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Incorporating Infrastructure and Vehicle Technology Requirements, Changes in Demand, and Decarbonization Policies' Considerations into Freight Planning

Miguel Jaller, University of California, Davis

Maria C. Valencia-Cardenas, University of California, Davis

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16. Abstract This report develops an equitable and sustainable freight-oriented land use (LU) methodology to support future planning activities, enabling the integration of freight activity across urban, suburban, and rural areas and facilitating the transition of heavy- and medium-duty vehicles toward zero-emission. The methods include a literature review to identify freight sustainable strategies, policy analysis at different scales, characterization of local context, and demand/supply patterns. The latter examines the spatial distribution and land use characteristics of freight facilities and retail/service sectors in the Sacramento region to inform sustainable and equitable planning strategies. This analysis identifies co-location patterns, accessibility gaps, and sectoral interactions using a multi-dimensional approach integrating spatial clustering, distance analysis, population-employment dynamics, and environmental burdens. Data sources include Longitudinal Employer-Household Dynamics Origin-Destination Employment Statistics (LODES), American Community Survey (ACS), CalEnviroScreen, and OpenStreetMap, alongside geospatial tools in R. The findings suggest the need for targeted interventions to address potential conflicts, service deserts, and environmental justice concerns. The study proposes actionable strategies for planners to support balanced economic development and improve access to essential services.		
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Disclaimer

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Incorporating Infrastructure and Vehicle Technology Requirements, Changes in Demand, and Decarbonization Policies' Considerations into Freight Planning

A National Center for Sustainable Transportation Research Report

Miguel A. Jaller, Department of Civil and Environmental Engineering, Sustainable Freight Research Program, Institute of Transportation Studies, University of California, Davis

Maria C. Valencia-Cardenas, Transportation Technology and Policy Program, Institute of Transportation Studies, University of California, Davis

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Executive Summary

Background and statement of research

Urbanization, environmental and social justice concerns, and profound changes in consumer behaviors challenge sustainable freight land use planning. Freight-oriented decarbonization policies are fundamental for tackling these burdens. The multiple dimensions of sustainability and the complexity of the demand and supply chains in the freight system make it difficult to evaluate road freight policies and strategies for improving sustainability. Therefore, this project develops an equitable and sustainable freight-oriented land use (LU) methodology to support future planning activities, enabling the integration of freight activity across urban, suburban, and rural areas and facilitating the transition of heavy- and medium-duty vehicles toward zero-emission. This report encompasses the results of each task: (1) the review of recent findings and trends to identify critical factors for a comprehensive characterization of freight activities; (2) the characterization of the local context of the region of study (Sacramento Region) through the analysis of Department of Transportation (DOT) Long-Range Transportation Plans (LRTPs), the Sacramento Area Council of Government's (SACOG) Metropolitan Transportation Plans (MTPs), decarbonization plans, equity policies, and labor conditions, with a particular emphasis on disadvantaged communities (DACs); (3) characterization of freight distribution patterns; and (4) review and evaluation of LU and transportation initiatives.

Methodology and data

The first task of the methodology involved five steps: (i) conceptual research design; (ii) data compilation from Scopus and Web of Science; (iii) bibliometric analysis incorporating the author's network, keywords, institutions, and countries to understand the data's underlying structure, patterns, and relationships; (iv) quantitative analysis leveraging deep learning models (e.g., Sentence-BERT) for natural language processing (NLP) in text analysis to understand better the documents collected and generate a theoretical review of the most prevailing topics using coding and thematic analysis; and (v) a synthesis of the findings with a discussion of gaps and opportunities for future research.

The second task involved five steps: (1) identifying the local and regional authorities in charge of the transportation planning process and their roles, (2) the most recent regional deep analysis, focusing on the case study of the Greater Sacramento region in California, (3) identifying the freight regulations that impact freight strategies based on the plan's analysis, (4) evaluating the plans to ensure that strategies that had been previously collected complied with these regulations, and (5) characterizing the local context evaluating socio-economic variables as well as social justice in the region of analysis.

A service-intensive sector with 31,918 establishments characterizes the region. Most freight-related establishments reside in Sacramento County (79%), followed by Yolo County (18%). Freight facilities are strategically situated along the region's highways and freeways to ensure easy accessibility. The rail system is crucial for freight locations, as certain facilities cluster in areas with rail access. The freight industry exhibits a clustering pattern, but this remains with low variation over time. There were two prominent peaks in 1998 and 2002, followed by a slight increase around 2015 that e-commerce growth could explain. The multidimensional scaling of variables shows a close relationship between freight hotspots and Native American communities, solid waste sites, and hazardous waste.

Several strategies exist to enhance sustainability in freight transportation. One option is shifting from road to rail or water systems, which requires significant investment and collaboration to expand capacity. Another approach focuses on improving logistics efficiency, addressing regulatory challenges, and fostering stakeholder cooperation. Additionally, transitioning to low-carbon fuels is essential; while electric trucks offer benefits, they face infrastructure and regulatory limitations. Thus, natural gas and biofuels can help during the transition as electric technology develops.

Based on the integrated supply and demand analysis, the team identified key zones in the Sacramento region that should be prioritized for charging and fueling infrastructure investments. These include: **(a) South Sacramento–Florin–Elk Grove**, a dense residential and retail area with high pollution burden and strong last-mile electrification potential; **(b) North Sacramento–Del Paso Heights–Natomas**, an environmental justice zone where freight-focused charging infrastructure can support underserved neighborhoods; **(c) West Sacramento and the Port District**, a strategic logistics hub ideal for large-scale clean freight transition infrastructure; **(d) Southern Yolo and Northern Solano Corridors**, where expanding e-commerce traffic and lack of centralized freight service create opportunities for intercity electric vehicle (EV) rest stops and rural smart-grid integration; and **(e) Northern Sutter and Yuba Counties**, growing freight deserts where equity-driven investments could support clean freight consolidation and rural charging infrastructure. These zones reflect opportunities for targeted, multimodal, and equitable infrastructure planning.

1. Introduction

Goods demand generates freight movements, necessitating transportation, infrastructure, logistics amenities, and the use of land for logistics centers and public infrastructure (*1*, *2*). The significant shifts in land use development, consumer preferences, and the regulatory landscape over a relatively brief period (mid-20th century)—driven by population growth and urban consumption—could markedly influence the logistics land use expansion trajectory. Meeting this demand while ensuring a sustainable land use pattern presents a considerable challenge for major metropolitan areas (*3*). Infill or mixed land-use development also emerged as a fundamental component of global environmental change mitigation by reducing vehicle miles traveled and lowering air pollution (*4*, *5*). Individuals developing land use (LU) plans and policies must rigorously evaluate the potential impacts on supply chains and freight operations. Neglecting these considerations could have significant consequences for communities, including increased pollution and compromised road safety.

Road transportation is one of the primary sources of pollutant and greenhouse gas (GHG) emissions, generating about 15% of global GHGs, from which road freight accounts for 29.4% (*6*). Despite being responsible for a substantial portion of these emissions, middle- and long-haul trucking have not achieved significant advances in decarbonization compared to light-duty vehicles (LDVs). This creates the need for new technological innovations, ambitious goals, and efforts to abate emissions from heavy road freight (*7*). Most of the current decarbonization strategies encourage modal shifts and the transition toward zero-emission heavy-duty vehicles (ZEV-HDVs) without considering LU requirements, which is crucial to solving the problem (*8*).

Additionally, freight disproportionately burdens disadvantaged communities (DACs), leading to negative externalities such as reduced safety, increased congestion, pollution, and noise (*9*). The rapid changes in freight patterns during the last two decades have significantly expanded the size of delivery fleets and the number of distribution facilities, generating negative impacts (*10*). For example, some studies found warehouses and distribution centers disproportionately situated in DAC areas, thus concentrating their negative externalities (*11*). Other studies show that this transformation affects labor because it disrupts brick-and-mortar retail jobs, access to employment, and commute times and distances (*3*). Recently, warehouses and distribution centers have increasingly relocated near downtown areas, increasing freight activity in local communities (*12*). These changes can affect current LU practices because freight activity intensity, concentration, and distribution patterns also change as the system evolves.

There is a need to rethink current LU practices to proactively incorporate system changes and those generated by new decarbonization policies and efforts. As LU is a crucial driver of development, it can facilitate the seamless integration of freight activity in urban, suburban, and rural areas (*13*), the transition toward zero-emission vehicles (ZEVs), the reduction of social and environmental injustices, the decrease of GHG emissions, and the promotion of multimodal travel. This integration will enable the development and prioritization of initiatives to realize a sustainable and equitable freight sector.

Freight-oriented planning strategies evaluate the impact of LU on the efficient movement of goods and can provide assessment tools for decision-makers to support the efficient movement of freight (*14*). However, current strategies and studies (e.g., NCHRP 998, Land-Based Classification Standards) have limited considerations of social and environmental concerns related to freight transportation, such as decarbonization policies, equity mobility, and labor conditions. Moreover, these systems and strategies do not consider the future impact of changes in consumer behavior on socio-economic conditions or the infrastructure requirements and operational changes due to a ZEV transition. Therefore, this study develops an equitable and sustainable freight-oriented LU methodology that integrates current planning strategies, requirements for freight infrastructure and ZEV technology, changes in freight demand, and decarbonization policies. The main purpose of this project is to support planning organizations across the U.S. in implementing LU strategies to improve freight efficiency while reducing GHG and pollution, improving social and environmental justice, and complementing other recent efforts (*14*).

The proposed framework comprises four main steps. The first focuses on characterizing the freight context based on local, State, and federal decarbonization plans, equity policies, land use plans, and labor conditions. The second step analyzes urban, suburban, and rural freight distribution patterns based on supply and demand characteristics. The third step analyzes potential freight-efficient LU and transportation initiatives that can be implemented locally (including decarbonization, social, and environmental policies). Finally, step four develops sustainable and equitable freight LU methodology considering impacts on environmental justice, GHG emissions, labor, and social justice. The case study for implementing this methodology is the Sacramento region, in California.

This report is organized as follows. Section 2 provides a systematic literature review identifying recent findings and trends on critical factors for a comprehensive characterization of road freight activities. Section 3 provides a policy analysis that examines the local and regional authorities responsible for the transportation planning process. It outlines the freight regulations that influence freight strategies based on the analysis of the plans, highlights challenges and freight-oriented strategies derived from each regional plan, and connects these elements to the goals of the regional authorities. Section 4 describes the local context, including socio-demographic and economic characteristics, social justice, and future needs for achieving decarbonization targets. Section 5 provides a demand spatial characterization. Section 6 integrates a freight spatiotemporal analysis. Section 7 summarizes some sustainable and equitable land use and freight strategies, as well as prioritizing zones for charging infrastructure. The last section presents the most essential conclusions from the report.

2. Literature Review

This section discusses the processes to identify recent findings and trends on critical factors for a comprehensive characterization of road freight activities, including social, economic, and environmental factors, as well as the best practices and initiatives for implementing a sustainable freight LU.

2.1. Methods

Figure 1 illustrates the methodology for conducting a systematic literature review to characterize critical factors related to freight activities and identify best practices and initiatives for sustainable freight LU. The methodology has six steps, starting with the conceptual research design to set essential concepts related to sustainability in transportation, research questions, and query search. The second step involves data compilation from source-neutral abstract and citation databases, followed by a data cleaning and screening process. The third step incorporates a bibliometric analysis to characterize the research domain, identify the major topics and emerging trends within the data, and analyze the most influential researchers and institutions and collaboration patterns among them. The bibliometric analysis began with an exploratory analysis of the authors, keywords, institutions, and countries to understand the data's underlying structure, patterns, and relationships. The fourth step includes a quantitative analysis leveraging deep learning models (e.g., Sentence-BERT) for natural language processing (NLP) in text analysis to understand better the documents collected and generate a theoretical review of the most prevailing topics. In addition, this step includes a thematic analysis used to identify patterns within the goals and methods followed by the documents selected. The next step delimited documents that targeted implemented policies/plans analysis and procedures for evaluating sustainable strategies that planners or policymakers have already implemented. In addition, the team selected documents that considered LU as a variable for the study, a mix of transportation and LU models, LU planning, and LU interaction with freight transportation. The final step provides a synthesis of the findings with a discussion of gaps and opportunities for future research.

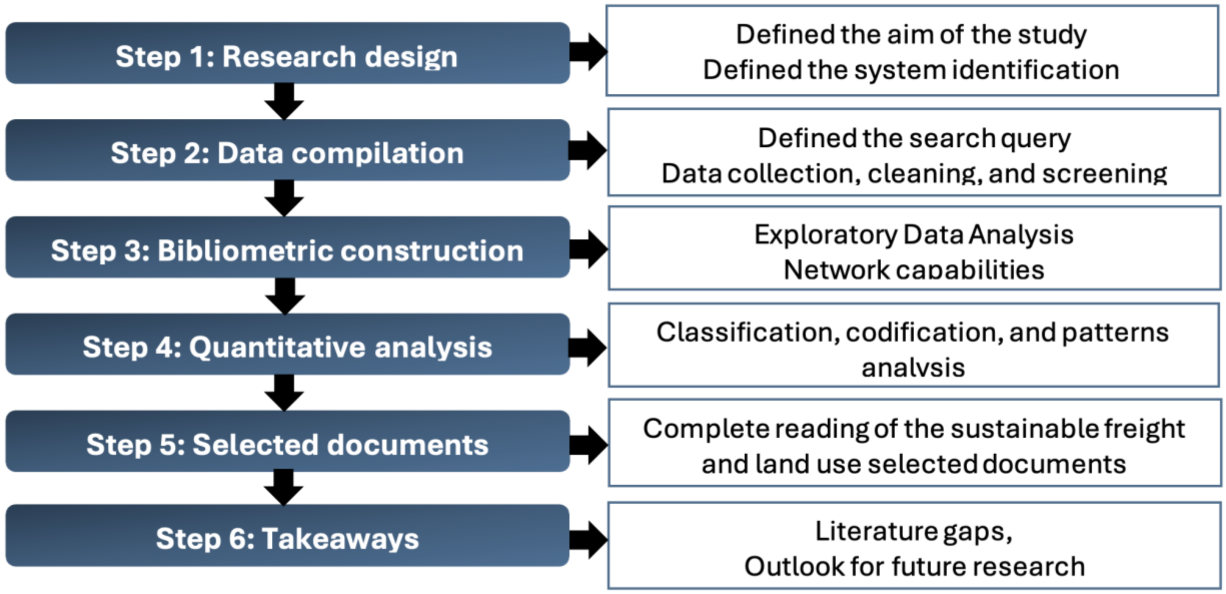


Figure 1. Workflow of the methodology for conducting the systematic literature review

2.1.1. Research design

This section explains how the key concepts considered in this project are interconnected to provide a delimitation of the research questions. Therefore, it is essential to start adopting a definition of sustainable transport (ST) to identify the dimensions of this analysis. There is no universal definition for this concept. Still, the one adopted by the United Nations (UN) is the most often cited, which sets ST systems as essential in fostering universal accessibility, mitigating adverse environmental effects, and enhancing safety and operational efficiency (*15*). This project adopts a more comprehensive definition based on the literature's widely used terms. Therefore, **ST in this study focuses on the efficient use and preservation of natural resources, ensuring that we meet the needs of current and future generations**. It emphasizes the utilization of renewable resources at a rate lower than their production capacity and the consumption of non-renewable resources at a rate less than the development of renewable alternatives. ST aims to control greenhouse gas emissions to mitigate abnormal global warming and improve community health by reducing air and noise pollution. Additionally, ST prioritizes social justice and gender equality by offering affordable, accessible services that emphasize safety and convenience for all users (*16*).

Several authors have adopted the three dimensions of sustainability: social, environmental, and economic (*16–19*), proposed by the Burdland report (*20*) and accepted by the World Bank and the UN. Therefore, this project also considered dimensions where social sustainability involves safety, health, noise, accessibility, congestion, and quality of life (*21*, *22*). Environmental sustainability refers to minimizing the adverse effects of transport activities on the environment. The objective of the economic dimension is to evaluate the benefits and expenditures associated with transportation. Some research also considers the political dimension (*21*, *23*). Policy and governance are transversal factors that involve all the other dimensions. However, this dimension also covers public-private partnerships, dedicated resources to sustainability strategies, and policy evaluation. Therefore, **this project considers four sustainable dimensions: social, environmental, economic, and governance.**

In this context, the road freight transport industry is crucial in achieving a sustainable future. The UN defines **sustainable freight transportation as one that possesses, among other characteristics, the capability to deliver transportation that is safe, economically efficient, competitive, socially inclusive, accessible, reliable, affordable, fuel-efficient, environmentally friendly, low-carbon, and resilient to external shocks, such as those caused by climate change and natural disasters** (*24*).

Logistics is the term currently used to refer to the transportation, storage, and management of goods as they progress from the source of raw materials through the production process to their ultimate point of sale or consumption (*25*). It also incorporates connections with various supply chain functions like warehousing, accounting, marketing, and customer relations while considering its organizational, financial, commercial, and operational elements as a complete entity (*26*).

Logistics facilities refer to particular buildings and warehouses that accommodate all activities related to logistics and freight transportation (*27*)**, including fabrication, storage, and distribution** (*28*). With its urban distribution focus, this study concentrates on logistics facilities in the North American Industry Classification System (NAICS) by the fourth digit numbers 4931 Warehousing and Storage and 4921 Couriers and Express Delivery Services. A warehouse is a facility designed for storing goods over extended periods, typically serving to replenish distribution centers that could be far away. In contrast, a distribution center generally holds goods for shorter durations, often daily, while fulfilling orders delivered directly to retail stores or consumers (*28*). The location of logistics facilities considers the availability and zoning of commercial and industrial land offered by the authorities (*29*). Different logistics facilities require land depending on the category and objective of the facility, and the stages can be categorized as follows. In the first stage, terminals (i.e., ports, airports), inbound cross docks (e.g., facilities designed to de-stuff international containers), or manufacturers to fulfillment centers (warehouse or distribution centers) provide the goods to meet regional demand. The second stage involves the dynamics between fulfillment centers that provide the infrastructure and logistics required to route parcels to the most suitable delivery channels and locations (flow-based facilities). The final stage consists of delivery stations, which means retail, delivery hubs, or final consumers. The final stage, the last mile segment, is crucial since it accounts for more than 25% of freight transportation's greenhouse gas (GHG) emissions (*30*).

The appropriate link between freight logistics and land use is fundamental for sustainable development since most freight activities require physical space. According to the

Environmental Protection Agency, **LU refers to how humans utilize land for various economic and cultural activities, such as agriculture, residential purposes, industry, mining, and recreation** (*31*)**.** It's important to note that LU is distinct from land cover since LU refers to human activities, while land cover refers to the physical characteristics of the land (*32*). Therefore, land cover can change (e.g., vegetative characteristics change), but their use does not necessarily change (e.g., agricultural). LU is typically determined through surveys that rely on field observations, whereas remote sensing methods or the interpretation of aerial photographs usually help assess land cover. Nonetheless, it is feasible to convert land cover data into LU classifications, enabling the examination of land use variability over time (*33*).

With the key concepts clarified, it is important to highlight that developing an equitable and sustainable freight LU methodology can serve as a model for freight-oriented planning systems in the U.S. An efficient LU improves freight operations, traffic flow, congestion, and delivery routes. The latter directly leads to business cost savings, reducing transportation costs and improving productivity. Integrating freight activity in regional urban and suburban development can minimize negative impacts on disadvantaged communities, leading to more sustainable and equitable transportation policies and practices.

The literature review is the first step in building a methodology for developing an equitable and sustainable freight LU. Therefore, this literature review aims to answer the following questions:

RQ1: What literature patterns relate to sustainable road freight transportation?

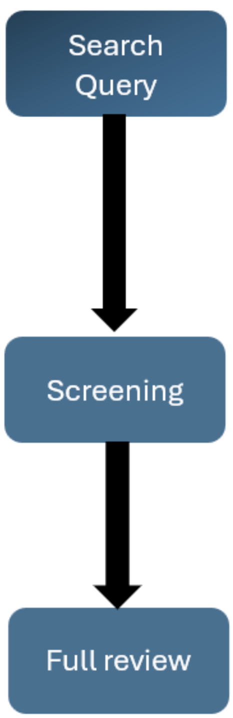
RQ2: What are the sustainable strategies and methods considered for improving road freight transportation?

RQ3: What are the primary considerations for incorporating freight logistics into land-use planning?

2.1.2. Data compilation

This step involves identifying the search keywords and the scientific databases used to gather the documents. Based on the research questions, the authors performed a query to consider sustainable road freight from the policy perspective and LU planning incorporating freight strategies. Figure 2 illustrates the process of search and delimitation, starting with the query search considering four groups of words with the number of documents found during each search. The first group involved this study's main target, freight movement or transportation. Sustainability over road freight transportation is the leading segment set in this review. Different theoretical approaches related to regulatory policies and planning and their relationship with LU represent the focus of the analysis. Lastly, after a trial-and-error search, it was possible to identify multiple documents that, in addition to their importance to the topic of sustainability, are outside the scope of the search described in the previous section and were excluded.

The two main databases included the Web of Science and Scopus for the literature review. The cleaning process started with the first screen, including titles and keywords. This process eliminated documents from other languages different than English, duplicates, and titles that were not directly related to the topic. The second screening process included an abstract analysis. The selection considered documents that somehow reflect the framework of the research domain described in the initial search query and provide enough details and quality to consider the paper worth a detailed review. The cleaning process resulted in 284 documents for the bibliometric analysis described in the following section.



Target	(Freight OR Goods) AND (Transport* OR Movement OR Shipment OR Distribution)	644,175
Characteristics	Sustainab* AND Road	34,150
Frame	(Plan OR Policy OR Policies) AND (Land-use OR Land AND Use)	6,081
Excluded	Ocean OR Costal OR River OR Ship OR Rail* OR Ferry OR Pipe OR Plant OR Geology	548
WoS= 242 & Scopus=306		
Titles and keywords	Selecting only documents in English, non-duplicates, titles related to the topic (e.g., query target, and research questions)	436
Abstract	Exclude papers if the abstract does not reflect some sort of framework about the research domain described in the initial search query or provide enough details and quality to consider the paper worth for detailed review.	284
Bibliometric and Quantitative Analysis (284 documents)		
Sustainable Freight	Documents related to regulatory policies or plans for road freight activities, measures for sustainable road freight transportation strategies effectiveness, and land-use planning incorporating freight strategies	89
Land Use	Documents that involve LU considering LU as a variable, mix of transportation and LU models, LU planning or LU impacts from freight transportation.	39
Deep Analysis (105 documents)		

Figure 2. Process of data collection

The bibliometric analysis delimited 89 documents that targeted implemented policies/plans analysis, methods for evaluating sustainable strategies that planners or policymakers have already implemented, and the effectiveness of sustainable policies, plans, or programs. This group of documents is essential for identifying trends and opportunities for implementing a sustainable freight LU strategy. In addition, the team selected 39 papers for a complete reading analysis that considered LU as a variable for the study, a mix of transportation and LU models, LU planning, or LU interaction with freight transportation.

2.1.3. Bibliometric construction

After data debugging and cleaning, the third step performs bibliometric analyses. This process starts with an Exploratory Data Analysis (EDA) of the authors, keywords, institutions, and countries to understand the data's underlying structure, patterns, and relationships. EDA provides an overview of documents through a metadata summary report and multiple visualization strategies. The word cloud strategy helps summarize the most frequent words in abstracts. The next process was to group those abstracts considering an embedding technique to represent words or phrases as vectors and, through the Uniform Manifold Approximation and Projection (UMAP) technique, transforming high-dimensional data (abstracts) into lower-dimensional space for visualization purposes (*34*). The authors generated a topological representation using a similar process given some low-dimensional data representation. Next, UMAP optimizes the topological representation of the data in the low-dimensional space, minimizing cross-entropy (*34*). This strategy also provides visibility to outliers due to possible missing data or unrelated documents to the main subject. Country-related participation (i.e., researchers' affiliation) through a tree map provides the number of country-identified documents. The technique used for this strategy was adjacency analysis to identify proximity and connections between authors based on citations. The network analysis was performed to identify the connection between authors due to frequent citations and cooperation.

2.1.4. Quantitative analysis

The quantitative analysis incorporated artificial intelligence to gain deeper insights into the collection of documents through the Sentence-BERT Deep Learning Model (SBDLM) (*35*, *36*). This strategy helped identify and classify the most significant themes within a large amount of text from the abstract information. The next step involved an alternative thematic analysis targeting documents that implemented policies/plans analysis, methods for evaluating sustainable strategies that planners or policymakers have already implemented, and the effectiveness of sustainable policies, plans, or programs. This strategy used an abstractive text summarization model (ABSM) that identifies the most significant sentences or phrases from the original text to create a concise version that effectively conveys its meaning. This task used the advanced method PEGASUS (*37*, *38*). Furthermore, this approach facilitated the extraction of the methodologies implemented in each publication included in the full review group. The authors analyzed the research goal theme from the ABSM to check possible mistakes based on the lack of information in some abstracts or because some documents were unclassified.

2.1.5. Sustainable freight documents and LU analysis

The research team classified the 89 documents selected for a complete reading process into the input-output approaches. The inputs refer to the main factor, scenario, policy, or strategy analyzed in the text, while the output corresponds to the effect or consequence of the input treatment. Based on the outputs, the authors classified the documents by their most representative sustainable dimension. Some documents were multidimensional since they tried to achieve at least two sustainable dimensions.

The last research question refers to the primary considerations for incorporating freight logistics into LU planning, which demands a deep analysis of those documents that address this question. Therefore, the research team identified 39 key documents that considered LU as a variable for the study: a mix of transportation and LU models, LU planning, and LU interaction with freight transportation.

2.1.6. Takeaways and research opportunities

In the final step, the team synthesizes the key findings from the literature review. In addition, the authors identified multiple gaps or opportunities for future research, including those highlighted in the references and others identified during the analytical process.

2.2. Summary of results

The query search and the screening process resulted in 284 documents between 2010 and 2024, including 218 articles, 21 conference papers, 18 proceedings papers, 13 book chapters, 10 reviews, two articles in press, and one book. The following subsections provide a detailed explanation of the bibliometric, quantitative, and full reading analysis.

2.2.1. RQ1: Literature patterns relate to sustainable road freight transportation

Figure 3 shows the word cloud resulting from the text analysis. Based on the highlighted words, the references are mainly related to “urban” and “logistic,” with an importance factor of 0.876 and 0.559, respectively. Other words to highlight are “model” (0.659), “emissions” (0.499), and “sustainable” (0.249). On the other hand, “planning” (0.321), “land” (0.269), and “policy” (0.154) show representative importance.

The 3-gram analysis provided insights into the concepts and techniques discussed in the documents, considering the most frequent consecutive 3-words. “Freight transport logistics,” followed by “urban freight transport,” were the most representative words. It is essential to highlight other frequent topics, such as “land use planning,” “input-output analysis,” and “decision support systems.”

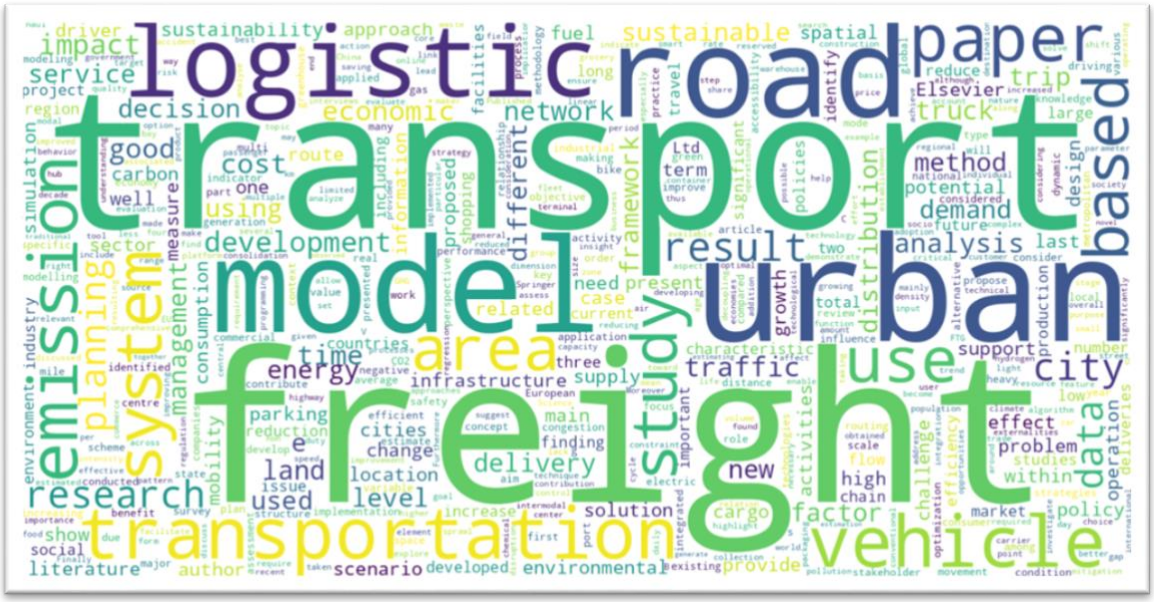


Figure 3. Word-cloud highlighting words from the literature text analysis

The subsequent phase in the EDA involved converting the abstracts into numerical representations. Specifically, the process transformed the abstracts into a Term Frequency-Inverse Document Frequency (TF-IDF) matrix or embeddings. Afterward, the authors used a dimensionality reduction technique, UMAP, to reduce the dimensionality to two dimensions for visualization. Finally, through a k-means algorithm, the authors grouped the data into clusters. This strategy resulted in five clusters of topics, as illustrated in Figure 4. The topic of sustainability and green logistics includes documents related to strategies to achieve sustainability, such as policies, plans, new technology, and behavioral changes. Equity aspects are also part of this group, with documents discussing job informality, discrimination, and perception. The next cluster considers research involving land use planning, urban strategies, freight facilities, and logistics sprawl. The third cluster involves documents related to smart energy systems, energy efficiency, alternative fuels, carbon reduction, and decarbonization strategies. Another cluster identified considers transportation efficiency and safety documents, such as vehicle routing problems, freight transportation networks, travel time, driver behavior, and influencing factors in the urban context. Most of those documents considered heavy-duty vehicles and long-haul segments. Finally, the last cluster is mainly related to last-mile delivery and e-commerce, considering different strategies such as cargo bikes, micro hubs, urban street networks, parking areas, loading/unloading areas, and grocery shopping behavior.

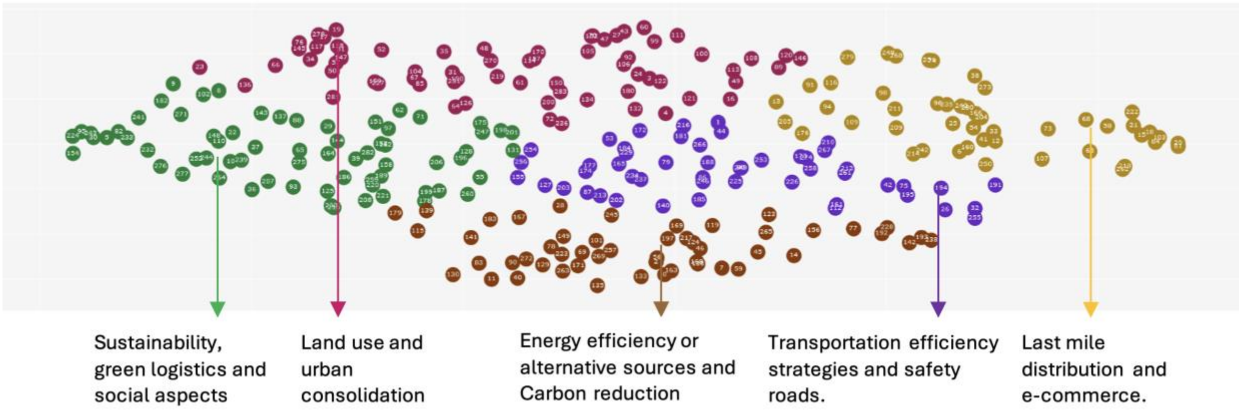


Figure 4. Document projection with UMAP and clusterization with k-means

The authors used a network analysis approach to identify the relationships between scientific publications, authors, and journals. This analysis provides collaboration patterns between authors or institutions, maps ideas within a field, or identifies critical publications or journals within a particular research area. The Collaboration Analysis helps understand how collaboration networks are structured, how they function, and how to leverage them to facilitate collaboration, knowledge sharing, and innovation. Figure 5 exhibits the most essential authors due to their productivity and collaboration. Examples include Antonio Comi, who has twelve documents and eight collaborators in his network. This means this author has participated in at least five documents as a coauthor with each of them. His research has focused on last-mile patterns, accessibility, and smart urban freight. Jesus Gonzalez-Feliu, with seven documents and a network of six other authors. His research mainly focuses on urban logistics, considering transport demand, freight trip generation/distribution, and accessibility. Jose Holguín-Veras is another representative author whose network is also connected to the Gonzalez-Feliu network. With six documents and a network of six authors, Holguín-Veras has participated in research related to freight efficiency, considering freight demand management upstream and last mile, freight (trip) generation, and freight-efficient land use. Figure 5 also shows the main author's countries and their network collaboration. The graph indicates that European researchers collaborate more with their peers in Europe, highlighting a solid network of intra-continental cooperation. One notable publication within this body of literature is Reference (*39*), published in 2010, which has garnered 530 citations. This study forecasts the carbon footprint associated with road freight transport by 2020. It delineates baseline logistics and supply chain management trends and analyzes the related environmental impacts leading up to that year. A second document to highlight is (*29*), published in 2016 and cited by 159 authors. It discusses the logistics sprawl phenomenon that affects emissions and employment in commuting logistics.

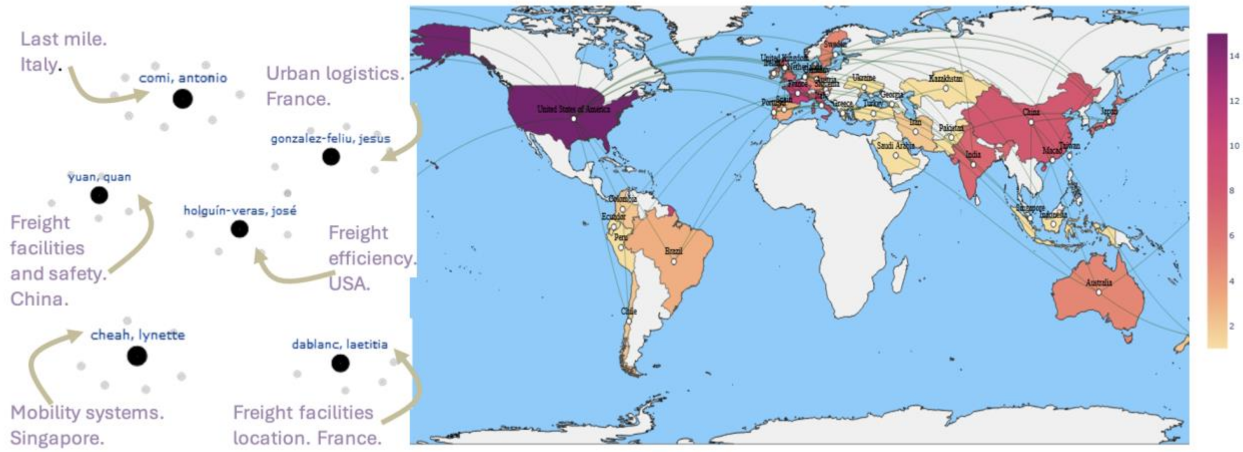


Figure 5. Collaboration analysis between authors, countries, and institutions

The team explored tendencies across the different continents by analyzing the keyword through the SBDLM. Urban freight and city logistics are the most important topics worldwide, considering last-mile delivery, urban consolidation centers, and optimizing delivery networks. Europe is the region with the most representative authors' participation in the literature with the following top topics: freight transport and logistics (logistics centers, logistics hubs, intermodal transport, synchro modal transport, modal shift); sustainability in transport and logistics (green logistics, social sustainability, environmental sustainability, carbon emissions); advanced optimization and technology applications (intelligent transportation systems (ITS), information and communication technology (ICT), geofencing, simulation-based optimization, decision support systems); and transport planning and policy (accessibility analysis, strategy, transport demand modeling, transport economics, stakeholder engagement). The second representative region is Asia with the next key topics: sustainable transportation and green logistics; freight systems and policy analysis (freight demand modeling, freight behavioral research, logistics planning); digitalization, artificial intelligence (AI), and technology in freight transportation; and emissions, environmental impact, and air quality. The next representative region is North America with the following topics: freight demand modeling and data science (Modeling freight demand, trip patterns, integrating freight movement data); land use and freight integration (Integration of freight systems with urban land use planning, understanding spatial dependencies, and impacts of freight on urban growth); Sustainability and Alternative Fuels (electrification, renewable energy, and digital technologies); and e-commerce and logistics sprawl (Impacts of e-commerce on logistics networks, suburbanization of warehouses).

Following the EDA and network analysis, the subsequent step involved using AI tools to extract deeper insights from the document collection. Techniques such as embedding, topic modeling, and text summarization, all grounded in deep learning methodologies, were employed to reveal hidden themes and patterns within the data. It was possible to identify and classify the most significant themes through SBDLM, as Figure 6 Illustrates.

The technique identified 168 documents related to freight logistics, followed by 68 papers related to energy efficiency/alternative and emissions-related research. Other topics resulting from this analysis were road safety (17 papers), social/societal and economic dimensions (16 papers), and governance related to planning processes and decision support frameworks (12 papers).

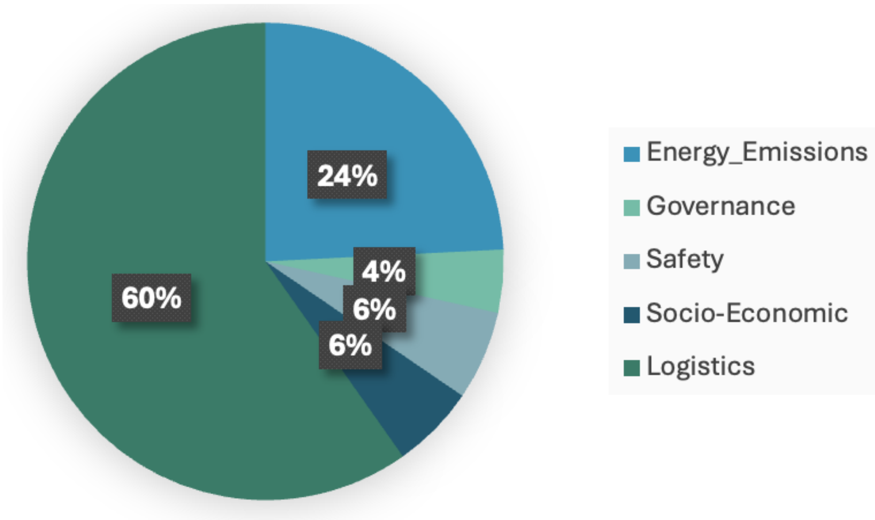


Figure 6. Thematic analysis classification by SBDLM

Figure 7 presents the evolution of this classification over time. Logistics research increased substantially over time, while research in energy and emissions provided significant documentation from 2016. The most representative year was 2022, with 15% of the total documentation considered in this analysis.

The ABSM helped identify research goals and the most representative methods applied in the studies. Results are illustrated for logistics (Figure 8) and energy/emissions classification (Figure 9). The review process concerning logistics encompasses an extensive examination of various strategies, specifically focusing on urban logistics, inbound logistics (including first- and middle-mile considerations), organizational strategies, prevalent methodologies, and pertinent data factors. Urban logistics emerges as the predominant subject within sustainable freight transportation. Suggested strategies within this framework include effective curbside management for optimized parking allocation (*40–47*), loading/unloading bay areas (*48–52*), and improved accessibility to the curbside (*53–55*). Additionally, the literature addresses the topic of freight consolidation in urban contexts, emphasizing location strategies designed to enhance efficiency, reduce costs, and facilitate connectivity among various modes of transport (*56–63*). Multiple modes were also analyzed, such as cargo bikes (*57*, *64–69*), drones (*70*, *71*), pickup collection (*61*, *62*, *72*), and waterways (*73*). Those analyses investigate implementation opportunities, inherent limitations, potential for modal shifts, contributions to decarbonization, and performance evaluation metrics.

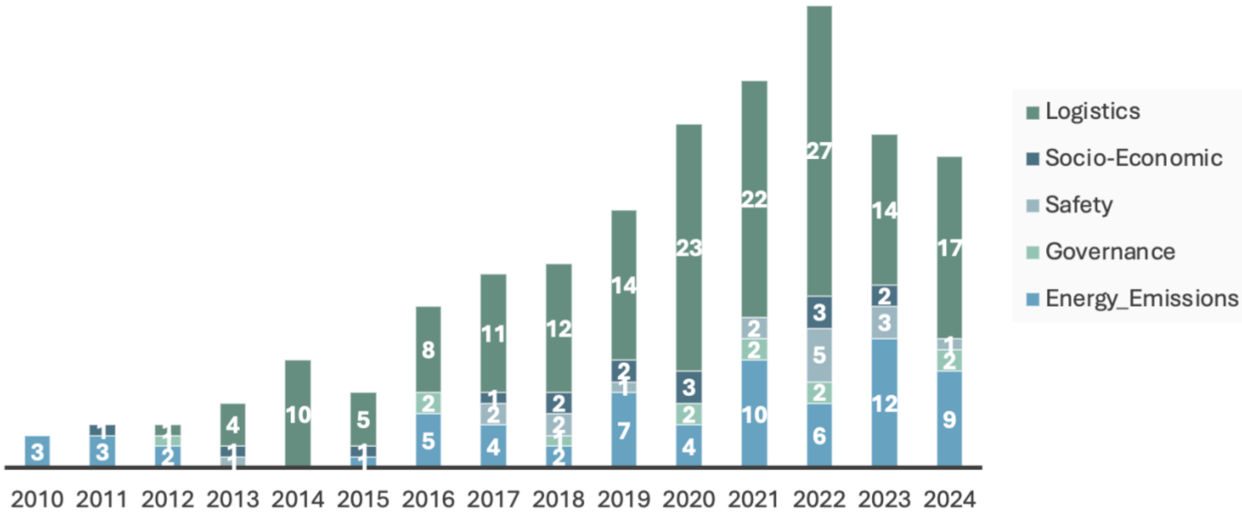


Figure 7. Yearly literature evolution

Furthermore, freight management strategies highlighted within the literature encompass a comprehensive review across all stages of transportation, focusing on aspects such as transportation (trip) generation analysis (*74–81*), the spatial allocation of freight facilities (*53*, *82–90*), and the effective management of the routing problem (*91–96*). In the area of inbound logistics, emerging topics include drayage operations (*96*, *97*), hyperconnected freight systems (*94*), and platooning techniques (*98*). Different strategies implemented to achieve sustainability in transportation include decision-support systems (*99–102*), optimization models (*94*, *103–105*), spatial analysis (*85*, *106–109*), estimation frameworks (*110–114*), and explanation/forecasting models (*55*, *77–80*, *85*, *115*). Data commonly used for analytical purposes include traffic flow, origin-destination statistics, vehicle trajectory information, package tracking details, warehouse locations, real estate data concerning warehouses, and various socio-economic and consumer behavior metrics.

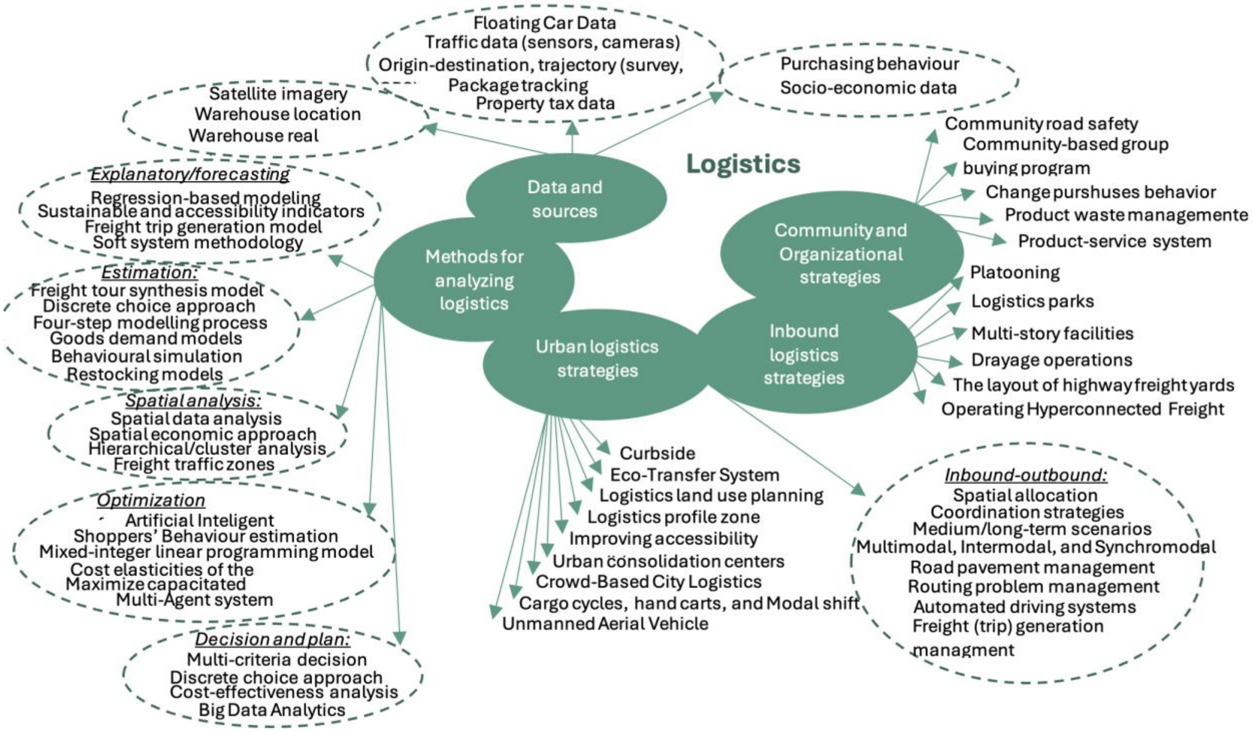


Figure 8. Sustainable literature: Logistics

Figure 9 shows the literature on energy efficiency, energy transition, GHG, and pollutant emissions. Findings were classified into decarbonization strategies, methods to analyze strategies, future needs, and human behavior.

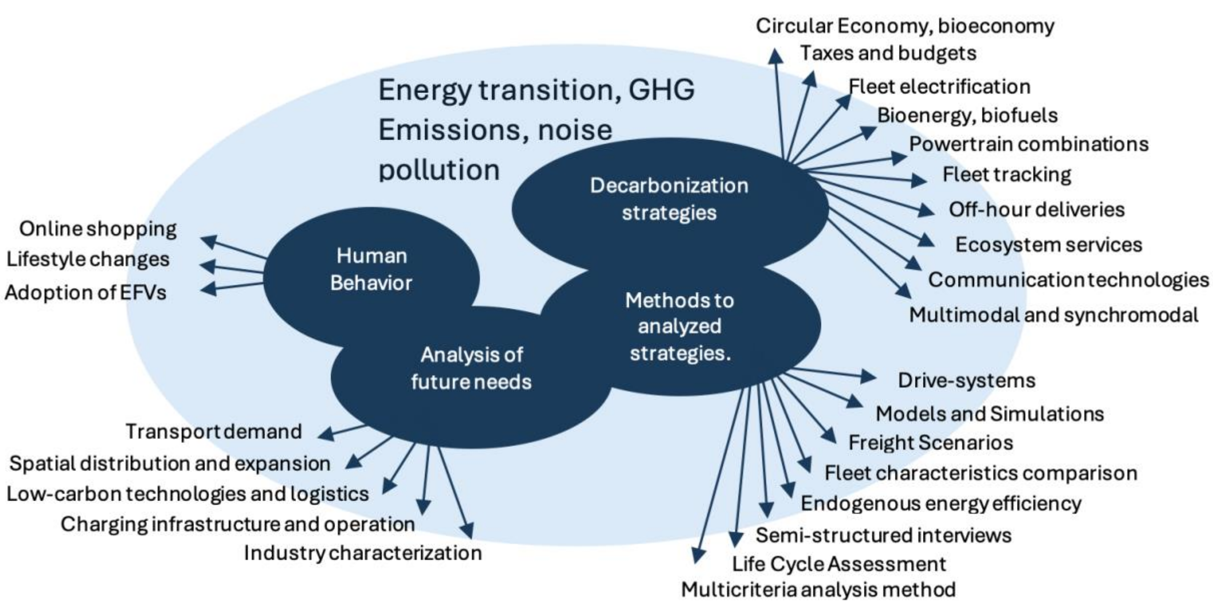


Figure 9. Sustainable literature: Energy and Emissions group

The literature addressing decarbonization strategies emphasizes two primary perspectives: vehicle operations and a more integrative framework. Within the vehicle operation domain, key strategies include using alternative fuels (*64*, *116–126*), optimizing powertrain combinations (*127, 128*), fleet tracking mechanisms (*129*), off-peak delivery practices (*41*, *130*), and both multimodal (*131*) and synchro modal operations (*58*). Conversely, the holistic approach encompasses concepts such as the Circular Economy (*132*, *133*), bioeconomy (*134*), and ecosystem services (*135*), thereby underscoring the interconnectedness of environmental and economic systems. Various methodologies have been employed to compare distinct characteristics within this field, including freight scenario analyses, comparative assessments of fleet characteristics, and qualitative interviews. Additionally, approaches that evaluate efficiency and cost, such as drive system analyses, modeling, and simulations, are prevalent.

Multi-criteria analysis has emerged as a strategy for facilitating decision-making among policymakers and transportation stakeholders over the different sustainable dimensions (*45*, *136–141*). Researchers frequently deploy spatial analysis techniques to address future demands in the decarbonization landscape and effectively inform infrastructure allocation and demand forecasting, transport demand assessments, and industry characterization (*125*, *135*, *142–146*). This comprehensive approach enables a more nuanced understanding of the complexities involved in sustainable transportation initiatives.

2.2.2. RQ2: Sustainability strategies and methods

Table 1 shows the result of the input-output analysis of the 89 references subjected to detailed review. In this case, sustainability dimensions provide an excellent opportunity to classify the literature review's findings based on the outputs for pattern and trend analysis. In addition, the Appendix provides a complete description of freight-related issues and strategies to mitigate those issues identified in the literature.

The environmental dimension includes two groups of outputs. The first group covers carbon reduction, emissions performance, noise pollution, and other decarbonization strategies. The second relates to the energy transition, energy efficiency strategies, and some barriers along the transition process. The literature includes multiple strategies for mitigating freight environmental effects. The most representative is freight logistic strategies such as route optimization (*91*, *141*), demand management (*53*, *59*, *147*), technology implementation (e.g., apps (*148*), multimodal synchronization (*65*)), and comparing multiple freight scenarios (*122*, *149–152*). Fuel technology or alternative fuel (e.g., biofuel (*119*, *153*), natural gas (*121*, *149*), electric (*64*, *122*, *126*, *154*, *155*)) is well documented in the literature, using techniques such as life cycle analysis, data analysis, or simulations to explore fuel consumption and emissions under different scenarios. The review then showed multiple policy inventories (*136*, *154*, *156*, *157*), policymakers' roles (*158*), policy scenarios (*154*), and barriers to emissions mitigation (e.g., additional cost (*121*), lack of or insufficient coordination (*159*).

On the other hand, the energy transition outcome review compares different strategies, regions, and scenarios, highlighting the evaluation of needs and barriers to energy transition. Those include wildness to adopt sustainable strategies (*160*), technical and operational issues (*155*), infrastructure limitations (*126*), and urban structure (*146*).

The literature also includes societal/social and economic dimensions. Road safety is a representative topic, and from the equity perspective, different analyses consider the spatial distribution of road crashes involving trucks and their effects on the population (*161*) as well as the transition strategies for road safety (*162*, *163*). Some strategies evaluated in these documents are inclusive transportation networks, linking mobility simulation and safety simulation models, and coordination among different plans. The literature also analyzes the economic effects of freight activity. Those documents include the effects of regional disasters on the economy due to the transportation infrastructure, which requires multi-stakeholder collaborative strategies (*164*). Other documents evaluate the integration of economic and spatial development policies (156) and policies that incorporate support for the economy with cycling as work (*165*).

Table 1. Dimensional and Input-output Classification

Dimension	References	Input	Output (Target)
Environmental (26)	(*57*, *64*, *91*, *131*, *148*, *150*, *151*)	Logistics operations, strategies, and technology	Carbon reduction, GHG emissions performance, noise pollution
	(*116*, *119*, *121*, *122*, *149*, *152*, *166*)	Fuel technology or alternative fuels	
	(*145*, *152*, *154*, *156*, *158*, *159*)	Policy/plan evaluation	
	(*167*)	Socio-economic characteristics	
	(*155*, *160*)	Logistics operations, strategies, and technology	Energy transition, energy efficiency, and barriers
	(*126*)	Fuel technology or alternative fuels	
	(*153*)	Policy/plan evaluation	
	(*146*)	Spatial analysis	

Dimension	References	Input	Output (Target)
Societal/social (8)	(*162*)	Policy/plan evaluation	Road Safety
	(*161*, *163*)	Spatial-temporal analysis	
	(*168*, *169*)	Social and environment	
	(*170*)	Logistics operations, strategies, and technology	
	(*147*)	Policy/plan evaluation	Equity impacts
	(*171*)	Policy/plan evaluation	Health impacts
Economics (5)	(*164*)	Relief logistics	Economic effects
	(*172*)	Oil demand	
	(*165*)	Labor opportunities	
	(*173*, *174*)	Infrastructure and land characteristics	
Governance (29)	(*55*, *59*, *65*, *100*, *175*, *176*)	Logistics operations, strategies, and technology	Decision support and collaborative solutions
	(*177*)	Decision criteria analysis	Land use demand, management, and patterns
	(*178*)	Model analysis	
	(*46*, *81*, *179*)	Logistics operations, strategies, and technology	
	(*180*)	Market conditions	
	(*13*)	Policy/plan evaluation	
	(*181–188*)	Policy/plan evaluation	Freight efficiency, accessibility, and location
	(*3*, *29*, *53*, *60*, *86*, *101*, *138*, *189*)	Freight logistics and management	
Multidimensional (21)	(*90*, *190*, *191*) (*136*, *157*, *192–196*)	Projects or program evaluation Policy/plan evaluation	Sustainable Freight
	(*140*, *197*, *198*)	Decision criteria analysis and collaborative solutions	
	(*57*, *63*, *64*, *91*, *131*, *148*, *150*, *151*)	Logistics operations, strategies, and technology	

The governance dimension exhibits a representative group of documents related to freight efficiency, accessibility, and location output. Some documents analyze literature to identify strategies for enhancing decision-making outcomes and operational performance.

These strategies include staying updated on changes and trends within the industry (*3*), utilizing open data (*29*, *138*), implementing urban freight transport plans (*138*), fostering collaborations and partnerships among various stakeholders (*3*, *29*, *181*), establishing suitable logistics facilities in central urban areas (*29*), managing passenger and freight transport as a cohesive logistics system (*138*), and integrating freight considerations into land use planning (*3*). Neglecting freight integration can have long-term and irreversible consequences for traffic flow, air quality, waste generation, and energy consumption (*3*).

Other documents analyzed specific cases from the policy and planning perspective. For instance, a framework for optimizing the establishment of small-scale logistics facilities was proposed for implementation in Inner Melbourne, considering the spatial relationships between the significant freight hubs and transport networks (*187*). Other research developed in Montreal, Canada, shows that including user costs in decision processes significantly reduces user costs, achieving a minimal impact on operator costs, thus easily satisfying a cost/benefit criterion. The findings provide new evidence for policymakers that the optimal sequencing of interventions in time and space on a network can significantly reduce societal costs, sustainability objectives, and environmental impacts (*186*). A study conducted in London relating to the 2012 Olympic and Paralympic Games highlighted the beneficial effects of collaborative efforts between policymakers and the freight industry (*181*). This collaboration fostered an environment where companies were encouraged to revise their delivery and collection schedules to off-peak hours, thereby enhancing freight planning within Transport for London-funded Road schemes. This agency's provision of electronic traffic information to the freight sector and the further development of freight journey planning tools were significant advancements in optimizing freight management. A comparative analysis assessed the before-and-after travel time performance metrics in Charlotte, North Carolina. This investigation employed a modeling approach to elucidate the interplay between land use characteristics and travel time performance. The findings significantly impact freight operational efficiency, highlighting the critical relationship between urban planning and transportation outcomes (*183*). The implementation of time restrictions for heavy goods vehicles on specific road sections in Gdańsk's city center, Poland, was evaluated and resulted in an enhanced level of service. However, the findings indicate that this measure can be most effective when developed collaboratively with transport companies (*185*).

Multidimensional documents consider at least two sustainable dimensions and represent a more integral analysis. Logistics operations, strategies, and technology are the most representative input in the literature. Evaluating Sustainability is one of the primary goals of those documents using strategies such as indicators (*199–202*), simulations (*203*), interviews (*141*, *200*), traffic data analysis (*204*), and multi-criteria data analysis (*205*). Other research evaluated sustainable policies, such as the connection between (multilevel) policy mixes for European climate change. The authors proposed transforming the focus of funding from infrastructure to broader mobility and institutionalizing multilevel cooperation (*157*). A separate study employed multi-criteria analysis to assess the measures proposed for Serre's Sustainable Urban Logistics Plan (SULP) in Northern

Greece (*136*). The findings of this research identified three primary strategies: enhancing user awareness and disseminating information regarding sustainable urban freight transport, developing informational maps, and implementing spatial and temporal restrictions. An additional study of significance focuses on ITS solutions in the planning and management of urban freight transport in Gdynia. This research employed a novel multilevel transport model to model and analyze freight vehicle traffic dynamics comprehensively. The findings underscore the critical role of integrating vehicle data obtained from surveillance cameras, traffic measurement stations, and the overarching street network. Such integration is essential for enhancing forecasting accuracy and optimizing the transportation planning process.

2.2.3. RQ3: Primary considerations for incorporating freight logistics into land-use planning

Literature provides frameworks to incorporate freight into LU planning to improve efficiency and sustainability. A key framework denominated "Freight-Efficient Land Uses (FELUs)" was proposed as a procedure to guide policymakers in the formulation of a plan capable of minimizing social, private, and external costs while fostering compactness of supply chains (*13*, *14*). The framework comprises four essential steps: **(1) acquire a thorough understanding of the key attributes of the local economy, freight operations, and supply chain trends in the region; (2) recognize the challenges and the opportunities; (3) pinpoint the most impactful FELU initiatives; and (4) involve stakeholders to establish a strategic direction moving forward.** The guide provides several initiatives and tools to implement the plan. Still, **it fails to offer equity metrics, strategies**, or tools for measuring the social impacts of displacement risk, gentrification, employment, and housing affordability derived from freight activity.

A second framework proposed by (*109*) advocates for incorporating urban freight initiatives into urban planning processes. This framework encompasses three key components: (1) a theoretical foundation rooted in economic geography theory, which aids in identifying, characterizing, and mapping **freight transportation zones based on the spatial and economic characteristics of companies and their freight demand**; (2) **a spatial cluster analysis that examines the integration of infrastructure, land use, and the locations of companies**; and (3) a **high-level grouping of urban freight initiatives**. However, some limitations of this framework include challenges related to its scalability in different urban contexts, a lack of stakeholder engagement, and considerations of equity impacts.

Some topics identified in the documents with LU as a key component include freight demand, freight logistics, transportation infrastructure, environmental sustainability, and socio-economic impacts (see Table 2). A representative topic in the documents was freight logistics. Some studies focus on the **spatial distribution of freight facilities and how this affects freight efficiency**, incorporating methods such as large-scale freight surveys (*206*), comparing freight activity in multiple urban areas (*179*), measuring accessibility by merging spatial analysis and logistic regression (*85*), identifying the e-tailing hubs trends using clustering analysis (*3*) and computing the cost of inter-regional distribution based on facility location (*105*). The literature also proposes simulations for **integrating land-use/transport modeling** (*101*, *178*), **simulations of shopping demand to assess the effects on the freight restocking incorporating LU development** (*207*), **and a simulation of commodity contracts, logistics, and vehicle operation to evaluate logistics solutions** (*203*). Alternatively, an interactive visualization tool for collaborative planning of construction transport was proposed by (*198*), which allows for evaluating strategies and assessing predicted consequences. In addition**, some documents proposed special areas for freight logistics, such as hubs for eco-transfer systems** (*208*) **and special airport economic zones** (*106*)**.**

Table 2. Land Use- related documents

Topic	Total	References
Freight logistics	15	(*3*, *85*, *101*, *105*, *106*, *139*, *142*, *178*, *179*, *187*, *198*, *203*, *206–208*)
Freight demand	11	(*53*, *54*, *87*, *180*, *183*, *196*, *200*, *209–212*)
Transportation Infrastructure	6	(*42*, *44*, *46*, *50*, *118*, *177*)
Environmental sustainability	3	(*143*, *145*, *182*)
Socio-economic impacts	2	(*174*, *213*)

Between the freight demand-related documents, it is essential to highlight the impact that freight demand management strategies and freight-efficient LUs can have on increasing urban freight accessibility through a framework proposed by the authors (*53*). In this case, accessibility measures were essential for targeting LU for freight facilities to ensure efficient logistics performance. **Measuring truck travel time and its relationship with LU was another factor identified for allocating resources to improve efficiency** (*183*, *209*, *210*). In addition, **measuring freight trip generation, shopping trips, and LU development were also representative strategies of the freight demand topic, considering LU as part of the built environment** (*211*), LU based on attractiveness and accessibility indicators (*54*), the surrounding LU of freight clusters (*87*), and using Multi-Criteria Evaluation in GIS for identifying suitability maps related to Freight Trip Generation Centers and LU compatibility (*200*).

An important factor related to the transportation infrastructure presented in the literature is curb-side management. This topic includes the identification of potential parking areas for heavy-duty vehicles through geo-fencing (*42*), the quantification of the usage of curb space in the densest urban area (*44*), and the implementation of a model to optimally locate loading bays in an urban environment (*50*). Other research evaluates the impact of home delivery when occupied public land for parking through scenario assessment, including electric vehicles (*118*).

2.3. Takeaways and research opportunities

This section synthesizes the key findings from the literature review while identifying existing gaps and opportunities for implementing sustainable strategies within freight transportation, as revealed through the analysis of the reviewed literature.

2.3.1. Takeaways

- Urban freight and city logistics are the most important topics worldwide. Europe has the most representative authors' participation, followed by Asia and North America.
- The literature's most representative freight logistics strategies are curbside management, freight consolidation in an urban context, and multimodality.
- Freight management strategies mainly focus on transportation (trip) generation analysis, freight facilities' spatial allocation, and effectively managing the routing problem.
- The literature addressing decarbonization strategies emphasizes two primary perspectives: vehicle operations (e.g., alternative fuel, off-hour deliveries) and a more integrative framework (e.g., circular economic, ecosystem service).
- Multi-criteria analysis has emerged as a strategy for facilitating decision-making among policymakers and transportation stakeholders over the different sustainable dimensions.
- The governance dimension of sustainability includes strategies such as staying updated on industry changes and trends, utilizing open data, implementing urban freight transport plans, fostering collaborations and partnerships among various stakeholders, and integrating freight considerations into land use planning.
- Multiple documents provide strategies for evaluating sustainability, including indicators, simulations, interviews, traffic data analysis, and multi-criteria data analysis.
- Some topics identified in the documents with LU as a key component include freight demand, freight logistics, transportation infrastructure, environmental sustainability, and socio-economic impacts.
- Different authors considered LU to measure efficient logistics performance, identify resource allocation, or evaluate freight accessibility and attractiveness.

2.3.2. Research opportunities

- Labor force disparities and disruption are absent from this review. The shift toward a carbon-neutral transportation system can affect employment in specific industries while generating new opportunities in others, such as manufacturing clean vehicles and developing electric and hydrogen fueling infrastructure. Therefore, developing research on this topic and proposing strategies to mitigate the disruption's side effects are important.

- The transportation policy structure highly depends on the region and the context (e.g., transit, freight). As a result, it is essential for policy analysis to effectively represent the decision-making frameworks and power dynamics and recognize the informal networks and sub-groups of stakeholders that gather around the policy matter.
- One area that remains underexplored in the literature examined in this study is the long-term sustainability of certain incentive policies. Both time scale and investment are often overlooked but are crucial for effective policy sustainability.
- Another critical gap is the disparities led by freight facility placement and operation. Prioritizing equity considerations by including marginalized and vulnerable populations and how planning processes impact them. Research should focus on environmental effects, housing effects, and gentrification patterns resulting from freight facility distribution because of policy and planning practices. This will provide helpful information for mitigating negative policy effects on communities.
- A representative gap in this literature search is the climate change discourse as a strategy to change population behavior that could impact decarbonization since some research has demonstrated that discourses of fear of climate change are pervasive and disengaged (*214*). More research is needed to identify the California climate change discourse and evaluate the effects of changing discourse toward human health and wellbeing instead of climate change.
- There should be increased global research collaboration to develop and enhance a comprehensive evaluation framework for sustainable performance. There is a great collaboration between European countries. However, there is still a great opportunity to cooperate with research at the international level and between countries with different levels of development.
- Efficient land-use distribution is a priority topic for policymakers and planners. An effective land-use plan highly depends on large-scale land demand forecasting using historical data. Therefore, a great effort is required to improve this forecasting process, incorporating the freight demand identified and its impact in each sustainable dimension. This will result in the identification of the most optimum locations for logistics in terms of sustainability.
- Tracking climate actions at various government levels is crucial to identifying each responsible agency's commitment to achieving environmental goals. Therefore, performing a multiscale policy analysis is essential to evaluate the alignment between national, state, regional, and city freight decarbonization targets and the level of compromise required to achieve those goals.
- Some sectors, such as waste transportation, construction transportation, and the long-haul sector, provide an excellent opportunity for policymakers to enhance sustainability because tracking and planning their routes is easier. For instance, literature has analyzed waste fleet electrification and operation as an excellent opportunity for energy transition that could be implemented and evaluated as a regional policy. In addition, decarbonization of drayage operations is an initiative

discussed in the literature. Still, it has some barriers, such as infrastructure barriers, high cost, complex ecosystem, and advanced technology, which require research, especially for the inequality between large and small operators.

- Several strategies require financial incentives, which have been essential for enhancing transportation sustainability. Many policies already implemented (e.g., tax reduction, subsidies) offer a great opportunity to analyze current performance using multicriteria analysis or simulations that can forecast decarbonization targets' performance. Another aspect to consider in this analysis is the unbalanced distribution of those benefits, where small enterprises can be affected. The most significant limitation is the data available for performing this research type.
- Information sharing is a recurrent strategy for enhancing sustainability in transportation. This offers an excellent opportunity to develop a framework for selecting useful data, collecting, administrating, and sharing this information. The initiative should also include regulatory considerations for its implementation.

2.3.3. Framework to incorporate sustainable and equitable freight strategies into the land use planning

This section provides valuable insights that contribute to developing a framework that facilitates the integration of freight strategies into land-use planning. The literature suggests conducting a **multiscale policy analysis** to assess the alignment between national, state, regional, and city freight decarbonization policies, decarbonization targets, and land development policies. This could be the first step in the framework, which must also consider key players in developing policies and incorporating sustainable and equitable freight strategies. Literature reveals fragmentation in freight policy integration, highlighting the need for vertical and horizontal coordination. A second step identified in the literature involves **analyzing the regional context**, including socio-economic characteristics, market conditions, policy performance, freight activity profiles, labor trends, and social vulnerability indicators. This can provide valuable insights into the achievements of decarbonization goals and opportunities to accelerate them. In addition, this step can identify regional disparities and contextual drivers/barriers. The land use literature analysis highlighted the need **to understand both the demand for goods and services and their supply, as well as their relationship to land use**, utilizing spatial and historical data to identify patterns and trends that represent step three in this framework. Aspects to consider in this step include an analysis of environmental effects, housing impacts, and gentrification patterns resulting from the distribution of freight facilities. Logistics sprawl and accessibility issues dominate the literature; freight-efficient LU models and spatial equity are needed. Results from the previous step would provide issues that represent **opportunities to incorporate freight strategies identified in the literature**. Table 20 resents a localized menu of sustainable freight solutions with the most common problems and their related sustainable strategies. This process facilitates the policymaking and planning process and represents the fourth step of the framework. Some common strategies suggested include curbside and parking management, loading/unloading zones, freight consolidation centers, and eco-zoning for logistics. A key aspect to incorporate in the framework is **the prioritization of zones for intervention**, resulting in step five. This step offers an excellent opportunity to integrate equity indicators (e.g., disadvantaged status) to prioritize zones of intervention. Literature also suggests other indicators, such as emissions intensity, freight accessibility, economic development potential, and distribution efficiency. The sixth step should consider **funding sources** (e.g., federal grants, state incentives, public-private partnerships) to secure the implementation of the framework. Some strategies require financial incentives to accelerate decarbonization or to motivate the implementation of sustainable strategies. Literature notes the uneven access to financial tools, especially for small businesses and disadvantaged areas. The seventh step proposed is **the involvement of stakeholders in the process of incorporating sustainable freight strategies**. It is essential for policy analysis to effectively represent the decision-making frameworks and power dynamics, and recognize the informal networks and sub-groups of stakeholders that gather around the policy matter. A significant literature gap exists regarding informal stakeholder networks and participatory governance models. The following step is **the implementation of solutions**, ensuring coordination with existing infrastructure projects or redevelopment efforts, and ensuring interventions are embedded in long-range planning. Finally, step nine should involve **the performance evaluation of each strategy** to verify its effectiveness and report the results to the public. Literature provides multiple strategies for evaluating freight strategies, including indicators, simulations, interviews, traffic data analysis, and multi-criteria data analysis. Key aspect of this step is the evaluation of sustainable dimensions that include environmental dimension with aspects such as GHG, noise, energy use; social dimension, considering displacement risk, access to goods and services; and economic dimension, which includes cost savings and job impacts.

3. Policy analysis

The planning of freight transportation poses several challenges for policymakers. A representative challenge is modifying behaviors, as receivers' actions largely influence freight patterns (*215*). A second challenge lies in fostering collaboration between the public and private sectors in sustainable initiatives (*216*). Additionally, public sector regulations play a crucial role, as public institutions are tasked with land use planning, promoting economic development, and managing financial mechanisms (*217*). The majority of the general plans aimed to address these challenges through seven key initiatives:

1) Enhancing infrastructure management to improve freight facilities;
2) Optimizing parking and loading area management to ensure adequate demand and accessibility for freight vehicles;
3) Implementing strategies to mitigate the externalities associated with vehicle use;
4) Managing traffic flow to enhance overall mobility;
5) Utilizing pricing, incentives, and taxes to alleviate the externalities generated by vehicles and industry;
6) Improving logistics for the last mile segment; and,
7) Promoting sustainability and efficiency through effectively managing freight demand and land use (*217*).

It is important to identify strategies that assist in achieving multiple objectives rather than those that solve one problem but exacerbate the others (*218*).

3.1. Methods

Despite the negative effects that freight transport can have on metropolitan areas, transport plans and regulations tend to focus primarily on passenger strategies (*219*). Since federal and state rules, procedures, and policies have been established in the U.S. affecting freight transport over the past decade, it is necessary to analyze the implementation of these requirements in regional plans and the crucial role that this sector plays in the planning process. Therefore, this section sets the following research questions:

RQ1: Who is responsible for the planning process?

RQ2: What are the freight regulations in the U.S. and California?

RQ3: What sustainable freight strategies are implemented in the Sacramento regional plan?

RQ4: How are the decarbonization targets in the freight sector aligned at the different government levels?

This analysis starts by identifying the local and regional authorities in the transportation planning process and their roles (see Figure 10). Then, the most recent regional plan was selected to develop a deep analysis, focusing on the case study of the Greater Sacramento region in California. The second step involved identifying the freight regulations that impact freight strategies based on the plan's analysis. This strategy encompassed an inventory of assembly bills, senate bills, and executive orders related to freight transportation. The authors evaluated the plans to check whether the strategies complied with these regulations.

The third stage of this process involved identifying challenges and freight-oriented strategies from each regional plan and linking them to the regional authorities' goals. According to the above literature review, the authors divided the sustainable strategies into targets: carbon reduction, noise reduction, operation efficiency, accessibility, road safety, health, and well-being. This study considers the following elements: vehicles, infrastructure, land, stakeholders, and the environment to identify the strategy's focus. It also associated freight strategies from the regional plan with each element and target.

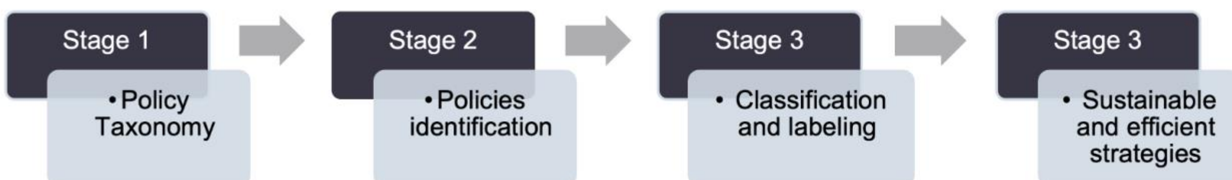


Figure 10. Framework for Policy Analysis

Table 3 shows three levels of importance assigned to each strategy based on whether or not the plan established monitoring performance for solving the issue: High, Medium, and Low. Finally, the authors compared current local, state, and federal decarbonization targets in the freight sector to validate their alignment and compliance.

Table 3. Level of importance of each strategy

Low (L)	Medium (M)	High (H)
This is not an essential factor since the local government does not consider related strategies in the plan.	Moderately relevant from the point of view of the local government. Strategies are set but not prioritized, and there is no performance monitoring.	This is a very important factor since the issue and the strategy to solve it are relevant to the local government. The plan defines performance monitoring with an indicator.

3.2. Results

3.2.1. Planning responsibilities and regulations

It is essential to delimit the scope of the policy analysis in this study, which incorporates seven elements: legislation, regulation, funding, guidance, plan, program, and enforcement. The legislation refers to the law passed by the legislative arm of government. The regulation relates to specific requirements for implementing legislation promulgated by the administrative branch. Funding is the revenue mechanism that includes taxes (e.g., gasoline/diesel, property taxes, sales), fees (e.g., vehicle weight, developer fees), and pricing. The funding can be by apportioned programs, allocated to states, MPOs, and transit agencies by formula (e.g., 87% of highway programs in the Infrastructure Investment and Jobs Act), and discretionary programs allocated competitively based on applications. The resources for those funding came mostly from federal gas tax, state gas tax, and regional sales. Guidance is related to processes, methods, or standards for policy adherence. The plan focuses on developing a vision, creating policies and strategies to support the vision, and is set for a long-term horizon. Programs prioritize proposed projects for short terms and match projects with available funds. The final element is related to enforcement, compliance, and certification.

Based on the previous scope, Table 4 exhibits different transportation sector-related policies and agencies involved with freight. From the executive branch at the federal level, the U.S. Department of Transportation (USDOT) is the top hierarchy agency responsible for implementing legislation related to specific policies and guidelines in the transportation sector. In addition, this agency plans for national infrastructure and distributes funding for transportation projects (*220*). The Strategy Plan for fiscal years 2022-2026 outlines the long-term goals the USDOT aims to achieve (*221*). It details the Department's actions to realize these goals and explains how it will utilize its resources most effectively. Among the agencies overseen by the USDOT, the National Highway Traffic Safety Administration (NHTSA), the Federal Highway Administration (FHWA), and the Federal Motor Carrier Safety Administration (FMCSA) are the most directly affected by the trucking sector (*220*).

Another vital agency affecting the freight sector is the Environmental Protection Agency (EPA), which sets goals and the roadmap for addressing climate change in the EPA's Fiscal Year (FY) 2022-2026 Strategic Plan. Although not directly engaged in local LU planning, the federal government significantly impacts LU through environmental regulations, transportation funding, and housing policies. Agencies such as EPA and the Department of Housing and Urban Development (HUD) implement federal laws concerning environmental protection, housing standards, and infrastructure funding. Furthermore, the Bureau of Land Management oversees more than 10 percent of the land in the United States and one-third of the country's minerals, according to the provisions of the Federal Land Policy and Management Act (FLPMA).

Table 4. Transportation policy taxonomy

Policy	Sector	Federal	State	Region
Agencies	Transportation	USDOT Federal Motor Carrier Safety Administration (FMCSA) National Highway Traffic Safety Administration (NHTSA) Federal Highway Administration (FHWA)	California State Transportation Agency (CalSTA) California Department of Transportation (Caltrans) California Transportation Commission (CTC)	Sacramento Area Council of Government (SACOG)
	Environmental and land use	Environmental Protection Agency (EPA) Department of Housing and Urban Development (HUD) Bureau of Land Management	California Air Resources Board (CARB) California Energy Commission California Department of Water Resources (DWR) Governor's Office of Planning and Research (OPR) California Wildfire & Forest Bureau of Land Management (BLM)	Sacramento Metropolitan Air Quality Management Districts (AQMDs) Yolo-Solano Air Quality Management District El Dorado County Air Quality Management District
Legislation	Transportation	ISTEA, 1991 TEA-21, 1998 SAFETEA, 2005 MAP-21, 2012 FAST Act 2015 IIJA 2021	SB 486: goals and performance measures SB 1: Transportation funding SB 517: efficient, sustainable, competitive freight and supply chain sector	
	Environmental	Clean Air Act (CAA) National Environmental Policy Act (NEPA) Water Quality Act National Climate Task Force Energy Policy Conservation Act	California Clean Air Act (CCAA) California Environmental Quality Act (CEQA) California Water Quality Act **AB32: Global Warming Solutions Act** AB 52, 2015 consultation with tribes under CEQA review AB 627: reducing pollution from heavy-duty trucks **SB375: The Sustainable Communities and Climate Protection Act** SB32: California Global Warming Solutions Act SB862: Greenhouse gases: emissions reduction SB 350: Clean Energy and Pollution Reduction Act SB 671 Clean Freight Corridor	

Policy	Sector	Federal	State	Region
	Land use	The National Historic Preservation Act of 1966: Limits land use The Federal Land Policy and Management Act of 1976: Covers land use plans for public lands Federal Land Policy and Management Act (FLPMA)	SB 9: Housing development: approvals (subdivide properties) SB 35, 2017: Planning and zoning: affordable housing: streamlined approval process AB 18, 2004 consultation with tribes for LU planning AB 98, 2024: Planning and zoning The Williamson Act (California Land Conservation Act) SB 330 Housing Crisis Act SB 743 Environmental quality: transit-oriented infill projects	
Regulation	Transportation and environment	Asset Management Plans and Periodic Evaluations – MAP-21 Hours of Service (HOS) Regulations Commercial Driver's License (CDL) Standards Electronic Logging Devices (ELD) Rule Federal Motor Vehicle Safety Standards (FMVSS) Corporate Average Fuel Economy (CAFE) Standards Vehicle Emissions Standards The Freight Analysis Framework (FAF) USDOT Metropolitan Planning Regulations U.S. Environmental Protection Conformity Rule E.O. 14008 (Tackling the Climate Crisis) E.O. 12898 (Environmental Justice)	EO B-30-15, GHG emissions target EO B-55-18 Carbon neutrality EO N-19-19 EO B-79-20 zero-emission sales by 2035 - Advanced Clean Truck Regulation, Advanced Clean Fleet Rule EO S-3-05, Reduce GHG emissions EO N82-20, Expanding nature-based solutions	

Policy	Sector	Federal	State	Region
Plans	Transportation	US Department of Transportation Strategic Plan National Freight Strategic Plan (USDOT)	Long-range transportation plan: California Transportation Plan CALTRANS 2020-2024 STRATEGIC PLAN California Freight Mobility Plan (CFMP)	The Metropolitan Transportation Plan/Sustainable Communities Strategy (2020 MTP/SCS)
	Environment	EPA Strategic Plan 2022-2026	Climate Action Plan for Transportation Infrastructure CAPTI	
	Equity	U.S. Department of Transportation Equity Action Plan	Race and Equity Action Plan	Race Equity Action Plan & Implementation
	Land use		Land Use and Resource Management Plan	Regional Housing Needs Allocation (RHNA) SACOG
Programs	Mixture or for revenue	Transportation Improvement Program (TIP)	Cap-and-Trade Program (revenue) Community Air Protection Program (AB 617) Clean Truck and Bus Vouchers (HVIP) (non-competitive)	Metropolitan Transportation Improvement Program Sustainable Mobility Program Intelligent Transportation Systems (ITS)
	Apportioned (formula-based) programs	FAST Act Formula Highway Programs National Highway Performance Program (NHHP) Surface Transportation Block Grant Program (STBG) Congestion Management/Air Quality Improvement (CMAQ) Highway Safety Improvement Program (HSIP) Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation	State Transportation Improvement Program (STIP) Highway Infrastructure Program (HIP) Surface Transportation Block Grant (STBG) Program and Congestion Mitigation and Air Quality (CMAQ) Improvement Program Regional Housing Needs Allocation (RHNA)	

Policy	Sector	Federal	State	Region
	Discretionary (competitive grant) programs	Infrastructure for Rebuilding America (INFRA) Grant Program National Infrastructure Project Assistance (Mega) Program Rebuilding American Infrastructure with Sustainability and Equity (RAISE) Rural Surface Transportation Grant Program (Rural) Nationally Significant Multimodal Freight and Highway Projects Charging and Fueling Infrastructure Grants Safe Streets and Roads for All (SS4A) Program Mega Grants Choice Neighborhoods Grants Brownfields Redevelopment Grants	Trade Corridor Enhancement Program (TCEP) Advanced Technology Demonstration and Pilot Projects Sustainable Transportation Equity Project (STEP) Zero- and Near Zero-Emission Freight Facilities Sustainable Comm unities Grants Climate Adaptation Planning Grants Strategic Partnerships Grants California Climate Investments Program (CCI) Agricultural Land Mitigation Programs Infill Incentive Grant Program Natural Community Conservation Planning (NCCP) Habitat Conservation Plans (HCPs)	
	No funding distributed	Partnership for Sustainable Communities (USDOT, HUB, EPA) Smart Growth Program (EPA) Transportation Planning Capacity Building (FHWA/FTA)	Farmland Mapping and Monitoring Program (FMMP)	
Guidance	Transportation	Department of Transportation Performance-Based Planning. MAP-21 Complete Streets Guidance (FHWA)	California Transportation Commission Guidelines Executive Branch Department or agency implements legislation–specific policies and guidelines. IIJA-2021	Project-Level Adaptation Strategies Guidance Document
	Environment	Design guidelines National Environmental Policy Act – NEPA	CEQA Guidelines Water Quality Standards Air Quality Standards	
	Land use	Smart Growth and Sustainability Guidelines - Smart Growth Principles (EPA, HUD, USDOT collaboration) and NEPA-Plus Principles	Land use General Plan Guidance	

Policy	Sector	Federal	State	Region
Enforcement, Certifications	Transportation and land use	Record of Decision (ROD) or Finding of No Significant Impact (FONSI) for projects Buy America Certification Uniform Relocation Assistance and Real Property Acquisition Act Statewide and Metropolitan Transportation Planning Certification	Caltrans Certification and Oversight CalEnviroScreen Compliance CARB oversees the Sustainable Freight Action Plan Freight facilities must meet emission and sustainability benchmarks	

Legislation to highlight at the Federal level includes Moving Ahead for Progress in the 21st Century Act (MAP-21) 2012, America's Surface Transportation Act (FAST) 2015, Infrastructure Investment and Jobs Act (IIJA) 2021, and National Environmental Policy Act (NEPA) 1960. MAP-21 Act focuses on expanding the National Highway System, establishing a performance-based program, supporting job creation and economic growth, and supporting the safety agenda. The act supports the national freight network, strengthens the ability of rural communities to access national and international trade markets, and supports regional economic development. FAST is a federal law that provides long-term funding certainty for surface transportation infrastructure planning and investment, including freight projects. The IIJA provides funding for infrastructure projects to protect people and the environment by advancing the safe transportation of energy and other hazardous materials. Division B, title I of this act includes the provision of expanding the National Freight Strategic Plan to include best practices for reducing environmental impacts of freight movement, strategies to increase the resilience of the freight system, and consideration of potential impacts of the freight system on rural and historically disadvantaged communities. NEPA, on the other hand, was designed to require agencies to consider the environmental impact of their actions before making decisions.

It is essential to emphasize that the Code of Federal Regulation defines the scope of the metropolitan transportation planning process (3 C.F.R. §§ 450.306), which directly includes the freight sector. The code demands that the metropolitan transportation planning process address these two factors related to freight: increase the accessibility and mobility of people and freight and enhance the integration and connectivity of the transportation system across and between modes for people and freight § 450.306(b). Furthermore, other factors also indirectly involve the freight system by supporting economic vitality, increasing safety, and protecting and enhancing the environment. On the other hand, the code § 450.322(f) sets the minimum requirements for MTP, which includes the freight sector in the transportation demand analysis.

The U.S. Department of Transportation Strategic Plan for 2022-2026, enacted by MAP-21, sets a performance-based planning and statewide target. Therefore, State Departments of Transportation and MPOs must annually report on progress to guarantee the effective and efficient use of transportation funding. On the other hand, as part of the National Highway Performance Program (NHPP), MAP-21 adopted a requirement for States to develop and implement risk-based asset management plans for the National Highway System (NHS) to improve or preserve the condition of the assets and the performance of the system and to establish minimum standards for States to use in developing and operating bridge and pavement management systems. The National Freight Strategic Plan from USDOT directs policy, initiatives, programs, and investments related to national freight. It will also guide the development of State freight plans and pinpoint areas for freight data and research requirements. Furthermore, it establishes a framework to enhance coordination and partnerships across various sectors, jurisdictions, and modes of transportation.

The U.S. Department of Transportation's Equity Action Plan marks a significant achievement for the USDOT, highlighting a change in the perspective and approach to transportation programs to enhance access and opportunities for all communities while prioritizing those that are underserved, overburdened, and disadvantaged.

At the State level, the California State Transportation Agency (CalSTA) is dedicated exclusively to tackling transportation issues within the state. It collaborates with various departments and divisions, including the California Department of Transportation (Caltrans) and the California Transportation Commission (CTC). Caltrans has the authority to manage and impose regulations on California's transportation system, encompassing highways, bridges, airports, and rail services. This agency executes the Strategic Plan to establish an inspiring direction for the future, determine the actions needed to reach the desired outcome, and monitor performance metrics as signs of advancement toward success. Meanwhile, the CTC allocates and programs funds to enhance the state's transportation infrastructure.

From the land use perspective, the Bureau of Land Management (BLM) is responsible for developing Land Use and Resource Management. This plan seeks more efficient and effective LU. It is linked to several resource management strategies, including watersheds, water use efficiency, groundwater quality, flood management, parks and recreation, climate change adaptive management, and agricultural lands stewardship.

California's legislation is far-reaching. Senate Bill (SB) 486, 2014, sets the Department of Transportation's goals and performance measures. SB 1, Road Repair and Accountability Act of 2017, is a legislative package that makes an annual investment to fix roads, freeways, and bridges in communities across California and puts more dollars toward transit and safety. Other important laws related to freight transportation include Assembly Bill (AB) 627, which focuses on reducing pollution from heavy-duty diesel trucks in California by enhancing funding mechanisms for zero-emission truck programs. The bill introduces a sliding scale for voucher amounts for Hybrid and Zero-emission trucks and Buses, which would significantly benefit smaller fleets. It also prioritizes vouchers for drayage trucks. SB 517 addresses the state’s need for an efficient, sustainable, competitive freight and supply chain sector. Key objectives of SB 517 include enhancing the coordination between state agencies, promoting innovation within the freight industry, and addressing environmental, health, and congestion impacts linked to freight transport. AB 98 is a new act that could potentially contribute to the inclusion of logistics in the planning process. Beginning in 2026, this bill sets various requirements relating to the review of development project permit applications (e.g., standards for building design and location, parking, truck loading bays, landscaping buffers, entry gates, and signage), demands each county and city to adopt a comprehensive, long-term general plan for the physical development of the county or city, modifies the duties of local agencies concerning the approval of logistics use development.

From the environmental perspective, the Clean Air Act sets air quality requirements for developing transportation plans. The California Clean Air Act (CCAA) establishes stricter state goals and provides a framework for achieving CAA standards. Local air districts that do not meet these state standards must develop air quality attainment plans. In that case, the Metropolitan Transportation Plan/Sustainable Communities Strategy (MTP/SCS) must fulfill the necessary criteria to reach air quality standards. Additionally, MTPs must comply with the California Environmental Quality Act (CEQA) and the State CEQA Guidelines. CEQA mandates that state and local government agencies evaluate the combined regional effects and environmental repercussions of projects they have discretionary control before deciding on those initiatives. Another important AB is the 32, which sets the state's global warming emissions reduction to 1990 levels by 2020, where the California Air Resources Board (CARB) is responsible for developing a scoping plan. AB 1279, The California Climate Crisis Act, declares the state's policy to achieve net zero greenhouse gas emissions as soon as possible, but no later than 2045, and achieve and maintain net negative greenhouse gas emissions afterward. SB 671 mandates that the CTC develop a Clean Freight Corridor Efficiency Assessment to pinpoint freight corridors or portions of those corridors, along with the necessary infrastructure to implement zero-emission medium and heavy-duty vehicles.

As required by AB 14, California develops a freight plan, which must be updated every four years by the Infrastructure Investment and Jobs Act (IIJA, 2021) (*219*). The scope of this plan is primarily focused on inbound logistics (long-haul and middle-mile) but also considers last-mile logistics (at the local level), which should reduce traffic congestion and air pollution from this sector (*219*).

Regional and/or local agencies supervise urban transport planning. Their responsibilities include providing mobility, mitigating negative externalities, and maintaining the city's integrity (*222*, *223*). In regional areas of California, transportation authorities are integrated within MPOs, Councils of Governments (CoGs) (*224*), and the Regional Transportation Planning Agency (RTPA) (*225*). California SB 375 requires those agencies to prepare and adopt a long-term General Plan that considers sustainable community strategies to guide future growth and development (207), and that must be updated every five years (SB 391) (*226*). Further, CARB has requested that a set of greenhouse gas emissions targets be incorporated into urban planning for the adoption of zero-emission vehicles (*227*). Additionally, those planes must include innovative technologies based on intelligent transportation systems (ITS) (*228*). These policies serve as a general guide toward sustainable urban transport that integrates all modes and segments of transportation.

Other key agencies are the California Air Districts. California's 35 local Air Districts are in charge of planning regional air quality, monitoring, and permitting for stationary sources and facilities. The districts manage grant programs to enhance air quality and serve as key partners with CARB to ensure that all Californians have access to clean air. For instance, the South Coast Air Quality Management District (AQMD) approved the Rule 2305 denominated Warehouse Actions and Investments to Reduce Emissions (WAIRE) Program or the Warehouse Indirect Source Rule (ISR). This rule mandates warehouse operators to track and record every truck trip entering and leaving the facility to monitor the indirect emissions produced by the trucks visiting their locations (*229*).

3.2.2. The planning process in the Sacramento region

SACOG, recognized by the federal government as the MPO, manages the regional transportation plan for the Sacramento area, which is revised every four years in partnership with local authorities (*230*). As appointed by the state of California, Placer and El Dorado counties act as RTPAs tasked with developing their state-level transportation plans. Serving as the RTPA for Sacramento, Sutter, Yolo, and Yuba counties, SACOG works with the Placer County Transportation Planning Agency and the El Dorado County Transportation Commission to ensure alignment between county plans and the more comprehensive regional strategy.

SACOG follows federal requirements and has developed the Sacramento region's MTP/SCS. It is a 20-year multimodal transportation plan adopted in 2020. The Sacramento region defined seven growth principles named the Regional Blueprint incorporated in this plan. Those principles are using existing assets, compact development, mixed uses, transportation choice, housing choice, preserving natural resources, and quality design.

According to the MTP/SCS 2020 Appendix L, the plan follows the mandatory procedures and regulations defined by the federal government (*231*). The FAST and MAP-21 requirements, which set the rules for preparing long-range regional transportation plans and updates, were found between them. For instance, SACOG prioritized Public Transit and Human Services Transportation, setting a coordinated Plan as the FAST Act requires. Regional Transportation Plan (RTP) federal requirements are also considered for developing the MTP/SCS 2020 under Title 23 of the code of federal regulations containing the principal highway rules. The Federal Clean Air Act of 1970 sets the mandates for examining long-term air quality to ensure it is compatible with the region’s goals. It also ensures federal funding approval. In addition, USDOT Metropolitan Planning Regulations and U.S. Environmental Protection Conformity Rule. According to the MTP/SCS 2020, SACOG reports three performance measures attending the federal and Caltrans requirements. These are safety performance management, pavement and bridge condition performance, and system performance management.

Air quality is another mandatory element incorporated into the MTP/SCS 2020, and it is subject to conformity determination by the U.S. EPA. Between the requirements are the conformity analysis beginning, as determined by the interagency consultation process, and the consideration of the estimates of current and future population, employment, travel, and congestion most recently developed by the MPO (40 C.F.R. § 93.11). The MTP/SCS 2020 (appendices) document the inclusion of those requirements.

Table 5. State Policies Adopted by the MTP/SCS 2020

Policy Number	Year	State Policy	SACOG
AB 6	2024	Transportation planning: regional transportation plans: Solutions for Congested Corridors Program: reduction of greenhouse gas emissions.	
AB 7	2022	Transportation: project selection processes.	
AB 32	**2006**	**The state's global warming emissions to reduce to 1990 levels by 2020**	**x**
AB 69	2023	Transportation: traffic signal synchronization: roadway improvement projects.	
AB 98	2024	Planning and zoning	
AB 241	2023	Air quality programs: funding.	
AB 251	2023	California Transportation Commission: vehicle weight safety study.	
AB 398	2017	Extends and improves the state's world-leading cap-and-trade program to ensure California continues to meet its ambitious climate change goals	
AB 410	2023	Shared mobility devices.	
AB 540	2023	Social Service Transportation Improvement Act: coordinated transportation services agencies.	
AB 617	2017	Community Air Protection Program	
AB 627	2023	Heavy-duty trucks: grant program: operating requirements	
AB 744	2015	California Transportation Commission: data, modeling, and analytic software tools procurement	
AB 802	2015	Enhancing energy efficiency of existing buildings	
AB 805	2024	Identification of disadvantaged communities, inclusion of strategies to reduce pollution exposure in those communities, and use of a skilled and trained workforce	
AB 823	2023	Clean Transportation Program: eligible projects.	
AB 914	2023	Electrical infrastructure: California Environmental Quality Act: review period.	
AB 1265	2023	Transportation fuels: gasoline specifications.	
AB 1279	2022	The California Climate Crisis Act.	
AB 1475	2023	Transportation Agency: performance dashboard	
AB 1525	2023	Transportation projects: priority populations.	
AB 1640	2023	Transportation: general service signs: electric vehicle charging stations.	
SB 1	**2017**	**Road Repair and Accountability Act of 2017**	**x**
SB 5	2022	Motor Vehicle Fuel Tax Law: limitation on adjustment.	

Policy Number	Year	State Policy	SACOG
SB 32	2016	Motor Vehicle Fuel Tax: greenhouse gas reduction programs	
SB 100	2018	100 Percent Clean Energy Act	
SB 226	2011	Implements changes to the CEQA	
SB 350	2015	The Clean Energy and Pollution Reduction Act	
SB 375	**2008**	**Transportation planning: travel demand models: sustainable communities' strategy: environmental review**	**x**
SB 486	2014	Department of Transportation: goals and performance measures.	
SB 517	2023	Economic development: movement of freight.	
SB 535	2012	Established that a quarter of the proceeds from the Greenhouse Gas Reduction Fund must also go to projects that provide a benefit to disadvantaged communities	
SB 743	**2013**	**Environmental quality: Transit-oriented infill projects**	**x**
SB 1014	2018	California Clean Miles Standard and Incentive Program: zero-emission vehicles.	
EO B-30-15	2015	Establishes a California Greenhouse Gas (GHG) reduction target of 40 percent below 1990 levels by 2030.	
EO B-55-18	2018	Carbon neutrality by 2045	
EO N-19-19, 2019	2019	Efforts to reduce greenhouse gas emissions and mitigate the impacts of climate change while building a sustainable, inclusive economy	
EO B-79-20	2020	100% of in-state sales of new passenger cars and trucks will be zero-emission by 2035	
EO S-3-05	2005	Reduce GHG emissions by 80% below 1990 levels by 2050	

Table 6. Factors associated with strategies adopted in the MTP/SCS 2020

Target	Element	Strategy	Measure	Importance
Operation Efficiency	Infrastructure	Road maintenance	Road Condition Index	H
		Curbside management		L
		Multimodal, Intermodal connectivity		M
		Synchro-modal connectivity		L
		Freight (trip) generation analysis		L
		Urban consolidation centers		L
	Vehicles	Routing problem management		L
		Automated driving systems		L
		Modal shift		L
		Drayage operations		L
	Land	Freight location management		L
		Logistics profile zone		L
		Consolidation centers		L
		Ecosystem services		L
	Services	Crowd-Based City Logistics		L
		Coordination strategies		M
Energy efficiency and transition	Infrastructure	Low-carbon technologies		L
	Vehicles	Powertrain combinations		L
		Fleet tracking		L
	Infrastructure	Charging infrastructure management		L
	Vehicles	Fleet electrification		L
	Industry	Industry characterization		L
Carbon reduction and noise reduction	Land	Zero-emission zones		L
	Vehicles	Off-hour deliveries		L
		Renewable energy		L
	Industry	Circular Economy		L
		Product waste management		L

Target	Element	Strategy	Measure	Importance
Increase Accessibility	Infrastructure	Curbside management		L
Road safety	Community	Community road safety	Number of fatal collisions	H
	Infrastructure	Complete street design		L
		Freight risk zone management		L
Improve Economic	Community	Employment development for Freight Industry		L
		Community-based group program		M
	Industry	Product-service system		L
		Industrial and economic nodes		L
Governance involved	Industry	Incentives for improving freight land use sustainability		L
		Coordination strategies		L

Level of importance, which means Low (L) in orange, Medium (M) in grey, and High (H) in green (see Table 2. Land Use- related documents).

The MTP/SCS 2020 defines and incorporates several state policies, as shown in Table 6. The plan incorporated SB 375, the Sustainable Communities and Climate Action Act, which aligns transportation, housing, and other land uses to achieve regional GHG goals. It is also aligned with the California Global Warning Solutions Act AB 32. SB 375 requires California MPOs to develop an SCS as a component of a RTP to reduce per capita passage vehicle-generated GHG emissions by identifying the general location of land uses, their characteristics, connectivity, and forecasting needs, which is also included in this plan. The CARB approves the GHG emission reduction target for automobiles and light trucks set by the MPO. SB 1 is considered in the plan as a mechanism for maintaining the transportation system in the region, especially highways and transit systems. In addition, following SB 743, SACOG documented and explained the land use, as well as the transportation components, of the MTP/SCS in detail. Some potential policies for freight improvement that the MTP/SCS does not consider include AB 98, AB 540, AB 627, AB 744, AB 802, SB 350, SB 517, and SB 1014.

3.2.3. Sustainable freight strategies implemented in the Sacramento regional plan

The MTP/SCS defines specific strategies to improve freight movement in the region. Highlighting the Union Pacific Railroad, the Sacramento International Airport, and the inland Port West Sacramento, the primary strategy is the investment to support the system's connectivity through the highway network. This strategy accomplishes the MAP-21, which establishes a policy to improve the condition and performance of the national freight network. This regulation also demands forecast freight volumes and the identification of highway bottlenecks that cause significant freight congestion. In the MTP/SCS, freight transportation is included from two perspectives. The first one is through the demand analysis in a simplified way using the standard “four-step” or “trip-based” model system approach (*232*). The second is a truck performance metric for limited-access freeways during peak hours. In addition, the plan provides some strategies for improving commuter operations and reliability, which means passengers and goods movement. Due to the importance of agriculture for the region’s economy, the plan also defined maintenance for rural roads as another important freight strategy.

Other strategies are mentioned throughout the plan, such as multimodal connectivity, coordination strategies, and community-based programs (see Table 6). However, there are no specific measures for these activities, which means they are moderately relevant to the plan according to the classification defined in Table 3. Road safety is highly prioritized due to Federal (MAP-21) and State requirements. However, no specific actions related to freight risk are mentioned in the document.

3.2.4. Decarbonization targets

MTP/SCS 2020 sets GHG reduction targets of 19% per capita by 2035 and relative to 2005, following the requirement of SB 375. The plan proposes taking advantage of the CEQA incentives for residential and mixed-use projects to meet this target. In addition, the plan set five strategies: shortened vehicle trips, increased transit, bike, walks, express lanes and pay-as-you-go fees, ITS/transportation spend management (TSM) for smooth traffic flows, and electric vehicles. SB 743 is also considered in the MTP/SCS due to the vehicle miles traveled (VMT) implementation as a transportation metric for measuring the system's performance. The plan set a target of a 10% reduction in VMT per capita in the year 2040 compared to 2020. This plan does not consider other California targets for decarbonization (see Figure 11).

Sacramento–Roseville developed a GHG emissions inventory based on sector, subsector, and county-level details, including El Dorado, Nevada, Placer, Sacramento, Sutter, Yolo, and Yuba counties (*233*). The on-road sector represents 41% of the Percentage Breakdown of 2019 Regional GHGs (10713 thousand Metric Tons of CO2e).

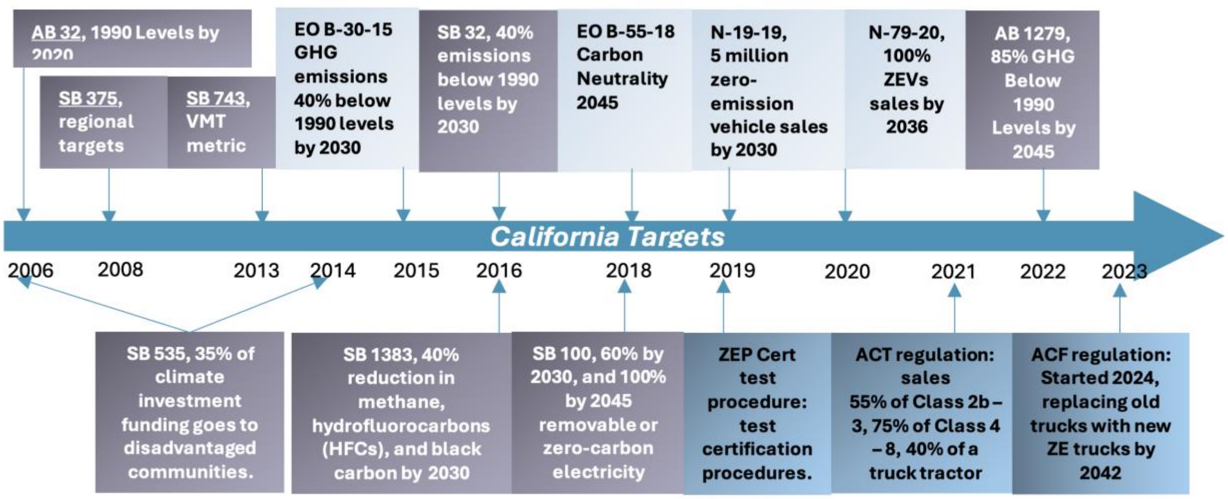


Figure 11. Primary targets for decarbonization in California impacting freight

Figure 12 shows that SACOG and the Air Districts play an essential role in climate action in the region through actions such as VMT reduction, fuel efficiency, and zero emissions. However, the MTP/SCS 2020 plan sets active mobility (increase transit, bike, walk, trips) and shortened vehicle trips as critical factors for reducing GHG emissions. The plan does not propose strategies for reducing VMT or improving fuel efficiency in the freight sector that could contribute significantly to the target. For supporting the energy transition, SACOG is developing the Northern California Megaregion ZEV Medium/Heavy Duty Vehicle Blueprint, a plan for at least 11 major zero-emission truck charging plazas to support the Northern California megaregion along Interstate 5, Interstate 80, and State Route 99, while also providing recommendations for Highway 50 from the corridor analysis (*234*). Caltrans awards the program and considers five electric and hydrogen charging station plazas. The timeline includes the capacity analysis at the end of 2022 and capacity analysis in partnership with industry and the Sustainable Communities program by 2023. The building process is not considered in this program.

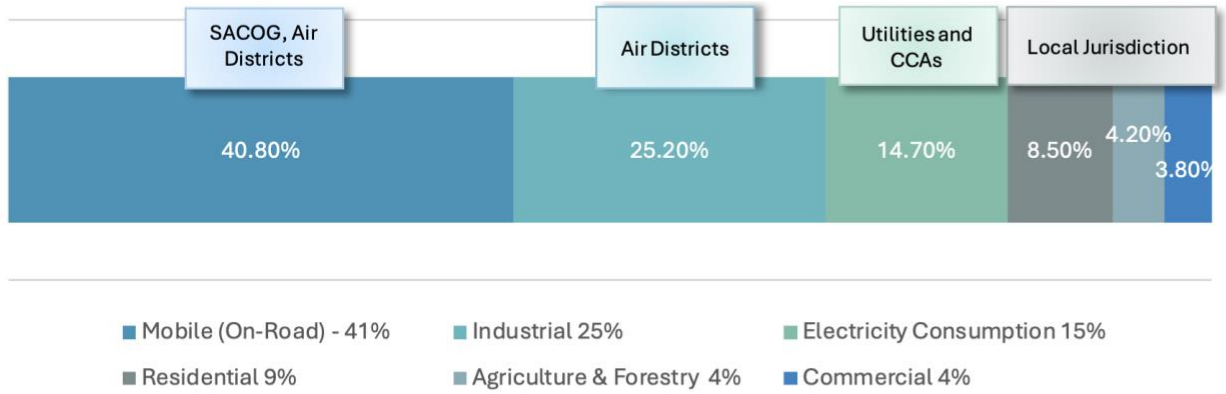


Figure 12. GHG emissions by sector in the region

3.2.5. Land Use Strategies in the Sacramento Region

At the regional level, SACOG has created a Community Types framework to define the future of the LU spatial distribution according to the community type: center corridor, established, rural residential, developing, potential developing, and agricultural/natural lands communities (*230*). However, each jurisdiction (cities and counties) within the Sacramento region has its zoning codes, which generally align with California standards.

Planners have formulated zoning codes to regulate and manage land development, typically incorporated into local land development regulations (LDR) (*235*). Euclidean zones are the traditional framework implemented in the region that sets dimensional criteria and additional guidelines, along with form-based codes that aim to control the shape of various land uses or developments instead of their classification. Performance zoning governs the permissible intensity of diverse land uses, while incentive zones operate on a rewards-based system (*235*). While these Euclidean zones separate industrial and residential areas, protecting them from pollution risks, this strategy can also worsen segregation issues, limit housing supply, and promote urban sprawl, the opposite proposed by the smart growth strategy, mixing land uses (*236*). In addition, it has been identifying other special purpose zones in the region, including specific plan zones for significant developments and others, such as airport zones, to ensure compatibility around the zone.

The zoning code has generally promoted the regional separation of residential and industrial areas. This development suffered some changes after 2002 when SACOG started promoting mixed-use and infill with the Sacramento Region Blueprint Project, which emphasized higher-density, mixed-use, and transit-oriented development (*230*). Two legislative regulations have also impacted this development: SB 375 (2008), which promotes the integration of land use and transportation planning to reduce GHG emissions; AB 32 (2006), which incentivizes local government to prioritize development patterns that would reduce VMT and emissions, and SB 743 that also promotes transit-oriented infill development. New legislation, including SB 517 (2023) and AB 98 (2024), is now targeting the freight sector, though the effects will be felt in the coming years.

While infill and transit development positively impact passenger VMT reduction, evidence suggests urban structure has a considerable effect on the mobility of goods (*155*) that should be considered in the planning process. The concentration and densification of freight-consuming activities—like shops, hospitality, offices, and services—in city centers stand in contrast to the spread of other sectors, such as industry and logistics. This dynamic significantly impacts cities' ability to maintain their supply (*155*). Additionally, logistics facilities are increasingly being established in suburban regions, particularly within major metropolitan areas (*237–239*), to meet the rising demand for goods and services. Those considerations were not identified in the SACOG general plan since they did not quantify the possible impacts of freight transportation for infill development.

Targeted environmental strategies aim to reduce emissions from warehouses in historically marginalized areas. A notable example is the Warehouse Indirect Source Rule (ISR) introduced in 2021 by the South Coast Air Quality Management District (AQMD) in Southern California, which implements a point-or-fee system for warehouse tenants occupying over 100,000 square feet of operational space (*229*). Tenants accumulate points by choosing from a selection of pollution reduction options: purchasing natural gas or zero-emission trucks, installing solar panels on-site, enhancing air filtration in facilities, or paying a $1,000 mitigation fee. These policies assume that warehousing will remain concentrated in historically marginalized neighborhoods to cater to consumers and businesses farther from the city center. Research is investigating how land use influences compact and efficient freight development (*14*, *240*), which is at odds with exclusionary zoning laws that separate residential, commercial, and logistics zones. Consequently, proactive zoning regulations are a crucial area for policies aimed at environmental justice (*241*), fostering sustainable compact development, and integrating logistics into communities that require substantial goods.

3.3. Discussion

California has intensified its efforts to address the environmental impacts of freight transportation by implementing various regulations, mandates, and strategic plans. Notable regulations include AB 32, SB 375, SB 743, SB 535, SB 32, SB 1383, SB 100, and AB 1279, as well as executive orders B-55-18, N-19-19, and N-79-20, all of which establish state targets for equitable decarbonization. The impact of freight facilities on local communities is a significant focus in California, particularly with AB 98, which will take effect in 2024. Beginning in 2028, this bill mandates that counties or cities—unless otherwise specified—update their circulation elements to identify and establish designated travel routes for transporting goods, materials, or freight for storage, transfer, or redistribution. This is intended to safely accommodate increased truck traffic while avoiding residential areas and concentrations of sensitive receptors as defined. Additionally, the bill prohibits any city, county, or city and county from approving the development of logistics facilities that do not comply with or exceed the standards outlined.

An overview of the SACOG MTP/SCS 2020 shows that it covers the following requirements from the state and federal government: forecast the land use pattern growth, set strategies to meet air quality health standards, propose actions for reducing GHG emissions from passenger vehicles, does not discriminate or deny equal access to benefits, cooperate with stakeholders, maintains consistency with other long-range plans, achieves state housing goals, and consult with other agencies. According to federal regulations and legislation, SACOG MTP/SCS 2020 includes the minimum requirements for incorporating the freight system into the planning process (transportation demand analysis). Some strategies focus on maintaining the main roads (highways and rural roads in agricultural sectors) where freight vehicles transit. Other sustainability strategies suggested in the literature review, such as curbside management, urban consolidation centers, or zero-emission zones, are not considered.

One crucial initiative proposed in the plan is developing more compact land with mixed and density uses. This initiative could effectively reduce VMT and emissions from this sector for passengers. On the other hand, freight movement could increase due to the demand in dense areas, raising its negative effects. Therefore, the plan should integrate sustainable strategies such as off-hour delivery, curbside management, and urban consolidation centers to mitigate those side effects (see Appendix).

Regional and state planning is essential for fostering a freight-efficient process. However, regional planning agencies cannot enforce the implementation of those plans, creating a large gap between plans and implementations. In addition, the lack of incentives and regulations at the metropolitan and city levels is the most significant constraint on implementing an equitable and sustainable freight land use plan.

Regions such as San Diego County, administered by the San Diego Association of Governments (SANDAG), and the Imperial County Transportation Commission developed a Sustainable Freight Implementation Strategy to help transition the freight sector. Similarly, the San Francisco Bay Area implemented a Goods Movement Plan to help move goods around the Bay, increasing the economy and reducing environmental impacts. Therefore, freight planning is of low interest for regions where the logistic transportation industry is not a priority, like the Sacramento region.

There is great potential to incorporate the California Freight Mobility Plan and other freight-related regulations (AB 627, SB 517, AB 98) at the state level for future regional plans with GHG reduction targets of 19% on roads. Still, multiagency cooperation and incentives are the main strategies to promote the inclusion of sustainable freight in regional and local plans.

4. Characterization of local context

The Sacramento region, also known as Greater Sacramento, comprises eight counties: Colusa, El Dorado, Nevada, Placer, Sacramento, Sutter, Yolo, and Yuba (*242*), with a total area of 8,436.97 sq. mi. The metropolitan area does not include Colusa County and is named the Sacramento-Roseville-Folsom, California Metro Area. The following subsections describe the Sacramento region's socio-demographic and economic characteristics, followed by an environmental justice analysis and the future needs for charging and fueling infrastructure for Zero-Emission Trucks. This analysis focuses on transportation, and data were gathered from the American Community Survey (ACS) 2022 5-Year Estimates Data Profiles.

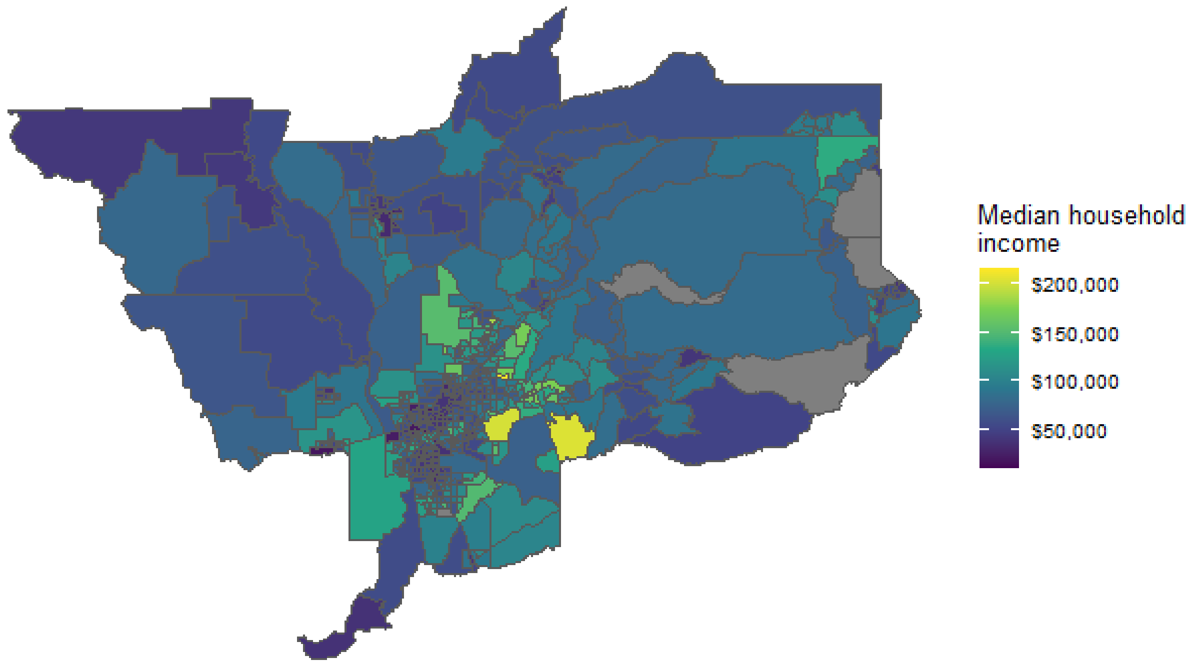
4.1. Socio-demographic and economic characteristics

Different demographic characteristics were identified from the ACS 2022 5-Year Estimates Data Profiles for the eight regional counties. The Sacramento region has a total population of 2,736,302, with a median age of 42. Most of the population is white (50.1%), followed by Hispanics (22%) and Asians (14%). The median household income is $88,611, 10% less than the state and 12% more than the nation, while the median household expenditure is $85,190. Figure 13 shows the population distribution over the Sacramento region based on the median household. Some zones are characterized by the lowest median household income, such as census tracts 7, 53.01, 65.05, and 68.02 (less than $25,000) in west Sacramento and 105.01 in Yolo, near the American and Sacramento Rivers.

There are 1,015,950 households in the region, with 623,036 families. Figure 14 presents the household income distribution by largest racial/ethnic group. The white population is better situated since most have a median household income of $50,000 or above. In contrast, most Hispanic people have a median income of the same value or below. Asian and Black populations are more widely distributed.

Educational attainment for the population age 25 or over shows that 35% of the Sacramento region's population graduated from high school or higher (lower than California, 36%), and 34% have some college or associate's degree (28% in California). The area has a labor force of 1,382,247 people. In 2022, the region had an average unemployment rate of 9%, less than the state's 10%. Management, business, science, and arts are the most essential occupations (42%), with median earnings of $79,629.14 (see Table 7).

On the other hand, production, transportation, and material-moving occupations represent 10% of the total employed population (12% in California). The median earnings for transportation occupations are $49,831, while $32,239 is for material movement occupations, both values higher than in California ($45,407 and $31,325 respectively).



Source: 2022 American Community Survey 5-Year Estimates Data Profiles

Figure 13. Household income distribution in the region by census tract

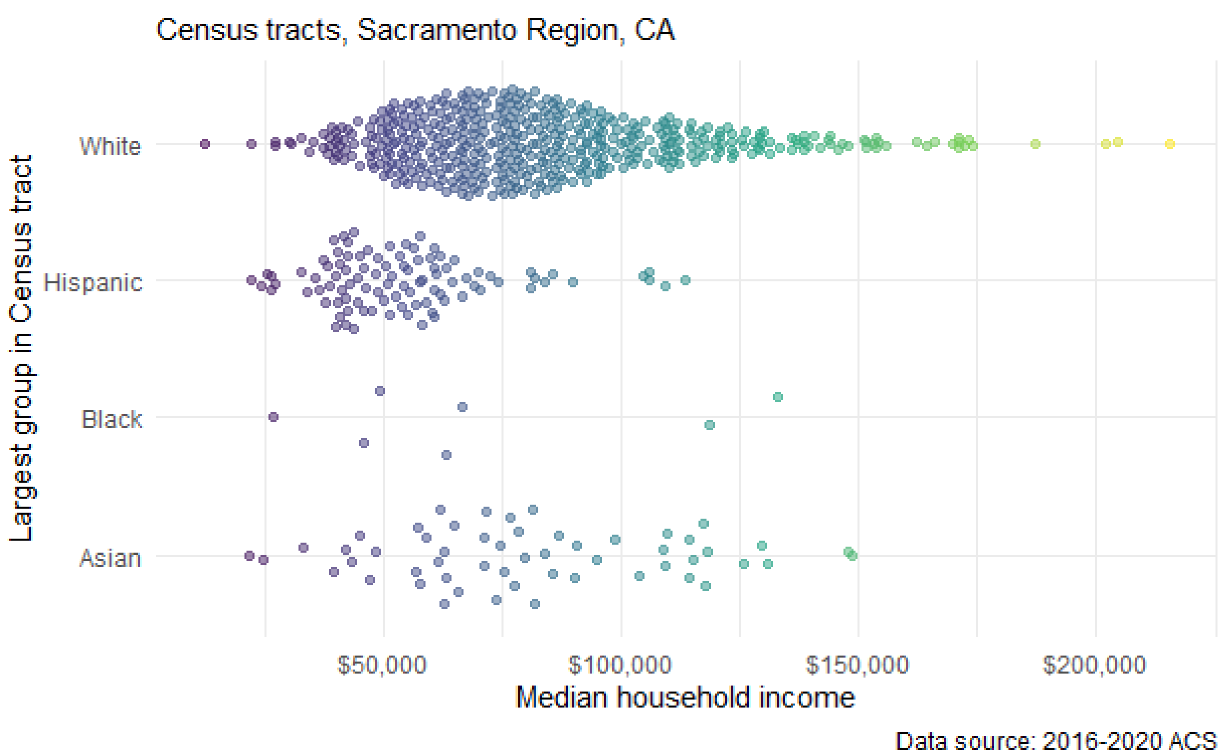


Figure 14. Household income distribution in the region by largest racial/ethnic group

Table 7. Occupation by percentage and median income

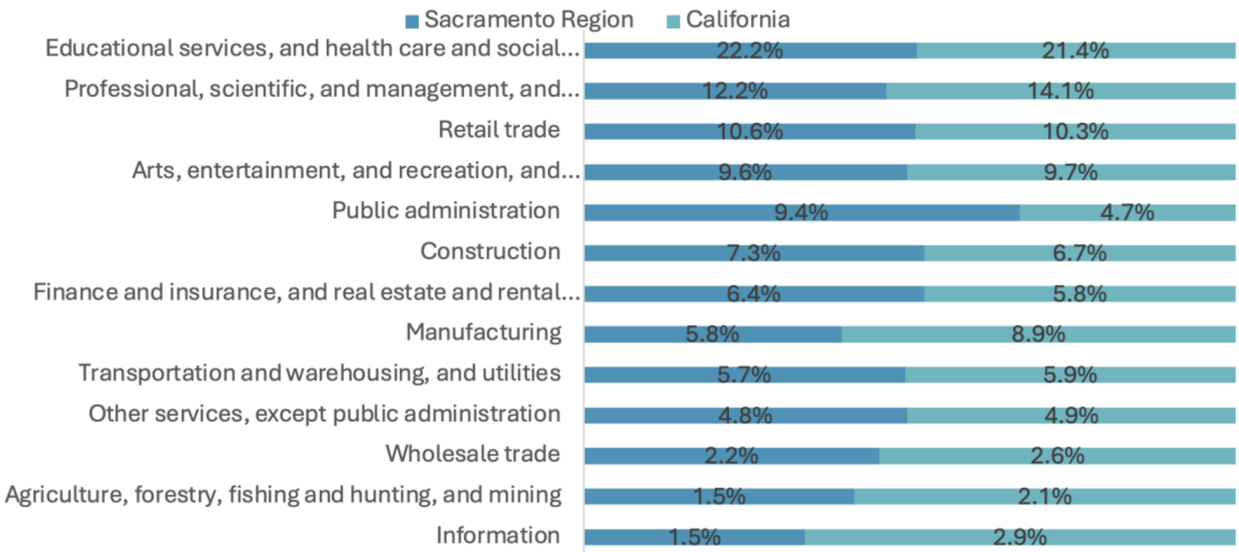
Civilian employed population 16 years and over	Percentage	Median Earnings
Management, business, science, and arts occupations	42%	$ 79,629.14
Service occupations	18%	$ 29,246.57
Sales and office occupations	21%	$ 41,923.29
Natural resources, construction, and maintenance occupations	8%	$ 51,114.71
Production, transportation, and material moving occupations	10%	$ 40,929.71

Source: 2022 American Community Survey 5-Year Estimates Data Profiles and American Community Survey 1-Year Estimates Data Profiles (Earnings)

Figure 15 illustrates that the predominant economic sectors within the region encompass education services, health care, and social assistance. Notably, the area is home to at least 19 higher education institutions, including two prominent public universities: the University of California, Davis (UC Davis), with an undergraduate enrollment of 31,637 students, and California State University, Sacramento, hosting 29,370 undergraduate students. Furthermore, UC Davis Aggie Square has established a mixed-use innovation district within the health services sector that concentrates on advancements in cell and gene therapy, genomics, and various imaging modalities. The BioSpace facility at The Bridge District also represents a substantial investment in life sciences, encompassing a 1.4 million-square-foot Class A life science campus (*242*).

The Sacramento region has significant agricultural biotechnology assets, primarily underscored by robust agricultural research initiatives, notably at UC Davis. This area is experiencing an evolving sector of Agricultural Biotechnology startups and numerous research and development facilities established by major global corporations, including Bayer Crop Science, Syngenta, and HM.CLAUSE, along with various incubators. Situated within California's Central Valley, recognized as the state's foremost agricultural region, the Sacramento area has fertile and productive land. This agricultural landscape generates a crop output value estimated at $2 billion across more than 7,200 farms distributed over 1.5 million acres of arable land (*243*). The entire sector contributes an economic impact exceeding $7.2 billion (*244*). Farming is the primary land use within the zone.

The transportation and warehousing sector ranks ninth in industry classification based on employment. According to the County Business Patterns of 2021, 1,976 regional establishments, accounting for 2% of California's total, are dedicated to the trucking segment as identified by the North American Industry Classification System (code 484). This segment represents 70% of the broader transportation sector (code 48-49). The trucking segment employs 10,721 individuals, constituting only 25% of total employment within the entire sector. The annual payroll for this segment amounts to $562,459,000. Overall, the logistics segment (including services and trucking) is exhibiting strong recent growth and projected employment increases in the region. However, average earnings remain low, indicating a need for further research to assess future patterns.



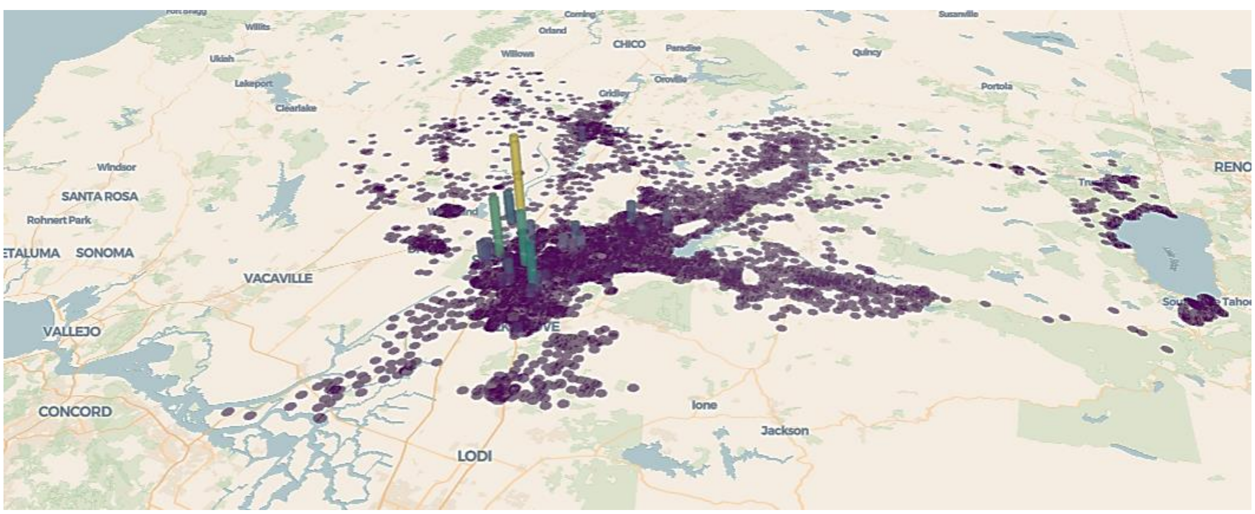
Source: 2022 American Community Survey 5-Year Estimates Data Profiles

Figure 15. Industry classification in the Sacramento region vs. California

Figure 16 shows the spatial distribution of transportation and warehousing facilities. The data from the Longitudinal Employer-Household Dynamics Origin-Destination Employment Statistics (LODES) Worker Area Characteristics (WAC) dataset provides a comprehensive overview of job geography. In this visualization, a column layer helps create a three-dimensional representation, whereby each facility is a vertical column with height and color corresponding to specific characteristics outlined in the dataset. The purple dots denote the block centroids, effectively illustrating the geographic locations of employment opportunities related to the transportation and warehousing sectors. A higher column height indicates a greater concentration of jobs within these industries. Figure 16 reveals a significant concentration of transportation and warehousing employment in Sacramento City and along the primary roadway infrastructure within the surrounding region.

Besides the logistics services, other subsectors of transportation that contribute significantly to employment include automotive wholesale, auto repair, maintenance, and Aerospace and rail manufacturing (*245*).

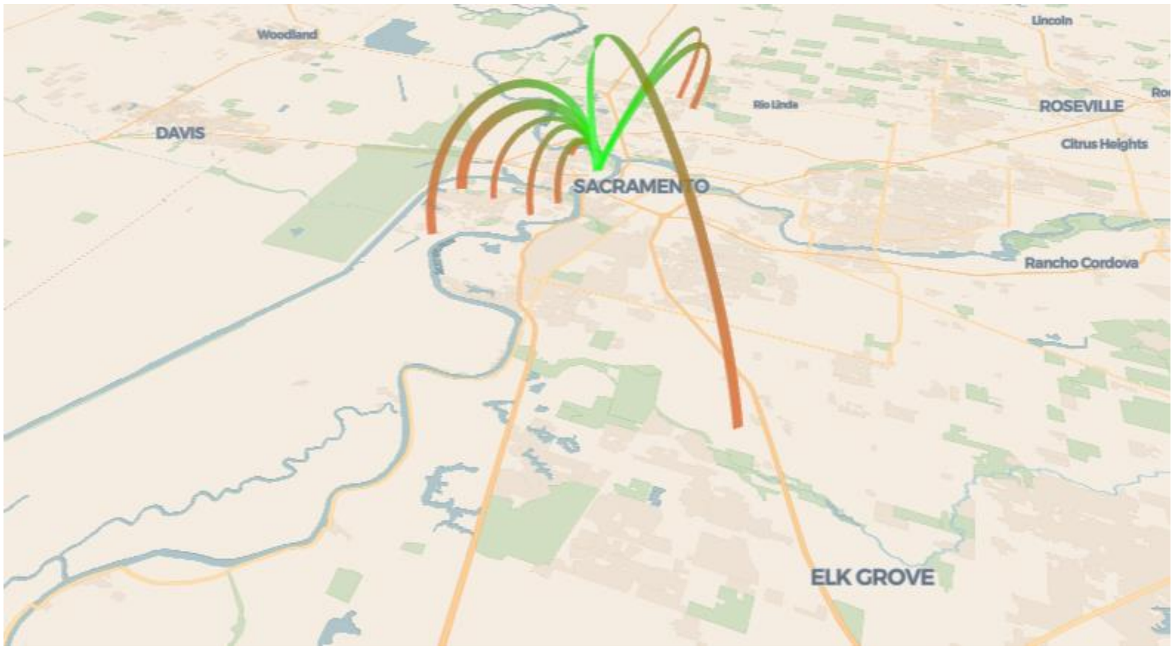
The 2022 ACS 5-Year Estimates indicate that commuting patterns within the transportation industry primarily favor driving alone in cars, trucks, or vans, with a secondary preference for working from home. As a result, this sector significantly contributes to passenger travel by car. On average, the commute time to work is 27 minutes; however, 27% of workers travel for 35 minutes or longer.



Source: 2020 LODES Worker Area Characteristics. U.S. Census Bureau

Figure 16. Spatial distribution of transportation and warehousing facilities

To analyze a prominent origin-destination flow in the transportation and warehouse industry, we selected a census tract (101.05 in Yolo County) to identify other census tracts that send at least 25 commuters to this area, characterized by warehouses and transportation-related activities. Figure 17 shows the flow map with the farthest place, about 16 miles. In general, this census registered 17.6 minutes of travel time to work.



Source: 2020 LODES Worker Area Characteristic U.S. Census Bureau

Figure 17. Origin-destination flow map

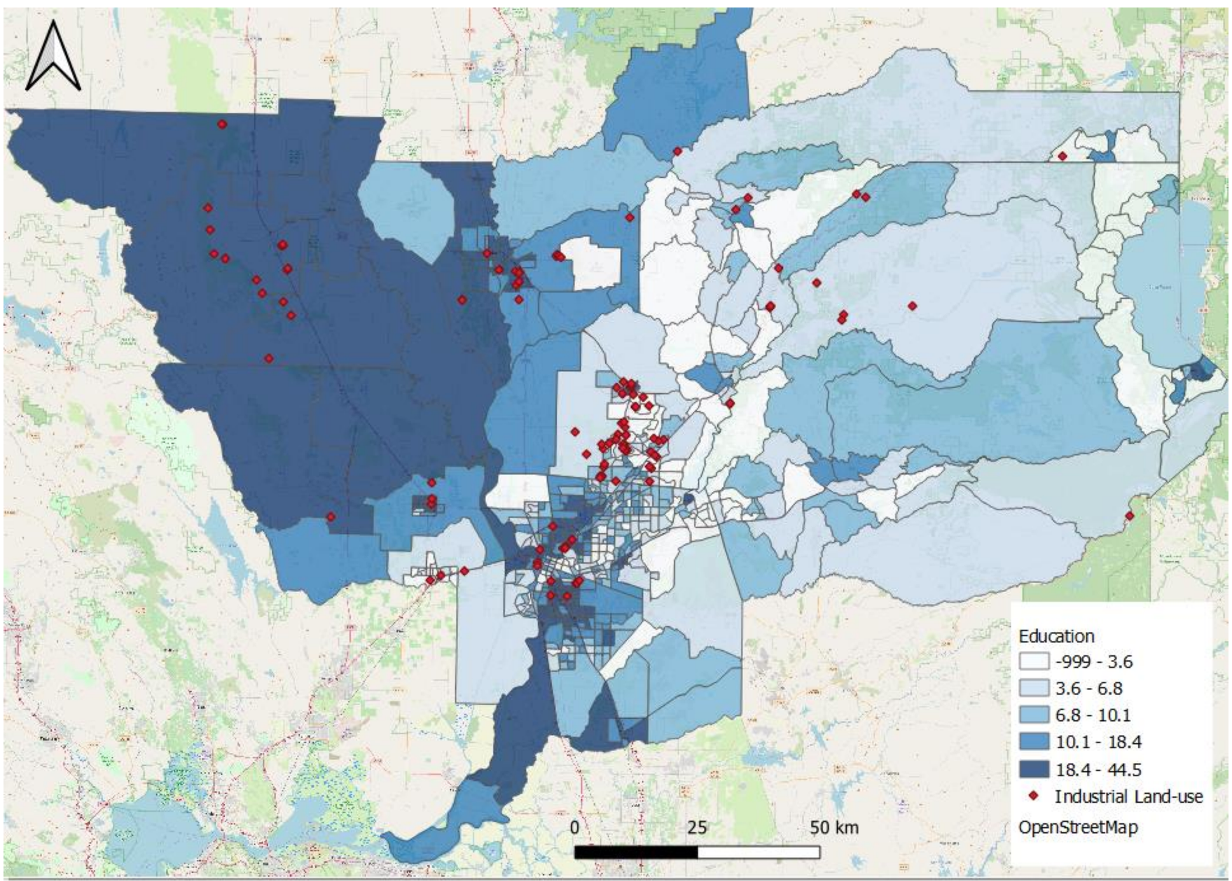
The SACOG MTP/SCS 2020 provides an Environmental Justice (EJ) analysis in Appendix H with a detailed characterization of the community and burdens in the Sacramento region. However, the analysis does not directly associate freight transportation with those burdens. Between the major findings, it is possible to highlight that about 38 percent of the region's population lives in the defined EJ Communities; roughly two percent of the region's population live within the 500-foot buffer of significant roadways; residents living in EJ Communities walk, bike, and take transit at a higher rate than the rest of the population but typically suffering from a history of disinvestment. EJ Communities are inhabited mainly by the non-white population.

Figure 18 illustrates red points highlighting the areas designated for industrial land use, highlighting four primary clusters in Colusa, Sutter, Placer, and Sacramento. According to the Caltrans Transportation Equity Index, these regions are recognized as transportation-based priority populations within the state, facing significant burdens from traffic exposure while receiving minimal benefits from the multimodal transportation network, as indicated by their access to destinations. Some researchers have demonstrated the spatial relationship between freight facility location and minority neighborhoods (*11*, *246*, *247*). The layout of urban areas, historical practices in land development, and the spatial arrangement of income can all influence the geography of externalities associated with warehousing. This suggests that the inequitable environmental distribution may primarily stem from the uniform allocation of economic, political, and institutional resources.

Figure 18 also illustrates the percentage of the population aged 25 and older without a high school education based on data from the California Communities Environmental Health

Screening Tool (CalEnviroScreen 4.0). Colusa and Sutter Counties, situated in the western part of the region, exhibit the highest percentages of individuals with low educational attainment, with approximately 80% of the population aged 25 and over holding a maximum educational qualification of a high school diploma. The regional economy primarily relies on agriculture and agricultural-related enterprises. Additionally, this area has a significant Hispanic population, comprising 37%, with about 9% of residents holding a bachelor's degree or higher and 56% graduating from high school.

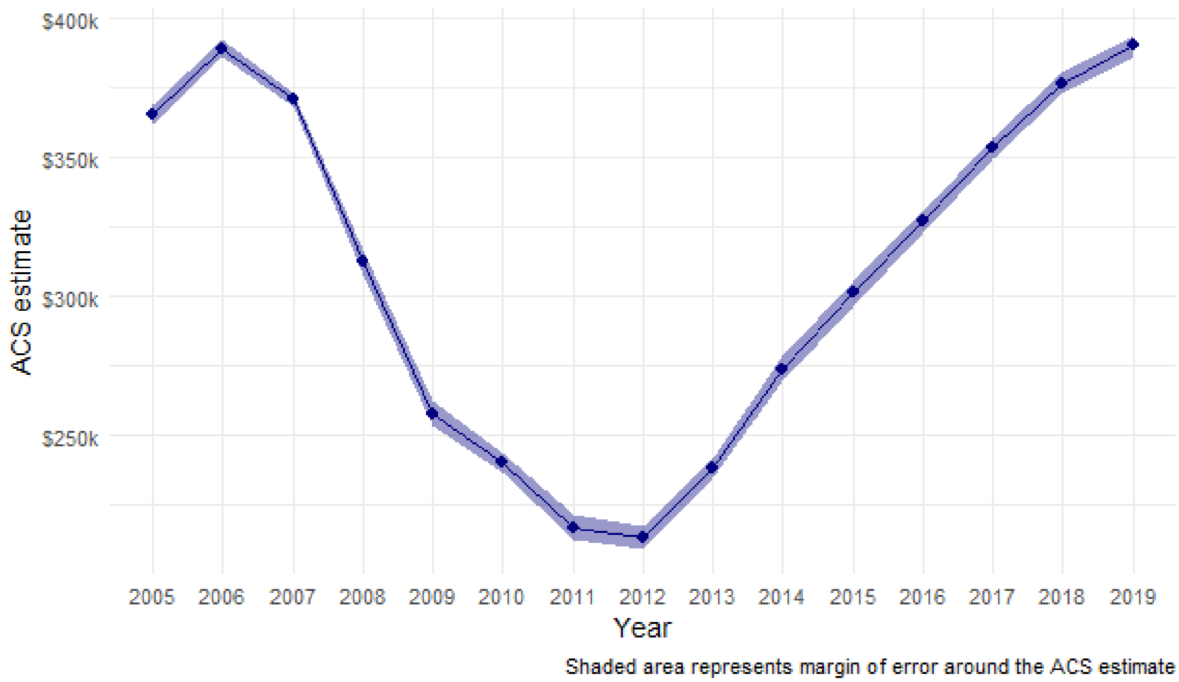
Although the workforce is fairly educated, more than one-third of the population struggles to meet daily expenses, with a large segment consisting of minorities and those with lower levels of education. Furthermore, there is an increasing disparity in the development of digital skills. Another important area of focus for the region is improving educational achievement, especially by assisting individuals near to finishing their education (*243*).



Source: CalEnviroScreen 4.0

Figure 18. Percentage of population over 25 with less than a high school education

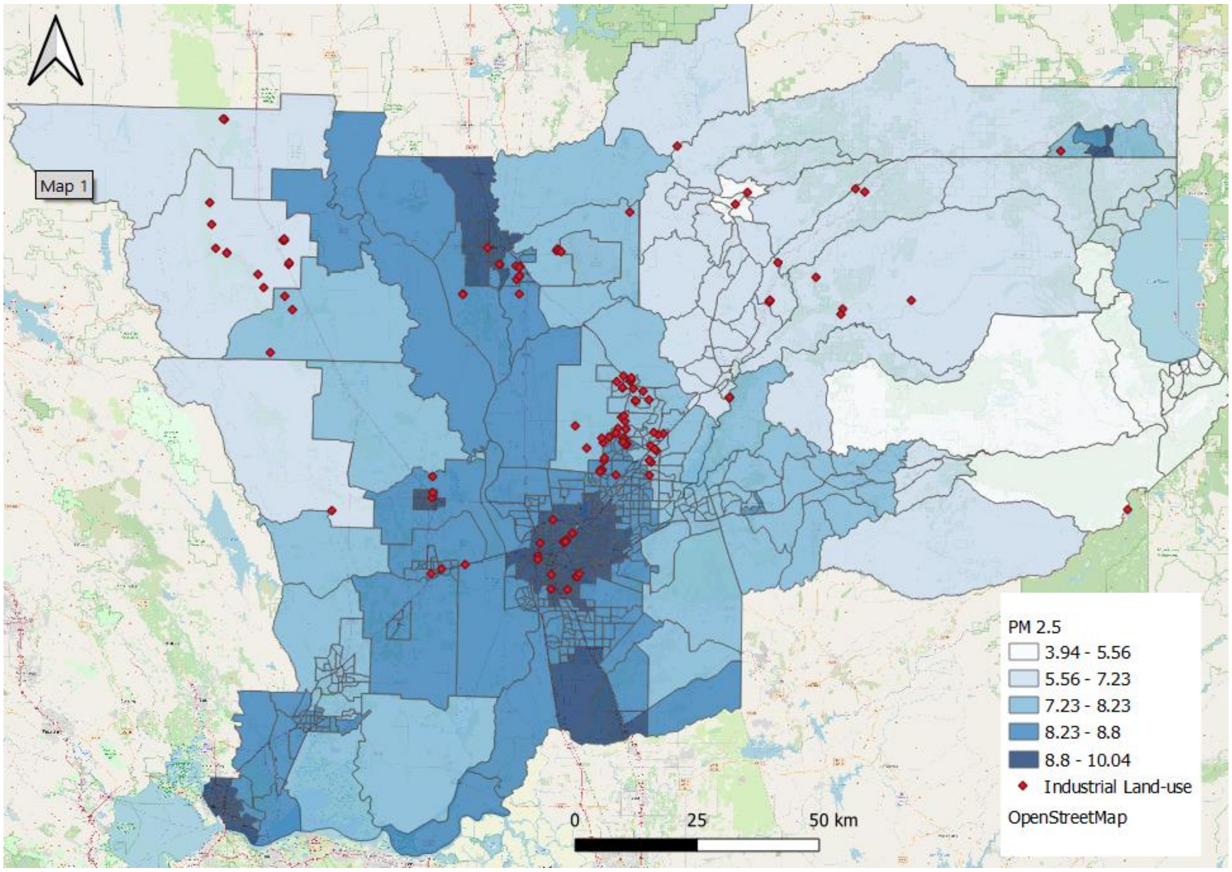
According to the 2005-2019 ACS, the region's population increased about 16% between those years. However, between 2020 and 2022, the region exhibited a decrease in population of about 3%, a trend that has been happening since the pandemic, and housing costs can be one of the reasons. In the region, 22% more households own their homes compared to those who rent. Nevertheless, as shown in Figure 19, the median home value in Sacramento County has significantly increased since 2012. Restrictive regulatory environments and limited geographic space have contributed to housing shortages in many regions of California, including Sacramento (*248*). The equilibrium level has historically benefited homeowners, as the fees and regulations placed on developers are reflected in housing prices. This situation has compelled potential homeowners to absorb the external expenses associated with growth. Additionally, it has reduced the housing market, making housing a limited resource and excluding the lowest-income groups (*248*).



Source: 2005-2019 American Community Survey 5-Year Estimates Data Profiles

Figure 19. Median home value in Sacramento County

The CalEnviroScreen provides information about annual mean particulate matter (PM) 2.5 concentrations in the region. There are two specific zones to highlight due to the PM 2.5 being 8.8 or above: Sacramento City and Yuba City. Those zones are dense in terms of population, with mixed land use. The Franklin Field airport in Sacramento and the Sutter County airport in Sutter are also included in those high PM 2.5 zones (see Figure 20). In addition, diesel PM emissions from on-road and non-road sources are in those zones, but they are near the main roads (I-5, I-80, US 50, CA 99, CA 160) and industrial land use zones where freight facilities are located. Besides, the Placer industrial area does not show high PM 2.5; it exhibits high values of diesel PM emissions and urban heat island (UHI) index in the zone. The largest UHI in the region spans from Roseville to Lincoln, including a section of Auburn, where temperatures are approximately 9-11°F (5-6°C) higher than the surrounding areas. The second highest category of UHI intensity includes Northeast Sacramento, Roseville, Rocklin, Granite Bay, Lincoln, portions of Folsom, and regions west of Auburn, with an intensity of around 7-9°F (4-5°C) (*249*).



Source: CalEnviroScreen 4.0 and OpenStreetMap

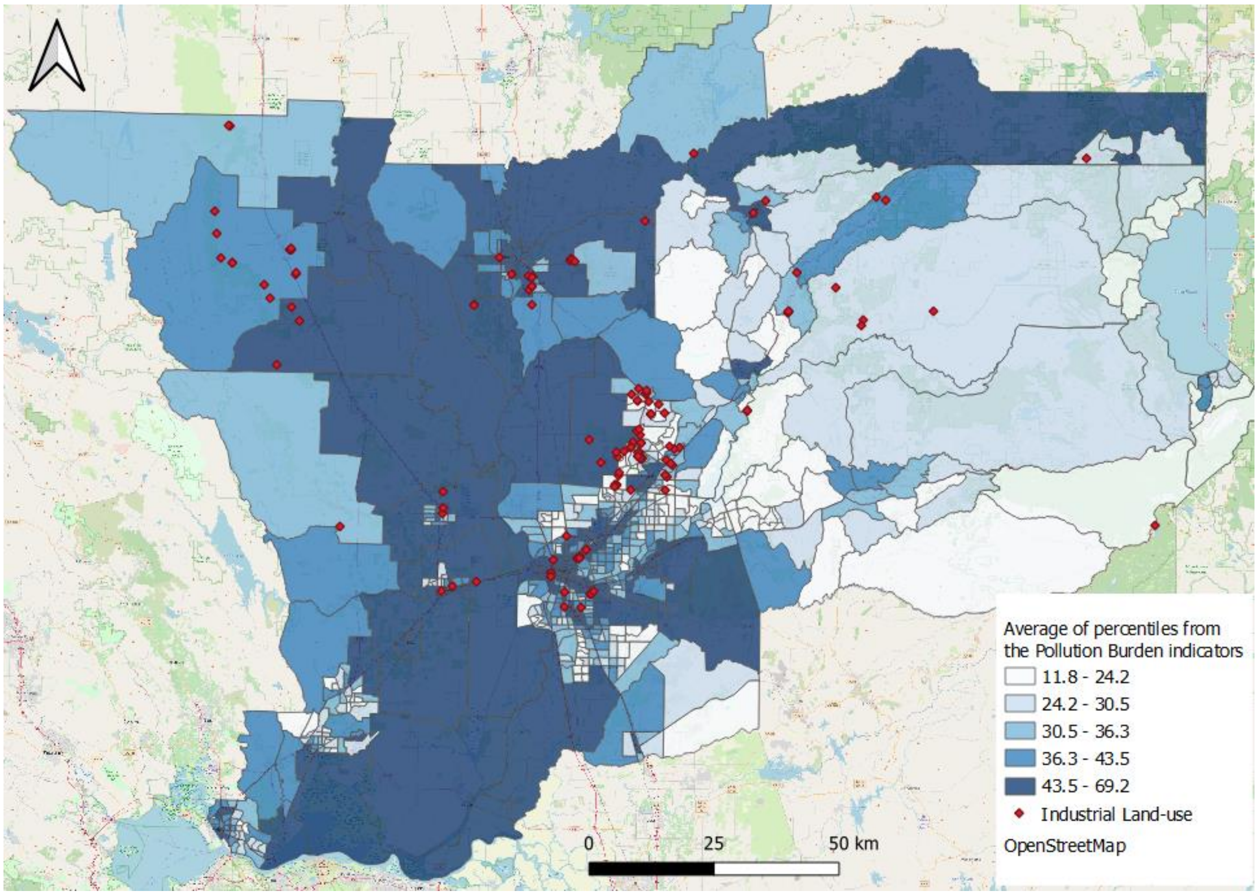
Figure 20. Annual mean PM 2.5 concentrations in Sacramento region.

The Clean Air Act mandates that the U.S. EPA establish health standards for six criteria air pollutants: ozone (O_3), particulate matter, carbon monoxide (CO), lead (Pb), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) (250). In Sacramento County, particulate matter and ozone are the pollutants of greatest concern. As illustrated in Figure 21, these pollutants significantly concentrate along the main roads of Sacramento near industrial areas and in a broader area in the western part of the region. The Sacramento Federal Nonattainment Area (SFNA) indicated a significant decline in CO and NOx emissions in mobile sources since 1990. Due to regional and local control measures, eight-hour ozone values have declined, especially since 2008, after implementing the National Ambient Air Quality Standard (NAAQS) (251).

4.2. Future needs

According to the California Energy Commission, after implementing new sales regulations for medium- and heavy-duty vehicles, California experienced a significant increase in sales. California registered a rise in bus, truck, and delivery van sales of 63% between 2022 and 2023 (see Table 8). However, in the Sacramento region, the increase has been slow (21%), where most of the sales are related to buses (*252*). California's proposed Advanced

Clean Fleets (ACF) rule would propel zero-emission truck (ZET) sales by 2036, resulting in the need to build over 500,000 chargers by 2050. This would require $12 billion in public and private investment and stimulate the creation of local construction jobs in California to build this infrastructure (*253*). The biggest challenges are scaling the infrastructure required to ensure grid reliability and developing technologies that can handle heavy-duty truck requirements.



Source: CalEnviroScreen 4.0 and OpenStreetMap

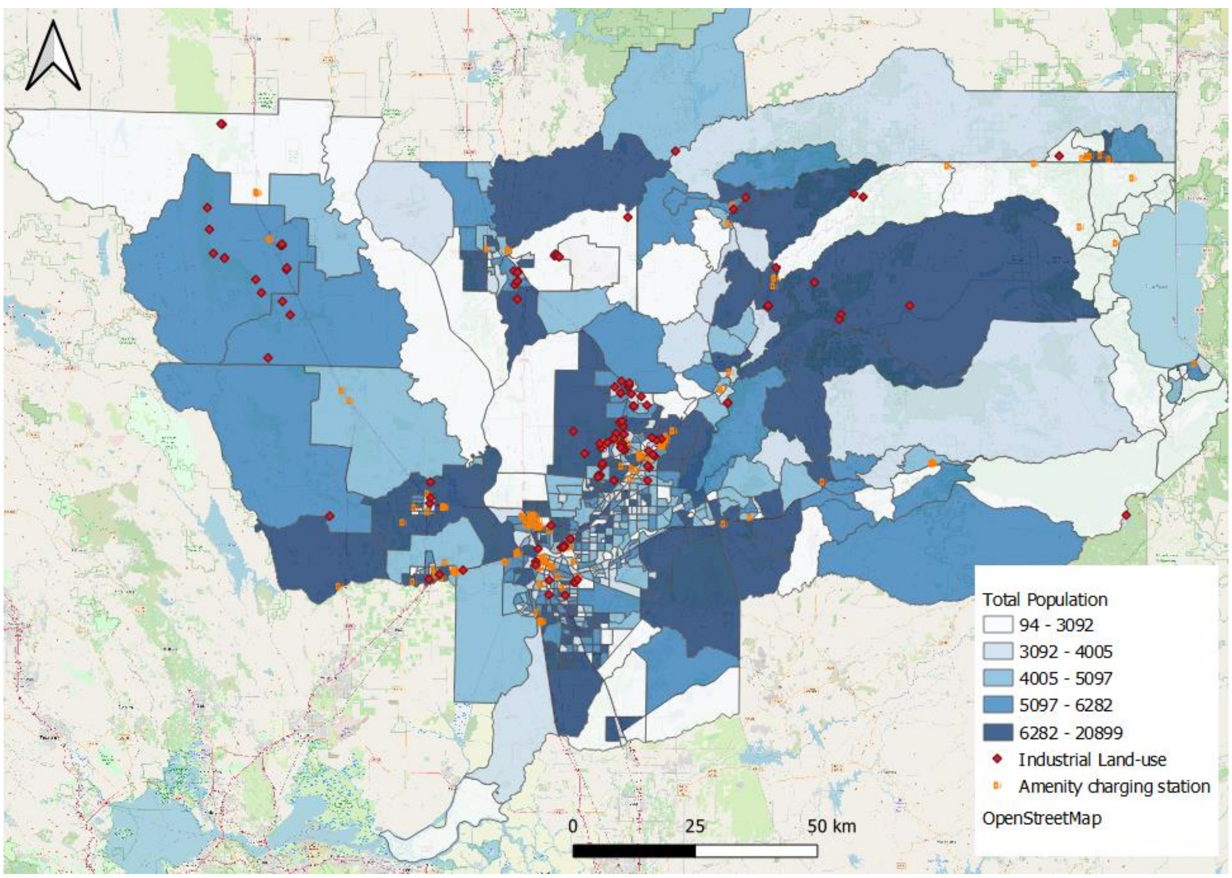
Figure 21. Average of percentiles from the Pollution Burden indicators in Sacramento region.

Table 8. Total Medium- & Heavy-Duty ZEVs

Year	2022				2023			
Type	**Bus**	**Truck**	**Delivery Van**	**Total**	**Bus**	**Truck**	**Delivery Van**	**Total**
California	1708	272	340	2320	2062	853	869	3784
Sacramento	90	1	2	93	94	11	6	111
Colusa	6	0	0	6	7	0	0	7
El Dorado	6	0	0	6	9	0	0	9
Placer	4	0	0	4	6	2	0	8
Yolo	13	0	0	13	13	0	0	13

Source: California Energy Commission (2024). Medium- and Heavy-Duty Zero-Emission Vehicles in California

The charging infrastructure for ZEVs provides great coverage in the Sacramento region, as Figure 22 shows, some conveniently located near industrial land-use zones. Sacramento city has 1,109 public charging station ports (Level 2 and Level 3) within 15 kilometers. Eighty percent of the ports are Level 2 charging ports, and 32% of the ports offer free charges for electric cars (*254*). However, the number of stations available for medium—and heavy-duty trucks is unclear. The U.S. Department of Energy reports 479 alternative fueling stations, both public and private, for medium and heavy-duty vehicles in California (41 electric stations with 241 ports) (*255*). Therefore, to guarantee the operation of zero-emission Trucks and achieve the N-79-20 target, the infrastructure should be in place before public and private fleet managers take the risk of purchasing electric and alternative fuel vehicles. As mentioned in section 3.2.4, the Northern California Megaregion ZEV Medium/Heavy Duty Vehicle Blueprint is committed to implementing a plan for implementing at least 11 charging plazas around the major goods movement highways in Northern California, including Interstate 5, Interstate 80, Highway 50, and State Highway 99 which are also the most critical zones in terms of emissions.



Source: 2022 American Community Survey 5-Year Estimates Data Profiles and OpenStreetMap
Figure 22. Amenity charging stations in the Sacramento region

In terms of employment, according to the Centers of Excellence's 2014 advanced transportation technology study, employers from both sectors identified four critical middle-skill technician occupations that could be heavily impacted by EV and alternative fuel vehicle (AFV) technologies: Automotive Service Technicians and Mechanics (Standard Occupational Classification (SOC) 49-3023); First-Line Supervisors of Mechanics, Installers and Repairers (SOC 49-1011); Bus and Truck Mechanics and Diesel Engine Specialists (SOC 49-3031); and Transportation, Storage and Distribution Managers (SOC 11-3071). In 2018, over 4,000 automotive service technicians and mechanics worked for auto shops and car dealers in the region, occupying 27% of all jobs in this industry sector. This value remains similar for 2023, with 3,990 employees registered. Occupational demand projections for this occupation were estimated to increase by about 680 openings annually (*245*). Further analysis is needed to identify the ratio of occupational technicians and supervisorial positions that repaired electric vehicles and alternative fuel vehicles in the region to evaluate the impact of the fuel transition impact.

It is essential to thoroughly explore the characteristics that define population subgroups in these areas to effectively identify and address the diverse impacts of truck charging stations on each community. This investigation should examine potential disparities related to housing types, land use, and the built environment. This will avoid possible safety risks.

In addition, it is vital to assess journey and travel times and the duration spent queuing and charging at stations, acknowledging these intervals as potential disutility (*256*). Moreover, examining the costs associated with various journey and charging activities is essential, particularly regarding their impact on lower-income groups who may rely on older electric vehicle models with varying battery capacities and charging efficiencies. Furthermore, research should aim to enhance vehicle charging infrastructure accessibility calculations to incorporate travel and activity patterns, emphasizing accessibility from both residential areas and workplaces to key destinations. Home Depot charging stations are a great opportunity to increase capacity, but collaboration between transportation agencies, companies, and shippers is required. Electric trucks can impact the infrastructure because the extra weight from electric batteries can accelerate road damage (*257*), the VMT can increase when the daily routes cannot be made with a single charge, and the electric power available can be insufficient (*258*). The extra weight faces another challenge in terms of regulation since California’s restrictions for trucks do not consider the battery weight (*259*).

Finally, conducting a thorough analysis and establishing a strategic framework for developing training programs and employment opportunities that align with the demands of alternative fuel initiatives is imperative. This approach is crucial for meeting California's ambitious environmental targets.

4.3. Discussion

The Sacramento region is characterized by its diverse community, which includes white, Hispanic, and Asian populations. Within this demographic, the Hispanic community faces notable economic challenges. The area is service-oriented, exhibiting a relatively low unemployment rate, yet more than one-third of the residents struggle to cover their daily expenses. Although transportation is not the dominant sector, it plays a significant role in local employment, primarily concentrated in central Sacramento. There is an urgent need to enhance middle-skill technician occupations, particularly in light of the growing influence of EV and AFV technologies.

Additionally, transportation infrastructure has negatively impacted minority neighborhoods, resulting in an inequitable distribution of resources. High levels of particulate matter and ozone are notably present along major roadways near industrial areas, particularly in the region's western part. Lastly, the availability of stations for medium- and heavy-duty trucks is unclear, yet their development is crucial for facilitating the energy transition.

The Sacramento region faces a unique intersection of equity, workforce, and infrastructure challenges that demand targeted planning interventions. While the area maintains relatively low unemployment, economic hardship persists, particularly within Hispanic communities, highlighting the need for inclusive workforce strategies. Investment in middle-skill jobs, especially in emerging sectors like electric and alternative fuel vehicle technologies, is critical to regional resilience. At the same time, freight and transportation infrastructure have disproportionately impacted minority neighborhoods, contributing to environmental and health burdens. Prioritizing the development of medium- and heavy-duty truck charging and fueling infrastructure, particularly in underserved logistics corridors, can support both environmental goals and economic opportunity. These efforts must be guided by a commitment to reducing pollution exposure, expanding clean job access, and ensuring a more equitable distribution of transportation benefits across the region.

Conducting a thorough analysis and establishing a strategic framework for developing training programs and employment opportunities that align with the demands of alternative fuel initiatives is imperative. This approach is crucial for meeting California's ambitious environmental targets. Therefore, the first part of building a sustainable and equitable freight land use methodology was completed in previous sections, providing the main sustainable freight strategies related to logistics, freight management, and emission reductions, as well as regional targets for zero-emission vehicle sales, greenhouse gas emissions reductions, and other federal and state regulations that must be complied with. The following Chapters 5 and 6 encompass a deep understanding of demand and supply to identify opportunities for implementing freight strategies and minimizing social costs.

5. Demand characterization

The team concentrated this task on residential demand for goods, such as home purchases and deliveries. This stage relies on various public data sources, taking into account demographic aspects of the study area, including regional size, population density, urban shape, and land allocated to streets. The team utilized previously developed models of shopping behavior based on data from the National Household Travel Survey (NHTS) and the American Time Use Survey (ATUS), employing weighted multinomial logistic models (WMNLs) and spatial clustering. The analysis also examined online shopping behaviors based on past studies conducted by the research team. Therefore, this section is divided into two subsections: 1) Demographic aspects to characterize shopping behavior and 2) the geographic locations of consumers, which will be assessed through spatial categorization.

This analysis focuses on answering the following questions, which provide planners with opportunities for intervention and guidance. Research questions were formulated based on key factors identified in the literature to characterize demand for goods and services. Additionally, several intervention opportunities from Appendix 1 are highlighted as potential solutions to mitigate possible issues identified in each research question analyzed. In this context, “S” denotes strategy, with the accompanying number referring to the specific strategy defined in Table 20. In addition, data were collected from open and official sources to ensure reproducibility and trustworthiness.

5.1. Shopping trends

This section's primary goal is to understand residents' shopping behavior to forecast future behavior for incorporating this variable into the planning process. Details of this methodology are available at (*260*). The first task is to identify the shopping categories, namely “No shopping,” which means individuals who did not perform any shopping activity on a given day; “In-store shopping,” or individuals who exclusively performed in-store shopping; and “Online shopping,” related to those who shopped solely online. As task one, the team used the 2023 ATUS data to analyze shopping behaviors, following previous studies developed by the team (*56*). ATUS microdata is available at IPUMS via Application Programming Interface (API) (*261*) from 2013 to 2023. The sociodemographic variables collected include age, sex, labor force status, education, mobility disability, marital status, income, number of children, county, and person weight. The time use variables related to shopping were also collected for purchase activity and travel to purchase. The team modeled the shopping behaviors as a WMNL model with time series (e.g., time is included as a variable), with the alternatives being not to shop at all (No Shopping), to shop exclusively in-store (In-store), and to shop solely online (Online).

Table 9. Demand characterization

Characterization	Research question	Method	Data	Opportunity
Shopping trends	How do individual characteristics (e.g., size, income, age, car ownership) correlate with the frequency of online vs. in-store purchases?	Generating a synthetic population and a Shopping decision as a multinomial logit model	ATUS and US Census data	Prediction of shopping patterns to anticipate delivery zones for intervention. S18, S19.
	What are the temporal trends in shopping choice?	Time-series modeling	ATUS and US Census data	Support equity-focused delivery and retail infrastructure policies. S20, S21
	What are the emissions generated by shopping and delivery trips?	Emissions rates and VMT	NHTS data EMFAC	Reducing VMT associated with shopping. S7, S48-51. Encourage low-emission delivery fleet adoption. S45-47.
Geographical distribution	How does residential spatial configuration influence shopping preferences and delivery frequency?	Spatial autocorrelation and hotspot analysis (e.g., Moran's I, Getis-Ord Gi*)	Shopping distribution	Potential zones for intervention with freight strategies. S6-8, S22
	What types of neighborhoods generate the most delivery demand per capita?	Descriptive statistical analysis	Shopping distribution	Potential for micro-fulfillment centers or pick-up/drop-off lockers. S13, S22, S53
	Is there a spatial mismatch between shopping demand and in-store retail access?	Overlay consumer clusters with zoning, land use, or transportation network datasets	Consumer clusters Land Use Transportation network (OSM)	Potential zones for land use intervention with mixed-use or reform zones. S7, S8, S10

Task 2 was to collect the same sociodemographic variables from U.S. Census data at the census tract level and perform synthetic population creation at the individual level. The synthetic population covers from 2013 to 2023 for validation and time series analysis, and the method implemented was a Monte Carlo (MC) simulation.

Task 3 incorporated shopping travel parameters from previous research (*56*). The shopping travel parameters include the number of shopping tours per person, the number of stops per shopping tour, the length of shopping tours in miles associated with stops, the proportion of in-store shopping activities in a shopping tour, and the significant shopping travel modes. Consistent with (*56*), the parameters used for delivery tours are: 1) delivery tour length and 2) stops per tour. Those parameters allow for determining emissions related to online shopping truck travel in a single MC simulation, considering the average emission rate for commercial trucks.

In Task 4, the team used emission rates developed by CARB (2018), which were used in this study to estimate GHG and criteria pollutants generated from shopping-related travel. This task aims to ultimately conclude with the externalities of shopping across different census areas.

5.1.1. How do individual characteristics correlate with the frequency of online vs. in-store purchases?

ATUS provides a large dataset that has been sampled in various U.S. cities for many years, and using ATUS data ensures scale, consistency, and validity of data acquisition. Table 10 shows the variables that comprise the WMNL models for counties in the SACOG coverage area as an MPO, such as Sutter, Sacramento, Yolo, and Yuba. SACOG also collaborated with Placer and El Dorado counties, which are also included in the analysis. The survey represents activities developed in one day.

The team defined the shopping decision based on the variable “activity purchase.” The variable “purchase travel” defined whether the purchase was made online (e.g., no travel) or in-store. The dataset for the region is weighted using the “WT20” variable for the year 2020 and “WT06” for the remaining years, representing the weights for the sample distribution in the selected area. The WMNL model results are presented in Table 11. The best model was selected using the Akaike Information Criterion (AIC). The best model, weighted 1, is the one that received the most support among those tested. The difference between the best and worst AIC is ~7 million, which is substantial, indicating a clear winner. Most coefficients are highly significant (***), meaning the model identifies meaningful relationships.

Table 10. Variables and counts per year of ATUS data

Variable	Category	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Generation	Baby_Boomer	25	20	22	31	28	19	18	22	17	24	33
	Gen_Z	8	5	3	5	2	5	6	8	3	2	4
	Generation_X	16	21	22	24	19	26	20	17	21	14	11
	Millennials	18	33	19	13	17	24	16	16	18	8	12
	Silent	7	16	5	9	9	12	8	10	16	17	15
Gender	Female	39	57	39	49	34	48	38	37	45	32	37
	Male	35	38	32	33	41	38	30	36	30	33	38
Labor_Force	Employed	37	54	40	47	45	46	39	33	39	28	45
	Not_in_labor_force	28	38	24	34	27	30	26	37	34	36	27
	Unemployed	9	3	7	1	3	10	3	3	2	1	3
Education_Level	Graduate	5	8	2	8	10	15	12	10	10	3	8
	No_education	2	0	0	4	2	2	1	0	1	2	0
	Primary	11	11	7	7	9	7	8	10	6	6	7
	Secondary	56	76	62	63	54	62	47	53	58	54	60
Children	NO_Children	50	58	42	60	53	54	39	49	46	48	56
	Own_Children	24	37	29	22	22	32	29	24	29	17	19
Disability	Disability	8	12	1	11	7	8	5	10	6	14	10
	No_Disability	66	83	70	71	68	78	63	63	69	51	65
Status	Divorced	15	7	10	16	10	12	12	10	15	12	8
	Married	35	47	32	41	38	43	40	35	38	33	42
	Never_married	17	34	21	20	20	26	12	18	15	11	17
	Separated	2	1	2	1	1	1	1	3	2	3	3
	Widowed	5	6	6	4	6	4	3	7	5	6	5
Total observations (individuals)		74	95	71	82	75	86	68	73	75	65	75

Table 11. Weighted Multinomial Logit (WMNL) Model with time series resulted for the Sacramento region.

Dependent variable:	Estimate, significance, and t-value (respectively) Ref: No shopping	
	In-store	**Online**
Generation: Generation Z	-1.136***	3.188***
	(-0.00004)	(-0.00003)
Generation: Generation X	0.120***	3.815***
	(-0.0001)	(-0.00002)
Generation: Millennials	-0.258***	4.313***
	(-0.00005)	(-0.00001)
Generation: Silent	-0.431***	3.027***
	(-0.00004)	(-0.00001)
Gender: Male	-0.915***	-1.244***
	(-0.00005)	(0.00)
Income; Low	-0.345***	-2.257***
	(-0.0001)	(0.00)
Income: Lower Middle	0.147***	-2.590***
	(-0.00005)	(-0.00001)
Income: Median	0.450***	-1.779***
	(-0.00005)	(0.00)
Income: Middle - Middle	-0.151***	-2.241***
	(-0.0001)	(0.00)
Income: Poverty Level	-0.875***	-9.877***
	(0.00)	(0.00)
Income: Upper Middle	0.088***	-2.006***
	(-0.00005)	(0.00)
Education Level: Non-education	-0.552***	-5.819***
	(-0.00001)	(0.00)
Education Level: Primary	-0.446***	1.529***
	(-0.00002)	(-0.00003)
Education Level: Secondary	-0.600***	0.371***
	(-0.00005)	(-0.00003)
Kids: Own Children	-0.110***	-2.848***
	(-0.0001)	(0.00)
Disability: No Disability	0.280***	1.739***
	(-0.0001)	(0.00)
Status: Married	0.391***	-2.010***
	(-0.00005)	(-0.00002)
Status: Never married	1.042***	-2.084***
	(-0.00003)	(-0.00004)

Dependent variable:	Estimate, significance, and t-value (respectively) Ref: No shopping	
Status: Separated	1.082***	-8.266***
	(-0.00001)	(0.00)
Status: Widowed	0.063***	-0.622***
	(-0.00002)	(0.00)
YEAR	0.058***	0.311***
	(0.00)	(0.00)
(intercept)	-117.902***	-633.105***
	(0.00)	(0.00)
Akaike Inf. Crit.	12,181,749,372.00	12,181,749,372.00
Note: *p<0.1; **p<0.05; ***p<0.01		

The model indicates the reference group has a high probability of "No shopping." If the reference person (intercept profile) rarely shops, the log odds of the other outcomes are strongly negative (e.g., significant negative intercepts). The variables associated with shopping include generation, income, gender, education, children, no disability, and marital status. There is also an apparent effect of time since "year" is a representative variable. Gen Z is less likely to shop in-store and more likely to shop online vs. the reference group. Millennials are highlighted as the group that is more inclined to shop online. During 2022, approximately 55% of Millennials made online purchases (*262*). Mobile commerce is also gaining popularity as consumers increasingly rely on their smartphones and mobile apps for shopping. Income and education levels substantially directly impact online shopping preferences versus in-store shopping. Median and upper-middle-income individuals are more likely to shop in-store than the reference group. The year is positively associated with online shopping.

5.1.1. What are the temporal trends in shopping choice?

The temporal trends were analyzed using the synthetic population, as aggregate data by census tract does not provide shopping characteristics. Therefore, using probability weights, the team generated a synthetic population from the census tract at the individual unit. Figure 23 shows a comparison between the census and the synthetic population, with some individual variables aggregated by census tract. The WNML model was utilized to analyze shopping decisions made in a single day using a synthetic population. This approach provides valuable insights into shopping trends and preferred locations based on census tracts.

Shopping is an activity that shows a general upward trend, indicating that consumers are increasingly inclined to make daily purchases (see Figure 24). The data also highlights the growth of online shopping over time, particularly after 2018. This aligns with the trend of e-commerce as a share of total U.S. retail sales from the first quarter of 2010 to the third quarter of 2024 (*262*). In 2021, online retail sales represented ten percent of total retail in the United States. Among the largest business-to-consumer e-commerce categories are clothing and accessories, including footwear. In 2024, this percentage rose to sixteen percent.

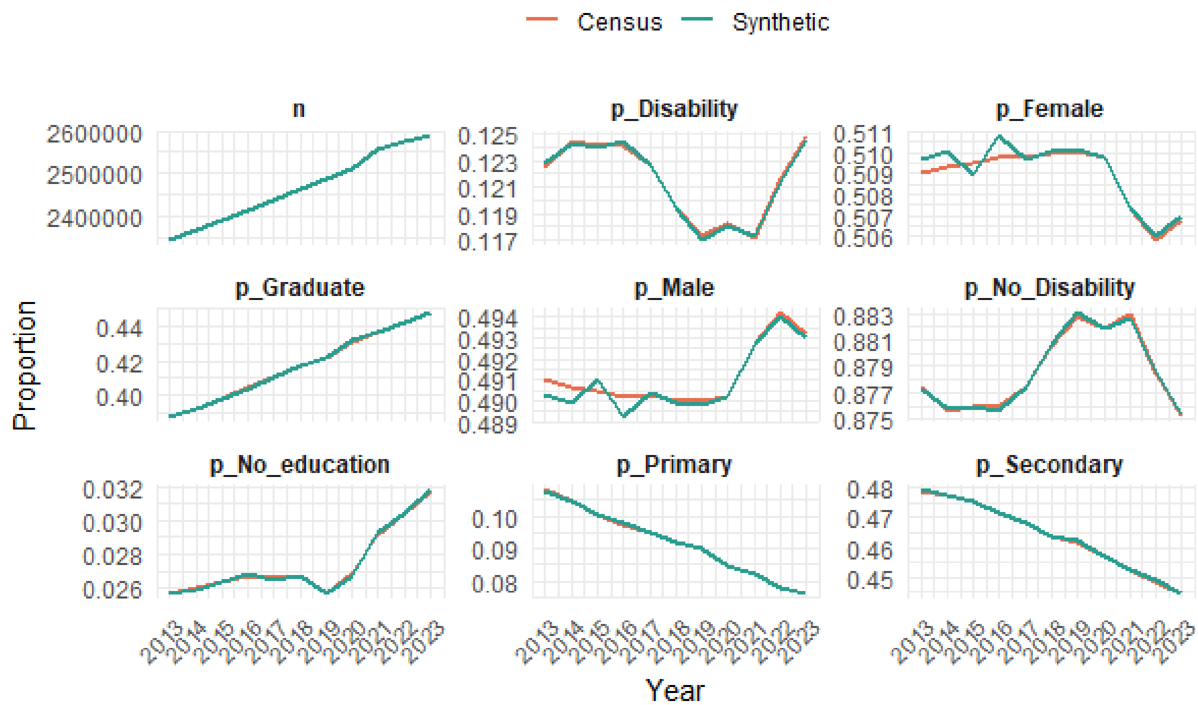


Figure 23. Summary statistic comparison by year

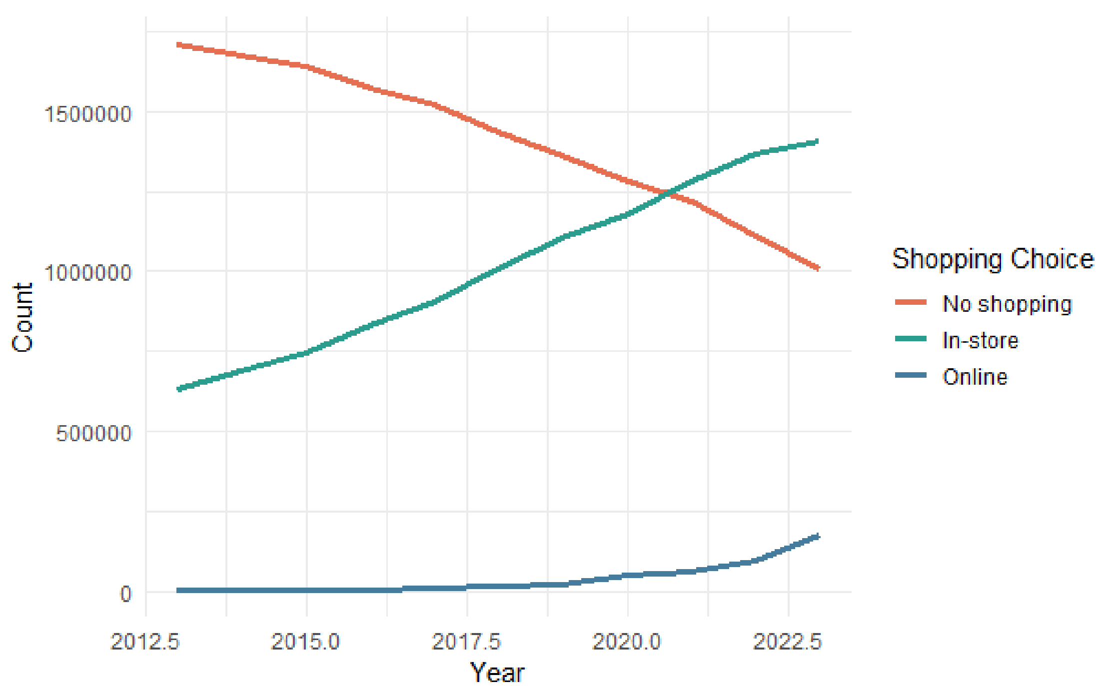


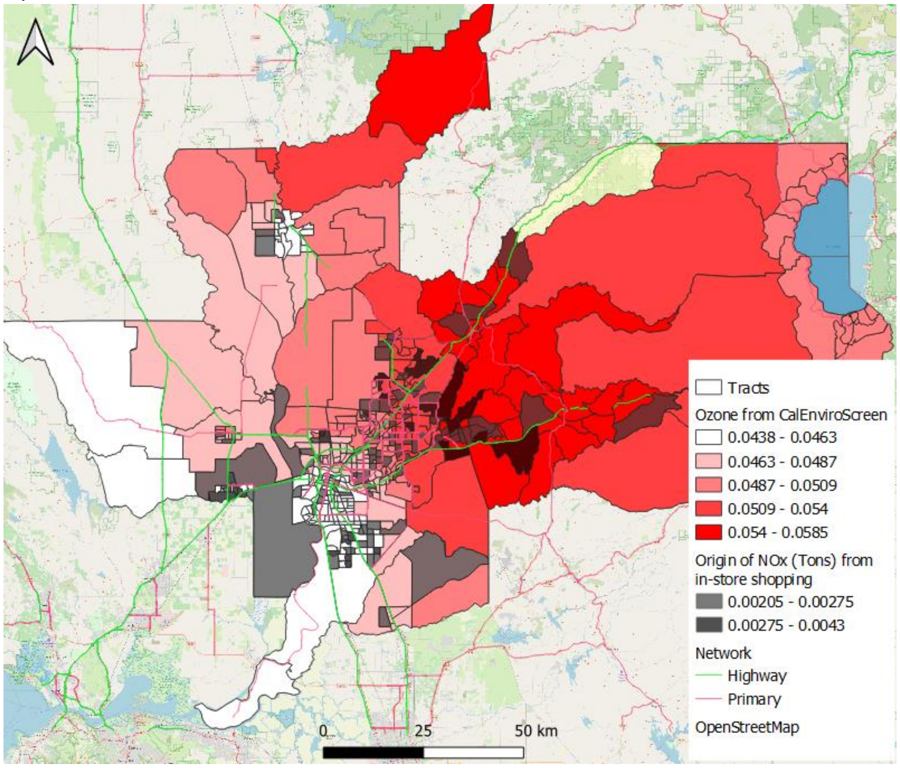
Figure 24. Daily shopping choice trends over time (Synthetic Population)

5.1.2. What are the emissions generated by shopping and delivery trips?

The team analyzed the main census tracts that generate the most shopping trips and emissions based on the 2017 NHTS dataset, the synthetic population, and California's emissions inventories of on-road mobile sources (using the EMission FACtor (EMFAC) 2021 software). The NHTS includes information from the counties selected for the study, where travel parameters for in-store shopping were collected. EMFAC provides the on-road daily emissions tons and vehicle miles traveled to identify emission rates. Later, these rates were used to estimate total emissions from in-store shopping developed by the synthetic population, assuming one tour per person.

According to the EPA, ozone and particle matter pose the most widespread and significant health threats of the six criteria for air pollutants. Figure 25 presents the origin of in-store shopping, the main concentration areas of NOx and PM 2.5, and ozone, according to CalEnviroScreen. Large portions of the northeast and central Sacramento Valley (e.g., parts of Placer, El Dorado, and Sacramento counties) are shaded deep red, indicating high percentile ozone values according to CalEnviroScreen. The locations of NOx emissions related to in-store shopping trip origin are concentrated in urban tracts, particularly around Sacramento's city center and adjacent densely populated areas. The freeway and primary road layers strongly align with both NOx origin clusters and ozone hot spots, indicating that vehicle travel is a key contributor to these emissions.

a)



b)

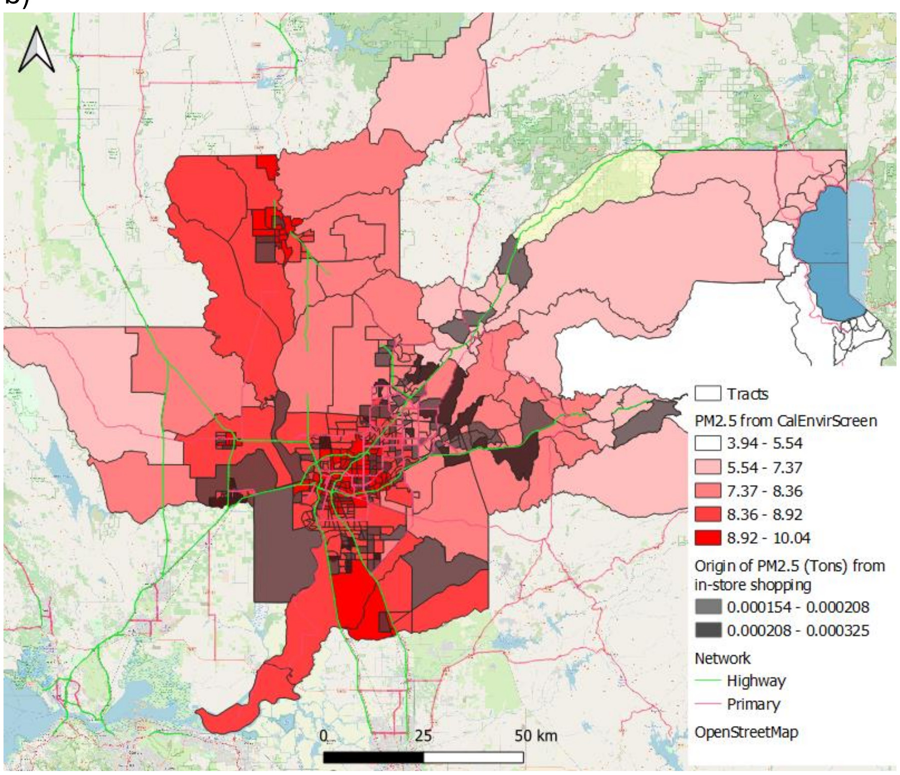


Figure 25. Estimated origin of in-store shopping emissions by tract and CalEnviroScreen indicators: a) NOx, b) PM 2.5

The darkest red tracts in Figure 25 b) indicate high PM 2.5 exposure levels (8.92–10.4 $\mu g/m^3$), as determined by CalEnviroScreen. These areas are concentrated mainly in South Sacramento, parts of Elk Grove, and central counties, such as San Joaquin and Stockton-adjacent zones. Strong alignment is evident between high PM 2.5 burdens and high emissions origins, especially in southwest Sacramento and central urban areas.

Evaluating the general emissions performance, there is a reduction between 2017 and 2023. However, emissions from passenger vehicles, Light- to Heavy-Duty Trucks (Gross Vehicle Weight Rating (GVWR) 8,501-10,000 pounds), and medium-duty vehicles are higher in 2023 than in 2017, indicating that further effort is required to mitigate this issue. However, emissions from in-store shopping are low, contributing approximately 0.01% of NOx and 0.06% of PM 2.5 to the total reported for 2017.

5.2. Geographical distribution

This section presents a spatial statistical analysis of shopping patterns to identify potential intervention zones for sustainable freight strategies that could mitigate related issues.

5.2.1. How does residential spatial configuration influence shopping preferences and delivery frequency?

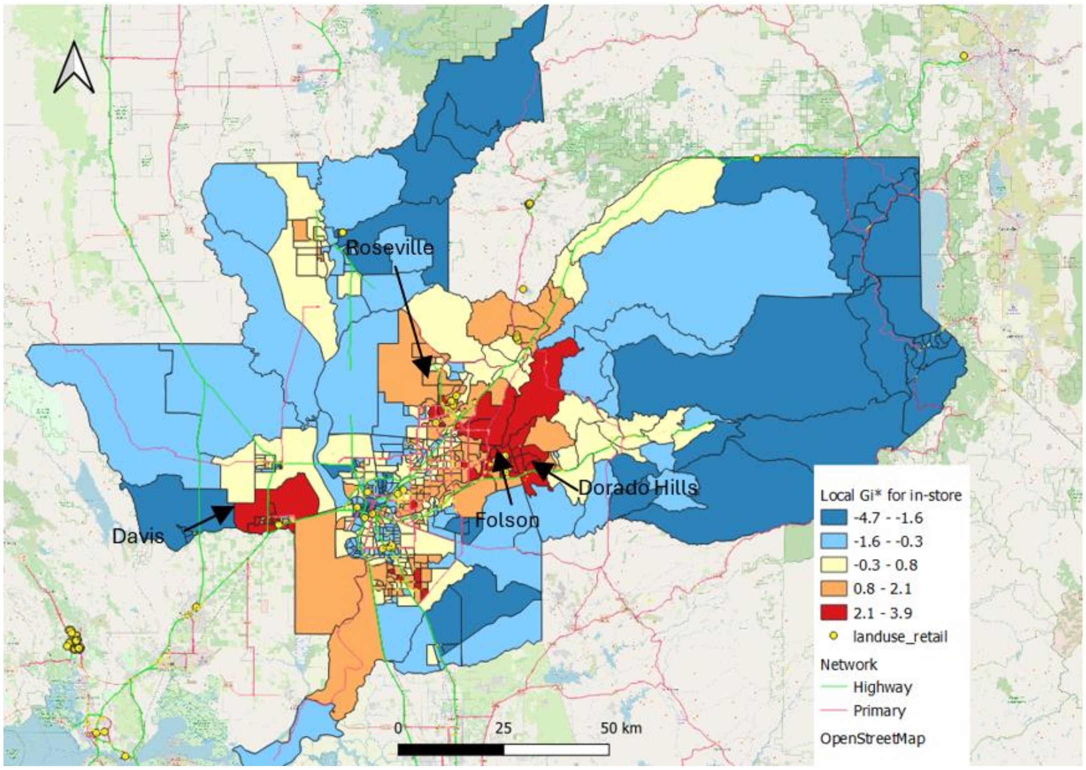
The team analyzed the spatial autocorrelation of shopping decisions using Moran's I with a MC simulation test and a queen matrix for neighbors that share a line segment (or border) or a point (or vertex). Shopping online yielded a Moran's I statistic of 0.25, while shopping in-store yielded 0.24, with a p-value approaching zero at the 95% significance level. Those results indicate low but spatial autocorrelation for both shopping types, suggesting some spatial patterns in shopping behavior. Both are reasonably correlated ($r \approx 0.75$), suggesting that their spatial patterns will likely overlap, especially in areas with higher population density or greater engagement. The local Getis-Ord method was implemented to identify hotspots and cold spots (46) for in-store and online purchases. The test returned z-scores between -4.66 and 3.92 for in-store shopping and between -4.82 and 4.30 for online shopping (see Figure 26). Both shopping decisions are correlated with areas of high income, high employment, and a high level of education.

Figure 26 presents local spatial clusters of in-store and online shopping behavior using the Getis-Ord Gi* statistic. The spatial clustering, with clear hot and cold spot patterns, is statistically significant. Hotspots are spatially clustered around the urban core, near land designated for retail is most prevalent, indicating a strong association between physical access to commercial areas and in-store shopping behavior. In-store shopping hotspots in South Sacramento, Davis, Folsom, Dorado Hills, and Roseville, among others, are more likely to make in-store purchases. Cold spots are most prominent in outlying areas with limited commercial density, possibly indicating lower overall shopping activity.

Hotspots for online shopping are concentrated in the urban core and some surrounding suburbs, overlapping but also extending beyond the retail-dense areas. Zones such as

Midtown Sacramento, Rocklin, Roseville, Yuba, and Elk Grove are more likely to make online purchases. Cold spots are widespread across the region's eastern, northern, and outer western periphery**.** Some reasons include the lower population density, which represents a higher cost sensitivity to delivery options.

a)



b)

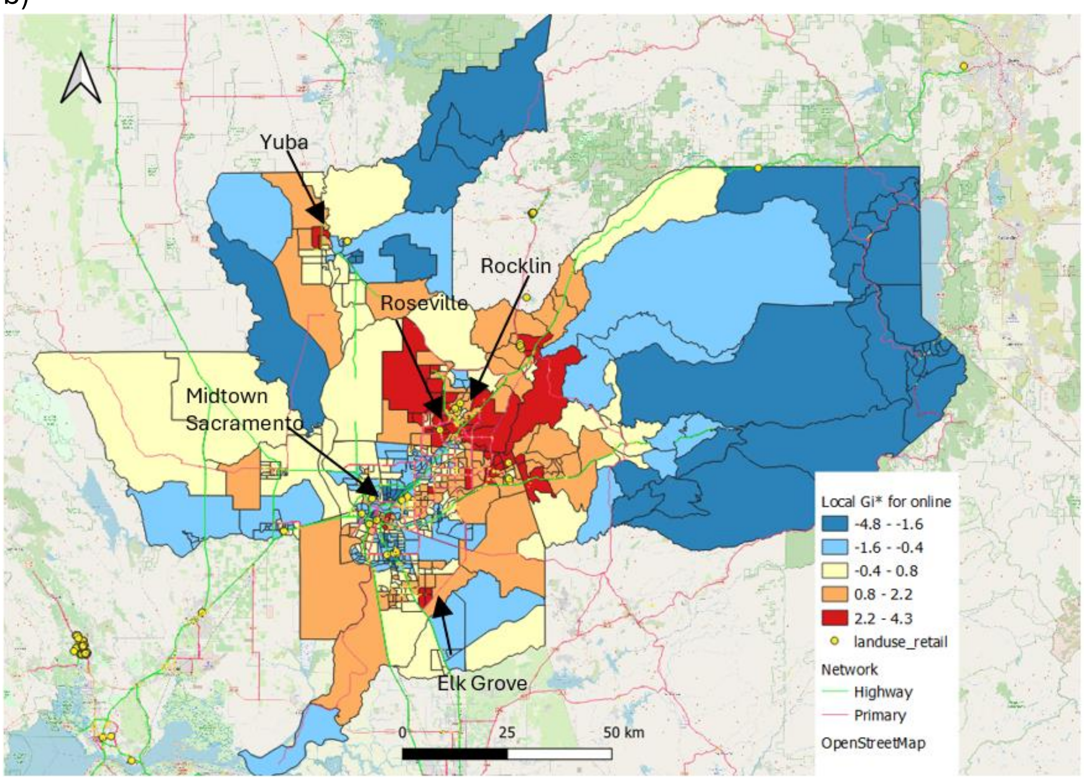


Figure 26. Hot and cold spots using Local Getis-Ord z-scores for in-store and online daily purchases.

5.2.2. What types of neighborhoods generate the most delivery demand per capita?

The team considered the total online purchases per population in each census tract to identify key zones that generate the most delivery demand, considering the standard deviation. Some representative tracts include 11.03 and 12.02 in Downtown Sacramento and 11.02 and 5.02 in Midtown Sacramento, which are zones characterized by high retail density. Another representative delivery zone in Sacramento is Tract 96.52, located in the south at the urban border and represents a community development zone according to the LU plan. Similarly, tract 87.06 is in the eastern area, which overlaps a development zone. Those two previous tracts represent opportunities for intervention in sustainable freight strategies due to future development. Woodland also has a representative tract, 112.10, well-located in the western region, close to an industrial and commercial zone.

5.2.3. Is there a spatial mismatch between shopping demand and in-store retail access?

The team assessed the spatial mismatch between in-store shopping and accessibility to retail locations. Retail sites were sourced from OpenStreetMap (OSM) and categorized into food and other retail services. The food category encompasses supermarkets, convenience stores, bakeries, dairy shops, and other food-related establishments. Conversely, other retail services include shopping destinations for clothing, boutiques, fashion accessories, electronics, furniture, books, and a range of services such as laundry, copy shops, beauty salons, and massage therapy.

Figure 27 shows a buffer of 0.65 miles for the first group (food-related establishments) to identify possible isolated areas with high retail demand. The selection of buffer distance was made considering moderate proximity, e.g., service/amenity co-location, which generates minor noise or traffic spillovers. A broader area could generate traffic impacts and more emissions. The distance could be modified to get a more regional planning scale.

The eastern region around Folson Lake is highlighted due to the zones without coverage of food-related establishments that could potentially promote higher vehicle miles traveled. The development zones in southern Sacramento are also susceptible to land-use interventions to promote this type of retail and increase the coverage of services. Promoting mixed land use also required freight-efficient strategies for future demand.

The second group exhibits a similar pattern. Most retail stores are located near the major road corridors and are separated from residential areas, highlighting the zone system (parcel schemes), although the regional plan promotes mixed development. Midtown and Downtown Sacramento are primarily mixed land use, while the rest of the region separates residential from the other segments (e.g., industrial and commercial). Some negative impacts related to the subdivision ordinance include freight circulation restrictions affecting shipping operations, delivery efficiency, and increasing emissions volume (*263*).

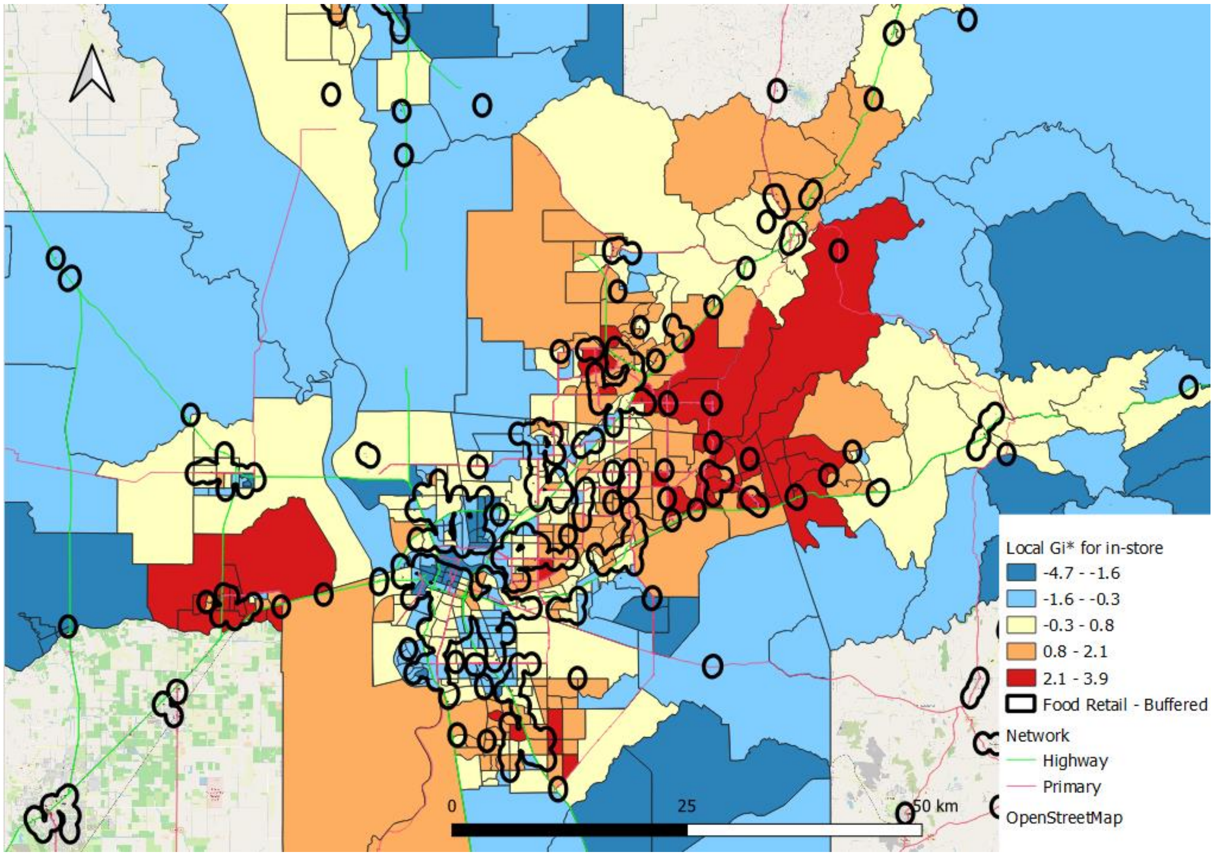


Figure 27. Hot and cold spots using Local Getis-Ord z-scores for in-store and food-retail buffer

5.3. Discussion

This demand characterization study provides crucial insights into how socio-demographic characteristics, temporal shifts, and spatial factors influence shopping behaviors and associated freight-related externalities in the Sacramento region. The integration of time-use surveys, synthetic population generation, and spatial statistics provides planners and policymakers with a robust analytical foundation to inform freight-oriented land use decisions.

5.3.1. Socio-Demographic Determinants of Shopping Behavior

The WMNL revealed that age cohort, income, education, gender, and family structure are all significant predictors of shopping channel choice. Millennials and Generation X are more inclined to shop online, while Baby Boomers and the Silent Generation are less likely to shop online and show lower shopping activity overall. Notably, lower-income and lower-education individuals exhibit lower online shopping rates, raising equity considerations for digital retail access. This finding suggests a need for inclusive strategies that address disparities in e-commerce infrastructure and digital accessibility.

5.3.2. Temporal Trends and Implications

Temporal modeling shows an apparent rise in both overall shopping activity and online shopping over time, particularly after 2018. This aligns with national trends in mobile commerce and the adoption of digital retail. The trend underscores the need for planning agencies to anticipate growing delivery needs and develop proactive zoning, parking, and curb management strategies to accommodate the increasing last-mile freight activity, particularly in residential neighborhoods.

5.3.3. Emissions and Environmental Justice

Although shopping trips account for a small share of total regional NOx and PM 2.5 emissions, the analysis revealed troubling correlations between in-store shopping emissions and existing environmental burdens. High-emission tracts often coincide with disadvantaged communities identified by CalEnviroScreen, particularly in South Sacramento and central urban areas. These findings underscore the importance of integrating freight demand planning with environmental justice considerations to mitigate the exacerbation of air quality disparities in overburdened neighborhoods.

5.3.4. Spatial Distribution and Freight Accessibility

Spatial clustering analysis using Moran's I and Getis-Ord Gi* statistics underscores the concentration of shopping hotspots around urban cores and mixed-use areas. Cold spots, conversely, tend to be in peripheral, car-dependent areas with limited commercial access. Importantly, online shopping also exhibits strong spatial clustering, though extending into some suburban zones. These patterns support targeted deployment of micro-fulfillment centers and locker systems in high-demand zones to improve delivery efficiency while minimizing emissions.

5.3.5. Mismatch Between Retail Access and Demand

Overlaying consumer demand with retail land use and road network data revealed spatial mismatches, particularly in developing areas of eastern and southern Sacramento. These gaps suggest opportunities for land use reforms that promote retail accessibility through mixed-use zoning and active transportation infrastructure. Furthermore, existing zoning ordinances that rigidly separate residential from commercial uses may hinder access for deliveries and increase travel emissions, highlighting the need for more flexible planning frameworks.

5.3.6. Conclusion and Policy Implications

The analysis supports the implementation of **data-informed, equity-focused freight land use strategies**. Planners should prioritize:

- Enhancing e-commerce access in lower-income and lower-education communities.
- Integrating freight considerations in land use plans, particularly in emerging residential zones.
- Implementing emissions-reduction strategies in high-burden areas through modal shifts and delivery consolidation.
- Supporting retail resilience via mixed-use development and improved accessibility.
- Leveraging spatial demand insights to inform the location of micro-distribution hubs and urban logistics facilities.

By incorporating freight demand dynamics into transportation and land-use policy, regional agencies can foster more equitable, efficient, and environmentally sustainable goods movement systems.

6. Supply Characterization

This analysis focused on identifying the locations of freight facilities and shopping establishments and the LU planning regulations relevant to spatial analysis, with some practical strategies for planning purposes. The first part involved gathering data on demand and conducting cluster analysis to uncover freight spatial patterns and logistics sprawl within the study area. The authors examined key aspects of the goods supply chain, considering the geographic locations of production and consumption and their interaction. The analysis includes counties in the SACOG coverage area as MPO, such as Sutter, Sacramento, Yolo, and Yuba. SACOG also collaborated with Placer and El Dorado counties, making incorporating those counties essential in this analysis.

As mentioned in the previous chapter, this region is characterized by a service-intensive sector with 31,918 establishments, emphasizing professional, scientific, and technical services (22.12%) and health care and social assistance (20.58%) (see Table 12). From the 24,012 freight establishments, it is possible to identify representative sectors such as retail trade (25.98%), construction (25.81%), and accommodation and food services (22.16%). The transportation and warehousing sector represents only a small proportion of establishments (less than 10%). The establishments from the freight sector per 1,000 residents are lower than other regions (9.32), such as the New York metro area (11.8), the Los Angeles metro area (10.9), and the Seattle metro area (11.1) (*14*). The service sector has a higher value of establishments per 1,000 residents, 12.39 (see Table 13).

The same service sectors emerge as the most significant in employment, exhibiting comparable proportions of job distribution. Among the 64,604 regional employments documented in the Business Pattern County, 22.12% were in professional, scientific, and technical services, while 20.34% were in health care and social assistance. The freight sector reported 37,326 jobs, with 33.41% in retail trade, 33.18% in construction, and 28.48% in accommodation and food services. The freight sector employment per 1,000 residents is 14.49, while service employment per 1,000 residents is 25.08.

Table 12. Freight and service sector characterization

Freight Intensive Sector (FIS)			
NAICS	**Meaning**	**Establishments**	**Employment**
11	Agriculture, forestry, fishing and hunting	0.49%	0.73%
21	Mining, quarrying, and oil and gas extraction	0.12%	0.13%
22	Utilities	0.32%	0.36%
23	Construction	25.81%	33.18%
31-33	Manufacturing	6.16%	7.90%
42	Wholesale trade	9.13%	11.70%
44-45	Retail trade	25.98%	33.41%
48-49	Transportation and warehousing	9.82%	12.59%
72	Accommodation and food services	22.16%	28.48%
	Total	**24,012 (100%)**	**37,326 (100%)**
Service Intensive Sector (SIS)			
NAICS	**Meaning**	**Establishments**	**Employment**
51	Information	2.93%	2.88%
52	Finance and insurance	10.25%	10.12%
53	Real estate and rental and leasing	11.34%	11.19%
54	Professional, scientific, and technical services	22.39%	22.12%
55	Management of companies and enterprises	0.91%	0.86%
56	Administrative and support and waste management and remediation services	9.97%	11.19%
61	Educational services	2.71%	2.66%
62	Health care and social assistance	20.58%	20.34%
71	Arts, entertainment, and recreation	2.64%	2.58%
81	Other services (except public administration)	16.11%	15.91%
99	Industries not classified	0.16%	0.15%
	Total	**31,918 (100%)**	**64,604 (100%)**

Source: 2021, Economic Surveys, ECNSVY Business Patterns, County Business Patterns

Table 13. Freight and service sector indicators

Indicator	Value
% Freight Establishments of Total	43%
% Service Establishments of Total	57%
% Freight Employment of Total	37%
% Service Employment of Total	63%
Residents in 1000	2575.48
Establishments (FIS)/1,000 residents	9.32
Establishments (SIS)/1,000 residents	12.39
Employment (FIS)/1,000 residents	14.49
Employment (SIS)/1,000 residents	25.08
Employment/establishments (FIS)	1.55
Employment/establishments (SIS)	2.02

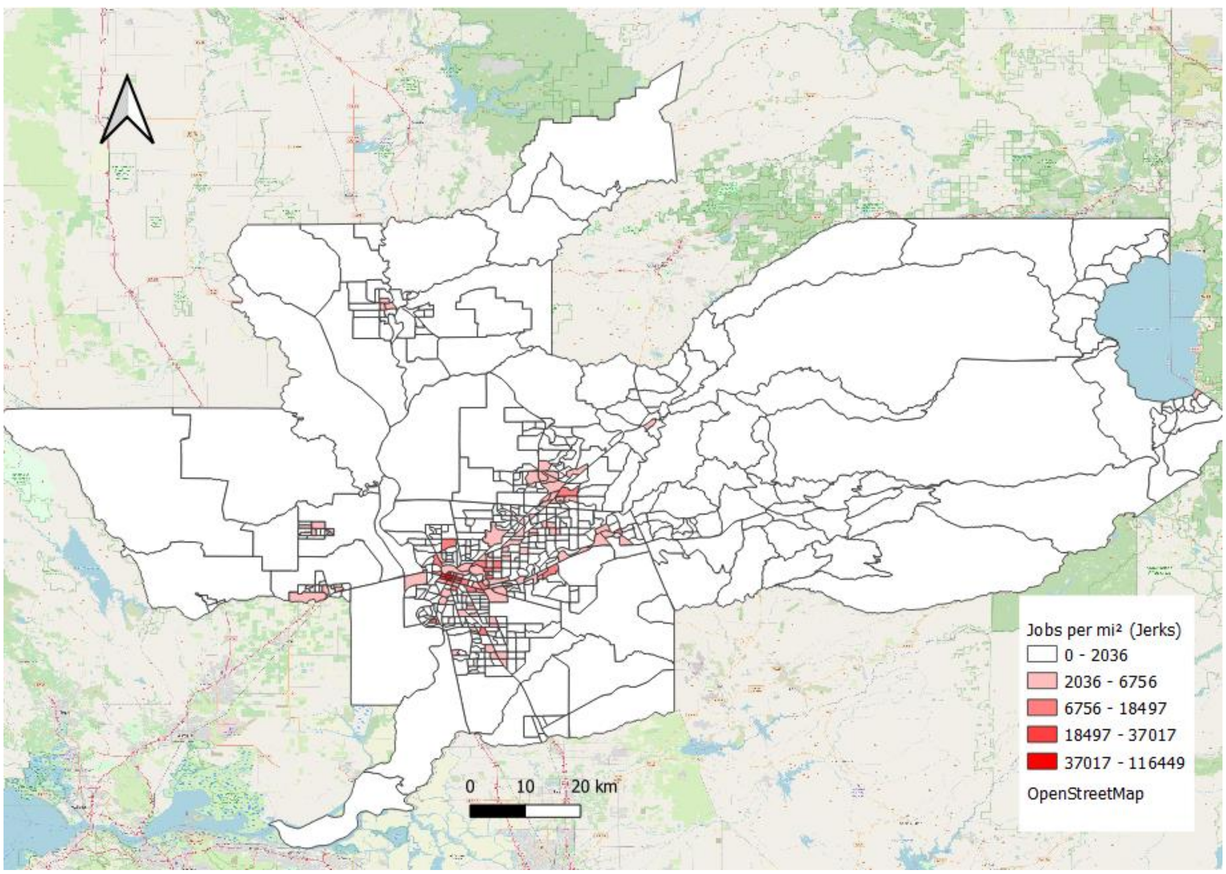


Figure 28. Economic Poles based on jobs density

The employment density based on jobs per mile square shows the concentration in urban areas, especially in Sacramento city, as Figure 28 shows. The urban structure tends to be monocentric for small cities and polycentric in the case of Sacramento. The census tracts with major employment density are mostly dedicated to retail trade and construction establishments, downtown Sacramento being the most important pole. Those areas also evidence high land mixture where retail is predominant, such as Marysville City, Yuba City, and Roseville, or dedicated industrial areas such as west Sacramento (see Table 14).

Table 14. Census tract economic pole

N	GEOID	County	Characteristic
1	06017031601	El Dorado County	Commercial and accommodation services, South Lake Tahoe
2	06061020717	Placer County	Commercial and medical services, Roseville
3	06067001103	Sacramento County	Commercial area, Downtown Sacramento
4	06101050102	Sutter County	Residential and commercial area, Yuba City
5	06113010105	Yolo County	Industrial area, West Sacramento
6	06115040100	Yuba County	Mix land use, Marysville

6.1. Freight sector patterns

The team collected the most representative freight sector establishments through a Google Place API search string (ref). The search string was defined considering NAICS codes for freight-intensive sectors: 23 Construction, 31-33 manufacturing, 42 wholesale trade, and 48-49 warehousing. In addition, the authors gathered building characteristics from Open Street Maps through a feature function using industrial buildings as a single query. The sample collected resulted in 2,142 facilities, representing almost 20% of the entire establishment population. It's statistically significant enough since it is greater than the required sample size. Table 15 describes the strategy implemented in this analysis to get freight patterns, leading issues, and opportunities to mitigate side effects. As in the previous section, each research question is linked to freight/land use strategies from Table 20 to show possible opportunities for mitigating issues that resulted from the analysis.

The data analysis of the freight industry considers the geographical distribution, clustering patterns, and time variation of the sample collected. Each section identified key research questions to explore opportunities to improve everyday issues derived from freight transportation.

6.1.1. What is the distribution at urban and suburban levels, considering establishment type?

The freight facilities are strategically situated along the region's highways and freeways to ensure easy accessibility. The rail system is crucial for freight locations, as certain facilities cluster in areas with rail access. The majority of the freight industry resides in Sacramento County (79%), followed by Yolo County (18%) and Placer County (2%). Approximately 2% of the industry operates within urban boundaries. The search query reveals a diverse range of freight facility types, the most prominent being automobile dead storage, logistics, wholesale distribution, cold storage, and general warehouses. Construction represents a significant sector, with 61% of these establishments located within city limits, while transportation and warehousing account for 51% of facilities in urban areas. Most manufacturing operations, however, are situated outside urban confines. In terms of size, larger establishments tend to be located in suburban regions or beyond city limits

Table 15. Freight sector characterization

Characterization	Research question	Method	Data	Opportunity
Geographical distribution	What is the distribution at urban and suburban levels, considering establishment type?	k-means clusters	Facility location and classification	Economy diversification, Market-oriented reform and land use efficiency. S2
	How accessible are freight establishments through the transportation network?	Travel time to network	Freight facility Road network	Freight Network Efficiency strategies, such as multimodality, technology adoption, or circular economy. S32-35
	What is the distance from freight establishments to the economic pole?	Average distance to the nearest pole	Freight facility origin-destination workflow	Freight-oriented development zones, Consolidation systems management. S39
	What are the significant clusters of the freight sector?	Spatial autocorrelation	Freight facility location	Optimal logistics space development. S39-41. Decentralized infrastructure supply. S1.
	How does the commuter's origin-destination flow to major clusters?	Distance to commute	Origin-destination flow	VMT reduction. S13-15, S23, S25, S26 Decentralized infrastructure supply. S1.
	What are the population burdens near major clusters?	Correlation with burdens	Freight facilities CalEnviroScreen	Evaluate social justice to prioritize zones. S6, S10
	What are the conflicts between freight clusters and residential areas?	A mismatch between LU plans and freight location	Freight facilities LU Plans	Evaluate social justice to prioritize zones. S6, S10

Characterization	Research question	Method	Data	Opportunity
Time variation	What are the growth rates of freight facilities?	Distance to the economic pole over time	Freight location Years of operation	Economic development. S2, S13-15
	What are the employment changes in freight-related industries?	Shifts in freight-employment	Freight location Employment	Workforce impact analysis as a decision support to create more opportunities. S1, S7-10
	What census tracts have more employment variation?	Rank Tracts by Variability from standard deviation	Freight location Years of operation Employment	Jobs-housing balance. S2, S5

The team performed a clustering analysis to explore the diversity of the freight sector and spatial patterns in the region. K-means was the method used for this analysis, which identified six clusters. Cluster four has a high concentration of the freight industry and is located in West Sacramento, Yolo County (see Figure 29). The sector is also recognized as a high employment zone in a suburban area. Through the I-80 and the Capitol Corridor rail network, this zone represents the primary access from other important economic areas, including San Francisco. It also covers the central economic pole of the entire region, downtown Sacramento, and various freight industry classifications (e.g., transportation, warehousing, manufacture, wholesale, and construction). Cluster number three has a high freight density and is in Southeastern Sacramento. This cluster includes an industrial park within the city limits with multiple warehouses and storage. Besides the highway connectivity, both zones are highly connected to the rail system with various rail switches, facilitating yard operations.

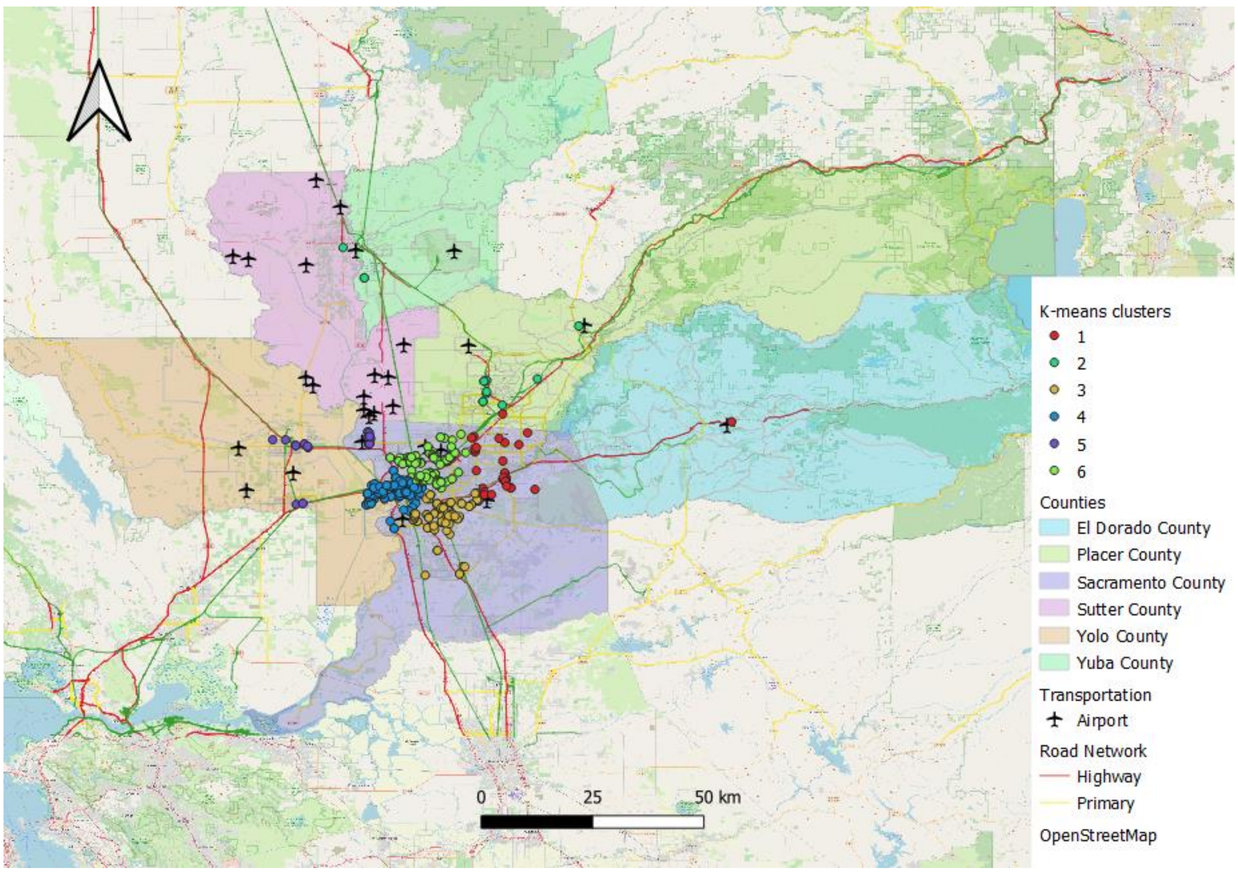


Figure 29. K-means clusters and study area

Cluster Six is influenced by McClellan Airfield (MCC) airport, which has some logistics companies, warehouses, distribution centers, and storage facilities. This airport is one of the most representative in freight establishment agglomeration, surrounded by commercial and industrial land and connected to the rail system. The Sacramento International Airport influences Cluster Five, and most of its freight industry includes fulfillment centers, distribution centers, and some manufacturers. The Mather Airport influences Cluster One, which is well connected to the rail system. The industry in this area includes manufacturers, petroleum storage, and fulfillment centers. Cluster Two is the most dispersed, with different freight facilities along the rail system and near Auburn Airport. This cluster includes fulfillment centers, storage, warehouses, and distribution centers.

6.1.2. How accessible is the transportation network?

The distance to main roads provides a good insight into freight accessibility, one of the most critical aspects of freight location. The average linear distance between facilities and primary roads (highways and freeways) was 0.44 miles, with a third quantile of 0.64 miles, as Figure 30 shows. This means most establishments are located less than a mile from a road, facilitating the distribution of goods.

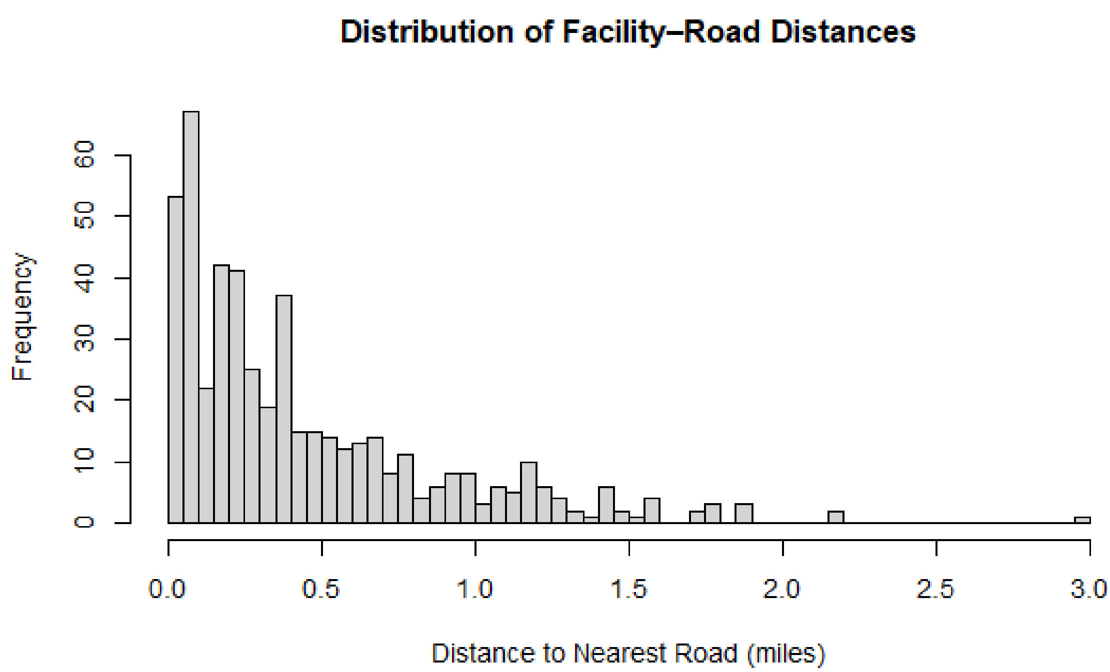


Figure 30. Distribution of Facility–Road Distances

To simplify the analysis for planning purposes, the team implemented transportation buffers of 0.35 miles (0.5 kilometers) for rail to see the area of influence of rail stops and switching points. Around 5% of establishments are within the buffer zone and mostly located in Clusters Three and Four. A bigger buffer zone was necessary to evaluate the influence of some airports on freight establishments due to the size of the infrastructure. Using a buffer of two miles, it was possible to find 0.5% of the facilities within the area. The most representative airports are McClellan Airfield (40 facilities), Sacramento International Airport (14), and Sacramento Execute Airport (14).

6.1.3. What is the distance from freight establishments to the economic pole of each county?

The team collected data on employment from the Longitudinal Employer-Household Dynamics (*264*). The economic pole was determined by calculating the highest employment per square mile values. Then, the team computed the distance from each freight facility to the nearest pole.

Figure 31 provides the histogram resulting from this analysis. The majority of the freight industry is located in less than 10 miles. Freight distribution is more efficient when the establishments are closer to the economic poles, and the results from this Figure 31 show similar behavior to that of other small metropolitan areas.

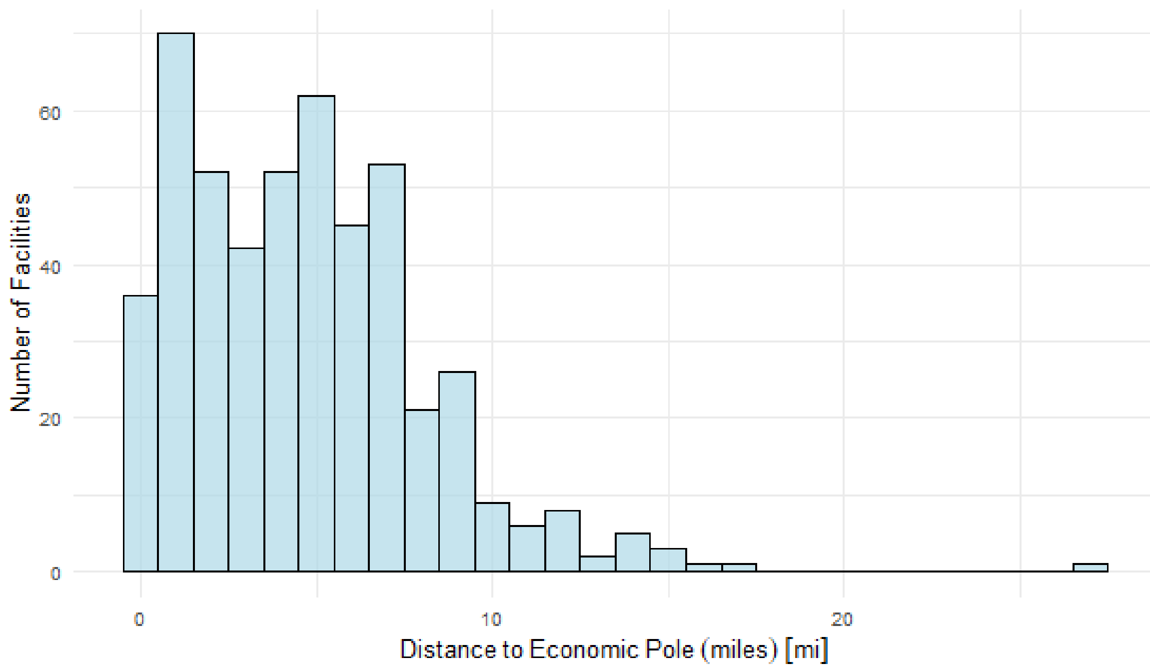


Figure 31. Distribution of Freight Facilities to the Nearest Economic Pole

6.1.4. What are the significant clusters of the freight sector?

The team implemented a point pattern analysis to examine the distribution of freight establishments, focusing on the mean center, standard distance, density, quadrat counts, and k-functions tests to evaluate the randomness of the facility distribution. The Chi-squared test to assess Complete Spatial Randomness using quadrat counts confirms a clustering pattern confirmed with another test, such as the Variance/Mean Ratio (VMR) test and distance function. In addition, the study incorporated Global Moran's I as the most popular and adopted spatial autocorrelation test for freight facility density.

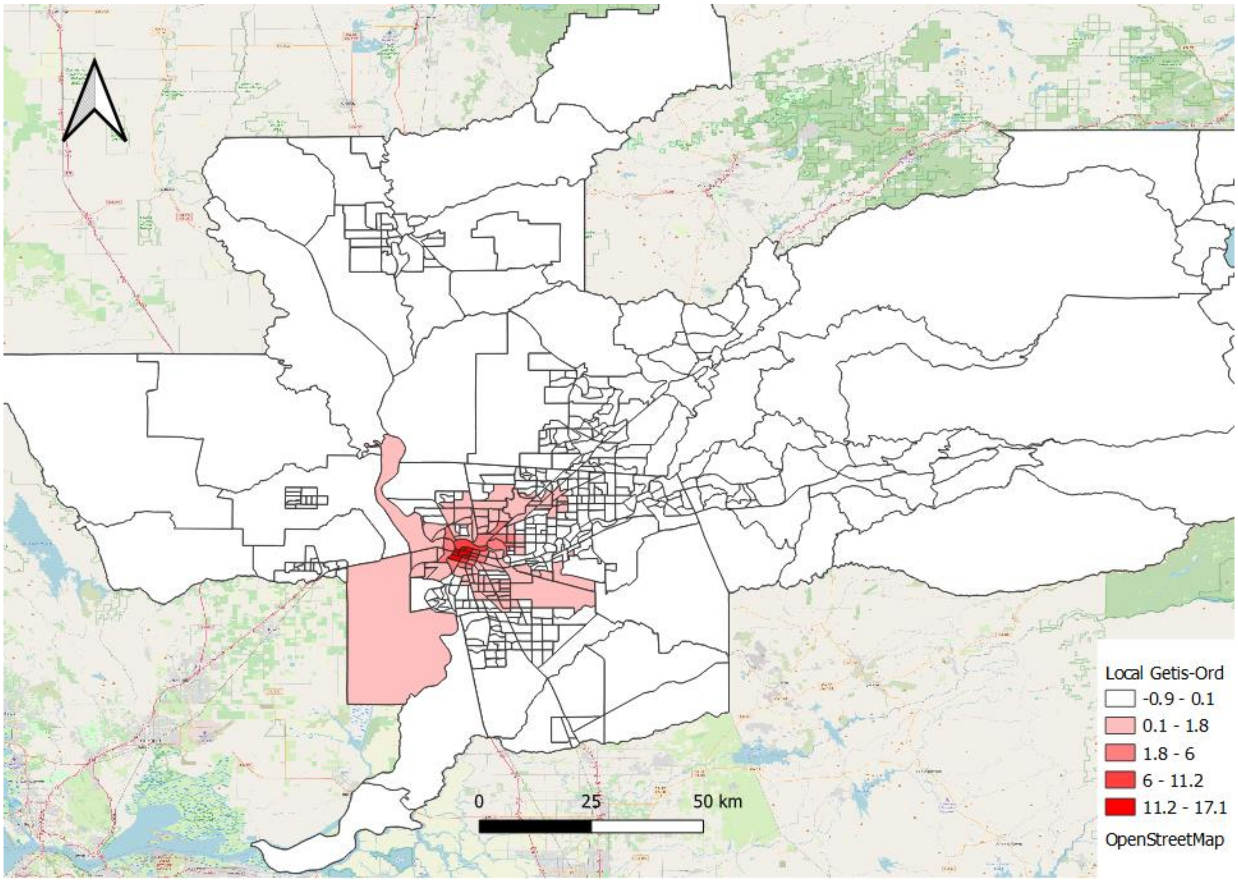


Figure 32. Freight hotspots using Local Getis-Ord

The team calculated the MC simulation considering the queen weighted matrix, resulting in a positive and significant global spatial autocorrelation with a value of 0.57. The test included the local Getis-Ord to determine local concentrations of high (hotspots) or low number (cold spots) of freight establishments (*265*). Figure 32 presents the region that exhibits hotspots in West Sacramento.

6.1.5. How does the commuter's origin-destination flow to major clusters?

LODES provides information about the origin-destination (OD) flow used to determine the top residential areas as the origin of workers' commutes to work. The team selected freight hotspots and identified commuters' residential areas in terms of census tracts for deep analysis. Five census tracts from the top 20 residential areas for commuting to freight hotspots placed both groups' residential and hotspots. Five censuses are out of the city limits but remain in urban areas. The top 20 residential areas have between 310 and 387 workers. Additionally, the team evaluated only workers in the trade, transportation, and utilities industry sectors (see Figure 33). Between 31 and 46 workers are in those top tracts, which are distributed around Sacramento's urban area.

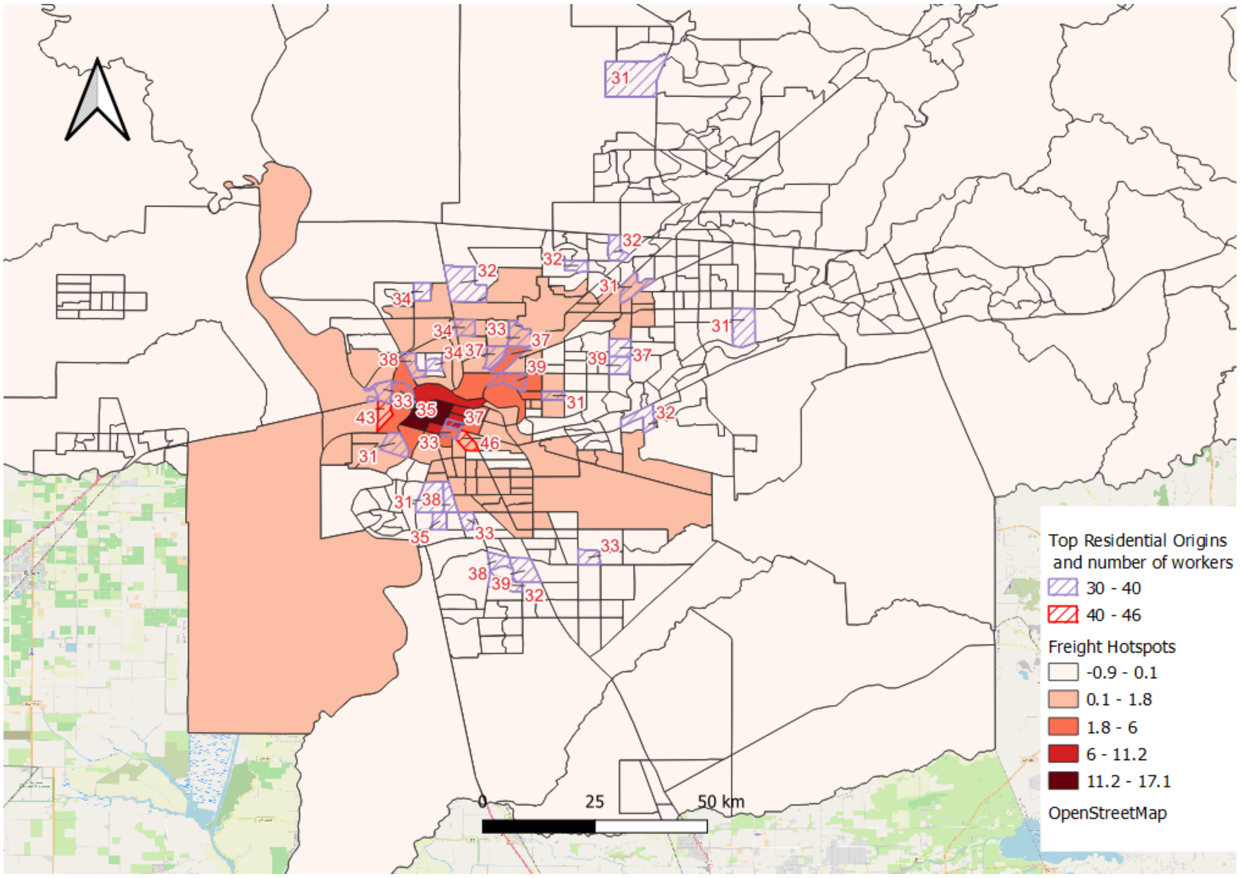


Figure 33. Transportation commuters' origin-destination flow to major clusters

Figure 34 shows the histogram of cumulative distance from the residential tract to the freight hotspot to commute using the OD workflow from LODES. The maximum distance between centroids to commute for all the residential tracts (centroids) was 14 miles, with a median of 4 miles. Most of those tracts register low values of CalEnviroScreen score, which means low burdens for those communities. When the analysis includes only the workforce in the Trade, Transportation, and Utilities industry sectors, the maximum commute distance is 13.3 miles with a mean of 5.3 miles. Therefore, transportation commuters drive longer distances than the average for all workers. For this industry, some workers live in tracts with high CalEnviroScreen scores, especially those near highways and primary roads (e.g., I-80, El Dorado Freeway, North Sacramento Beltline Freeway) or airports.

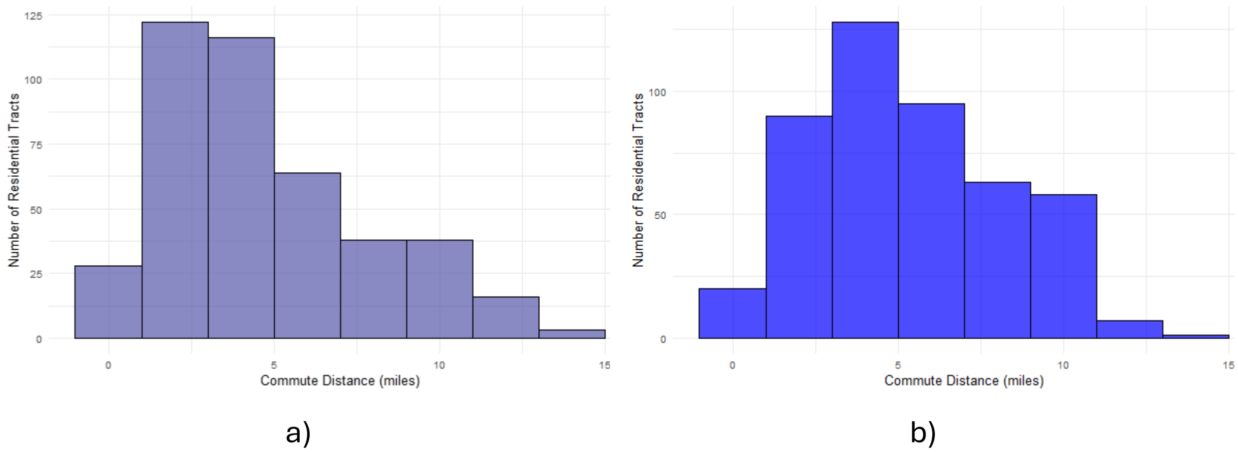


Figure 34. Commuter's origin-destination distance using the Haversine formula. a) All the workforce, b) Trade, Transportation, and Utilities industry sectors

6.1.6. What are the population burdens near major clusters?

The CalEnviroScreen 4.0 provides multiple risk factors that could be associated with freight activity. Therefore, different tests were carried out to identify the relationship between dense areas of freight facilities and risk factors such as low-income communities, pollution, or other environmental issues. The multidimensional scaling of variables shows a close relationship between freight hotspots or freight-intensive areas and Native American communities, solid waste sites, and hazardous waste. In general, freight establishments are located in zones that register high values of CalEnvirScreen score, representing a risk for local communities (see Figure 35).

In addition, there is a statistically significant positive relationship between freight facility density and pollution burden in the Sacramento region. The higher Spearman correlation (0.39) suggests a potential nonlinear relationship, indicating that the pollution burden may increase more sharply in areas with a high concentration of facilities. There is a linear correlation between diesel and freight hotspots (0.35). The CalEnviroScreen score registered a statistically significant positive relationship with freight density (0.4), but the Spearman test suggests a nonlinear relationship.

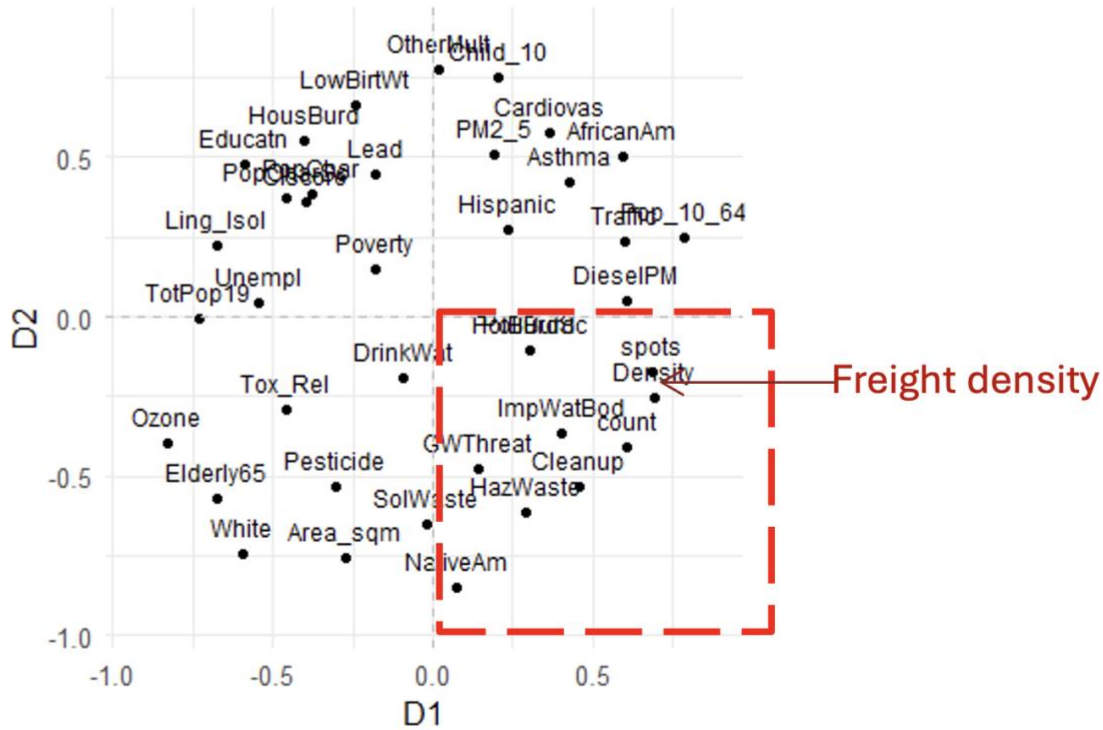


Figure 35. Multidimensional scaling of variables reported in CalEnviroScreen and freight density in each census tract.

6.1.7. What are the conflicts between freight clusters and residential areas?

The team compared land use and freight establishments, and there was no mismatch since all the facilities are located in industrial, commercial, or mixed-use areas. However, due to their closeness, some freight establishments can affect residential, educational, or recreational areas.

To identify those zones, the team developed a buffer around facilities of 0.2 miles in agreement with AB 98 to determine the intersection between freight zones and the sensitive receptors (e.g., residential areas, schools, nursing homes, and hospitals). Building data with classification was gathered from the Overture Maps Dataset (*266*). This intersection resulted in some problematic regions, including the Census Tracts 102.03, 108, 106.06 in Yolo County, and 51.02 in Sacramento. Census Tract 102.03 is the most critical freight hotspot, as shown in Figure 36. That zone requires special attention, including mitigation strategies to reduce freight impact. Planners must ensure local zoning regulations do not conflict with AB 98 and work with the community and freight establishments to guarantee compliance.

Figure 36. Spatial proximity conflicts with sensitive receptors

6.1.8. What are the growth rates of freight facilities across sectors?

The team explores the variation of freight facilities over time to identify spatiotemporal patterns by collecting information regarding the company's starting operation. Freight facilities remain constant, with two prominent peaks in 1998 and 2002. There was a slight increase around 2015 that e-commerce growth could explain. However, most freight buildings were set up before 1993 (68%). After 2018, most of the new facilities are categorized as fulfillment centers (34%), warehouse/storage (34%), and distribution centers (9%). Amazon owns 28% of those facilities, and Walmart 7%. Some census tracts aggregate several facilities: 71.01 in West Sacramento at the limits of the urban area, 103.10 near Sacramento International Airport, and 92.01 in the Industrial Park of Southeastern Sacramento. The last one is in an opportunity zone as defined by the California Department of Finance as of 2019.

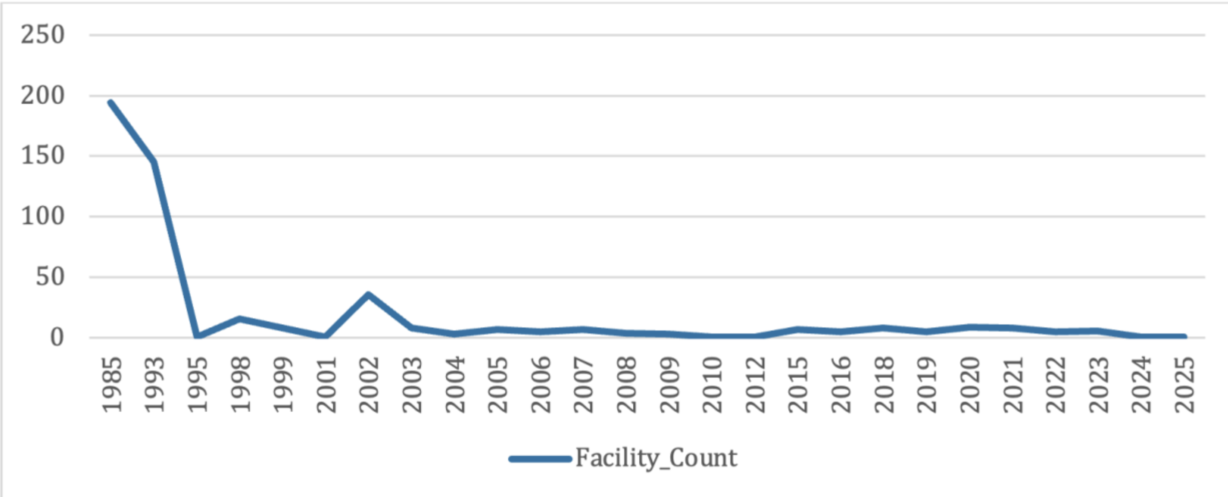


Figure 37. Freight establishments count per year

The distances to the pole economic areas were evaluated annually to assess the proximity of the freight industry to this key economic zone. Figure 38 exhibits the mean distance, the standard deviation, and the interquartile distance range between freight facilities and the nearest economic pole. The distance increases for the entire region over time. Yolo, Sacramento, and Placer Counties exhibit varying trends over time, though their distance patterns differ. Yolo demonstrates a reduction in distance to the pole, while Sacramento and Placer fluctuate between decreasing and increasing distances. Conversely, Yolo and Yuba remain unchanged in this regard.

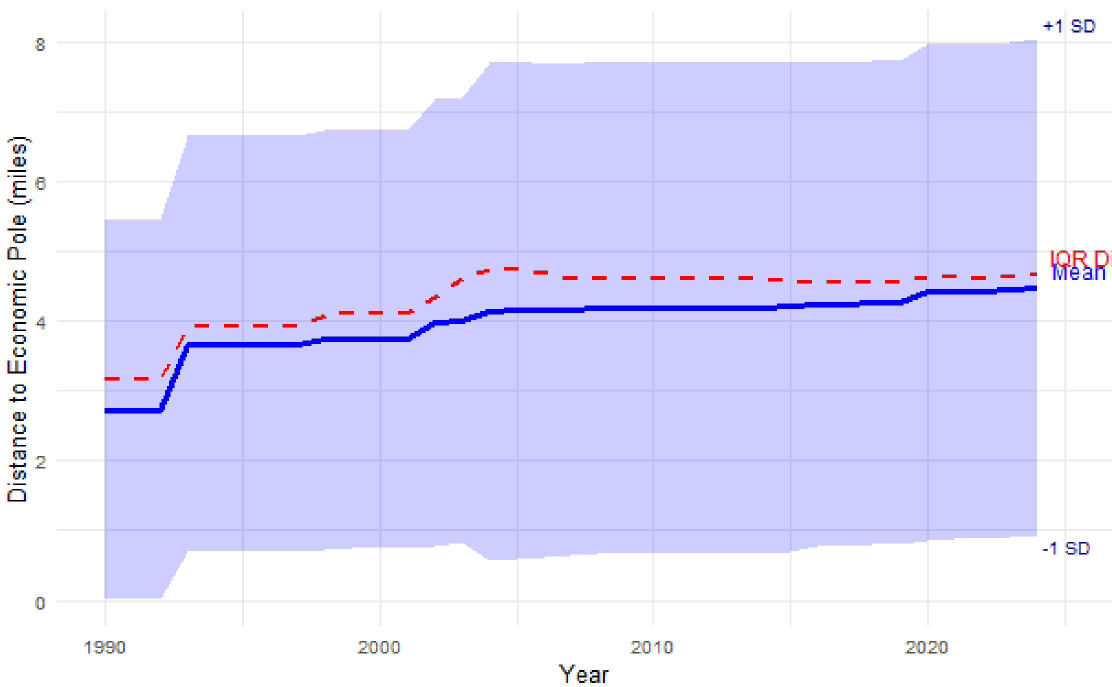


Figure 38. Change the distance between freight establishments and economic pole

6.1.9. What are the employment changes in freight-related industries?

The LODES data offers employment microdata from 2002 to 2022, serving as a valuable resource for analyzing trends in freight-related jobs. Consequently, the team focused on employment information from the relevant NAICS sectors: 23 Construction, 31-33 Manufacturing, 42 Wholesale Trade, and 48-49 Transportation and Warehousing. Figure 39 illustrates job trends, highlighting construction as the most prominent sector. The manufacturing sector shows low variability, while transportation and warehousing exhibit a growth pattern, particularly following 2015.

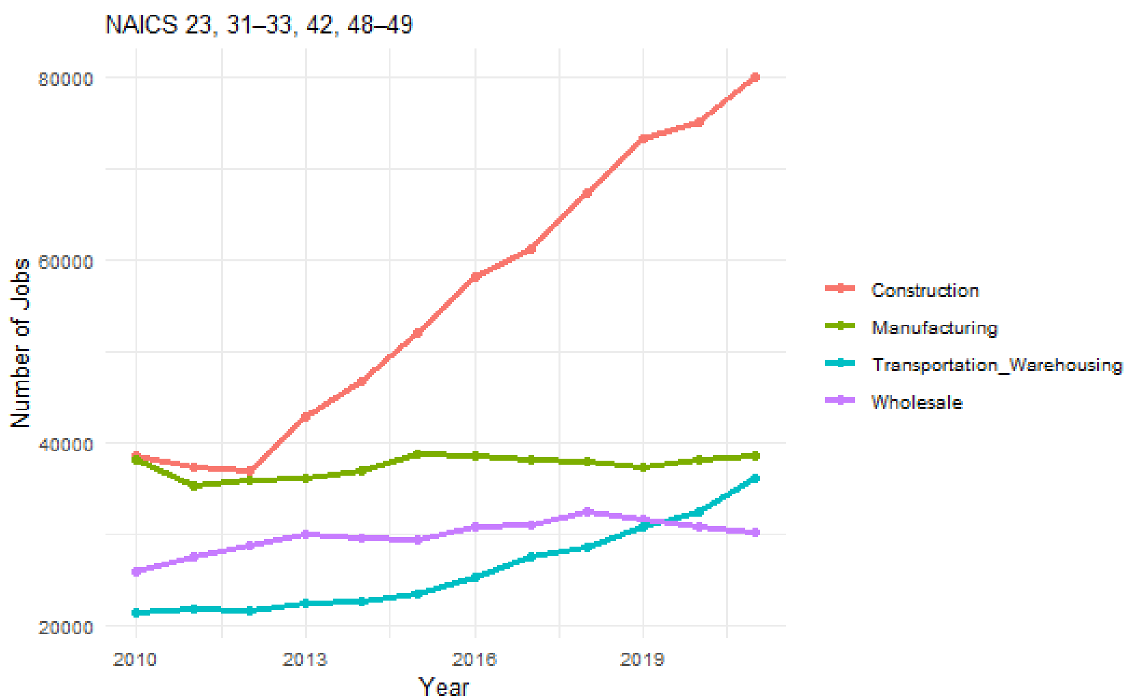


Figure 39. Jobs in freight-related sectors in the Sacramento Region

6.1.10. What census tracts have more employment variation?

A standard deviation analysis reveals significant variability in employment across certain census tracts. Notable tracts experiencing substantial growth in freight-related employment include: 1) Census tract 92.01, which encompasses the industrial park in the City of Sacramento; this area has shown a steady increase in employment, despite a dip in 2017, followed by a strong recovery in 2018; 2) Census tract 112.08 in Woodland, characterized by an industrial zone that has experienced a gradual increase in employment, albeit with a slight peak in 2017; and 3) The area surrounding Sacramento International Airport (census tract 71.01), which has seen significant growth following 2016. In contrast, certain censuses indicate a decline in employment, such as in census tract 87.06, situated in an industrial area of east Sacramento near Muther Airport. This tract experienced a decrease starting in 2015, followed by a recovery in 2020. To the left of the same airport lies the industrial census tract 52.05, which also exhibited a reduction in employment after 2017 and a recovery pattern in 2020.

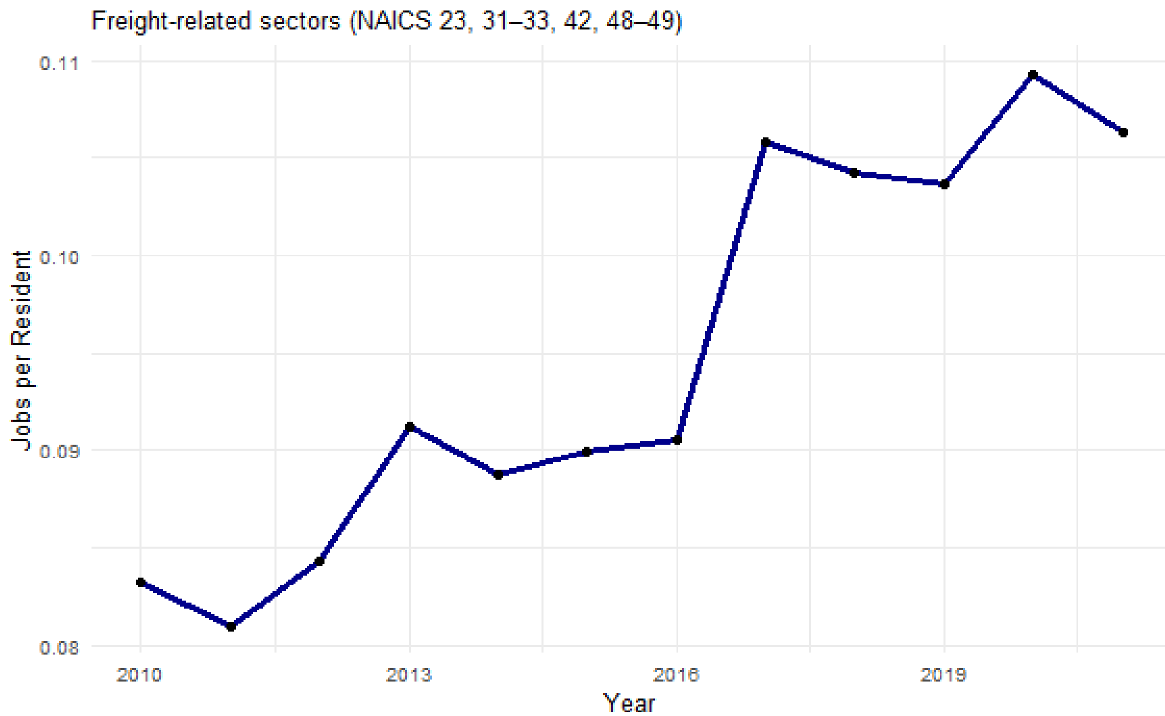


Figure 40. Correlation between employment in the freight sector and population growth

The team analyzed how employment in the freight sector correlates with population growth from 2010 to 2021, as illustrated in Figure 40. The ratio rose from approximately 0.084 in 2010 to over 0.11 by 2020, marking an increase of about 30%. This indicates that employment in the freight sector is outpacing population growth. A significant spike can be observed between 2016 and 2017, likely attributed to substantial expansions in logistics and warehousing, driven by the growth of e-commerce, as well as a recovery in construction following the Great Recession and a concentration of jobs in specific areas. Although minor fluctuations have occurred after 2017, the ratio has consistently remained elevated, staying above 0.10. This trend signifies ongoing freight activity, even during and after the COVID-19 pandemic.

6.2. Characterization of retail and services establishments

This section offers insights into the distribution of retail and other service establishments within the analyzed region, aiming to identify spatial patterns and potential negative impacts associated with this distribution. The team gathered data from OpenStreetMap (OSM) on the locations of various sectors, including retail trade, accommodation, food services, professional, scientific, and technical services, as well as health care and social assistance. This information enables the team to characterize the retail and service sector effectively by addressing the questions and methods outlined in Table 16.

Table 16. Retail and service sector characterization.

Characterization	Research question	Method	Data	Opportunity
Geographical distribution	How is the distribution of retail/services establishments in the region?	Point pattern analysis	Retail location and classification	Economic diversification. S2, S3
	What are the significant clusters of the retail/service sectors?	Spatial autocorrelation	Establishment's location	Decentralized infrastructure supply. S1. Hub allocation. S13.
	What is the distance from freight clusters to retail/service establishments?	Distance to the nearest cluster	Freight clusters, Establishment's location	Use of space intensity and accessibility. S14-17
	Are retail/service uses consistent with zoning & land use plans?	Land use overlay analysis	Zoning shapefiles, retail locations	Identify zoning conflicts and reform land use. S14-15
Coverage	What are the service deserts?	Overlapping dense urban areas and retail buffers	Residential clusters, Establishment's location	Reform LU plans to induce mixed regions. S3, S5

6.2.1. How is the distribution of retail/service establishments in the region?

Retail and service establishment locations were found using OSM, which provides a general service description. The search identified 2348 food services (e.g., restaurants, fast food, café, bars), 620 accommodation retailers, 576 food retailers (e.g., grocery, convenience, and special food retailers), 322 health and personal care retailers, 281 offices (e.g., government buildings, real estate, leasing, professional, technical services). Those retailers are well distributed along the primary and secondary roads and inside the economic poles. About 63% are in urban zones; the most significant concentration is in the Sacramento downtown/midtown.

The team conducted a point pattern analysis to examine the patterns related to clustering, dispersion, and randomness. This analysis incorporates the mean center, standard distance, density, quadrat counts, and k-function tests to evaluate the randomness of the facility distribution (*265*). The 95% significance level chi-square test indicated a complete spatial clustering pattern supported by a VMR greater than 1. The K-function, calculated with 49 MC simulations, revealed that retailers are closely clustered, particularly in the Sacramento center area and the east region, specifically in South Lake Tahoe city.

6.2.2. What are the significant clusters of the retail/service sectors?

In this case, the team tested K-means and Density-Based Spatial Clustering of Applications with Noise (DBSCAN) for clustering analysis. The method selected was DBSCAN since it could highlight local clusters and outliers by identifying natural hotspots or emerging activity centers. The K-means resulted in three clusters, which provide a broader retail zone classification that does not reflect real-world geography.

The result reveals high-density clusters concentrated in urban cores (Figure 41). These clusters correspond with existing urbanized areas, indicating a strong co-location of retail and service amenities within transit-accessible, high-population zones. Some clusters merit particular attention due to the observed patterns. Cluster Zero demonstrates the most random distribution, scattered throughout the region, with some retail and service establishments located far from major roadways. Most of those establishments offer accommodation services and food services.

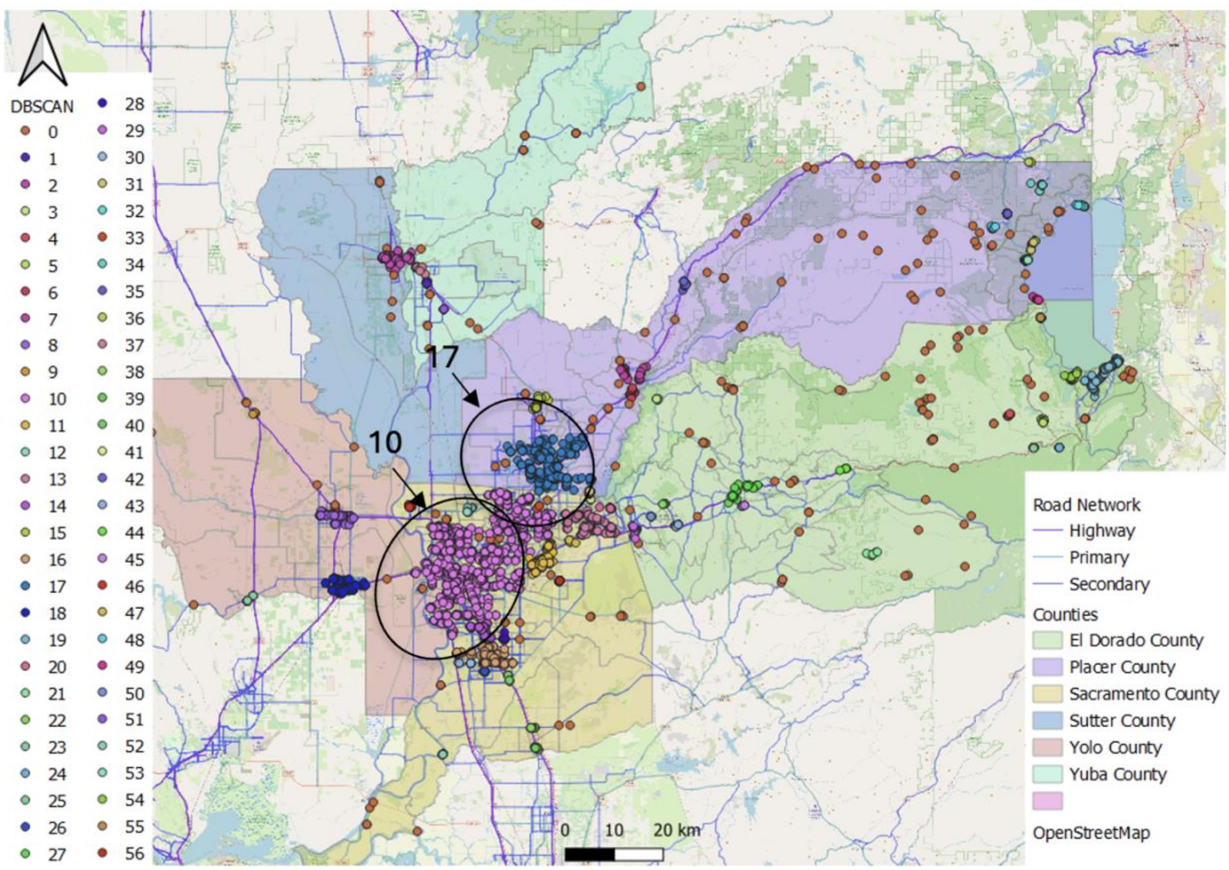


Figure 41. Retail/Service clustering analysis with DBSCAN

Cluster Ten is the most significant and consolidated cluster in central Sacramento. This cluster comprises 42% of all food service retail, 44% of offices for multiple services, 44% of food retail, and 37% of health and personal care services. A second vital economic zone is Cluster 17, located in Roseville, which is especially important for health services, housing 22% of total establishments. Additional retail hubs include Cluster 18 in Davis, Cluster 13 in Folsom, Cluster 16 in Elk Grove, and Cluster 11 in Rancho Cordova. Woodland, Elk Grove, and Folsom feature mid-sized clusters that suggest the emergence of growing retail corridors or regional centers. These areas could benefit from proactive land use planning to enhance walkability and prevent urban sprawl. In addition, these are opportunity areas for commercial zoning updates, service expansion, and last-mile delivery infrastructure.

On the other hand, Yuba, Sutter, and parts of El Dorado County exhibit smaller, isolated retail clusters. The spatial fragmentation could signal limited access to essential services and possible retail deserts. Those areas may require incentives for service expansion, mobile services, or investment in local hubs for underserved populations.

Some retail clusters follow primary highways and secondary road corridors (e.g., I-80, CA-99), suggesting a strong dependence on auto-oriented accessibility. This means those roads must integrate freight access, retail delivery routes, and road maintenance planning in these zones.

6.2.3. What is the distance from freight clusters to retail/service establishments?

Identifying the freight service coverage in terms of business closeness as a measure of distribution efficiency is essential for planning purposes. Although there is a data limitation in terms of the number of freight facilities and retail, which are not included and not classified due to the lack of information, it is still possible to get a general idea of the distribution efficiency using strategies such as buffers or isochrones that are methods identified in the literature review. A distance between 0.5 and one mile captures the typical service radius for last-mile logistics and reflects the zone of potential environmental and traffic impacts in urban-suburban contexts.

Using buffers of 0.65 miles (1 kilometer), the team identified 43% of retail/service establishments covered by freight influence. Most are food service (64%) and food retailers (16%). There is a strong co-location in central Sacramento and surrounding urban areas. A high concentration of retail/service points (especially food, services, and health) lies within 0.65-mile buffers of freight facilities, particularly in Sacramento County, Elk Grove, and the I-80 corridor. Therefore, these areas show intense land use overlaps, which may benefit accessibility but raise potential conflicts such as noise, traffic congestion, pollution exposure, and zoning tension.

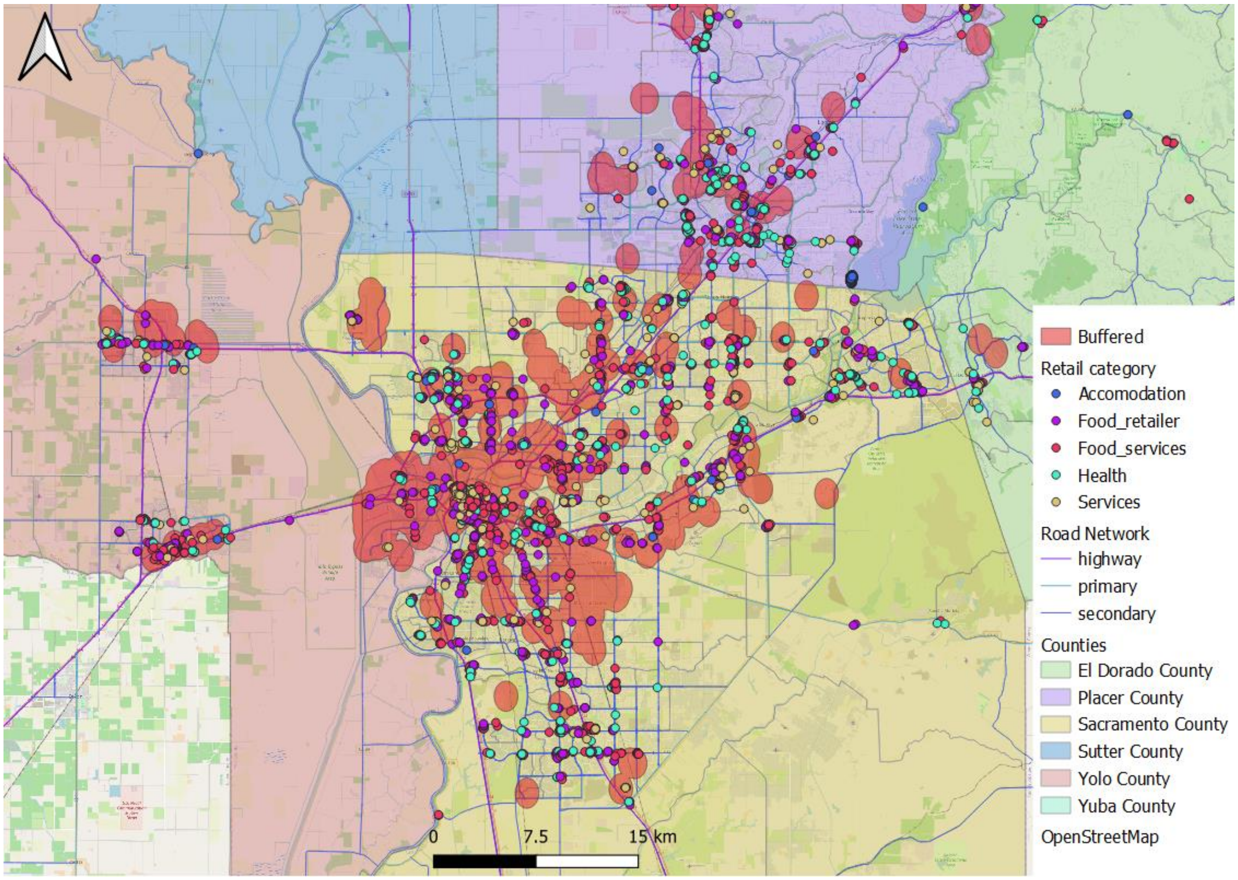


Figure 42. Freight buffers influence over retail/service category

Most overlap is observed along primary and highway routes, especially near I-5, I-80, and CA-99. That also means those freight and retail clusters overlap in vulnerable tracts according to the CalEnviroScreen score. Some implications to consider are these corridors likely serve as shared freight and commercial access zones, which are efficient from a logistics perspective but may lead to safety risks (e.g., pedestrian vs truck traffic) and demand for mixed-use infrastructure planning.

6.2.4. Are retail/service uses consistent with zoning and LU plans?

As mentioned in previous sections, LU plans in the region are developed according to a zoning scheme that designates separate areas for residential, industrial, and commercial purposes, as Figure 43 shows. In contrast, Downtown and Midtown Sacramento feature a diverse mix of land uses, incorporating the different types of land. There is generally a strong correlation between land use designations and retail/service locations in urban and suburban areas, indicating that the planning process aligns well with the actual distribution of land.

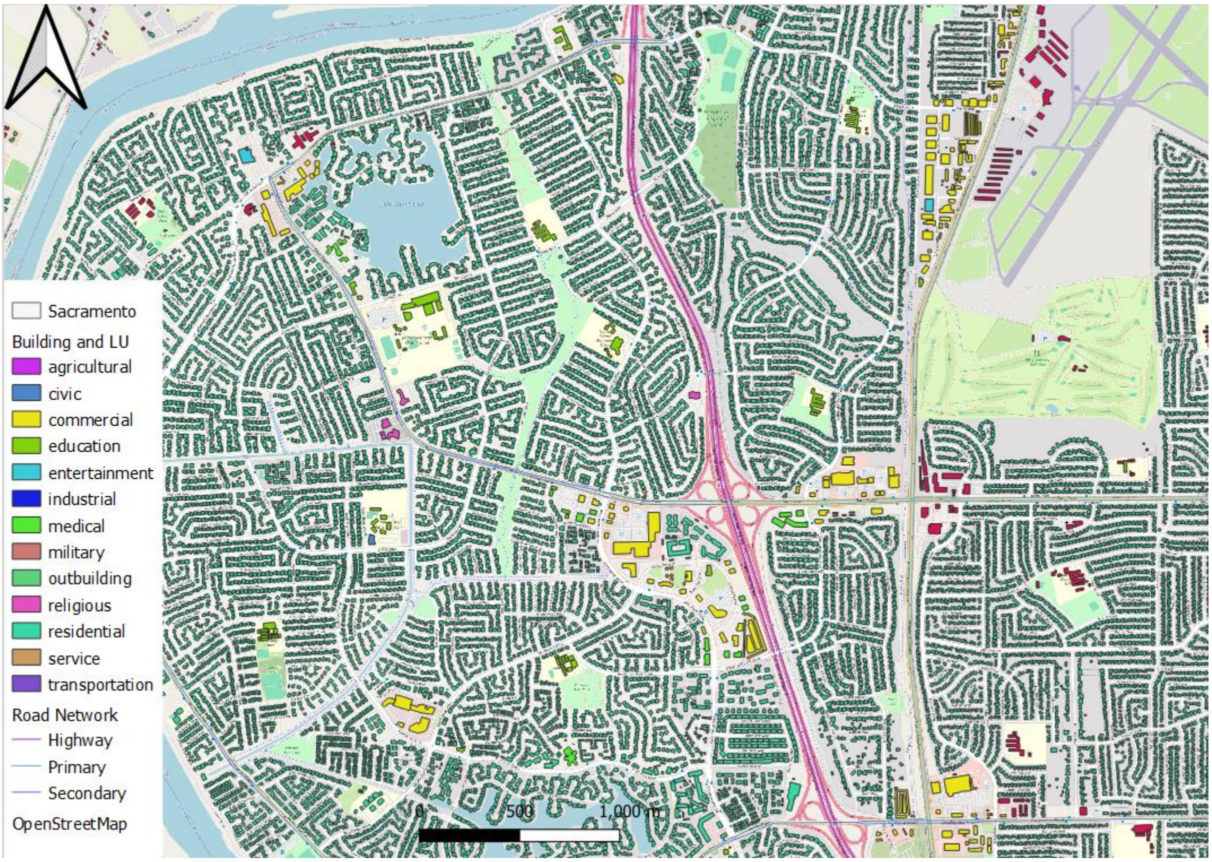


Figure 43. Zoning scheme and LU by building

6.2.5. What are the service deserts?

From the previous freight buffer analysis, it was possible to identify some isolated retail/service zones that deserve some attention for planning purposes. Freight facilities exist in Yuba, Sutter, and parts of El Dorado and Yolo counties without many adjacent retail/service points. These may be freight-exclusive zones, indicating potential freight hubs with minimal land use conflict, limited service availability for freight workers or local populations, and opportunity zones for smart growth or targeted service expansion.

Some service gaps exist in semi-rural and fringe suburban areas (see Figure 44). Areas in eastern Sacramento County, western El Dorado, northern Placer, and southern Yolo counties have tracts with moderate to high populations but no visible primary service presence nearby. These are potential service deserts, particularly concerning if they lack transit access or are isolated from food and health services. These tracts may require intervention through incentives for service investment, mobile or satellite health/food services, and integrated transit service planning.

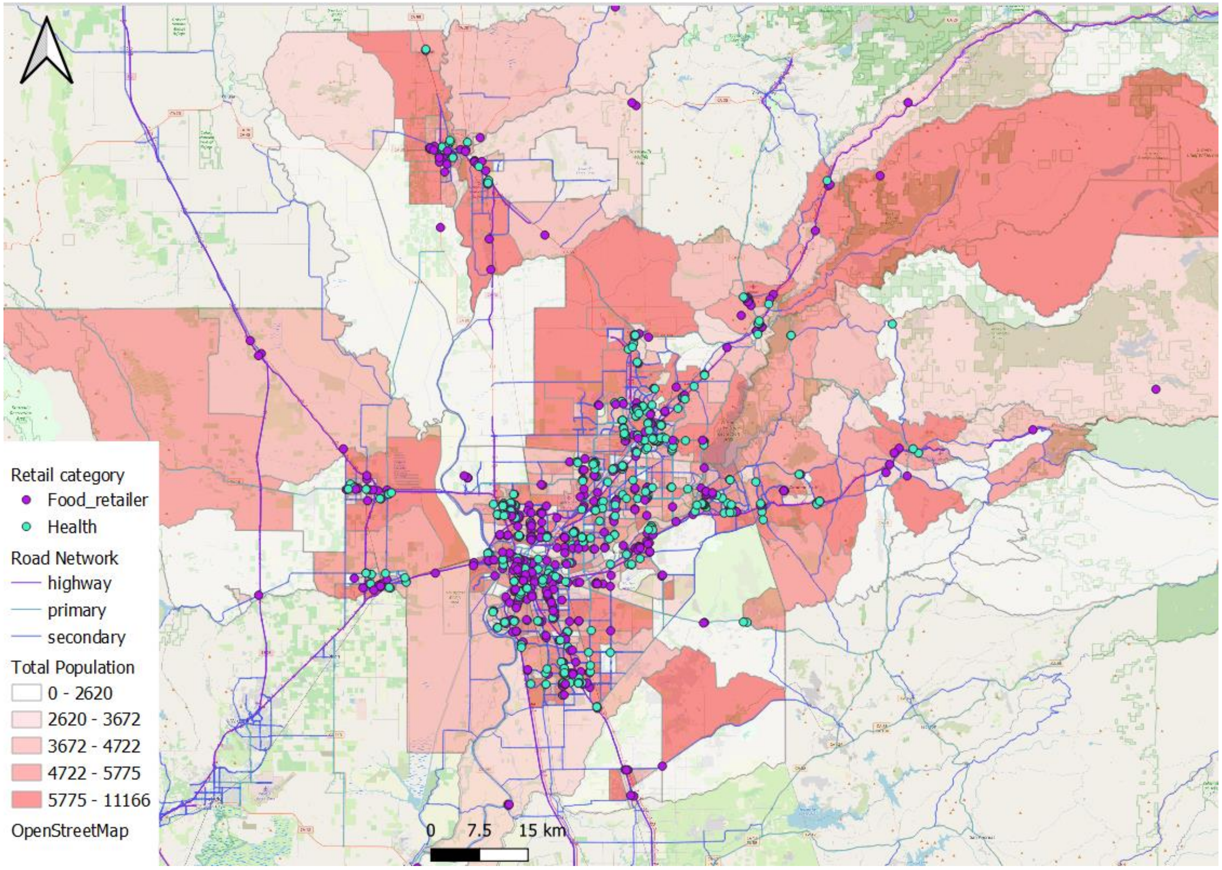


Figure 44. Coverage of primary retail and healthcare services and population density

6.3. Discussion

The analysis of freight facility patterns across the Sacramento region reveals a complex and evolving landscape shaped by logistics trends, policy gaps, and spatial inequalities. Freight development remains geographically concentrated, particularly in counties like Sacramento and Yolo, with a noticeable suburban shift driven partly by the rise of e-commerce and fulfillment centers. These trends pose challenges for smart growth and regional coordination, as land use decisions often lag behind logistical market demands. Importantly, clustering patterns overlap with communities with high pollution burdens, raising urgent environmental justice concerns. While freight employment has grown significantly, often outpacing population growth, many workers still face long commutes, reflecting a disconnect between job location and housing. High-variability tracts show signs of economic instability, suggesting a need for more adaptive and resilient planning. These findings underscore the importance of integrating freight considerations into land use, housing, and workforce development policies. Planners can better align freight growth with community well-being and sustainability goals by prioritizing equity, emissions mitigation, and regional coordination.

The spatial organization of freight and retail-service facilities reveals co-location benefits and conflict potential. While clustering enhances efficiency, overlapping zones with high environmental burdens and limited population services raise equity concerns. Notably, job-to-population ratios increased across the Sacramento region from 2010–2020, reflecting growth in freight-related employment. However, these gains were unevenly distributed, leaving certain census tracts with stagnant or declining employment despite population growth.

The co-location of freight with retail raises key questions about zoning practices, access equity, and land use compatibility. Buffer analysis shows retail and essential services are highly concentrated within freight-dense urban areas, leaving peripheral and rural zones under-served—suggesting emerging retail/service deserts. Additionally, many freight facilities are far from the road network, raising concerns about network efficiency and last-mile delivery logistics.

These insights stress the need for integrated land-use strategies that align freight infrastructure with labor and service accessibility while ensuring equitable environmental outcomes. Addressing zoning conflicts, ensuring multimodal connectivity, and targeting service expansion in underserved areas are crucial steps toward sustainable urban logistics.

There is a need for a coalition of many organizations supporting decarbonization strategies in California involving the public and private sectors. Being part of that collision and involving private local companies in those efforts is key to mitigating burdens, especially in freight hotspots. In that way, companies may invest in efficient and clean transportation systems. Consortiums of charging stations can also be a strategy to increase the number of energy and hydrogen stations. Bugged allocation is another tool for investing in infrastructure and programs like free freight emissions zones. Funding sources include the Carb and Trade program, Clean Hydrogen program, market base programs, and utility credits.

7. Sustainable and equitable freight LU strategies and investment priorities selection

Previous chapters (e.g., literature review, policy analysis, and data analysis) guide policymakers in conducting a planning process that includes sustainable and equitable freight land use strategies. Figure 45 illustrates the selected steps, which are elaborated further in the following subsections.

Figure 45. Steps for incorporating freight into the planning process

7.1. Step 1: Understanding policy

Effective freight strategy implementation must begin with a robust understanding of the multilevel policy framework that governs freight, land use, environmental health, and equity outcomes. This includes reviewing federal, state, regional, and local policies that shape infrastructure decisions, zoning, air quality, and community protections. It is also essential to identify the inter-agency influence, which involves federal and state mandates and goals related to the regional agencies' compliance and the city's zoning response (see Table 17).

Federal agencies, including the USDOT and EPA, may consider freight strategies in alignment with programs such as the IIJA, the National Freight Strategic Plan, and USDOT's Justice40 objectives, which emphasize equity in infrastructure funding. The federal government plays a key role in establishing environmental and emissions regulations, as well as funding programs to incentivize decarbonization.

California has a multi-agency approach to freight planning, with agencies such as CalSTA, Caltrans, and CARB participating. Some policies are highly linked with land use, including

SB 375, which promotes sustainable communities through transportation and land use integration aligned with GHG reduction goals; **SB 743**, which replaces level of service (LOS) with VMT as a metric for environmental impact, incentivizing infill development, and better multimodal outcomes; **AB 617**, which targets local air quality improvements in overburdened communities, encouraging freight emission mitigation in hotspot zones; **AB 98**, which requires compatibility between logistics development and nearby housing or sensitive receptors, including buffers and truck access design; and **SB 1000**, which requires environmental justice elements in General Plans, helping prioritize underserved communities in freight and retail decisions.

Regional agencies, such as SACOG and regional air quality management districts, further shape implementation through SCS, regional air quality plans, and transportation funding priorities. Local General Plans, Specific Plans, and zoning codes translate these policies into on-the-ground land use compatibility, access, and emission management rules.

As outlined in Chapter 2, this policy foundation creates a layered system of responsibilities and compliance requirements. For instance, planners must adhere to AB 98 conformance checklists when locating or permitting freight-related land uses, ensuring proper setbacks from housing, schools, and other sensitive receptors. Understanding these overlapping requirements is essential for identifying constraints and opportunities for integrated, sustainable freight infrastructure development.

Table 17. Players implementing equitable and sustainable freight strategies that also involve LU

Scale	Player	Policies	Action/Intervention
Federal	• USDOT • U.S. EPA • HUD • BLM	• Legislation: FAST Act, MAP-21. NEPA, UJA • Program: INPRA, RAISE, CMAG, NHPP • Guidance/regulation: NEPA, E.O. 14008, FMCSA & NHTSA safety rules	• National Freight strategic plan • Environmental and emissions rules such as CAFE, ELD, E.O.B: 35 • Performance-based planning requirements • Freight corridor funding priorities
State (California)	• CalSTA, Caltrans, CARB, CTC • OPR • Assembly and Senate	• Legislation: AB 32, SB 375, SB 743, SB 671, SB 517, AB 98 • Programs: Clean Truck and Bus Voucher (HVIP), Cap-and-Trade, STEP • Plans: California Freight Mobility Plan, CAPTI, CEQA, AB 617	• GHG reduction mandates (e.g., net zero by 2045) • Clean Freight Corridors • Land use–freight planning rules (AB 98, CEQA) • Vehicle electrification and emissions standards
Local (region, county, city)	• SACOG, MPOs, RTPAs • Regional Air Quality Management Districts (e.g., SMAQMD, Yolo-Solano AQMD)	• Regional Plans: MTP/SCS, TIP • Strategies: Smart growth, mixed-use zoning, VMT reduction, Blueprint Principles • Incentives: RHNA, infill development tools	• Include freight in long-range planning (MTP/SCS) • Support compact development and ZEV charging infrastructure • Develop freight performance indicators (road safety, emissions) • Coordinate with air districts on enforcement (e.g., ISR, WAIRE)

7.2. Step 2: Understanding the context

This step assesses the region's spatial, demographic, and economic conditions, environmental justice analysis, and future charging and fueling infrastructure needs for Zero-Emission Trucks. It includes spatial-temporal analysis of variables such as income, racial/ethnic groups, occupancy, industrial classification, environmental risk zones, and freight regulations compliance.

There are some priorities resulting from the previous analysis:

- **Advanced Equity in Transportation Planning**: This priority includes mitigating the historic and ongoing impacts of transportation infrastructure on minority and underserved neighborhoods and ensuring resource distribution, such as transit access, freight buffers, and green infrastructure, prioritizes vulnerable communities.
- **Support Economic Resilience in Hispanic Communities** by addressing economic disparities, targeting job training, business development, and infrastructure improvements in neighborhoods with high Hispanic populations.
- **Strengthen Middle-Skill Workforce Development** with strategies such as investing in training for middle-skill technician roles, especially related to EV and AFV sectors, which are expected to grow and coordinate with community colleges, workforce boards, and private industry to align talent pipelines with freight and green technology demand.
- **Enhance Clean Freight Infrastructure:** This priority demands expanding planning and deployment of medium- and heavy-duty EV charging and fueling infrastructure, especially in industrial corridors and logistic hubs, and clarifying and mapping station availability, ensuring alignment with truck routes and freight clusters.
- **Reduce Pollution Exposure in Impacted Communities**: it is essential to target interventions in areas with high levels of PM and ozone, especially near major roadways and industrial zones in the region's western part. In addition, this priority requires promoting clean delivery zones, green buffers, and electrified freight networks in pollution hotspots.
- **Elevate the Transportation Sector's Role in Employment Planning**: Recognize the strategic role of transportation jobs (despite not being the largest sector) in shaping access to economic opportunity, particularly in central Sacramento.

7.3. Step 3: Identification of issues from demand and supply

Cross-reference demand factors (e.g., shopping behavior, retail clusters, commuter flows) with supply-side conditions (e.g., freight hubs, road access, emissions). Issues may include mismatches between retail needs and freight access, "freight deserts," or congestion in residential zones. Chapters 5 and 6 provide some key questions that can guide the identification of issues, but planners can implement additional questions according to the region's context and priorities. Table 18 provides some issues identified in answering each research question. This step generally involves selecting key questions, performing measures, and analyzing issues.

Table 18. Main findings and recommendations from the characterization of supply

Topic	Issue	Opportunity	Strategies	Policy to consider
Shopping classification				
Individual characteristics correlate with shopping	Variables such as generation, income, gender, and education affect shopping decision	Use a synthetic population + WMNL model to anticipate behavior across space and time.	• Incorporate e-commerce behavior predictions into General Plan scenarios • Target outreach by population segment	**SB 375** (Sustainable Communities Strategy)
Temporal Trends	Shopping behavior is changing rapidly, especially online growth post-2018	Anticipate future needs of digital commerce and transportation infrastructure	• Update transportation and digital infrastructure plans with future shopping trends • Support equity-focused delivery and retail infrastructure policies	**AB 1014** (Smart Growth Planning)
Trip Pattern	In-store shopping contributes to VMT and emissions; online shopping shifts trip generation	Shift toward lower-emission shopping trips and reduce unnecessary travel	• Support mode shift and last-mile delivery policies • Encourage low-emission delivery fleet adoption.	**SB 743** (Vehicle Miles Traveled Reform)
Emissions	Shopping-related travel generates GHG and pollutants	Quantify environmental impact and prioritize clean delivery zones	• Adopt freight emission caps in Climate Action Plans • Support incentives for zero-emission delivery • Targeting emission reduction strategies (e.g., EV incentives, local delivery options, retail infill)	**AB 617** (Community Air Protection Program) **SB 535** – Requires CalEPA to prioritize environmental justice areas
Geographical distribution of residential areas				
Residential spatial configuration	Shopping demand and behavior vary spatially	Identify hotspots/cold spots to target place-based strategies	• Use zoning overlays to target delivery hubs or in-store expansions • Incorporate demand maps in land use plans	**General Plan Guidelines (OPR)** – Supports spatial equity analysis in land use planning.
High Delivery Demand Areas	High demand in some tracts is not served well by existing freight or retail infrastructure	Locate micro-fulfillment centers or pick-up/drop-off infrastructure	• Support urban freight hubs or smart locker programs • Use planning tools to ensure equitable accessibility.	**SB 1383** – Promotes short-haul logistics improvements, which can support last-mile delivery in dense neighborhoods.

Topic	Issue	Opportunity	Strategies	Policy to consider
Retail Access Mismatch	Disconnect between retail services and population needs (underserved areas)	Land use reform and improved access to food and goods	• Promote mixed-use development in underserved tracts • Reform parcel zoning to integrate retail	**SB 1000** – Requires environmental justice elements in General Plans, emphasizing equitable access to services.
Geographical distribution of freight facilities				
Establishments distribution	Uneven distribution of freight facilities across urban-suburban zones	Balance freight access and mitigate land use conflict	• **Incentivize sitting near major corridors outside residential zones** • **Promote freight-supportive zoning overlays**	**SB 375 The** Sustainable Communities and Climate Protection **Act, and SB 743 -** evaluate transportation impacts
Transportation network access	Road is the predominant transportation system	Improve logistics performance and lower emissions	• Identify priority corridors for infrastructure investments • Encourage multimodal facility integration	**SB 1-**Transportation funding, **MAP-21**
Distance to economic poles	Growing spatial mismatch over time	Increase land-use efficiency and reduce vehicle miles	• Introduce freight-oriented development zones • Incentivize proximity planning in industrial parks	**SB 743-**evaluate transportation impacts, **AB 32 – Global Warming Solutions Act**
Freight desert's location	Limited location of freight in some counties (e.g., Sutter, Yuba)	Reduce inefficiencies and increase regional balance	• Regional freight land-use coordination • Identify potential areas for last-mile consolidation hubs	**AB 98 – Planning and Zoning**, **SB 517 -** efficient, sustainable, competitive freight and supply chain sector
Commuter clusters' origin	Commuter flows to freight hubs	Reduce job-housing mismatch and VMT	• Encourage worker housing near freight hubs and out-of-buffers • Improve transit to freight clusters	**AB 1525**, **SB 375 -** Sustainable Communities and Climate Protection
Population burdens	Hotspots near vulnerable communities	Target environmental equity interventions	• Implement freight emission buffers and corridors • Prioritize near-zero emissions in hotspot zones • Improve green logistics strategies (electrification, truck routes, mitigation of pollution hotspots).	**AB 617 – community air protection program, SB 535 – disadvantaged communities, Warehouse ISR (like SoCal), SB 671** - Clean Freight Corridor

Topic	Issue	Opportunity	Strategies	Policy to consider
Residential conflicts	Freight facilities adjacent to homes	Mitigate negative land use externalities	• Require health impact assessments • Apply buffer zones or truck route restrictions	**AB 802**, **SB 226 - California FAIR plan**, **SB 743 – measuring transportation impacts**
Time variation of freight facilities				
Freight growth trends	Expansion driven by fulfillment centers and e-commerce	Align planning with market dynamics	• Support micro-fulfillment zoning • Plan last-mile networks with smart routing	**AB 1279 -** California Climate Crisis Act, **SB 1014 -** California Wildfire Mitigation Strategic Planning Act
Employment shifts	Jobs are growing faster than the population in the freight sector	Build workforce resilience	• Invest in upskilling and technical training • Expand programs for freight/logistics careers	**AB 517 – efficient, sustainable competitive freight, AB 1475 – transportation projects**
High-variability tracts	Job instability in specific industrial zones	Support adaptive land use & economic resilience	• Monitor zoning responsiveness • Encourage mixed-use adaptive reuse for obsolete freight zones	**SB 375 -** Sustainable Communities and Climate Protection, **SB 350**
Retail distribution				
Retail/service distribution	Uneven access to services across urban/rural areas	Identify underserved zones and guide new location planning	• Analyze spatial equity using population and road access • Guide services to underserved tracts	**SB 1000**, **AB 879**, General Plan Guidelines
Retail/service clusters	Clustering may reinforce access gaps in fringe areas	Evaluate cluster density and accessibility	• Use spatial autocorrelation & DBSCAN/K-means • Assess walkability/public transit coverage	**AB 1324**, local TOD (Transit-Oriented Development) zoning
Distance to the freight influence area	Retail may or may not benefit from freight proximity	Leverage co-location for efficient distribution	• Evaluate service-freight overlaps • Incentivize logistics-retail synergies (e.g., last-mile pickup)	**SB 743**, Sustainable Freight Action Plan
Zoning consistency	A mismatch between retail needs and industrial zoning	Promote integrated or mixed-use zoning	• Reform zoning to allow flexible commercial/service integration • Avoid incompatible industrial encroachment	**SB 6**, **AB 2011**, freight-compatible zoning overlays
Retail/Service's desert locations	Essential services (e.g., food, health) absent in high-need tracts	Direct investment to "service deserts"	• Map distance to primary services • Use buffers and equity screens (CalEnviroScreen, income)	**SB 535**, **AB 617**, Healthy Places Index (HPI)

7.4. Step 4: Identification of opportunities and strategies to mitigate issues

Use data-driven insights to find leverage points where co-location could improve efficiency or where electrification could reduce emissions. This includes identifying last-mile freight corridors, underserved retail areas, or zones with high demand for delivery services.

Table 18 compiles the main findings from the previous analysis and proposes several strategies that could be incorporated into the general plan. The key questions set in previous Chapters 5 and 6 provide guidance to understand supply and demand better and direct the strategies proposed by the literature.

Choose spatial, regulatory, or investment strategies tailored to local conditions, such as emission buffers, freight-supportive zoning, clean delivery zones, or micro-fulfillment centers. Incorporate results from spatial clustering, proximity analysis, and travel behavior models. Appendix 1 provides several strategies identified in the literature that are classified by issues to support decision-making. Choices should be evaluated by planners to identify the most suitable for the context and resources.

7.5. Step 5: Prioritized zones of intervention

Apply equity filters using tools like CalEnviroScreen or Healthy Places Index to ensure interventions target the most vulnerable communities. Prioritize zones where freight, retail, and residential sectors interact and where environmental burdens are most severe. In addition, planners should consider those priorities and recommendations presented in the Caltrans Mobility Plan to guarantee alignment with state goals. For instance, from previous analysis and connecting the supply and demand sectors, the team identified some key zones that may be prioritized for charging and fueling infrastructure investment:

a) South Sacramento–Florin–Elk Grove Area. This area has a high population density and retail/service establishments. There is a strong overlap with residential zones, which have a high potential for last-mile delivery electrification. The existing road network and proximity to highways in this zone make it suitable for hub-and-spoke models. This area is classified as having a high pollution burden.
Investment Opportunity Zone in the CalEnviroScreen. It is important to consider Public EV freight charging stations near warehouses and retail hubs and incentivize electric delivery fleets to operate in this zone.
b) North Sacramento–Del Paso Heights–Natomas. This sector has a moderate freight and retail overlap zone and is categorized as an environmental justice priority area (based on CalEnviroScreen and AB 617). Those underserved neighborhoods could benefit from clean delivery zone Investment Opportunities by creating freight-focused charging infrastructure tied to urban consolidation centers and including solar EV infrastructure in brownfield or industrial reuse zones.

c) West Sacramento and Port District. This is a key intervention zone due to the strategic access to I-80, I-5, the port logistics corridor, and the freight intensity sector. Some areas overlap with residential neighborhoods. In addition, proximity to large-scale industrial parcels provides potential investment for redevelopment by supporting clean freight transition zones and building large charging/fueling depots for heavy-duty truck fleets.

d) Southern Yolo and Northern Solano Corridors (Davis–Woodland). Transit corridors with growing e-commerce logistics traffic characterize this zone. There is a significant distance from centralized freight service, an underserved "charging desert." Investment can focus on pilot intercity EV rest stops for mid-range delivery fleets and combine rural EV charging with smart grid and renewable generation.

e) Northern Sutter and Yuba Counties (e.g., Yuba City outskirts). The team identified freight desert areas with a growing population that are underserved in logistics and infrastructure. There is a high need for equity-based investment (per SB 535 and AB 1550 guidance). Some investment opportunities include incentivizing clean freight consolidation hubs and combining them with rural community EV infrastructure.

7.6. Step 6: Identification of funding sources

Securing funding from diverse and multi-level sources is critical to implementing sustainable and equitable freight strategies. Planners must align project objectives, such as reducing emissions, improving access, and supporting economic resilience, with available federal, state, regional, local, and private-sector funding streams.

Federal Programs

Leverage national infrastructure and freight-focused funding opportunities:

- **INFRA (Infrastructure for Rebuilding America Grants)**: Supports freight and highway projects of national or regional significance, ideal for large-scale logistics hubs, intermodal facilities, or emission-reduction corridors.
- **RAISE (Rebuilding American Infrastructure with Sustainability and Equity)**: Prioritizes multimodal, climate-resilient, and community-benefit projects, especially in underserved areas. Freight hubs near residential zones and clean delivery corridors may qualify.
- **Carbon Reduction Program (CRP)**: Funds projects that reduce transportation emissions; applicable to EV charging infrastructure or smart routing for last-mile logistics.
- **USDOT's Justice40 Initiative:** Ensures at least 40% of the benefits from federal investments reach disadvantaged communities. This supports equity-focused freight projects in overburdened census tracts.

State-Level Funding in California

Utilize state-led climate, transportation, and energy programs:

- **CTC Programs** – Includes Trade Corridor Enhancement Program (TCEP), Local Partnership Program (LPP), and Active Transportation Program (ATP), supporting intermodal upgrades and safe access near freight and retail nodes.
- **CALeVIP (California Electric Vehicle Infrastructure Project) –** Offers rebates and incentives for EV charging installations, including medium- and heavy-duty vehicle infrastructure near freight hubs or retail nodes.
- **Cap-and-Trade Revenues / Greenhouse Gas Reduction Fund (GGRF) –** Funds zero-emission freight, clean mobility, and community air protection programs.
- **California Energy Commission (CEC) Clean Transportation Program –** Supports hydrogen, EV, and renewable fuel infrastructure with potential for freight fleet transitions.

Regional and Local Sources

Regional agencies like SACOG often administer state or federal pass-through funding and prioritize projects aligned with the SCS, GHG reduction, or economic development:

- Consider Regional Transportation Improvement Program (RTIP) funds for road upgrades or delivery access near retail zones.
- Explore local sales tax revenues, climate resilience bonds, or parcel tax measures for supporting infrastructure retrofits or buffer zones near residential areas.

Public-Private Partnerships (P3s)

Some opportunities for private funding include:

- Encourage partnerships with logistics companies, retailers, and utilities for co-investment in charging hubs, intelligent locker networks, or urban consolidation centers.
- Engage industrial park developers to fund last-mile connections and ensure freight-retail-residential compatibility.
- Leverage utility programs (e.g., Pacific Gas and Electric Company's EV Fleet program) for installing truck-charging infrastructure on private or publicly owned freight properties.

7.7. Step 7: Involving stakeholders

Engage a broad coalition of planners, freight operators, community-based organizations, health agencies, and retailers to align goals, surface local knowledge, and promote accountability. This step ensures legitimacy and helps resolve land-use tensions. To effectively involve the private sector, it is essential to develop channels for dialogue regarding freight challenges with private entities and local communities to explore possible solutions, clarify the responsibilities of different stakeholders, and obtain commitments to a strategy for enhancements (*217*).

7.8. Step 8: Implementation of solutions

Roll out projects incrementally or through pilots, installing charging hubs, designating clean freight corridors, or adapting zoning overlays. Ensure coordination with existing infrastructure projects or redevelopment efforts.

7.9. Step 9: Evaluation of the performance

Measure the effectiveness of interventions using indicators like job access, VMT reduction, emission levels, retail access, or delivery efficiency. Track outcomes across time and demographics to inform adaptive planning and performance-based funding. Planners should consider the current thresholds implemented for measuring transportation performance (SB 486).

8. Final Reflections and Integration of Insights

This final section synthesizes the report's takeaways and connects them to the practical implementation of the planning framework outlined in Section 7. The goal is to ensure a continuous, cooperative, and collaborative planning environment where land use and freight transportation strategies are effectively aligned.

1. **Integrated Governance and Planning Timeline** The success of the proposed freight land use strategy depends on coordinated actions across planning, regulatory, and infrastructure phases. For instance, zoning reforms that support mixed-use and freight-supportive overlays must be enacted before new EV charging infrastructure or fulfillment centers are built. Table 19 illustrates policy backmapping for ensuring the implementation of the sustainable and equitable freight LU framework. Policy backmapping begins from the desired outcome and works backward to identify the enabling conditions, actors, and actions needed.

2. **Sustained Collaboration Across Sectors** Achieving equitable and sustainable freight outcomes requires collaboration between land use planners, transportation agencies, air quality managers, community stakeholders, and private sector freight operators. These actors must collectively:

   - Monitor spatial mismatches and update demand forecasts
   - Manage emissions in high-burden communities
   - Align workforce development and economic opportunity with freight transitions

3. **Embedding the Four Dimensions of Sustainability**

   - **Social**: Prioritize community protection and equitable access to services.
   - **Environmental**: Target clean delivery zones and emissions reductions aligned with CalEnviroScreen indicators.
   - **Economic**: Promote logistics and retail efficiency in high-demand corridors.
   - **Governance**: Encourage cross-sector partnerships and adaptive regulatory frameworks.

4. Actionable Recommendations

- Embed demand maps and shopping behavior modeling in general and specific plans.
- Establish performance metrics tied to VMT reduction, emissions, and retail accessibility.
- Use state and regional incentive programs to catalyze infrastructure in underserved zones.
- Update plans regularly with new shopping/emissions data and community feedback.

By integrating the demand insights with the policy framework and placing sustainability at the center, this planning structure enhances regional capacity to build a resilient, low-emission, and inclusive freight landscape.

Table 19. Policy Backmapping for Implementing a Sustainable and Equitable Freight LU Framework

	Stage 4 – System Implementation	Stage 3 – System Readiness	Stage 2 – Policy Structuring and Targeting	Stage 1 – Agenda Setting and Coalition Building
WHAT must be in place?	• Functional EV charging, zero-emission delivery infrastructure, and urban logistics hubs in priority zones • Enforcement mechanisms for VMT/emissions targets and EJ protections • Adaptive freight-supportive zoning and monitoring tools in place	• Finalized regional freight-supportive LU overlays • Identified investment priority zones with costed project pipelines • Local codes updated to support mixed-use logistics integration	• Freight demand and emissions analysis tools embedded into planning practices • Designated priority intervention zones with shared criteria (e.g., demand, burden, equity) • Coordination across freight, equity, housing, and climate planning	• Clear articulation of the need for equitable freight LU • Stakeholder coalitions (freight operators, planners, community orgs) • Alignment with state climate and housing goals
WHO is responsible?	• **Local Governments:** Implement zoning, approve facilities, monitor land use permits • **Regional Agencies (MPOs):** Integrate freight LU in RTP/SCS, conduct regional evaluations • **State Agencies (CARB, OPR):** Monitor compliance with SB 743/SB 1000, enforce ISR if applicable • **Private Sector:** Operate hubs, comply with local freight policies, invest in zero-emission logistics	• **City/County Planners:** Update General & Specific Plans, revise zoning codes • **SACOG & Other MPOs:** Coordinate interjurisdictional demand zones and network **improvements** • **State DOT & CARB:** Approve emissions reduction investments, build EV infrastructure	• **OPR/CalSTA:** Define freight-EJ planning integration standards • **Regional & Local Governments:** Adopt demand-based prioritization models • **Academic/Research Institutions:** Validate methodology, support data infrastructure	• **Policy Entrepreneurs & Researchers:** Frame the issue and socialize it • **Advocacy Orgs:** Mobilize support in overburdened communities • **State Leaders (Legislators, ARB, OPR):** Signal urgency through hearings, pilot funding

	Stage 4 – System Implementation	Stage 3 – System Readiness	Stage 2 – Policy Structuring and Targeting	Stage 1 – Agenda Setting and Coalition Building
HOW to enable this?	• Mandatory freight elements in General Plans • Cap-and-Trade funds or GGRF incentives directed to disadvantaged communities • Public-private delivery pilot programs and impact assessment mechanisms	• SB 375 performance metrics integrated into LU updates • Technical assistance for disadvantaged communities • Clear guidance on EV permitting and zoning code templates	• CalEnviroScreen + Demand Model integration in SB 1000 toolkit • Dedicated freight LU planning grants • Regional guidance documents and capacity-building workshops	• Host regional workshops and legislative briefings • Release policy briefs showing VMT/emissions reductions and EJ benefits • Leverage ongoing planning updates (e.g., 6th cycle housing element, SCS) to insert freight LU narrative

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Data Summary

Products of Research

The proposed project created subsets of data from public-existing datasets for seven months. These include:

Source	Description	Format	Chapter
American Community Survey (ACS) collected through IPUMS USA collects, using API key in R	Demographic characteristics were identified from the ACS 2005 to 2022 5-Year Estimates Data Profiles for the eight regional counties	GeoPackage	4, 5, 6
Longitudinal Employer-Household Dynamics (LEHD), using API key in R	Microdata of Origin-Destination Employment Statistics (LODES), Residence Area Characteristics (RAC), and Workplace Area Characteristics (WAC), all at census block geographic detail for 2020	GeoPackage and csv	4, 6
California Communities Environmental Health Screening Tool (CalEnviroScreen 4.0) using API key in R	Pollution Burden and Population Characteristics	GeoPackage and csv	4, 5, 6
California Energy Commission from the website	Medium- and Heavy-Duty Zero-Emission Vehicles in California The charging infrastructure for zero-emission vehicles	GeoPackage and csv	4
American Time Use Survey (ATUS), collected through IPUMS USA collects, using API key in R	Sociodemographic variables and shopping behavior from 2013 to 2023	GeoPackage and csv	5
National Household Travel Survey (NHTS) from the website	Sociodemographic variables of 2017 NHTS dataset	csv	5
California Air Resources Board, EMission FACtor (EMFAC) tool	Emissions inventory for 2018	csv	5
Economic Surveys, ECNSVY Business Patterns County Business Patterns (CBP) from the website	Freight and service employment and establishments by census tract	csv	4, 6

Source	Description	Format	Chapter
OpenStreetMap (OSM) using API Key in R	Retail, services and freight establishments point location	GeoPackage	4, 5, 6
Overture Maps Dataset from Amazon S3 and Microsoft Azure Blob Storage using API key in R	Building infrastructure with category and location of polygons	GeoPackage	5, 6

Data Format and Content

The data was documented in a spreadsheet that lists each element, its attributes, description, source, and code, considering that the potential users will be planners and local authorities. The team provided all the data collected in the same format, .csv, with the data documentation in the spreadsheet.

Data Access and Sharing

All relevant data was deposited to Dryad, an open data-sharing and publishing repository (https://datadryad.org). The data is publicly available and findable through a DOI (https://doi.org/10.5061/dryad.tb2rbp0d1). The repository provides long-term storage and preservation through the backend Merritt Repository. In addition, the data was submitted to the USDOT National Transportation Library (NTL) digital repository for public use. The electronic version contains all the data collected from public sources and the results.

Reuse and Redistribution

The tool will stay accessible for public use, and the data processed and generated with it will remain free for public access without any sharing requirement.

Appendix

Table 20 presents the freight-related challenges and sustainable strategies identified in the literature. These strategies have been categorized into several sections. The first section, “Understanding Conditions,” encompasses elements the literature frequently emphasizes as necessary to comprehend, given their relevance to the freight sector. The second section, called “Freight Issues,” outlines the primary challenges that impact or are influenced by the freight sector. The third section details the key strategies for addressing or gaining insight into these freight-related issues. Lastly, various methods have been identified in the literature for implementing the techniques mentioned in the previous section. Some topics are highlighted due to their marked importance in the literature review.

Table 20. Freight-related issues and sustainable strategies

	Understanding conditions	Freight Issues	Strategies	Methods	Reference
1.	**Land use patterns and development impacts**				
1.1.	Policy: regulation, legislation	Negative effects on communities	S1. Estimate the demands for infrastructure services and the potential for decentralized infrastructure supply	Random utility modelling	(*174*)
		Inefficient distribution	S2. Market-oriented reform on land use efficiency and government-enterprise relationships.	Regression discontinuity design	(*180*)
			S3. Estimate the effect of land use developments under different scenarios	Travel Time Reliability: before and after comparison	(*183*)
				Spatial analysis indicators using the centrographic method.	(*86*)
			S4. Investigating the main factors affecting the priority of the supply of land used for transportation for decision support	Multi-objective decision support system	(*177*)
			S5. Ecosystem services approach for land management.	Policies and funding to motivate participation	(*135*)
1.2.	Residential development	Displacement, gentrification, and health-related issues	S6. Evaluate the external costs associated with producing, transporting, and consuming goods for decision support.	Decision-Support Tools	(*13*)
		Access to retail, services, and employment zones	S7. Evaluate the impacts of retail land use on shopping trips for decision support	Shopping trip chain estimation and zonal freight trip generation model with a land use module	(*54*)

	Understanding conditions	Freight Issues	Strategies	Methods	Reference
			S8. Simulate travel time variations on neighboring links of new developments	Travel Time Reliability: before and after comparison	(*183*)
		Economic disparities and lack of opportunities	S9. Account for the household and workforce to estimate future demands linked to land use	Random utility modelling	(*174*)
			S10. Evaluate social justice in transport	Capability approach	(*267*)
		Safety mobility	S11. Complete street design for multimodality		(*162*)
			S12. Community road safety	Collaborate with the community to identify the key issues affecting their community.	(*193*)
1.3.	Industrial development	Location choice	S13. Analysis of hubs distribution for land allocation and infrastructure connections	Spatial dynamics of the locations of logistics hubs	(*189*)
			S14. Identify the main freight-generating centers within the city to assess surrounding land use and transport infrastructure	Linking property tax data with cordon survey data	(*87*)
			S15. Territorial Intelligence Analytics for decision making for improving urban logistics	Combining functional and spatial clustering techniques	(*268*)
1.4.	Commercial development	Freight accessibility	S16. Analysis of commercial and industrial land use patterns to identify accessibility issues for decision making.	Examining road freight transport activity and its relationship with facility location, logistics management and urban form	(*179*)
				Linking property tax data with cordon survey data	(*87*)

	Understanding conditions	Freight Issues	Strategies	Methods	Reference
			S17. Identify the impacts of retailing development on freight trip generation and shopping trip structure and composition for decision support.	Shopping trip chain estimation and zonal freight trip generation model with a land use module	(*54*)
2.	**Spatial dynamics of economic activities**				
2.1.	**Consumption**				
2.1.1.	Shopping Preferences	Demand for goods and services	S18. Analyses demographic changes in urban shop restocking	Surveys analysis and future demographic scenarios using urban restocking models	(*269*)
			S19. Understand the factors that affect shopping decisions	Econometric behavioral model	(*56*)
				Theory of Planned Behavior	(*270*)
			S20. Understanding online grocery shopping and everyday mobility as social practices	Qualitative interviews combined with travel diaries analysis	(*271*)
			S21. Lifestyle changes in mitigation pathways	Policy implementation based on a multidisciplinary approach	(*272*)
2.1.2.	Transportation patterns	VMT for shopping activities	S22. Attractiveness analysis	Trip attraction (FTA) and a shopping trip attraction (STA) model	(*79*)
2.2.	**Production**				
2.2.1	Participants				
2.2.1.1	Transportation facilities and network	Freight accessibility	**Curbside management**		(*44*)
			S23. Optimal location of loading bays in an urban environment	Model for assessing the associated costs and benefits for bay areas	(*50*)

	Understanding conditions	Freight Issues	Strategies	Methods	Reference
			S24. Complete street design for improving safety.	Multi-modal approach	(*162*)
			S25. Identifying and predicting potential parking areas for heavy commercial vehicles	ST-DBSCAN methods and a Gaussian mixture model	(*42*)
			S26. Estimate the on-street parking demand for urban commercial traffic	Freight trip generation, service trip attraction, and e-commerce deliveries	(*41*)
			S27. Regional freight accessibility analysis	Distance-weighted topological analysis with multiple relevant indicators	(*273*)
				Centrality and reliability measures	(*75*)
			S28. Identifying potential corridors/areas for the implementation of truck-exclusive lanes	Truck travel time performance measures	(*210*)
			S29. Truck signal priority at intersections	Truck travel time performance measures	(*210*)
			S30. Layout of highway freight yards	Trajectory data extraction, classification, and visualization for describing the operating characteristics of trucks	(*274*)
		Safety conditions	S31. Shoulders along intermodal connectors		(*213*)
		Efficiency	**Multimodality:**		(*173*)
			S32. Multimodal network integration	Integrated weighting method (economic and transportation network)	

	Understanding conditions	Freight Issues	Strategies	Methods	Reference
			S33. Shifting freight from road to multimodal	Toolbox: consulting services, multimodal planning guidelines, IT visualization, and CO2 calculator.	(*131*)
			S34. Electronic provision of traffic information		(*181*)
			S35. Transition to Circular Economy and Digitalization	Mathematical and simulation models for selecting parameters of intermodal transport	(*275*)
2.2.1.2.	Suppliers	Emissions	S36. Electrified cargo bikes	Life cycle assessment for measuring the impacts caused by the production	(*64*)
			S37. Assessing the impacts of road freight transport on sustainability	Quantitative indicators to classify impact intensity	(*202*)
		Waste	S38. Integration of circular economic principles with supply chain processes	Roadside interviews of freight vehicles and establishment surveys of manufacturing and trading units	(*276*)
2.2.1.3	Freight facilities	Impacts of freight location	S39. Consolidation systems management	Consortium of implementation locations and expert partners for developing plans and long-term strategies	(*57*)
				Consolidation scheme identifying externalities cost	(*60*)
			S40. Multi-story facilities, renovation of obsolete facilities, and reorganization of existing facilities	Examining the trajectory of logistics space development	(*3*)

	Understanding conditions	Freight Issues	Strategies	Methods	Reference
			S41. Quantify the impact of logistical decisions.	Measure a subset of economic and environmental factors	(*90*)
		Efficiency	S42. Eco-Transfer System	Supply-demand quantification with a study on market conditions and infrastructure requirements	(*208*)
		Waste	S43. Reusable or low-impact packaging	Compare the energy requirements for multiple scenarios of packaging	(*160*)
		Disruption	S44. Re-planning and re-consolidation options in response to disruptions	Synchro-modal transportation planning	(*58*)
2.2.1.4	Carriers	Emissions	**S45. Alternative energy adoption**		(*57*)
				Mixed fleets (conventional and electric)	(*155*)
				Fuel Cell electric vehicles	(*122*, *126*)
				Carbon-neutral biodiesel	(*116*)
				Bioethanol to substitute gasoline.	(*119*)
				Dual compressed natural gas (CNG) vehicle	(*149*)
				Hydrogen fueling	(*126*)
			S46. Implement technologies to reduce emissions.	Stop-Start System for high-capacity vehicles	(*149*)
				Global navigation satellite systems in fleet tracking	(*129*)
			S47. Adoption of cargo bikes	Low-carbon city logistics measures	(*57*)
				Multi-criteria assessment framework	(*139*)

	Understanding conditions	Freight Issues	Strategies	Methods	Reference
		Efficiency	**S48. Route optimization with information and communication technologies**	Route Optimization Theory	(*91*)
				Modeling Road Link-Level Truck Travel Times Using On- and Off-Network Characteristics	(*209*)
			S49. Online Navigation Route	A demand-network approach based on online route recommendations	(*277*)
			S50. Auto-match the consignor's demand and the carrier's supply based on mobile Internet.	Implementation of freight apps in road freight transport	(*148*)
			S51. Hyperconnected Freight Transportation in the Physical Internet	Multi-agent network architecture	(*94*)
			S52. Off-peak hours delivery program		(*181*)
			S53. A collaborative last-mile distribution network with logistics hubs	Optimize the number and location of the logistics hub.	(*63*)
			S54. Container port drayage operation		(*97*)
			S55. Spatial synchronization between cargo bikes and vans	Two-echelon city distribution scheme	(*65*)
			S56. Drones for Last-Mile Delivery	Stated preference survey to assess end-user propensity toward drones	(*70*)
			S57. Automated driving systems with electrification	Evaluation of different transportation scenarios	(*278*)

	Understanding conditions	Freight Issues	Strategies	Methods	Reference
			S58. Platooning system	efficient decision-making systems with computerized planning tools	(*98*)
2.2.1.5	Receivers	Disruption	S59. Collaboration among stakeholders	Quantitative analysis and agent simulations of relief logistics	(*164*)
			S60. Exploring the geography of retail decline	Identifies attributes that make some of the retail centers a viable proposition for the future	(*279*)
2.3.	**Governance**	Planning	S61. Identify and assess barriers and opportunities	Place-based action plans	(*159*)
			S62. Freight-Efficient Land Uses Plan	FELU methodology	(*13*)
			S63. City logistics long-term planning	Simulation of shopping mobility and goods restocking and related support systems	(*207*)
			S64. Integrating urban freight initiatives (UFIs), or city logistics initiatives, into urban planning	Three economic geography theory principles-location, agglomeration and urbanization	(*109*)
			S65. Crowd-Based City Logistics	Transportation system integrated into a network to optimize the overall city performance	(*280*)
		Decision support	**S66. Mobility in an integrated, holistic fashion considering equity and sustainability**	Public engagement to identify patterns of movement	(*158*)
				Integrating transport and land use model system	(*81*, *178*)
				Multimodal mobility system	(*138*)

	Understanding conditions	Freight Issues	Strategies	Methods	Reference
			S67. Assess the energy and carbon footprint of different highways and traffic flow scenarios.	HERA (Highway EneRgy Assessment) methodology	(*151*)
			S68. Multi-pole urban structure for compact development	Utility theory to estimate individual demand for goods and Individual energy consumption under different scenarios	(*146*)
			S69. Optimal infrastructure management	traffic modeling, policy modeling using the Markov decision process, and management decision simulations.	(*186*)
			S70. Sustainable scenarios evaluation with stakeholder participation	Scenario design through iterative cycles	(*281*)
			S71. Evaluate the traffic safety along freight intermodal connectors (Freight risk zone)	a model system for estimating goods attracted within urban and metropolitan areas	(*212*)
			Logistics facilities optimization		
			S72. Optimizing the establishment of small-scale logistics facilities	Multi-Criteria Analysis Framework with stakeholders participation	(*29*, *187*)
			S73. Optimizing the establishment of logistics facilities	The density of logistics establishments, tracking the changes in such density, and evaluating logistics park attraction.	(*184*)
			S74. Port-city underground logistics system		(*176*)

	Understanding conditions	Freight Issues	Strategies	Methods	Reference
			S75. Special airport economic zone	Spatio-economic model for Aerotropolis region determination	(*106*)
		Identify future needs	S76. Modeling future energy, economic, and environmental systems in an integral approach	Transport demand in aggregate or multi-sectoral models	(*150*)
			S77. Road freight electrification	Sufficiency-oriented planning approach (transportation demand and technology)	(*166*)
			S78. Freight demand Management	City Logistics Analysis and Simulation Support System tool with land use scenarios and demographic changes	(*101*)
				Implement a modeling framework to forecast urban goods flows	(*282*)
		Reduce emissions and increase efficiency.	S79. Price-based policies and a cap on total emissions	Target fuel producers and/or car manufacturers and influence the use of alternative fuels and technologies.	(*156*)
			S80. Logistics informatization, auto emissions standards	LEAP model for emissions quantification and scenarios testing	(*154*)
			S81. Vehicle energy efficiency programs	Fleet model for energy efficiency measure	(*153*)
				Life cycle assessment (LCA) as the environmental assessment tool and Input Output (IO) analysis as the economic assessment tool	(*119*)

	Understanding conditions	Freight Issues	Strategies	Methods	Reference
			S82. Promote vehicle-use Compressed Natural Gas/gasoline and Liquefied Natural Gas/diesel.	Natural gas station deployment is related to local land-use planning, energy planning, and safety issues. Financial incentives	(*121*)
			S83. General awareness campaigns of the environmental effects of their logistics choices	Cooperation between politicians and automobile manufacturers	(*155*)
			S84. Decoupling of emissions related to imported goods and services	International cooperation and coordinated mitigation efforts of trading partners	(*167*)
			S85. Receiver-Led Consolidation (RLC) programs		(*59*)
			S86. Freight Traffic Flow Regulations	Identifying daily traffic volumes	(*185*)
			S87. Policies aimed at increasing the sustainability of production and consumption	International cooperation to target production practices for exports worldwide	(*283*)
		Labor conditions	S88. Cargo-cyclists workers regulations	Studies, experience, and consultation with experts	(*165*)
		Performing evaluation	S89. Noise Pollution Assessment	Street functionality approach	(*145*)
			S90. Evaluate the footprints of goods movements.	Global OLS and Multiscale Geographically Weighted Regression models	(*142*)
			S91. Evaluates the traffic safety along freight intermodal connectors	crash characteristics, and statistical significance of attributing traffic and geometric factors	(*213*)
			S92. Testing the evolution of both the energy and transport systems		(*126*)

	Understanding conditions	Freight Issues	Strategies	Methods	Reference
			S93. Freight policies evaluation	Economic Order Quantity (EOQ) model	(*59*)
				Freight accessibility framework	(*53*)
				An agent-based urban freight simulator	(*203*)
				Multi-criteria analysis	(*136*)