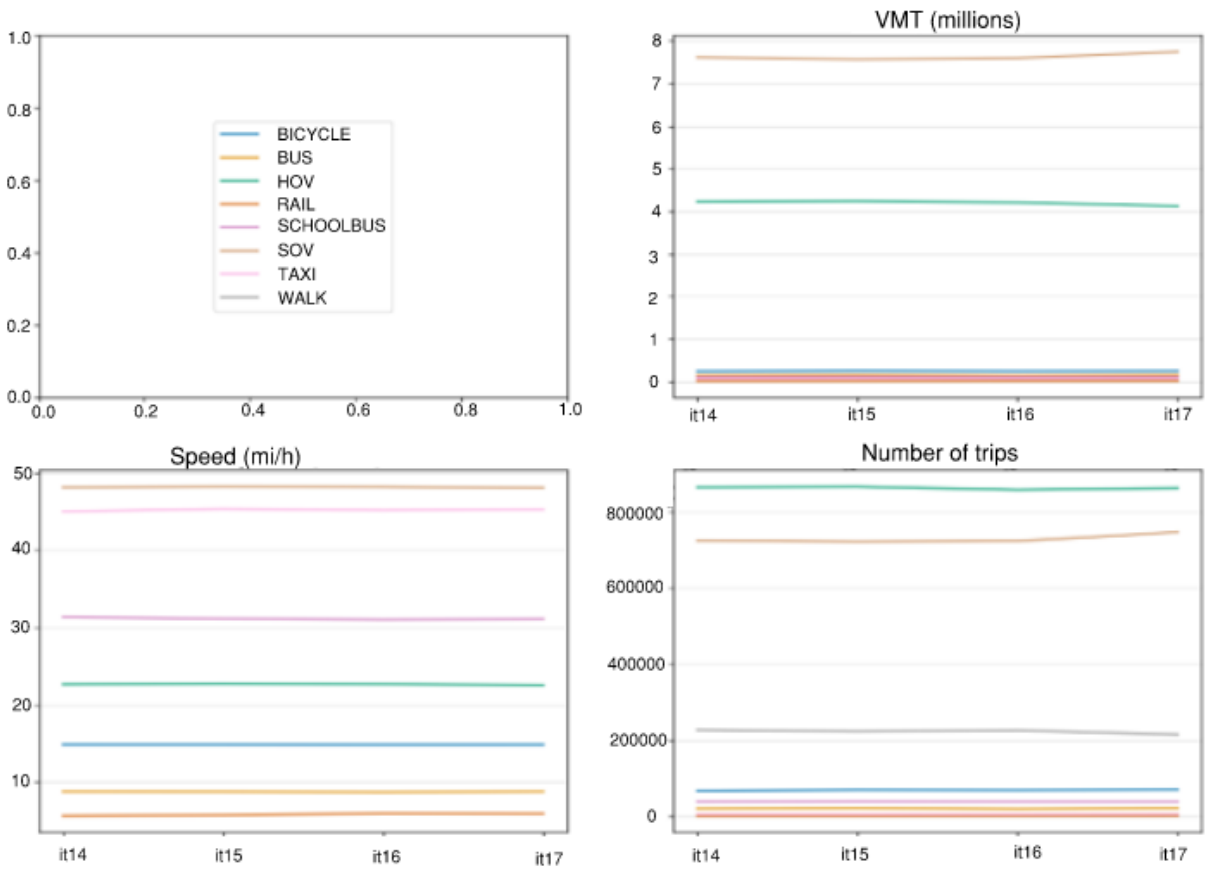


Figure 4. Average vehicle speed, VMT, and total trips across simulation iterations 14 to 17.

The stability of VMT and trip generation results indicates that the model was producing consistent representations of regional travel demand and that traveler decision-making processes had stabilized by the final iteration.

Travel Speed Analysis

Average travel speeds were also evaluated as an additional indicator of network performance and model convergence. Travel speeds were examined across major travel modes and roadway facilities to verify consistency in traffic operations.

Results indicate that average travel speeds remained relatively constant across the final iterations. Minor fluctuations were observed, reflecting natural variability in network conditions; however, no systematic changes were identified that would suggest instability in the simulation.

Because travel speed directly influences vehicle energy consumption and emissions estimation, confirmation of speed stability was particularly important for the subsequent SVTrip and Autonomie analyses.

Model Convergence Summary

The convergence analysis indicated that key travel demand and network performance were relatively stable during the final simulation iterations. Skim matrices, VMT, trip counts, and average travel speeds exhibited generally consistent patterns across iterations 14 through 17.

Based on this assessment, the final iteration outputs were used in the subsequent vehicle energy consumption and emissions analyses. However, convergence does not establish agreement with observed travel conditions. Independent validation against observed regional travel demand and traffic data was not demonstrated in this study, and this limitation should be considered when interpreting the simulation results.

Results and Discussion

This chapter presents the results of the scenario analyses conducted to evaluate transportation decarbonization strategies in the Houston metropolitan region. The integrated modeling framework described in the Research Methodology section was used to examine travel activity, vehicle energy consumption, and vehicle-level emissions under alternative electrification assumptions. The analysis considered multiple electrification scenarios, including rideshare fleet electrification, full passenger vehicle fleet electrification, and expanded rideshare fleet deployment. In addition, transit bus electrification was evaluated using transit activity measures generated by the POLARIS model and emission-factor-based calculations.

The chapter begins with an overview of travel demand and transportation system characteristics generated by the activity-based simulation model. Subsequent sections present the impacts of alternative electrification scenarios on energy consumption and emissions. The chapter concludes with a discussion of the findings and their implications within the scope of the analysis.

Travel Demand and Transportation System Characteristics

Prior to evaluating electrification scenarios, it is important to understand the travel demand patterns and transportation system characteristics generated by the activity-based simulation model. These outputs provide insight into traveler behavior, transportation system utilization, and operational characteristics that influence energy consumption and emissions.

Transportation Network Company Operations

TNC operations play an important role in understanding the impacts of rideshare electrification. The simulation results indicate that occupied TNC vehicles account for the majority of VMT and VHT (Figure 5). Approximately 700,000 vehicle miles were accumulated while transporting passengers, compared with approximately 250,000 vehicle miles traveled without passengers. Similar patterns were observed for vehicle hours traveled.

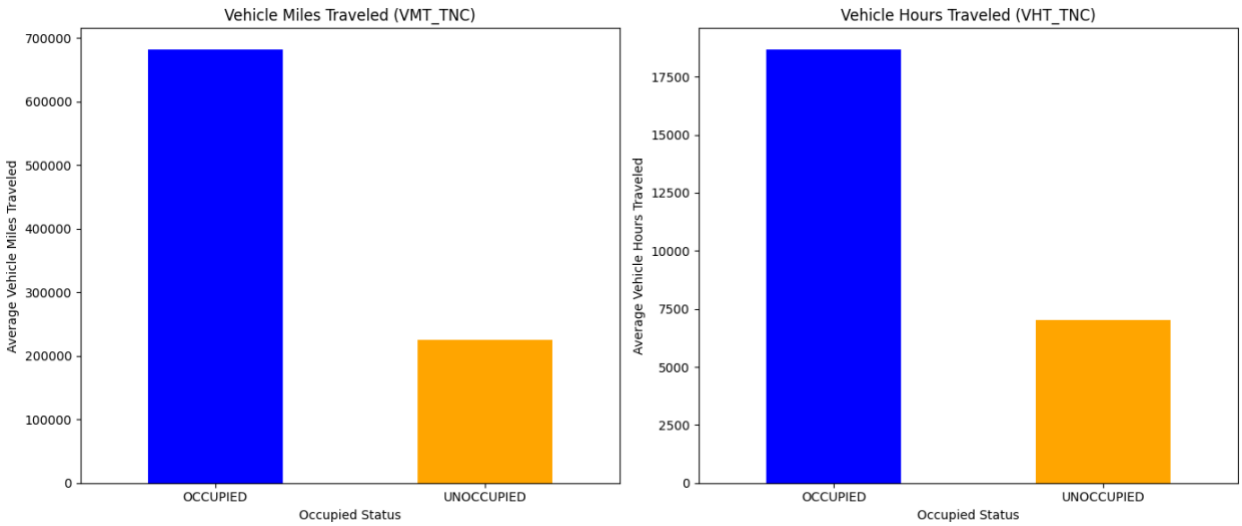


Figure 5. VMT and VHT for occupied and unoccupied TNC operations.

These findings indicate that occupied travel accounts for a substantial portion of the modeled TNC vehicle activity. However, the results also reveal considerable unoccupied vehicle travel associated with repositioning, passenger pickup activities, and deadheading. Because unoccupied travel contributes to vehicle mileage and energy consumption without directly transporting passengers, it is an important consideration when interpreting the energy implications of TNC electrification.

Analysis of trip status further revealed that drop-off activities generated substantially more VMT and VHT than pickup activities (Figure 6). These results illustrate differences between the modeled pickup and drop-off activity categories. However, the interpretation of these differences depends on how these activities are defined and represented within POLARIS..

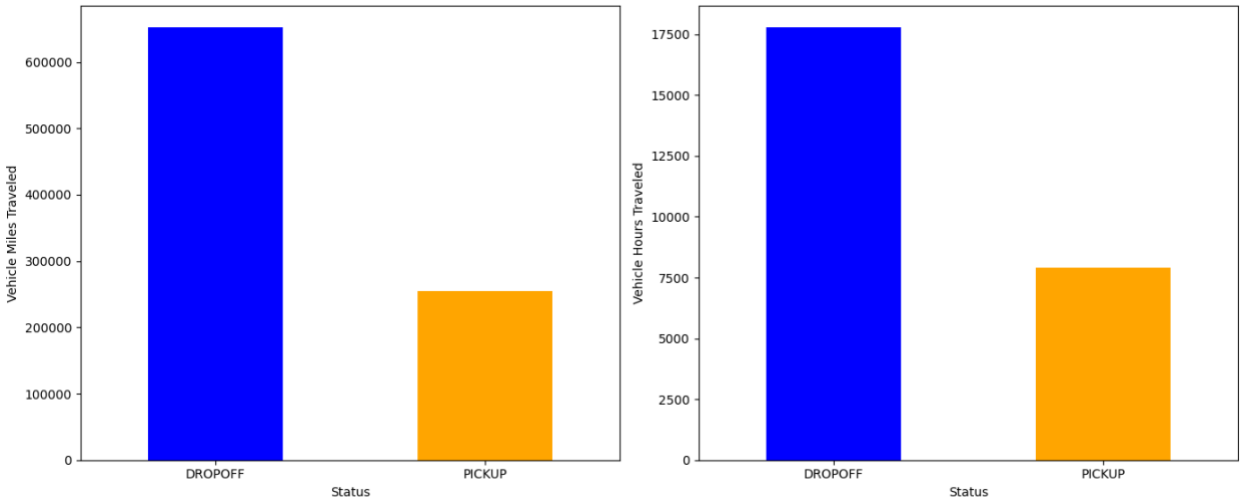


Figure 6. Average TNC VMT and VHT for passenger pickup and drop-off activities.

Activity-Based Model Performance

The activity-based simulation demonstrated good agreement with observed travel behavior patterns. Activity generation results closely matched calibration targets for work, school, shopping, social, healthcare, and recreational activities (Figure 7). The model accurately reproduced expected temporal patterns, including morning peaks associated with work and school activities and evening peaks associated with home activities.



Figure 7. Calibration of activity timing distributions for major activity types.

Transit boarding and alighting patterns were also consistent across model iterations. Metro bus services accounted for the largest share of transit ridership, while Connect bus services and Metro rail services maintained lower but stable ridership levels (Figure 8). The consistency of these results across successive simulation runs provides confidence in the stability and reliability of the travel demand model.

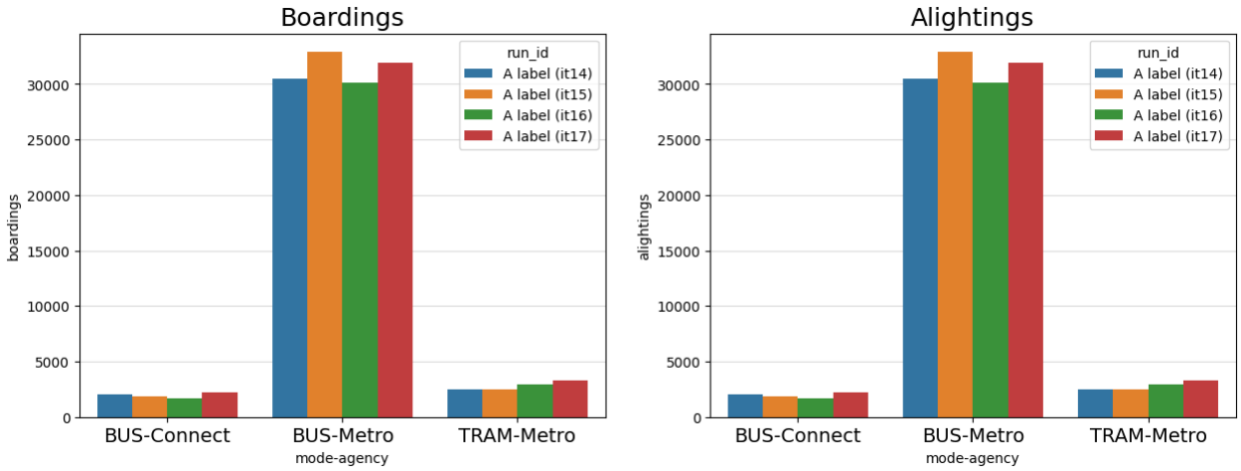


Figure 8. Transit boardings and alightings across simulation iterations by transit service provider.

Overall, the activity-based simulation provided travel activity and network performance outputs for the subsequent vehicle energy analyses. The convergence results indicate relative stability across the final iterations, although independent validation against observed regional travel conditions was not demonstrated in this study.

Baseline Energy Consumption and Emissions Analysis

The baseline scenario represents the travel demand patterns and vehicle fleet characteristics embodied in the Houston POLARIS model. This scenario serves as the reference condition for examining the alternative electrification cases considered in this study. The baseline analysis characterizes vehicle-level energy consumption and emission rates under the modeled travel and vehicle operating conditions.

Baseline Vehicle Fleet Characteristics

The travel demand simulation generated a regional vehicle fleet consisting of 128,107 vehicles. The fleet was dominated by conventional ICEVs, which accounted for approximately 99 percent of all vehicles in the simulation. The remaining fleet included small numbers of HEVs, PHEVs, and BEVs. This fleet represents the vehicles included in the simulation and should not be interpreted as the total registered vehicle population of the Houston metropolitan region.

Of the total simulated fleet, 7,436 vehicles were associated with valid trips and complete speed trajectories suitable for vehicle energy simulation. These vehicles were subsequently processed through the SVTrip and Autonomie workflow to estimate energy consumption and emissions. Because detailed vehicle operating profiles are required for the energy analysis, only vehicles with suitable trip trajectories were included. The 7,436 vehicles therefore represent the subset used for the vehicle energy analysis rather than the entire simulated regional fleet..

To facilitate comparison among alternative vehicle technologies, each valid trip was evaluated using alternative powertrain configurations, including conventional ICEVs, BEVs, HEVs, FCEVs, and PHEVs. This approach allowed the impacts of vehicle technology to be isolated while maintaining identical travel conditions across simulations.

Baseline Energy Consumption

The baseline analysis revealed substantial differences in energy efficiency among vehicle powertrains (Table 1). Conventional internal combustion engine vehicles exhibited the highest energy consumption, averaging approximately 0.73 kilowatt-hour (kWh) per kilometer (km). Hybrid electric vehicles reduced energy consumption to approximately 0.63 kWh/km, while plug-in hybrid electric vehicles achieved significantly lower energy requirements of approximately 0.31 kWh/km.

Table 1. Fuel economy and energy consumption across vehicle powertrain technologies.

Powertrain	Fuel Economy (km/l)	Energy Consumption (kWh/km)
ICE	12.914	0.73
HEV	13.416	0.63
PHEV	63.844	0.31
BEV	N/A	0.214

BEVs demonstrated the highest energy efficiency among all evaluated technologies. Simulation results indicated an average energy consumption of approximately 0.214 kWh/km, representing less than one-third of the energy consumption associated with conventional gasoline-powered vehicles. These findings highlight the substantial efficiency advantages associated with vehicle electrification.

The relationship between trip distance and energy consumption further illustrated differences among vehicle powertrains (Figure 9). Energy consumption generally increased with trip distance, although the patterns varied across powertrain technologies. BEVs exhibited lower energy requirements than conventional ICEVs under the modeled operating conditions, while hybrid and plug-in hybrid vehicles generally exhibited intermediate energy consumption characteristics.

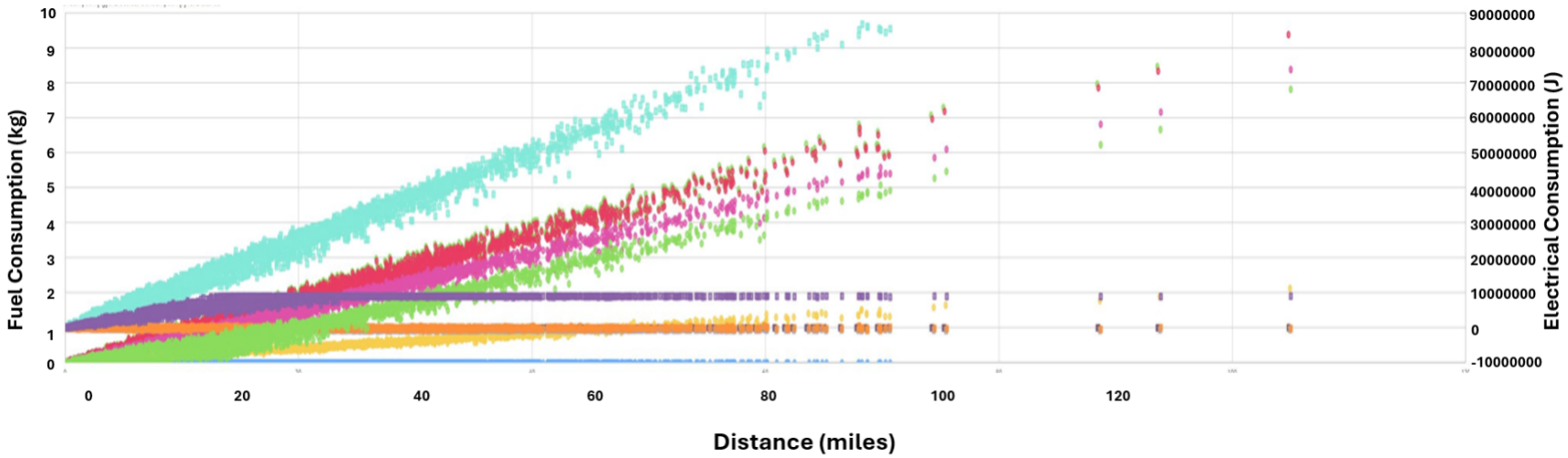


Figure 9. Energy consumption as a function of trip distance for different vehicle powertrain technologies

The baseline results therefore demonstrate differences in vehicle-level energy consumption among the powertrain technologies evaluated under the modeled operating conditions.

Baseline Greenhouse Gas Emissions

GHG emissions were evaluated using carbon dioxide equivalent (CO_2e) measures derived from the Autonomie simulations (Table 2). Results indicate that vehicle powertrain technology has a substantial influence on emissions performance.

Table 2. Average emissions (g/km) by pollutant and vehicle powertrain technology.

Vehicle Type	GHGs	VOC	CO	PM_{10}	$PM_{2.5}$	NO_x	SO_x	BC	POC	CH_4	N_2O
ICE	221.54	0.197	1.488	0.0206	0.0105	0.148	0.0515	0.00173	0.00312	0.275	0.0106
Electric	112.04	0.0114	0.0318	0.0244	0.00854	0.0715	0.194	0.00083	0.0015	0.201	0.00163
HEV I	213.65	0.190	1.435	0.0199	0.0101	0.143	0.0497	0.00167	0.00301	0.265	0.0102
HEV II	168.66	0.0190	0.0479	0.0199	0.00823	0.0755	0.0796	0.00102	0.00163	0.387	0.00119
HEV III	163.46	0.145	1.098	0.0152	0.00773	0.110	0.0380	0.00128	0.00231	0.203	0.00779
PHEV	125.00	0.0722	0.522	0.0178	0.00734	0.0822	0.103	0.00096	0.00173	0.183	0.00432

The average GHG emission rate for conventional ICEVs was approximately 222 grams per kilometer (g/km). HEVs reduced emissions modestly, while PHEVs achieved considerably greater reductions. BEVs demonstrated the lowest GHG emissions among all technologies evaluated, with average emissions of approximately 112 g/km, representing nearly a 50 percent reduction relative to conventional gasoline-powered vehicles.

Overall, the results confirm that electrified vehicle technologies can substantially reduce GHG emissions while maintaining equivalent mobility levels.

Criteria Pollutant Emissions

In addition to GHG emissions, the baseline analysis examined several criteria pollutants commonly associated with transportation activities, including volatile organic compounds (VOC), carbon monoxide (CO), particulate matter (PM_{10} and $PM_{2.5}$), nitrogen oxides (NO_x), sulfur oxides (SO_x), black carbon (BC), primary organic carbon (POC), methane (CH_4), and nitrous oxide (N_2O).

The results presented in Table 2 indicate differences in modeled emission rates across vehicle technologies for several pollutants, including VOC, CO, NO_x, and particulate matter. The magnitude and direction of these differences vary by pollutant and powertrain technology.

These results provide supplementary information on the emission characteristics of the evaluated vehicle technologies. They represent modeled emission rates rather than estimates of regional air quality impacts.

Baseline Scenario Summary

The baseline analysis establishes a reference for examining vehicle energy consumption and emissions under alternative electrification assumptions. Results demonstrate differences in energy consumption and emission rates across the evaluated vehicle technologies. BEVs exhibited the lowest reported energy consumption, while conventional ICEVs generally exhibited higher energy consumption and GHG emission rates under the modeled operating conditions.

These findings provide a basis for interpreting the vehicle-level energy and emission characteristics presented in the subsequent rideshare and passenger-vehicle electrification analyses. The results should not be interpreted as estimates of total regional energy savings or emissions reductions.

Electrified TNC Fleet Scenario (20,000 Vehicles)

Transportation Network Companies (TNCs) represent an important application for vehicle electrification because their operations include both passenger-serving and unoccupied vehicle travel. This section examines vehicle energy consumption and emission characteristics under the analytical scenario involving 20,000 electric TNC vehicles operating within the Houston metropolitan region.

Scenario Overview

The rideshare electrification scenario considers an analytical fleet of 20,000 battery electric TNC vehicles operating within the study area. The electrified rideshare fleet consisted of 20,000 vehicles with an assumed driving range of approximately 300 miles. Vehicle operations were subject to charging constraints, including a minimum state-of-charge threshold of 15 percent and a charging cutoff threshold of 95 percent.

The scenario was used to examine the vehicle energy consumption and emission characteristics associated with electric TNC operations under the modeled travel conditions. The 20,000-vehicle fleet represents an analytical case rather than a forecast of future TNC deployment or an adopted electrification target for the Houston region.

Energy Consumption Impacts

Simulation results indicate differences in vehicle energy consumption between battery electric and conventional gasoline-powered vehicles under the modeled TNC operating conditions. Battery electric vehicles generally exhibited lower energy consumption per unit of distance traveled, reflecting differences in powertrain efficiency (Figure 10).

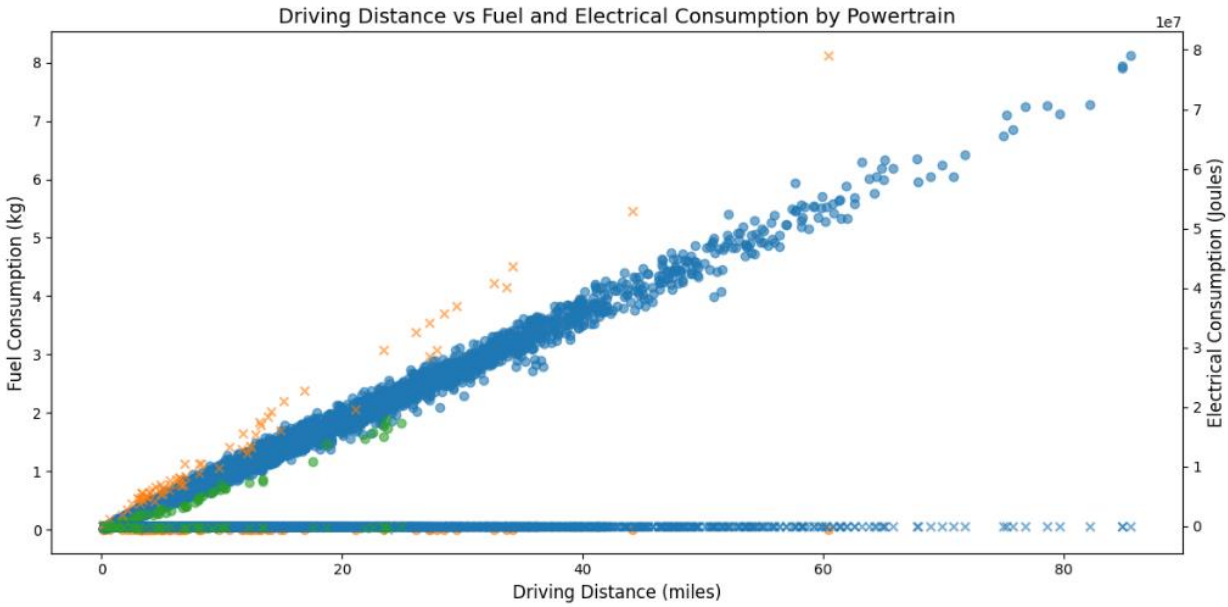


Figure 10. Per-link fuel and electricity consumption under the electrified TNC fleet scenario.

Greenhouse Gas Emissions Impacts

The modeled GHG emission rates differed across vehicle powertrain technologies under the TNC electrification scenario (Table 3). Conventional ICEVs exhibited an average emission rate of approximately 220.75 g/km, compared with 107.47 g/km for electric vehicles. These results represent vehicle-level emission rate comparisons rather than estimates of total emissions reductions from electrifying the 20,000-vehicle TNC fleet.

Table 3. Average GHG and criteria pollutant emissions (g/km) by vehicle powertrain technology under the TNC electrification scenario.

Vehicle Type	GHGs	VOC	CO	PM_{10}	$PM_{2.5}$	NO_x	SO_x	BC	POC	CH_4	N_2O
ICE	220.75	0.196	1.483	0.0205	0.0104	0.148	0.0513	0.00173	0.00311	0.274	0.0105
Electric	107.47	0.011	0.030	0.0234	0.0082	0.068	0.1862	0.00080	0.00144	0.193	0.00156
HEV I	161.57	0.143	1.085	0.0150	0.0076	0.108	0.0375	0.00126	0.00228	0.200	0.0077
PHEV	152.01	0.105	0.782	0.0188	0.0082	0.101	0.0910	0.00117	0.00212	0.209	0.006

Criteria Pollutant Emissions Impacts

Table 3 also presents modeled emission rates for several pollutants, including CO, NO_x, VOC, and particulate matter. The results indicate differences in emission rates between conventional and electrified vehicle technologies under the modeled TNC operating conditions.

These results provide supplementary information on vehicle emission characteristics and should not be interpreted as estimates of regional air quality improvements associated with TNC electrification.

Operational Consideration

Table 3 also presents modeled emission rates for several pollutants, including CO, NO_x, VOC, and particulate matter. The results indicate differences in emission rates between conventional and electrified vehicle technologies under the modeled TNC operating conditions.

These results provide supplementary information on vehicle emission characteristics and should not be interpreted as estimates of regional air quality improvements associated with TNC electrification.

Another important consideration is empty vehicle travel associated with repositioning and passenger pickup activities. As discussed earlier in this report, a significant portion of rideshare vehicle travel occurs without passengers. This unoccupied travel contributes to total vehicle mileage and should be considered when interpreting the potential energy and emissions implications of TNC electrification.

Discussion

The electrified TNC fleet scenario provides a vehicle-level comparison of energy consumption and emission characteristics under the modeled rideshare operating conditions. The results indicate that battery electric vehicles generally exhibit lower energy consumption and modeled GHG emission rates than conventional gasoline-powered vehicles.

The operational characteristics of TNC services, particularly the distinction between occupied and unoccupied vehicle travel, are important considerations when interpreting these results. Although the scenario assumes an analytical fleet of 20,000 electric TNC vehicles, the reported findings do not quantify the total regional energy savings or GHG emission reductions associated with this fleet size.

Overall, the analysis illustrates differences in vehicle energy and emission performance associated with electric TNC operations. Further analysis would be needed to quantify fleet-wide or regional impacts and evaluate charging infrastructure requirements and operational management strategies.

Full Passenger Vehicle Fleet Electrification Scenario

To examine the energy consumption and emission characteristics associated with widespread passenger vehicle electrification, a full fleet electrification scenario was developed in which all eligible passenger vehicles were assumed to operate using battery electric vehicle (BEV) technology. This scenario provides an analytical comparison of

vehicle energy consumption and emission rates under alternative powertrain assumptions rather than an estimate of total regional emissions reductions.

Scenario Overview

The full fleet electrification scenario replaced conventional internal combustion engine vehicles with BEVs while maintaining the same travel demand patterns generated by the activity-based simulation model. Traveler behavior, trip-making characteristics, and network conditions remained unchanged, allowing differences in modeled vehicle energy consumption and emission rates to be examined under alternative powertrain assumptions.

By holding travel demand constant, the analysis focused on differences in vehicle energy consumption and emissions associated with the assumed powertrain technologies. This approach provides a basis for examining vehicle-level energy and emission characteristics under the full passenger vehicle electrification scenario.

Energy Consumption Impacts

Simulation results indicate that battery electric vehicles generally consumed less energy per unit of distance traveled than conventional gasoline-powered vehicles under the modeled operating conditions. These differences reflect the energy efficiency characteristics of the evaluated powertrain technologies.

The results provide a vehicle-level comparison of energy consumption under the full passenger vehicle electrification assumption. However, the analysis does not quantify total regional energy savings or establish that this scenario produces greater aggregate savings than the electrified TNC fleet scenarios.

Greenhouse Gas Emissions Impacts

The full passenger vehicle electrification scenario was also examined in terms of modeled vehicle emission rates (Figure 11). The results characterize emissions associated with battery electric vehicle operation under the assumptions used in the analysis.

Compared with conventional internal combustion engine vehicles, battery electric vehicles exhibited lower modeled GHG emission rates, consistent with the differences reported in the baseline vehicle technology comparison. However, these results do not represent a calculation of total regional GHG emissions or the aggregate emissions reduction associated with electrifying the regional passenger vehicle fleet.

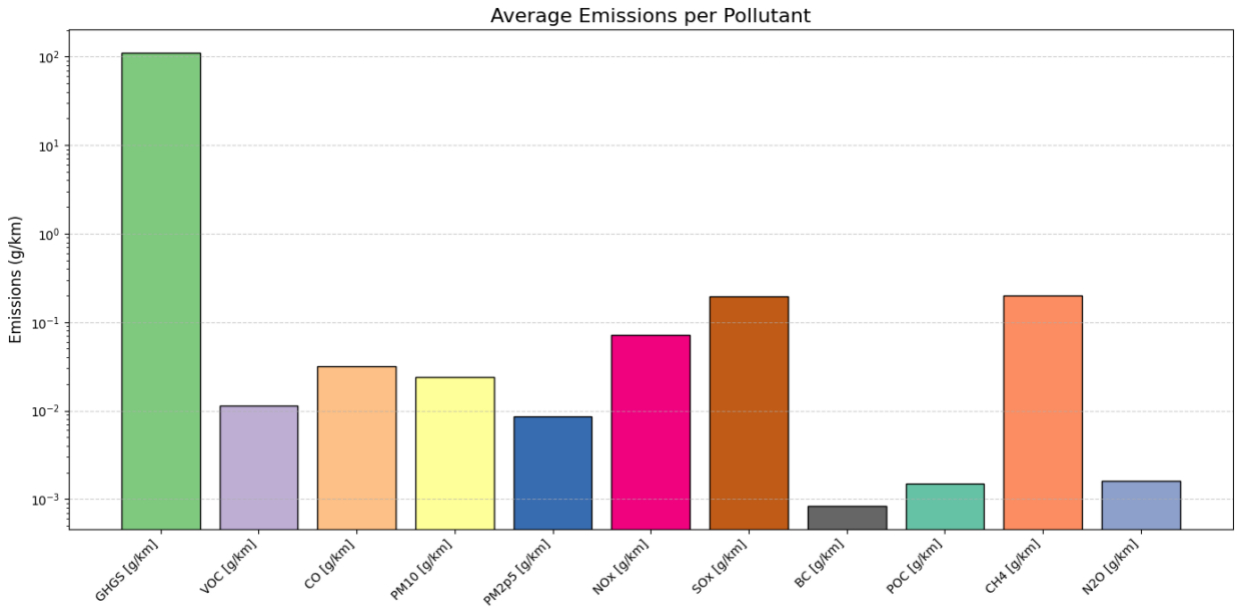


Figure 11. Average emissions by pollutant for BEVs.

Criteria Pollutant Emissions Impacts

The full passenger vehicle electrification analysis also provides information on modeled emission rates for several pollutants, including CO, NO_x, VOC, and particulate matter. These results supplement the GHG emissions analysis by characterizing differences in emission rates associated with the evaluated vehicle technologies.

The reported emission rates should not be interpreted as estimates of total regional pollutant reductions or changes in ambient air quality. Such assessments would require additional fleet activity, emissions aggregation, and air quality analyses beyond the scope of this study.

Comparison with Rideshare Fleet Electrification

The full passenger vehicle electrification and electrified TNC fleet scenarios represent different analytical assumptions regarding the application of battery electric vehicle technology. The TNC scenarios focus on specified electric rideshare fleet sizes, while the full fleet scenario assumes electrification of eligible passenger vehicles.

The results presented in this report primarily characterize vehicle-level energy consumption and emission rates. Because comparable fleet-wide energy consumption and emissions totals were not established for these scenarios, the analysis does not support a quantitative ranking of their aggregate regional impacts.

Discussion

The full passenger vehicle electrification scenario illustrates differences in energy consumption and emission characteristics between battery electric and conventional vehicle technologies under the modeled travel conditions. The results indicate lower vehicle-level energy consumption and modeled GHG emission rates for BEVs compared with conventional ICEVs.

The scenario provides an analytical representation of widespread passenger vehicle electrification rather than a forecast of future vehicle adoption or a comprehensive assessment of regional transportation decarbonization. The analysis does not quantify aggregate regional emissions reductions, changes in electricity demand, or charging infrastructure requirements.

Overall, the findings contribute to understanding vehicle-level energy and emission performance under alternative powertrain assumptions. Further analysis would be required to evaluate the aggregate transportation system impacts of widespread passenger vehicle electrification.

Expanded Electrified TNC Fleet Analysis

The previous TNC electrification scenario considered an analytical fleet of 20,000 electric rideshare vehicles. To examine an alternative fleet-size assumption, an expanded scenario was developed with 40,000 electric TNC vehicles. This scenario provides additional information on vehicle energy consumption and emission characteristics under the modeled operating conditions.

Scenario Overview

The expanded electrified TNC fleet scenario assumed 40,000 electric rideshare vehicles operating within the Houston metropolitan region, compared with 20,000 vehicles in the previous TNC scenario. All vehicles were assumed to operate as BEVs and were subject to the same charging constraints used in the previous rideshare electrification scenario, including a minimum state-of-charge threshold of 15 percent and a charging cutoff threshold of 95 percent.

The purpose of this scenario was to examine vehicle energy consumption and emission characteristics under a larger assumed electric TNC fleet size. The scenario does not represent a forecast of future TNC deployment or an assessment of the optimal number of rideshare vehicles for the Houston region.

Energy Consumption Impacts

The expanded TNC fleet scenario considered battery electric vehicles under the modeled operating conditions. As discussed in the preceding analyses, electric powertrains

generally exhibited lower energy consumption per unit of distance traveled than conventional gasoline-powered vehicles.

However, the results presented in this section do not quantify total fleet energy consumption or establish how aggregate energy demand changed between the 20,000-vehicle and 40,000-vehicle TNC scenarios.

Greenhouse Gas Emissions Impacts

Table 4 presents modeled GHG and pollutant emission rates for alternative vehicle powertrain technologies under the expanded TNC fleet scenario. The average GHG emission rate was approximately 221.79 g/km for conventional ICEVs and 102.67 g/km for electric vehicles. These values represent vehicle-level emission rates rather than total fleet emissions.

Table 4. Average GHG and criteria pollutant emissions (g/km) by vehicle powertrain technology under the expanded TNC electrification scenario.

Vehicle Type	GHGs	VOC	CO	PM_{10}	$PM_{2.5}$	NO_x	SO_x	BC	POC	CH_4	N_2O
ICE	221.79	0.197	1.490	0.0206	0.0105	0.149	0.0516	0.0017	0.0031	0.275	0.0106
Electric	102.67	0.010	0.029	0.0223	0.0078	0.066	0.1779	0.0008	0.0014	0.185	0.0015
HEV I	165.81	0.147	1.114	0.0154	0.0078	0.111	0.0385	0.0013	0.0023	0.206	0.0079
PHEV	156.62	0.109	0.809	0.0193	0.0085	0.104	0.0931	0.0012	0.0022	0.215	0.0062

The modeled emission rates differ somewhat from those reported for the 20,000-vehicle TNC scenario in Table 3. However, these per-kilometer values do not establish how total fleet emissions changed with the larger assumed fleet size. Such a comparison would require corresponding fleet activity and aggregate emissions estimates for both scenarios.

Operational Efficiency Considerations

Operational efficiency is an important consideration when evaluating TNC electrification because rideshare vehicles accumulate mileage during both passenger-serving and unoccupied operations. As discussed earlier in this report, unoccupied vehicle travel contributes to total vehicle activity and associated energy consumption.

The vehicle-level results presented for the expanded TNC fleet do not establish whether increasing the assumed fleet size changed the amount of unoccupied travel, vehicle utilization, or dispatching efficiency. These operational effects would require additional scenario-specific analysis.

Discussion

The expanded electrified TNC fleet scenario provides an additional vehicle-level assessment of energy consumption and emission characteristics under an assumed fleet size of 40,000 electric rideshare vehicles. The results indicate that electric vehicles generally exhibit lower modeled GHG emission rates than conventional gasoline-powered vehicles under the evaluated operating conditions.

Although the expanded scenario assumes twice as many electric TNC vehicles as the preceding scenario, the reported results do not quantify changes in total fleet energy consumption, GHG emissions, passenger waiting times, or transportation system performance. Consequently, the analysis does not establish whether increasing the electric TNC fleet from 20,000 to 40,000 vehicles produces greater or smaller aggregate environmental benefits.

The findings therefore provide information on vehicle-level energy and emission characteristics under alternative TNC fleet-size assumptions. Further analysis would be required to assess the operational and regional environmental implications of expanding the electric TNC fleet.

Transit Bus Electrification Assessment

In addition to evaluating passenger vehicle and rideshare fleet electrification, this study examined the potential environmental benefits associated with transit bus electrification within the Houston metropolitan region. Public transit systems are widely recognized as an important component of transportation decarbonization strategies because they provide high-capacity mobility while reducing dependence on single-occupancy vehicles. Electrification of transit fleets may also reduce operational GHG emissions associated with bus transportation.

Unlike the passenger vehicle analyses presented in the previous sections, the transit bus assessment was performed using transit operational outputs generated by POLARIS in combination with published energy consumption and emission factors. Transit VMT obtained from the simulation was used to estimate and compare operational GHG emissions for diesel and battery electric bus operations under equivalent service mileage assumptions. A separate simplified assessment of manufacturing-related emissions is also presented.

Transit System Characteristics

The POLARIS simulation generated detailed transit operating statistics, including VMT, PMT, vehicle occupancy, passenger boardings, and passenger alightings. These outputs provided the basis for estimating emissions associated with transit operations in the Houston metropolitan region.

The simulation estimated a total transit vehicle mileage of approximately 125,055 vehicle miles. This mileage was subsequently used to estimate and compare operational GHG emissions under conventional diesel bus and hypothetical battery electric bus operating assumptions.

Operational Emissions Analysis

GHG emissions from diesel buses were estimated as a function of vehicle miles traveled, fuel economy, and fuel-specific emission factors:

$$\mathrm{GHGs}_{\mathrm{Diesel}} = \mathrm{VMT} \times \frac{\mathrm{EF}_{\mathrm{fuel}}}{\mathrm{MPG}}$$

where

- $\mathrm{GHGs}_{\mathrm{Diesel}}$: greenhouse gas emissions from diesel buses (kg)
- VMT: vehicle miles traveled
- $\mathrm{EF}_{\mathrm{fuel}}$: diesel fuel emission factor (kg GHG/gallon)
- MPG: average fuel economy (miles/gallon)

Based on data reported by the U.S. EPA (EPA, 2025), the GHG emission factor for diesel fuel was estimated at 10.21 kg CO_2e per gallon. An average fuel economy of 4.1 miles per gallon was adopted based on NREL (NREL, 2006) transit bus performance data.

The resulting GHG emission rate for diesel buses was:

$$\frac{10.21}{4.1} = 2.49\ kg/mile$$

Using the simulated transit VMT of 125,054.71 miles, total diesel bus GHG emissions were estimated as:

$$\mathrm{GHGs}_{\mathrm{Diesel}} = 125054.71 \times 2.49 = 311{,}416.73$$

The analysis further indicated that approximately 136,159.78 kg of GHG emissions occurred during peak-period operations and 175,256.95 kg during off-peak operations.

For electric buses, GHG emissions were estimated using electricity consumption and grid emission factors:

$$\mathrm{GHGs}_{\mathrm{Electric}} = \mathrm{VMT} \times \mathrm{EC} \times \mathrm{EF}_{grid}$$

where

- $\mathrm{GHGs}_{\mathrm{Electric}}$: greenhouse gas emissions from electric buses (kg)
- EC: electricity consumption rate (kWh/mile)
- EF_{grid}: electricity grid emission factor (kg CO_2e/kWh)

EPA (2024) estimates indicate a grid emission factor of approximately 0.352 kg CO_2e per kWh. Electric transit buses typically consume between 2.0 and 2.6 kWh per mile, and a representative value of 2.3 kWh per mile was adopted based on NREL (2018).

The resulting GHG emission rate for electric buses was:

$$2.3 \times 0.352 = 0.81\ kg/mile$$

Applying this value to the same transit VMT yields:

$$\text{GHGs}_{\text{Electric}} = 125054.71 \times\ 0.81 = 101{,}294.31\ \text{kg}$$

Comparison of diesel and electric bus operations indicates a substantial reduction in operational GHG emissions:

$$\%\ \text{Reduction} = 1 - \frac{GHGs_{Electric\ per\ mile}}{GHG_{Diesel\ per\ mile}} = 1 - \frac{0.81}{2.49} = 67\%$$

Under the assumed energy consumption and emission factors, replacing diesel bus operations with battery electric bus operations over the same simulated service mileage would reduce estimated operational GHG emissions by approximately 67 percent.

Simplified Manufacturing-Related Emissions Assessment

In addition to operational GHG emissions, vehicle and battery manufacturing contribute to emissions associated with transit bus technologies. A simplified calculation was performed to illustrate the contribution of assumed manufacturing-related emissions over the vehicle's service life. This calculation is not intended to represent a comprehensive lifecycle assessment.

Vehicle-cycle emission factors were calculated as:

$$EF_{vehicle\ cycle} = \frac{GHGs_{vehicle} + GHGs_{battery}}{B_{Life}}$$

where

- $GHGs_{vehicle}$: emissions associated with vehicle manufacturing
- $GHGs_{battery}$: emissions associated with battery manufacturing
- B_{Life}: vehicle lifetime mileage

Based on published literature and transit vehicle life-cycle assumptions, values of 25 metric tons of GHG emissions were assumed for vehicle manufacturing, 30 metric tons for battery manufacturing, and a service life of 500,000 miles over approximately 12 years for a standard 40-foot transit bus.

The resulting lifecycle emission factor for electric buses was:

$$EF_{vehicle\ cycle,electric} = \frac{25+30}{500000} = 0.11\ kg/mile$$

Combining operational and manufacturing-related emissions yields:

$$0.81 + 0.11 = 0.92\ kg/mile$$

For the total transit mileage, lifecycle emissions for electric buses were estimated as:

$$125054.71 \times 0.92 = 115{,}050.33\ kg$$

A similar calculation was performed for diesel buses. Assuming vehicle manufacturing emissions of 25 metric tons and the same vehicle lifetime mileage:

$$EF_{vehicle\ cycle,diesel} = \frac{25}{500000} = 0.05\ kg/mile$$

Total lifecycle emissions for diesel buses were therefore estimated as:

$$311416.73 + (125054.71 \times 0.05) = 326{,}987.55\ kg$$

Discussion

The transit bus electrification assessment indicates that battery electric buses can have lower estimated operational GHG emissions than conventional diesel buses under equivalent service mileage assumptions. Using the simulated transit VMT and the adopted energy consumption and emission factors, the estimated operational GHG emissions for electric buses were approximately 67 percent lower than those for diesel buses.

The simplified manufacturing-related emissions assessment illustrates that vehicle and battery production can contribute to the emissions associated with transit bus technologies. However, this calculation does not constitute a comprehensive lifecycle assessment, and its results should be interpreted within the assumptions and boundaries of the calculation.

Unlike the passenger vehicle and TNC analyses, the transit bus assessment estimates total operational emissions for a specified amount of simulated bus travel. These findings provide a separate comparison of diesel and electric bus operations and should not be interpreted as an estimate of total regional transportation emissions reductions or as directly comparable to the vehicle-level results presented in the preceding scenarios.

Transportation Decarbonization Implications

This chapter presented the results of alternative transportation electrification scenarios examined for the Houston metropolitan region, including rideshare fleet electrification, full passenger vehicle fleet electrification, expanded electric rideshare fleet deployment, and transit bus electrification. The analyses provide information on vehicle-level energy

consumption and emission characteristics under alternative powertrain assumptions, along with a separate operational GHG emissions comparison for diesel and electric transit buses.

One of the principal findings of this study is that vehicle powertrain technology influences energy consumption and GHG emission rates under the modeled operating conditions. BEVs generally exhibited lower energy consumption and modeled GHG emission rates than conventional internal combustion engine vehicles. These findings illustrate the potential energy efficiency and emission advantages of electric powertrains at the vehicle level.

The TNC analyses also highlight the importance of vehicle operating characteristics when interpreting electrification results. Occupied and unoccupied vehicle travel both contribute to energy consumption and emissions. However, the results presented in this study do not establish how changes in the assumed electric TNC fleet size affect total vehicle activity, operational efficiency, or aggregate regional emissions.

The transit bus electrification assessment provided a separate comparison of operational GHG emissions under equivalent simulated service mileage. Using the adopted energy consumption and emission factors, battery electric bus operations were estimated to produce approximately 67 percent lower operational GHG emissions than conventional diesel bus operations. This result applies to the modeled bus service mileage and assumptions rather than total regional transportation emissions

The study also demonstrates the application of an integrated modeling approach combining activity-based travel demand simulation, detailed vehicle operating profiles, and vehicle energy and emissions analysis. The POLARIS–SVTrip–Autonomie framework provided a basis for examining vehicle-level energy consumption and emission characteristics under alternative electrification assumptions. The transit bus assessment used simulated service mileage and published emission factors as a separate analytical approach. Additional model validation and aggregation of vehicle-level results would be necessary to quantify regional transportation energy and emissions impacts.

Overall, the findings indicate that vehicle electrification can offer energy efficiency and GHG emission advantages under the modeled operating conditions. The results provide a foundation for further investigation of transportation electrification strategies, while highlighting the need for additional analysis to establish their aggregate regional energy, emissions, and operational impacts.

Conclusions and Future Research

Summary of Research

This study investigated transportation energy consumption and emissions under alternative vehicle electrification scenarios in the Houston metropolitan region. An integrated modeling framework combined activity-based travel demand simulation (POLARIS), vehicle speed profile generation (SVTrip), and vehicle energy simulation (Autonomie) to examine vehicle-level energy consumption and emission characteristics under alternative powertrain assumptions. A separate transit bus assessment used simulated transit mileage and published energy consumption and emission factors to compare diesel and battery electric bus operations.

The Houston region was selected as a case study because of its large population, high automobile dependency, extensive transportation network, and growing interest in transportation sustainability initiatives. Multiple electrification scenarios were evaluated, including rideshare fleet electrification, full passenger vehicle fleet electrification, expanded electric rideshare fleet deployment, and transit bus electrification. Together, these analyses provided vehicle-level comparisons of alternative electrification assumptions and a separate operational emissions assessment for transit buses.

Key Findings

Several important findings emerged from this research. First, vehicle powertrain technology influenced energy consumption and GHG emission rates under the modeled operating conditions. BEVs generally demonstrated lower energy consumption per unit of distance traveled and lower modeled GHG emission rates than conventional internal combustion engine vehicles. These results characterize vehicle-level performance rather than total regional energy or emissions reductions.

Second, the 20,000-vehicle electrified TNC scenario provided an assessment of energy consumption and emission characteristics under an assumed electric rideshare fleet size. The results indicated lower modeled GHG emission rates for electric vehicles compared with conventional gasoline-powered vehicles. However, the analysis did not quantify aggregate fleet-wide emissions reductions.

Third, the full passenger vehicle electrification scenario examined vehicle energy consumption and emission characteristics under the assumption that eligible passenger vehicles operated using BEV technology. The results illustrated the vehicle-level implications of this assumption but did not establish the total regional emissions reduction associated with widespread passenger vehicle electrification.

Fourth, the expanded 40,000-vehicle electrified TNC scenario provided an additional comparison under a larger assumed electric rideshare fleet size. The results characterized vehicle-level energy consumption and emission rates but did not establish how the increase in fleet size affected total vehicle activity, service availability, or aggregate emissions.

Fifth, the transit bus electrification assessment indicated that battery electric bus operations could produce approximately 67 percent lower operational GHG emissions than conventional diesel bus operations under equivalent simulated service mileage and the adopted energy consumption and emission factors. This estimate applies to the modeled bus operations and does not represent a regional transportation-wide emissions reduction.

Finally, the analysis also reported emission rates for several criteria pollutants under alternative vehicle powertrain assumptions. These results provide supplementary information on vehicle emission characteristics but do not establish changes in regional air quality or public health outcomes.

Study Limitations

Although the study provides valuable insights into transportation electrification strategies, several limitations should be acknowledged. First, the analysis focused primarily on energy consumption and emissions and did not explicitly evaluate the economic feasibility of alternative electrification strategies. Vehicle acquisition costs, charging infrastructure investments, electricity pricing, and long-term maintenance costs were not considered. These factors may influence the practical implementation of large-scale electrification programs.

Second, the analysis used assumed electricity grid emission factors and did not explicitly model future changes in electricity generation portfolios. Consequently, the reported electricity-related emissions estimates depend on the adopted emission factors and may differ under alternative electricity generation conditions.

Third, the transit bus assessment relied on simulated service mileage and published energy consumption and emission factors rather than detailed vehicle-level simulation. The manufacturing-related emissions calculation was also simplified and did not constitute a comprehensive lifecycle assessment. Future research could incorporate more detailed electric bus operational models, charging simulations, and lifecycle assessment methods.

Fourth, the passenger vehicle and TNC analyses primarily reported vehicle-level energy consumption and emission rates rather than aggregate fleet-wide or regional emissions estimates. Consequently, the results do not establish total regional emissions reductions or directly comparable aggregate impacts across the electrification scenarios. In addition,

the model convergence assessment does not constitute independent empirical validation of the simulated travel demand and vehicle activity outputs.

Finally, the study focused on a single metropolitan region. While Houston provides an important case study due to its size and transportation characteristics, results may differ in regions with different travel patterns, transportation networks, climate conditions, and electricity generation sources.

Future Research

Several opportunities exist for extending this research. Future studies should incorporate economic analyses to evaluate the cost-effectiveness of transportation electrification strategies. Comparisons among vehicle acquisition costs, charging infrastructure investments, operating costs, and environmental benefits would provide a more comprehensive assessment of implementation feasibility.

Additional research should examine charging infrastructure planning and deployment strategies. Optimizing the location, capacity, and utilization of charging facilities will be critical for supporting large-scale adoption of electric vehicles and electric transit fleets.

Future analyses could also investigate the interactions between transportation electrification and evolving electricity generation systems. Integrating transportation and power-sector models would provide a more complete understanding of long-term decarbonization pathways.

For transit systems, future work should evaluate electric bus scheduling, charging requirements, route-specific performance, and lifecycle costs. Such analyses would provide transit agencies with practical guidance for fleet transition planning and investment decisions.

Future research should also focus on empirical validation of the integrated modeling framework and aggregation of vehicle-level results to estimate fleet-wide and regional energy consumption and emissions. Developing consistent measures across electrification scenarios would enable more direct comparisons of their transportation system and environmental impacts.

Finally, the modeling framework developed in this study can be extended to evaluate emerging transportation technologies and policies, including autonomous electric vehicles, shared autonomous mobility services, dynamic pricing strategies, and multimodal transportation systems. Application of the framework to additional metropolitan regions would further improve understanding of how transportation electrification strategies perform under varying geographic and operational conditions.

Overall, the study provides insights into vehicle-level energy consumption and emission characteristics under alternative transportation electrification assumptions, along with a

separate operational GHG emissions comparison for diesel and electric transit buses. The findings indicate potential energy efficiency and emission advantages associated with electric vehicle technologies under the modeled conditions. Further research is needed to quantify aggregate regional impacts and evaluate the practical implementation of transportation electrification strategies.

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Data Summary

Products of Research

This study utilized regional transportation and travel demand datasets to evaluate the energy and environmental impacts of rideshare and transit electrification in the Houston metropolitan region. The primary data inputs consisted of transportation network, socioeconomic, land use, and travel demand data developed for the Houston-Galveston metropolitan area and incorporated into the POLARIS activity-based travel demand model.

The research relied on the U.S. Department of Energy's SMART Mobility modeling workflow, including the POLARIS, SVTrip, and Autonomie platforms. These tools were used to simulate transportation system performance and evaluate alternative electrification scenarios. No new public-use dataset was developed as part of this project. The Houston POLARIS model, primarily used during this project, was further developed through an Argonne internship funded by DOE.

Data Format and Content

The study utilized transportation planning and travel demand datasets obtained through the Houston-Galveston Area Council (H-GAC) regional travel demand modeling program. These datasets included:

- regional roadway and transportation network data;
- Traffic Analysis Zone (TAZ) information;
- population, household, and employment data;
- travel demand and trip generation data; and
- transit network and service characteristics.

Through an Argonne internship, this data was converted into a format compatible with the POLARIS modeling framework, including network databases, tabular data files, and transportation model input files.

Data Access and Sharing

The primary datasets used in this study were obtained from the H-GAC and the right to share is reserved by H-GAC. The POLARIS model was further developed during an Argonne internship for use with the modeling frameworks developed by Argonne National Laboratory under the U.S. Department of Energy SMART Mobility Program. As a result, access to the Houston POLARIS model may be subject to restrictions established by the original data providers.

Researchers interested in obtaining the underlying transportation network and travel demand datasets should contact H-GAC or the appropriate data owner directly. Information regarding the POLARIS modeling framework is available through Argonne National Laboratory.

No project-specific public dataset or DOI was generated as part of this study.

Reuse and Redistribution

Reuse and redistribution of the data utilized in this study are subject to the policies and requirements of the original data providers, including H-GAC and Argonne National Laboratory. Users should obtain data directly from the respective providers and comply with all applicable licensing, attribution, and usage requirements.

This report may be cited as the primary documentation of findings developed through the project.