Improving the Efficiency of Urban Freight Systems in California

August 2024

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Executive Summary

The Urban Freight System (UFS) is indispensable in local economies, facilitating the seamless movement of essential services and goods from businesses to customers. The UFS is responsible for the physical movements resulting from the economic transactions between entities (e.g., businesses and individuals) from the point of origin to its destination. Origins and destinations include freight facilities such as warehouses, distribution centers, manufacturing plants, and even households in the new environment of business-to-business, business-to-consumer, consumer-to-consumer, and other types of commerce. While goods can also travel from other regions and geographies, the UFS concentrates on those having origins and destinations within or near the urban areas.

Moreover, these operations are intrinsically tied to consumer satisfaction, fueling a substantial transformation in the sector to meet the growing demand for e-commerce, just-in-time supply, and expedited services. This transformation has spurred the expansion of UFS fleets and an increased frequency of trips to ensure the rapid delivery of goods within tight timeframes.

However, many of these needed movements still rely on internal combustion vehicles using fossil fuels, exacerbating environmental concerns related to greenhouse gas emissions (GHG) and pollution, which can disproportionately impact vulnerable communities (*1*, *2*). In California, the transportation sector alone is responsible for nearly 40% of total CO2 emissions, and approximately a quarter are attributed to freight operations (*3*). The final leg of deliveries (last mile) operations can account for about 40% of UFS' energy consumption and emissions (*4*, *5*).

Despite the benefits and critical role played by the UFS for a vibrant economy and to allow for everyday activities, it also poses air quality issues, further compounded in densely populated regions with greater demand for goods movement (*6*). The environmental repercussions are not limited to emissions (*7*); the UFS also contributes to noise pollution, with trucking operations often exceeding World Health Organization (WHO) noise recommendations by approximately 32% (*8*). The increased presence of vehicles within urban areas also worsens the unequal distribution of negative externalities (*9*), simultaneously impacting communities near pollution and noise sources with additional burdens related to poverty, nutrition, and education (*2*, *10*), and with impacts differing based on locations, vocations, and vehicles used (*11*). In California, for example, this results in significant economic implications, with annual costs of $61 billion due to time and fuel wasted in traffic crashes and congestion and operating vehicles in deteriorated roads (*12*, *13*).

These adverse impacts have spurred government agencies, communities, and businesses to formulate strategies for achieving sustainable UFS. However, the path to sustainability has challenges that demand attention to enhance supply chain efficiency. This white paper aims to shed light on these challenges and

ongoing initiatives by consolidating critical literature on the environmental, economic, and social impacts of the UFS. It encompasses an analysis of recent trends and the challenges faced by various supply chain stakeholders, a review of current initiatives for improving UFS, and key recommendations for advancing efforts to mitigate the impacts of UFS.

Challenges and trends in UFS

To effectively tackle the challenges associated with the UFS, it is imperative to understand and anticipate the behavior of various stakeholders within the supply chain, encompassing consumers, businesses, carriers, and government entities.

Consumers' behavior emerges as a pivotal challenge in the quest for sustainable UFS. Consumers' shopping habits drive many transformations in the upstream supply chain. The surge in online shopping can be attributed to convenience, a wide range of product choices, competitive prices, and improved logistics and delivery services (*14*). However, this surge has posed significant logistical challenges, primarily linked to the increased demand for expedited deliveries that exacerbates the environmental impacts of the UFS. Rising customer expectations have also spurred innovation and challenges to businesses, compelling them to refine their processes and inventory management to predict and meet consumer needs while reducing environmental impacts. These challenges include reducing vehicle miles traveled (VMT), emissions, food, and packaging waste and adopting more sustainable materials (*15*).

Carriers have leveraged information systems to optimize logistics and transportation routing in urban areas. Vehicle Routing Problems (VRP) have been prioritized for organizing delivery routing patterns and increasing cost efficiency (*16*) while diminishing emissions and energy consumption. From a governmental perspective, official institutions actively develop comprehensive urban freight plans encompassing freight activity along the supply chain. These initiatives also address the needs of vulnerable road users and disadvantaged communities and focus on improving the working conditions of truck and van drivers, dock workers, and e-commerce fulfillment centers, which can improve equity and accessibility (*17*). A summary of key trends and challenges concerning these actors is provided in Table 1.

Table 1. Challenges and trends of UFS stakeholders.

Stakeholder	Challenge	Trend
Consumer	1. How to influence consumers' shopping habits to improve sustainability?	1. Multichannel shopping, including online and in-person.
		2. Shopping preferences and motivations. The selection of the shopping channel depends on the motivation of the purchase.
		3. Shopping patterns vary according to the demographics.
		4. Technology adoption. The population's age is a driver for online shopping.
Businesses	2. How can private sector participation in sustainability initiatives be fostered without affecting their cost bottom line?	1. Technology adoption is to attend to customers' needs.
		2. Digital marketing to promote the image of sustainable responsibility.
		3. Integration and collaboration with other actors in the supply chain.
		4. Logistics and inventory management.
Carriers		1. Vehicle routing problem to optimize logistics.

	3. How to perform sustainable and efficient transport to serve demand and supply?	2. Automation, electrification, and shared mobility for curbside management
		3. Micro-hubs and alternative delivery methods to attend rush/expedited delivery services
Government institutions	4. Engage stakeholders in sustainability efforts	1. Decarbonization policies and plans.
		2. Incentives for new vehicle technologies.
		3. Comprehensive plans to integrate UFS into equity and land-use policies.
		4. Collaboration and cooperative strategies.

Innovations and mitigation strategies

To address the environmental, health, safety, and equity challenges associated with the UFS, various stakeholders have proposed, studied, and implemented strategies as potential tools for enhancing UFS sustainability. These strategies can be broadly categorized into strategic planning, cleaner technologies and materials, good organizational practices, and governance actions. A comprehensive overview of these strategies and their potential benefits is provided in Table 2.

Table 2. Innovation and mitigation strategies of UFS

Strategy type	Strategy	Challenges	Benefits
Strategic planning	Management commitment	1-4	Reduction of operational cost. Improve economic performance. Positive attitudes from consumers.
	Eco-routing planning	2-4	Fossil fuel consumption: -12% to -33%. Reduction of GHG and urban pollution.
	Urban consolidation centers	2-4	Route length: -15% to -35% Pollution: -11% to -21% Operational costs: -2% to -24%
	Parcel-self collection	1-4	Travel time: -50% to -60% Dwell time: -33% Operational costs: -11% CO2e emissions per delivery: -1.75% to -2.5%
	Sharing economy for freight vehicles	1-4	Operational costs per detour: -9 to -37% Trip length: -1.6 km More job opportunities
	Alternative delivery strategies for the last mile	1-4	GHG: -9% to -30% when using drones.
	Curbside management	2-4	Reduction in parking fines. Safer behavior. Reduction in search and walking time. Improvement of parking access. Reduction on delivery trips. Balance supply and demand for parking.
	Ensure safety	3, 4	Reduction in fatalities. Reduction in UFS costs. Satisfaction of public expectations.
	Zero-emission vehicles and automation	2, 3	Improvements in efficiency and safety. Fuel savings.

Cleaner technologies and materials			Operational cost reduction.
	Zero-emission zones	2-4	Freight emissions: -15%
	Green packaging	1, 2	Waste reduction Reuse of packaging materials
Good organizational practices	Adoption of standards, certifications, and sustainability reporting.	2-4	Pollutant emissions: -2% to -5%
	Horizontal collaboration	2-4	Reduction of distribution costs Improved customer service
Governance	Freight resilient, efficient, and sustainable land use practices	2-4	Improved efficiency of urban freight. Mitigation of environmental externalities.

Recommendations

This document outlines a series of targeted recommendations aimed at effectively addressing the critical challenges surrounding UFS sustainability:

1. **Integrated land-use planning:** To bolster UFS sustainability, practitioners and planning organizations should elevate the importance of UFS within land-use planning activities. This involves identifying logistical spatial patterns, analyzing market shifts, and understanding evolving consumer shopping behaviors. Assessing past policies and strategies incorporating environmental and economic sustainability metrics is crucial. This approach ensures readiness for the sector's green transition shocks.
2. **Harmonized framework for assessing UFS sustainability:** The absence of a unified evaluation framework for UFS sustainability underscores the need to define clear metrics encompassing all dimensions of sustainable operations within the UFS. Defining such metrics will equip stakeholders with transparent and objective frameworks for informed decision-making.
3. **Efficient parking and infrastructure management:** A multifaceted approach is essential for optimizing parking and infrastructure management in the UFS. Initiatives encompass educational programs, expanded loading/unloading bays, dynamic parking pricing strategies, sharing data on parking availability, and rigorous analysis of freight trip generation. Simultaneously, leveraging emerging technologies such as autonomous trucks and unmanned aerial vehicles (UAVs) and incentivizing zero-emission vehicles (ZEVs) are pivotal for UFS sustainability.
4. **Private sector commitment:** Policymaking should establish a regulatory framework to encourage private sector commitment to environmental concerns. Encouraging actions include eco-routing, locker installation in large residential and commercial buildings, enabling freight-on-transit operations, embracing crowd-shipping, and promoting micro-mobility.
5. **Collaborative approach and data sharing:** Collaboration is the most important factor in improving UFS efficiency. Bringing together representatives from different sectors is essential to establish a shared vision for the UFS and ensure effective communication channels for information exchange and activity coordination. Developing collaborative transport network systems, fostering mutual trust between private stakeholders and government agencies, and creating strategic information systems for data-sharing among all actors is crucial. Access to reliable, comparable data is vital for evaluating UFS sustainability and developing advanced models or tools.

Improving the efficiency of Urban Freight Systems in California

Chapter1: Introduction

The Urban Freight System (UFS) encompasses the intricate network of operations that facilitate the gathering, transportation, and distribution of goods within urban environments. They are vital for cities to thrive, enabling their functionality. The UFS components have continually evolved, responding to the evolving needs of urban residents and businesses. In an era dominated by service-focused enterprises prioritizing customer satisfaction, there has been an upsurge in the demand for express transportation and courier services. On the retail front, supply chain management strategies have shifted from maintaining extensive inventories to embracing a just-in-time supply culture (*18*). This shift highlights the growing reliance on the UFS for efficient and timely goods transportation.

While the transformation of demand and supply dynamics has noticeably impacted how urban logistics operates, it has also affected air quality, land use, and the pressing issues of traffic congestion and pollution. Beyond these concerns, truck operation and loading and unloading goods are often accompanied by significant noise pollution and safety issues, especially for vulnerable road users, such as pedestrians, bicyclists, and motorcyclists. These problems have contributed to a negative perception of freight systems within communities. Many view the interaction between urban residents and freight in cities as a substantial health and safety hazard. Furthermore, the increasing demand for limited urban land caused by the expansion of freight-related activities frequently creates tension between freight and non-freight stakeholders (*19*). As a result, communities often remain indifferent to freight systems' needs as the city and the freight industry continue to grow and evolve.

Realizing a vision of an efficient and sustainable UFS is challenging. The surge in e-commerce has dramatically transformed the structure of demand and supply chains by introducing numerous additional components. What initially consisted of producers, distribution centers or wholesalers, retailers, and consumers has expanded to include additional upstream and downstream distribution layers, such as micro-consolidation centers and delivery lockers, as depicted in Figure 1 and Figure 2.

In the current landscape, achieving efficiency and sustainability necessitates comprehensively examining each facet within the intricate demand and supply chain of UFS and city logistics. This document aims to pinpoint the inefficient links in the chain, unveil the underlying causes of these inefficiencies, and devise interventions and operational strategies to mitigate them. Over the past decade, numerous researchers have delved into this domain, proposing, testing, and implementing various technical innovations and strategies at the national level to improve the system. These innovations encompass an array of initiatives, including assessing the sustainability of alternative vehicles like cargo bikes, deploying zero-emission vehicles for last-mile delivery, implementing urban goods consolidation strategies, technological advancements in routing and planning, and formulating related policies.

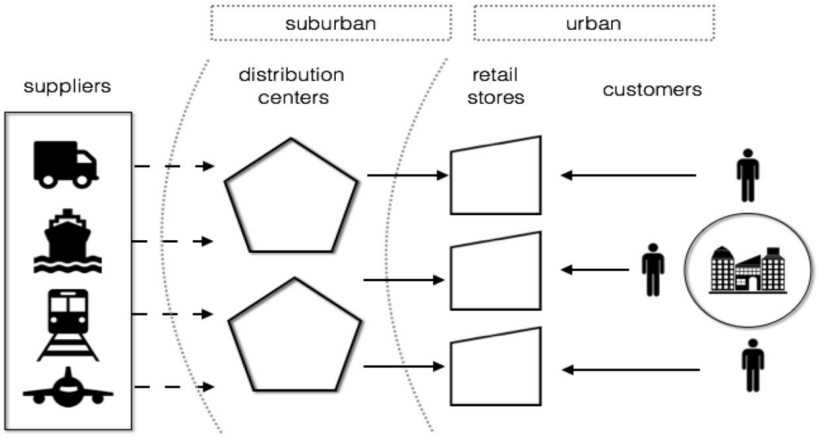

Figure 1. Traditional retail distribution (20).

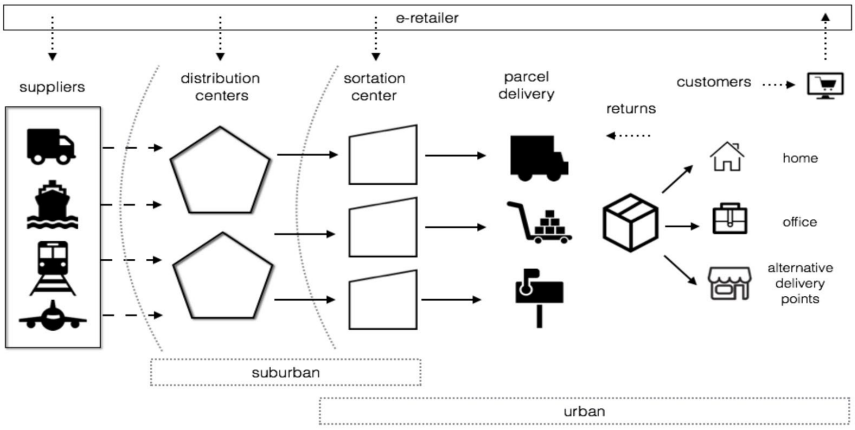

Figure 2. E-retailer distribution (20).

This white paper seeks to highlight these ongoing efforts by consolidating critical literature on the environmental impacts of UFS, which encompasses the analysis of recent trends and challenges of various supply chain actors. This review includes exploring the impact of e-commerce on the structural dynamics of the supply chain and travel behaviors, as well as the sustainability challenges associated with the existing last-mile delivery system. Additionally, it analyses the influence of prevailing land use structures on UFS and vice versa. Furthermore, the paper discusses emerging trends that have the potential to reshape the system and provides an overview of the strategies, initiatives, and policies that are impacting this landscape. Ultimately, it identifies the strategies that can improve the efficiency of UFS within the context of California.

In the state of California, various policies and strategies, such as the Sustainable Freight Action Plan (CSFAP) and the Freight Mobility Plan, have predominantly centered on specific facets of freight transportation, such as long-haul and international trade gateways, substantial freight facilities, and high-volume flows linked to agriculture and other industries. Although some of these documents make cursory mentions of the UFS, they have not garnered much attention. Therefore, the principal focus of this white

paper revolves around the movement of goods within urban areas, specifically in the context of last-mile delivery operations, and it does not encompass regional, inter-city, and long-haul multimodal freight, short movements of containerized bulk flows, or specific strategies aimed at enhancing efficiency at freight facilities.

Chapter 2: Urban Freight Impacts

The current trends in UFSs have represented a significant challenge in freight transportation. This situation calls for coordination between all the supply chain parties (*18*), leading freight companies to increase the size of their fleets and transport lighter truckloads, increasing vehicle miles traveled (VMT). Therefore, as a **large share of trucks is still fossil fuel-powered, it exacerbates environmental issues related to greenhouse gasses (GHG) and pollution, affecting mainly the most disadvantaged communities** (*1*, *2*). Thus, governments and organizations at the international, national, regional, and local levels are developing ambitious policies, plans, strategies, and initiatives to decarbonize freight transport while reducing the negative externalities and maximizing social, economic, and environmental benefits. These efforts consider several complex perspectives, such as technological readiness and economic feasibility, while reducing social, environmental, and economic impacts, as described below.

Environmental impacts

The UFS plays a pivotal role in modern society, ensuring the efficient flow of goods within urban areas. However, estimating the environmental impacts of UFS is a complex task, influenced by many factors that interact with one another, affecting the intensity and efficiency of the distribution of goods. These factors are contingent on demand, shaped by consumer behaviors, and supply, determined by logistical decisions made by retailers. Several elements, including returns, basket size (the number of items purchased in a single transaction), the availability of the product, and delivery options, can significantly influence distribution efficiency and cause several impacts on current society. **The most prominent concerns in current discussions about the environmental impact of the UFS center around greenhouse gas emissions (GHG), pollution, and noise.**

Combating climate change has prompted governments, institutions, and organizations to decarbonize efforts to achieve net-zero GHG emissions in the coming decades (*21*). The transportation sector, however, remains a challenge in these objectives, primarily due to its reliance on fossil fuels. In 2021, this sector **accounted for approximately 37% of global CO2 emissions**, with a substantial portion attributed to the movement of goods (*22*). Despite significant efforts to decrease GHG emissions from transportation, freight-related CO2 emissions experienced growth in 2022 and 2023(*23*).

In the U.S., the situation is very similar to the global trends. In 2022, the transportation sector contributed around 37% of the nation's total CO2 emissions (*24*). Freight operations accounted for roughly a third of this share, with trucking emerging as the primary source of freight's tailpipe CO2 emissions (*24*). Particularly in **California**, the transportation sector contributed to almost 40% of total CO2 emissions, with approximately **a quarter of these emissions attributed to freight operations** (*3*). This substantial contribution underscores the pivotal role of freight in GHG emissions, mainly driven by the significance of on-road freight transportation in daily activities. **Last-mile deliveries**, for instance, bear a considerable responsibility, as they **can represent about 40% of energy consumption and emissions** (*4*, *5*). Moreover, on-road freight transportation, the primary method for moving goods within urban areas, produces higher average CO2 emissions than other transport modes, excluding air cargo (*25*). Moreover, parcel deliveries

exacerbate the environmental impact of transportation since they involve the circulation of more trucks and buses in urban areas, which increases travel time and delays. Emissions are estimated to range between 0.880 and 3.400 kgCO2e per product (*26*).

The dependence on fossil fuels in the UFS establishes it as a significant GHG emitter and positions it as the primary source of urban pollution (*22*, *27*). The concentration of UFS activities in urban areas exacerbates air quality concerns, leading to adverse health outcomes in the population, including respiratory issues, tissue damage, and premature mortality (*28*).

In the U.S., although UFS vehicles account for only around 20% of urban traffic, they are responsible for over 50% of certain pollutants, such as NOx (*29*), and more than 30% of the volatile organic compounds (VOCs), as well as 20% of particulate matter (PM), including black carbon (*30*). The emissions rate of some pollutants, in grams per mile, are detailed in Figure 3. Furthermore, the California Air Resources Board (CARB) estimates that **over 90% of California residents are exposed to polluted air at some point during the year** (*7*). The issue of PM2.5 has become concerning, with five Californian cities (Bakersfield, Fresno-Madera-Hanford, Visalia, Los Angeles-Long Beach, and San Jose-San Francisco-Oakland) ranking among the highest in the U.S in 20219. for concentrations of this pollutant according to the American Lung Association (*31*). While factors like wildfire seasons contribute to this problem, vehicular emissions, particularly those related to UFS operations, play a significant role.

Figure 3. Pollutant emissions of vehicle segments in grams per mile [g/mi]. Data from: (24)

Efforts to address the emissions associated with transportation operations have led to more stringent emissions standards in the vehicle market. This has resulted in the reduction of vehicles' emission rates. For example, emissions linked to on-road freight transport have seen a 70% reduction between 2000 and 2020, including a decrease in PM emissions (*24*). However, it is essential to note that these standards primarily focus on tailpipe emissions, while other PM sources, such as brakes and tires, are growing in relevance. Projections suggest that 2030 emissions related to these elements may account for approximately 75% of the total PM emissions originating from on-road freight (*24*). This shift highlights the evolving nature of the environmental challenges tied to UFS.

Social and health impacts

In addition to emissions, UFS impacts noise pollution, emerging as a prominent health concern due to its adverse effects on human health, including sleep disorders and cardiovascular diseases (*32*). While road freight operations are not the sole contributors to urban noise exposure (*10*), numerous factors can contribute to this phenomenon. Nevertheless, according to the Noise Pollution map generated by the US Bureau of Transportation Statistics, trucks contribute up to 80 dB of noise levels in significant cities (*33*). Additionally, **trucking operations can produce noise levels that exceed the WHO's recommendations by about 32%** (*8*). Despite concerted efforts to address these environmental impacts, **the challenges posed by UFS are expected to persist and even grow** (*34*). This trend is driven by urban development and consumption (*6*, *35*), boosting urban freight shipments and increasing truck traffic in urban areas (*35*, *36*).

As urban freight and last-mile delivery services extend, so do the associated negative externalities. These include increased air pollution, contributions to climate change, noise pollution, traffic congestion, and a rise in traffic crashes (*37*). These externalities can have significant implications for the well-being of local populations, giving rise to equity concerns related to freight operations. In 2019, for instance, nearly **99% of the world's population resided in areas that failed to meet air quality recommendations** set forth by the World Health Organization (WHO) (*38*). In the U.S., 2018 statistics reveal that nearly 40% of the population resided in areas characterized by unhealthy air quality (*39*). Also, in some counties within California's Southern region, pollution levels exceeded federal standards for three consecutive months in the same year (*39*). Communities affected by these externalities experience various health issues, including elevated cancer risks and increased instances of cardiac and respiratory diseases (*11*). Much of this can be attributed to elevated levels of fine PM, ozone pollution, and noise pollution associated with urban freight activities. These health risks can become more pronounced near freight facilities and distribution hubs (*40*). The demand for these facilities has surged, potentially intensifying health risks for nearby communities (*41*), especially for vulnerable populations such as children (*42*).

In California, disadvantaged areas often host a concentration of warehouses and distribution centers (W&DCs) (*1*), amplifying the disproportionate impacts on already disadvantaged communities (*11*). Moreover, **the increased flow of freight vehicles within urban areas exacerbates the unequal distribution of negative externalities associated with the UFS** (*9*). These communities, located near pollution and noise sources, face additional burdens related to poverty, nutrition, and education (*2*, *10*).The surge in freight activity within urban centers also disrupts traffic flows and exacerbates urban congestion, creating safety hazards and road conflicts. **Truck traffic alone contributes to approximately 17% of congestion costs in the United States (U.S.), with 7% of this congestion occurring in urban areas** (*43*). As freight vehicles compete for road space with vulnerable road users, the potential for conflicts increases, particularly with changing spatial patterns of freight delivery. Between 2009 and 2015, crash rates occurring on local roads and arterials surpassed those in interstates, raising concerns for the safety of vulnerable road users while e-commerce and urban freight activity continued to increase (*41*). Statistics from the Insurance Institute for Highway Safety (IIHS) reveal that over 4,000 fatalities resulted from large truck crashes nationwide in 2020, with **16% of these fatalities affecting vulnerable road users, such as pedestrians, bicyclists, and motorcyclists** (*44*).

Economic impacts

The UFS is a cornerstone of the global economy, facilitating the seamless movement and exchange of goods. Its relevance is closely linked to the economic activity of retail, which **constitutes the most significant economic sector, contributing to approximately 9% of the global Gross Domestic Product (GDP) and indirectly influencing roughly 20% of global GDP** (*45*, *46*). Retail generates nearly 12.1% of the value-added GDP (*47*, *48*). Beyond its economic contribution, the retail sector is the world's largest private employer, providing over 150 million employees globally (*45*, *46*).

While the UFS fuels economic development, the freight transportation industry finds itself at a crossroads, shaped by a dynamic interplay of challenges and opportunities driven by generational shifts in the workforce and the rapid development of new technologies (*48*). In California, a set of factors adds complexity to this scenario. **High living costs, insurance expenses, regulatory burdens, inexperience, insufficiently qualified personnel, and the lack of parking facilities are exacerbating shortages of drivers and high turnover rates in the freight transportation sector** (*48*). Furthermore, elements such as California's Assembly Bill 5 (AB5) (*49*) stricter criteria for classifying workers as independent contractors and the expansion of automation in the freight sector (*50*) have raised concerns about its potential impact on the trucking industry, particularly regarding the possible loss of drivers and its effects on urban goods transportation. However, these workforce-related challenges are not the unique complexities of this industry.

The pollution generated in urban areas makes the transportation sector a significant contributor to public health costs (*11*, *51*). According to the WHO, air pollution, primarily driven by transportation, ranks as the fourth leading cause of premature mortality worldwide (*51*). In the U.S. alone, it leads to approximately 107,000 premature deaths annually (*52*). In 2014, these health-related effects cost about 5% of the national GDP (*53*). In 2020, Los Angeles presented the highest air pollution cost per capita, roughly $2,700 per person (*54*).

Last-mile deliveries are one of the critical aspects of UFS that significantly impact the economy. This segment can represent the most inefficient portion of the delivery system, accounting for approximately 40% of the total supply chain costs in the U.S. (*55*). Moreover, as last-mile delivery operations are primarily concentrated in urban areas, they create a feedback loop: **UFS exacerbates congestion, which, in turn, has a significant impact on the UFS logistics operations** (*56*). For instance, in the New York Metropolitan Area, congestion issues resulted in industry losses of approximately $8 billion, considering additional operating costs and revenue loss (*57*). Furthermore, truck congestion led to approximately $11.3 billion in fuel and travel time costs in the U.S. in 2020 (*8*, *58*).

California residents experienced an annual financial burden of roughly $28 million due to the time and fuel wasted due to traffic congestion (*13*). Moreover, **traffic crashes imposed an additional economic change, costing residents approximately $7.3 billion annually,** encompassing lost productivity within households and workplaces and other insurance and financial burdens (*13*). These challenges are expected to intensify as urban last-mile deliveries are projected to surge by 80% by 2030 (*12*).

Chapter 3: Recent Trends in Urban Freight System

How people consume and their behaviors have significantly changed in recent years. The large populations of urban areas and their extensive commercial establishments make them dependent on large quantities of goods and services for domestic and commercial purposes. In addition, e-commerce and e-marketplaces have gained significant importance, playing an integral part in businesses' advancement, expansion, and success. It is imperative to understand and anticipate the behavior of the different actors in the transaction, namely, consumers, businesses, carriers, and government, to address the challenges associated with transportation freight. The following subsections discuss recent literature trends related to those actors.

Consumers trends

Several factors influence consumer behavior when purchasing groceries. Literature reviews have identified the availability of channel strategies, sociodemographic characteristics, and technology adoption as important factors (see Figure 4). Considering the several studies on consumer behavior, the biggest challenge is:

Challenge 1: how to influence consumer's shopping habits to improve the sustainability of urban freight

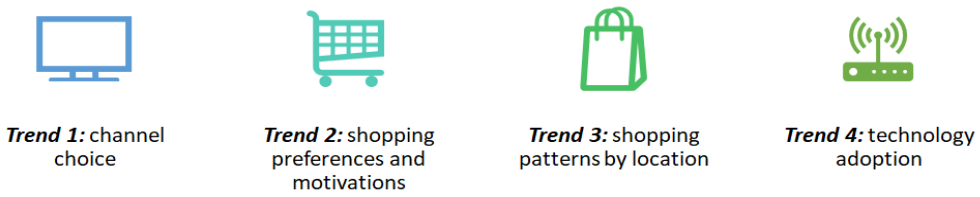

Figure 4: Examples of consumer trends

A multichannel strategy caters to diverse consumers' shopping motives. Online shopping has increased due to convenience, a wide range of product choices, competitive prices, and improved logistics and delivery services (*14*). In 2019, e-commerce sales in the USA totaled around $571 billion, accounting for around 10% of all retail sales (*59*, *60*). This marked a significant increase from approximately $443 billion in 2017, as shown in Figure 5.

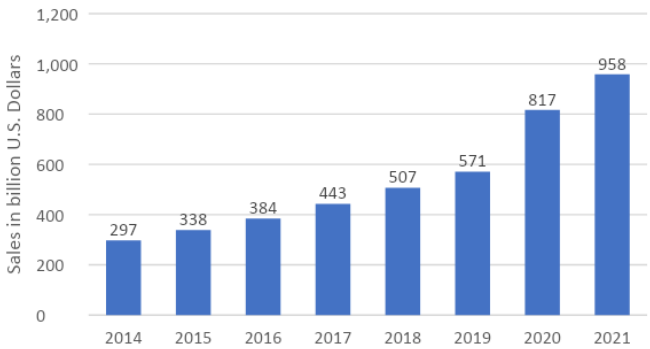

Figure 5: Retail e-commerce sales in the US from 2014 to 2021 (59)

The advent of the **COVID-19 pandemic further accelerated this online shopping growth**. While lockdown and social distancing were significant contributors to the sudden popularity of online shopping, the steep increase in e-commerce sales, especially in the early months of the pandemic (31.8%), can be attributed to opportunistic buying (*61*). Customers started stockpiling daily essentials, groceries, healthcare products, etc. The results of the COVID-19 Mobility Survey, administered by the Institute of Transportation Studies in Davis, showed a fivefold increase in respondents who shopped online at least once a week between fall 2019 and spring 2020 (*62*). Perceptions of threat and scarcity primarily drove this behavior, and individuals sought to establish control and alleviate anxiety (*63–65*). Consequently, urban freight systems and the supply chain structure are severely strained.

Several studies developed during the pandemic exhibit online shopping preferences (*64*, *66–69*). Restaurant deliveries were the predominant commodity purchased mainly by people from urban areas under the age group of around 25 and earning more than 100K annually (*69*). It is expected that online shopping will likely be fueled by the continued utilization of online food shopping services and customer loyalty towards delivery subscription services like Amazon Prime (*64*, *66*, *67*). Additionally, online shopping is preferred for electronics, books, and entertainment, while store shopping is preferred for groceries and household essentials (*68*). There was a relatively high preference for fast or expedited delivery services followed by the standard delivery service amongst people from suburbs and small towns aged 25 -35 years and earning more than 100K annually. On the other hand, locker pick-up seems to be the least frequently used type of delivery (*69*).

As non-traditional channels (such as the Internet) are now more widely available, **it has become more relevant to analyze the dichotomy between utilitarian and hedonistic shopping motivations that determine the selection of channels** (*70*, *71*). Some findings indicate that the online potential of some product categories remains untapped (*72*). When purchasing groceries online, consumers hesitate due to the lack of sensory cues, particularly haptics (*73*, *74*). Despite technological advances, there is still a sensory gap in online channels since technology hasn't replaced touch (*75*). However, when consumers create a mental representation of a product, the presence or absence of the touch dimension does not affect their purchase decision (*76–78*). Research shows that a sensory stimulus such as sight or sound is more important than touching food (*79*), meaning that touch plays a minor role when other senses are stimulated (*78*). In virtual reality and augmented reality, as well as mobile shopping gamification, new research gaps are emerging that need theoretical and empirical studies to be addressed (*71*) since this technology will affect shopping decisions.

Besides shopping online and in-store, there is an intricate relationship that depends on consumers' preferences and shopping habits; **some locations experience varying levels of online and in-store shopping activity** (*80*). Several factors contribute to these differences, including consumer behavior within the regions, the topology of distribution structures, and the population's demographic composition (*80*). For instance, online shopping growth patterns vary by metropolitan area. Then, as more traffic is evenly distributed and public transit use increases (such as Washington D.C., Chicago, and NYC), the share of online shopping might continue to increase, while in metropolitan areas dominated by passenger cars (such as Los Angeles and Dallas), online shopping decreased VMT (*80*).

Businesses trends

Businesses usually refer to companies, such as manufacturers, wholesalers, or retailers involved in sales transactions. Several efforts are involved in supply chain logistics, primarily focusing on raising profits and reducing operational costs. Due to this, the biggest challenge is:

Challenge 2: fostering private sector participation in sustainability initiatives without affecting their cost bottom line.

Figure 6. Business trends from the literature

Increasing customer expectations have spurred innovation in retail business models considering technology adoption, supply chain integration, logistics challenges, and digital marketing strategies (*81*) (see Figure 6). These innovations mean higher operating costs that can cause retail businesses to fail, further contributing to lower retail property values (*82*). Retailers who have not already adopted advanced digital business have been affected. When a new fulfillment center is established in the vicinity, the National Bureau of Economic Research states an approximate 4% decline in sales for an average brick-and-mortar retail store (*83*). Consequently, increasing home deliveries and other delivery alternatives (e.g., parcel lockers) modifies last-mile operations, impacting capacity, traffic flows, transportation volumes, the environment, road safety, and load factor (*84*, *85*). The net effect of increased freight traffic for home deliveries depends on various factors such as personal shopping substitution rates, the types of vehicles used for those trips, distance traveled, and the efficiency of the distribution network. The effects include impacts on traffic levels, infrastructure requirements (e.g., parking), and conflicts with other users.

Digitalization can affect all dimensions of business models, including value creation, value delivery, and value capture. Therefore, some companies have adopted digital technologies to get more tailored and personalized products and services and understand the market niches that can be expanded and where they should invest, resulting in mutual influencing (*15*). Artificial Intelligence for capturing customer behavior, chatbots that generate responses, and virtual reality to enhance the customer experience are some innovations that impact consumer decisions (*81*). Consumer search within the platform must be governed by a sub-optimal algorithm that balances the cost of platform fees against the volume of transactions (*86*). In addition, sustainability social media communication is especially prone to *greenwashing,* promoting a false image of responsibility (*87*). As a final point, despite the benefits of technology, its rapid development requires a workforce with specific skills to enhance the company's competitiveness and manage the complexities of a global supply chain (*88*).

The literature also emphasizes the importance of ecosystem partnerships and strategic alliances in creating a robust local economy, in addition to digitalization. Key aspects include: i) local logistics service

providers increase horizontal collaboration (*89*) relations among manufacturer-wholesaler and wholesaler-retailer (*90*); ii) collaboration can lead implementation of strategies improving the sustainability performance in the supply network (*15*); iii) It may also be beneficial for small food companies to develop supply chain collaboration, both through the development of interfirm relationships and the exchange of information, to access more coordinated supply chains in which procurement, distribution, and phased service phases can be managed together (*91*). The biggest challenge in the cooperation is that there are no clear strategies for forming these ecosystems (*81*).

Companies must address two significant societal challenges: environmental restrictions and unforeseen events, such as pandemics and conflict (*92*). As environmental restrictions become more stringent worldwide, eco-friendly management is becoming increasingly important. Consequently, today's energy consumers must consider operational costs and carbon emissions when purchasing energy (*92*). Also, complex supply chain problems result when multiple tiers and stakeholders are involved in enhancing the efficiency and sustainability of supply chain operations (*92*). Concerns relating to the environment include food waste during the supply chain, packaging processes (such as cleaning, drying, and preserving), and materials used in packaging (*15*). The other societal challenge is the uncertainty resulting from various risk sources, such as environmental, network-related, and organizational, highlighting risk drivers and risk mitigation strategies, which can be avoided, controlled, cooperated, and accommodated (*93*).

Demand forecasting is an essential trend in the literature to anticipate customers' needs, manage inventory and in-store shelves, and ensure a continuous supply of products (*94*). Currently, technology is profoundly influencing and transforming the retail sector of food and groceries to address the above issues and take advantage of new opportunities related to online retail operating models that combine rapid digitalization with local geography and consumer behavior (*95*). Consequently, new business models, such as ghost or dark kitchens–those businesses that serve customers exclusively by delivery and pick-up based on phone and online channels–are being introduced. Several challenges are associated with this emerging field, including the need to sharpen behavior traits to support operational activities, stakeholder support, regulations, and urban implications (*96*, *97*).

Carriers' trends

The last mile refers to the final link in e-retail distribution that connects sortation centers or fulfillment centers to customers through delivery at their residences or other collection points. The last mile is often the least efficient and most expensive part of the supply chain, especially for companies engaged in e-commerce and couriers (*98–100*). Transfer of goods in the last mile is inefficient, complex, and expensive for several reasons, including the nature and number of logistics activities performed during the transaction, the availability of parking/staging areas, curbside access, building/store access, customer readiness, among others (*101*).

Figure 7 illustrates some of the most important trends related to carriers. Advanced information systems can facilitate logistics and transportation optimization in urban areas. This optimization deems factors such as traffic environment, congestion, safety, and energy savings, all within the context of a market economy (Taniguchi, 2014). Therefore, **distribution network management is one of the most crucial**

trends in the supply chain, which involves: 1) Vehicle Routing Problems (VRP) focus on addressing the problem of organizing delivery routing patterns without incurring additional costs (*16*), and the routing organization in an urban context in which there are several constraints due to regulations and to daily retail operations (*102*, *103*); and 2) the Inventory Routing Problem (IRP) deals with the integration and coordination between these two aspects for minimizing the distribution costs.

Challenge 3: Perform sustainable and efficient transport serving demand and supply under policy requirements

Figure 7. Carrier's trends from the literature

Adding to it is the trend of expedited delivery services. E-commerce channels offer faster and free delivery services and free returns for certain products at a slightly higher cost to capture more customers. This leads to the deconsolidation of goods and poor vehicle utilization in the last-mile operations. It also produces high emissions and operational costs for the retailer (*104*). Further, e-commerce players now offer the option of selecting specific time delivery windows, which makes it harder for carriers to plan optimal routes that meet the time constraints. Sometimes, delivery windows aren't met, or consumers aren't accessible during delivery, resulting in failed delivery attempts. Due to the increase in online purchases and multichannel management, researchers are striving to solve the vehicle routing problem (*16*, *105*, *106*).

California has a large and increasing urban population, and in 2010, 95% of the California population lived in urban areas (*48*). This has led to a sizable increase in home delivery packages and consequently increased freight flows and truck traffic in urban centers (*107*, *108*). **Regulatory constraints and a lack of dedicated logistics infrastructure like curbside access and parking spaces worsen it** (*14*). Carriers travel longer distances in search of parking to deliver products to consumers, directly resulting in larger VMTs and emissions. The absence of proper curbside access at commercial establishments also serves as a safety hazard to other road users. In addition, carriers park farther away from the delivery establishment or are forced to park illegally and pay hefty parking fines (*109*, *110*). Local authorities also regulate truck routes and parking zones for trucks (*110*). Since the penalties are imposed on the carriers, this represents a market failure due to carriers being forced by the receivers to be at a particular place and a specific time. Therefore, some research has focused on evaluating the implementation of automation, electrification, and shared mobility strategies to mitigate this failure (*101*).

Several delivery strategies have been implemented to meet the needs of consumers. App-based delivery platforms have recently emerged, generating several challenges that must be addressed. These include market conditions under which crowd-shipping services were discovered as an option; independent contractors or platform employees' working conditions or formality; trust, reliability, and the level of

service; the impact of the service on society, the environment, and equity; requirements and conditions for infrastructure and systems; pricing and payment strategies (*111*). For final last-mile delivery, low-pollution, low-volume vehicles such as cargo bikes are other strategies widely discussed in the literature (*111*). Its primary advantage is its flexibility in the distribution structure, resulting in a shorter time window. Its main challenge, however, is the critical performance for the share of packages served via micro-hubs and collection points (*111*). Electrifying light commercial vehicles is another trending topic related to low-pollution strategies highly promoted by policies. One concern is the technological innovation required to mitigate adverse impacts such as mineral resource scarcity (*111–113*). A customer pickup at a collection point is also an alternative to home delivery and is considered more sustainable (*111*, *113*). Nonetheless, further research is needed regarding the type of customers who choose to self-collect and the conditions under which pickup points can reduce net carbon emissions (*113*).

Governance trends

Public institutions are responsible for land use planning, economic development, and the administration of financial mechanisms (*114*). Furthermore, its role is crucial to developing freight transportation policies, which present several challenges. The most important one in terms of urban freight is:

Challenge 4: Engage each actor in sustainable efforts.

Figure 8: Governance trends from the literature

Decarbonization policies have been the most significant trend in the transportation sector in the past decade, as Figure 8 shows. According to the literature, reducing carbon intensity is the primary policy objective of climate action (*115*, *116*). For instance, following the California Air Resources Board's Scoping Plan for Achieving Carbon Neutrality (*116*), the State proposes a sector-by-sector plan to reduce its dependence on petroleum as part of its climate target to attain carbon neutrality by 2045 or earlier. The second goal of policymakers is to align electrification rates with the pace of decarbonization in the power sector (*115*). In response to these policies, industries are taking a more active role in reducing emissions, primarily due to the impact they have been recognized for (*115*)

Nevertheless, concerted efforts are needed to improve the electricity grid mixed with green energy policies. It will provide a clear policy roadmap for encouraging broader adoption of environmentally friendly and economically viable last-mile delivery vehicles for fleet operators seeking to balance cost-effectiveness and environmental sustainability (*112*). Adopting green sources such as hydrogen and battery electric vehicles represents another policy objective. Policy measures and incentives are still required to promote low-carbon vehicle adoption and overcome market barriers (*117*). Also, carriers and freight stakeholders must contribute substantially to this transition.

Adopting new technologies to improve efficiency and sustainability is another crucial critical pathway. Several significant developments in trucks and light vehicles have occurred, such as automated freight routes (especially for long-haul), electric cargo bikes, and warehouse automation (*101*). Despite these technological developments, some barriers still prevent the widespread diffusion of these devices, especially when referring to the potential impacts on employment and quality of jobs (*50*). No laws or policies allow them to operate freely (*101*).

A lack of equity and mobility justice in urban freight systems has resulted in an imbalance of power within the transportation decision-making process. Apart from the primary social benefit derived from freight as a source of sustenance for the city, there are also multi-scalar inequalities caused by unattended aspects of the system (*17*). **A comprehensive urban freight plan incorporating freight activity along the supply chain, vulnerable road users, particularly in disadvantaged neighborhoods, and the working conditions of truck and van drivers, dock workers, and fulfillment centers can improve equity and accessibility** (*17*).

As part of efforts to improve freight transportation, **several strategies have been developed to provide planners with specific strategies to incorporate into their programs and projects**. For instance, the California Sustainable Freight Action Plan includes a series of white papers developed by academics, industry, and government experts (*118*). Several issues are discussed in these papers, including funding strategies for optimizing asset utilization, planning, and policy processes for improving efficiency, technological opportunities, and suggestions for improving information systems (*118*). Despite this, planners do not always consider these recommendations since they do not constitute a mandatory policy.

As a critical driver of urban development, land-use management can facilitate the seamless integration of freight activity across urban, suburban, and rural areas (*119*). The possible impacts on supply chains and freight activity should be considered when formulating land-use planning and policy. There have been a few efforts to integrate freight into land use planning. For example, as required by Assembly Bill 14, California develops a freight plan, updated every four years according to the Infrastructure Investment and Jobs Act (*120*). However, some regional plans do not consider those initiatives and policies. In addition, researchers have been providing some tools to minimize private and external impacts incurred when goods are produced, transported, and consumed. For instance, freight-efficient land uses (FELUs) are proposed as a guide for designing policy procedures for planners (*119*)These strategies allow land-use and transportation agencies to pursue innovative and effective initiatives to support achieving their goals.

For each strategy to be practical and feasible, complementary strategies may be required (e.g., sponsored programs for acquiring technologies, incentives to encourage behavioral changes, and funding for capital investments). Collaboration and cooperative strategies are particularly suitable for this. **In the freight industry, collaborative and cooperation agreements have long been practiced, either through the sharing of information and knowledge or through the sharing of physical assets** (*121*).

Chapter 4: Innovations and Mitigation Strategies in Urban Freight Systems

Multiple innovations have emerged in response to urban freight systems' environmental, health, safety, and equity-related concerns. Solutions to UFS-specific problems can be broadly categorized into strategic planning, cleaner technologies and materials, best organizational practices, and governance actions. It is important to note that these practices are interconnected. The depiction of problems and solutions differs based on which stakeholder perspectives are considered: demand side, supply, or the physical environment regulated by the local government (Kiba-Janiak et al., 2021). These actors must take specific actions to mitigate the impact of UFS, as described in the previous chapter. This chapter proposes fourteen pillars that comprise key strategies for effective freight sustainability implementation (see Table 3).

Strategic planning

The first step in advancing from conventional systems to sustainable ones is management commitment. In addition, managing supply chains effectively requires collaboration, which enables organizations to coordinate activities, share information, and achieve mutual objectives. However, since shopping behavior is dynamic, different business models have emerged in the last decade, making fostering sustainability more challenging. Some strategies proposed in the literature include outsourcing delivery through crowd-shipping platforms, setting up micro consolidation centers or micro-hubs near urban developments, using alternate delivery locations or pick-up points instead of delivering to homes, and using transit to move freight. These strategies show the potential to make last-mile delivery sustainable by reducing the number of delivery trucks in urban environments and by reducing emissions. More details about the planning strategies are presented in Appendix 1.

Cleaner technologies and materials

The pressing need to combat climate change and the accompanying air quality concerns tied to the transportation sector has pushed the development of transformative, enduring solutions to diminish the sector’s reliance on fossil fuels. UFS has not been exempt from these compelling trends, and various technologies and materials have been systematically advanced and promoted as strategies to curtail the environmental, social, and economic externalities linked to this sector.

Adopting zero-emission vehicles for last-mile deliveries has been deeply explored among various strategies. Technologies like electric vehicles and cargo bikes have emerged as promising solutions to enhance the environmental performance of UFS. Furthermore, automation has been proposed as an innovative alternative, serving the dual purpose of reducing fossil fuel consumption and streamlining the routing process to elevate delivery efficiency. Finally, endeavors to enhance materials and minimize waste are also gaining prominence as viable alternatives, intending to mitigate the environmental impacts from a packaging perspective (see Appendix 2. Cleaner technologies and materials).

Table 3. Innovative Urban Freight Transportation pillars.

Type	No	Pillars	Short - description
Strategic planning	1	Management Commitment	The private sector's highest-level management directly participates in environmental and efficiency initiatives.
	2	Route optimization	Optimal routing for reducing travel time/distance and fuel consumption/emissions.
	3	Consolidation management	Combining multiple shipments into one last-mile delivery.
	4	Delivery management	Management of the last-mile movement of goods using technology, economic sharing, and environmentally friendly solutions.
	5	Ensure safety	Reducing fatalities and serious injuries on all public roads.
Cleaner technologies and materials	6	Low and zero-emission technologies	Technologies that emit null or low levels of greenhouse and pollutant emissions.
	7	Recycling, Reuse, and adopting Green Packaging	Materials and manufacturing techniques that reduce energy consumption and the environmental impact of packaging.
Best organizational practices	8	Tracking of fleets	A fleet management system uses GPS tracking to monitor vehicle and asset activity.
	9	Infrastructure intervention and modernization	Enhancement of mobility and safety through modernization and digitalization of road-based technologies
	10	Sustainability Reporting	Communication of a company's progress and efforts toward its environmental, social, and governance goals.
	11	Standards & certifications	Ensuring social and environmental accountability, transparency, and public transparency.
	12	Training and Education	Training professionals and consumers aimed at reducing the environmental impact of freight.
	13	Network collaboration	Collaboration with supply chain stakeholders and transportation planners to reduce transportation costs and improve environmental and economic sustainability.
Governance strategies	14	Freight efficient land use practices	Land use strategies for efficient movement of goods within the overall urban planning framework.

Best organizational practices

Governments, supply chain actors, researchers, and societies are all motivated to promote sustainable practices in their organizations as part of the United Nations' sustainable development agenda. Several logistics companies are adopting sustainable performance standards to achieve this goal, as Appendix 3. Best organizational practices shows. These practices include the development of practical certification and other assessment tools, the implementation of green sourcing practices through circular economics, continuous improvement in compliance with regulations, and the dissemination of government reports on greenwashing, sustainable companies, and practices. Furthermore, good organizational practices are contributing to the improvement of social responsibility. These strategies, including certification, circular economic adoption, and cooperation, are presented in this section.

Governance strategies

Private and social objectives are aligned because of the interconnections between supply chains, the economy, and the externalities created by freight activity. As supply chains become more efficient, the private sector will benefit, and transportation externalities will be reduced. Formulating land-use planning and policy is the best way to orient these interconnections, reducing negative impacts. Therefore, land use planning is crucial in sustainable urban freight systems, as it integrates considerations for efficient goods movement within the overall urban development framework. As outlined in Appendix 4. Governance strategies, planners can promote those practices by implementing a freight-efficient land use strategy (FELU) that minimizes the external and private costs related to the production, transportation, and consumption of goods. Moreover, e-commerce is a key aspect in the planning process due to its impact on spatial configuration and land use, especially in dense cities (*122*).

Chapter 5: Quantitative Research

Several innovations and mitigation strategies discussed in Chapter 4 of this document have already undergone comprehensive exploration and analysis in various regions across California (e.g., Southern California, Sacramento, and Bay Area). This chapter synthesizes quantitative results showcasing the enhancements achieved in UFS when these alternatives are implemented. Additionally, it encompasses the projection of emissions and VMT resulting from in-store and shopping activities across various scenarios of implementing some of these strategies. Finally, it highlights the government practices already implemented in select regions within the state.

What is the performance of the different last-mile strategies?

The performance of different last-mile distribution strategies was compared in the Los Angeles region, California (*111*). An essential component of this study is the evaluation of the efficacy of electric delivery vehicles in last-mile distribution, assessing crowdsourced delivery services, and developing a case for micro-hubs combined with cargo bikes in last-mile delivery as the rationale for customer pickups at collection points. The study also considered diverse delivery environments, with the impact of the time-window length and customer density on the performance of each strategy. In addition, the results of this study provide insight for both large and small e-tailers planning to offer higher levels of service and diversify their operations while also providing insight for traditional retailers planning for omnichannel distribution. As a result of the findings, alternative distribution strategies are more competitive than traditional diesel-truck-based door-to-door distribution methods, as Figure 9 shows.

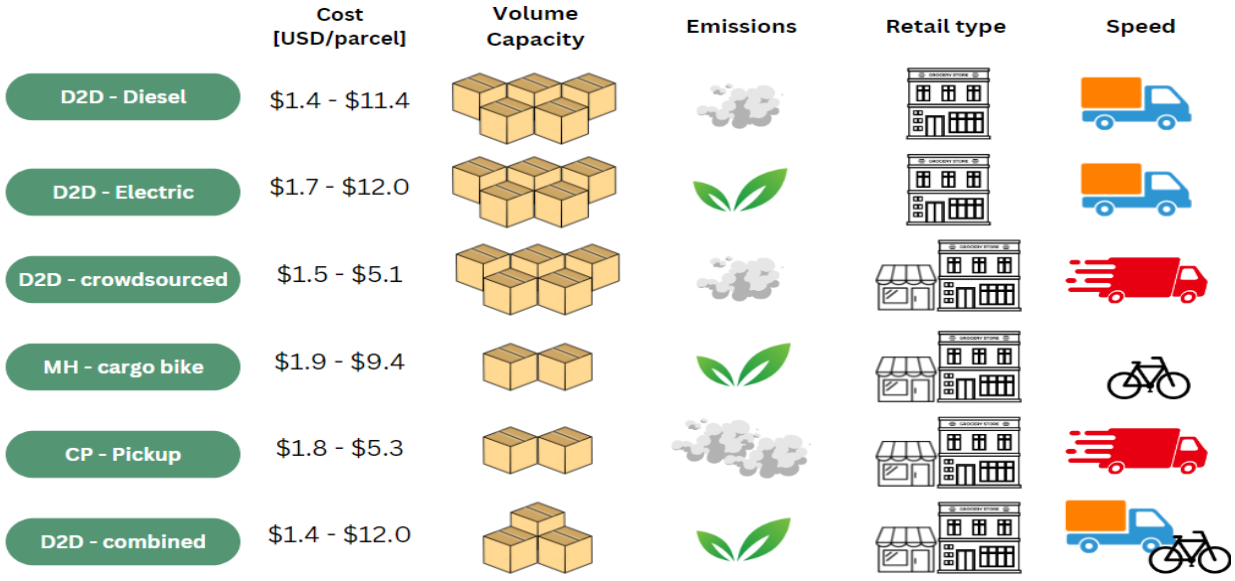

Figure 9. Key characteristics of different last-mile strategies (111)

D2D: Door-to-door, MH: Micro-hub, CP: Collection Point. For volume capacity, the number of packages represents higher or lower capacities; green leaves vs. smoke clouds represent cleaner to dirtier systems; small and larger

buildings represent the type of business location; and box trucks represent regular last-mile distribution. Red trucks refer to faster delivery services, and bikes refer to cargo bikes.

The last-mile delivery strategy of small-size e-retailers with a dedicated fleet may increase reliability. Still, it may be better for the e-retailer to outsource delivery to crowdsourcing fleets or customers for self-pickup at collection points (curbside, store, lockers). This is because small market shares and sparse customer distribution render purchasing and operating truck fleets inefficient, resulting in high distribution costs.

E-retailers can encourage crowd-shipping by raising wages or offering cheaper shipping and faster pickups. The success of collection points depends on customers' willingness to collect packages, a factor impacted by the pandemic's influence on shopping behaviors and risk perceptions. This makes it challenging for e-retailers to predict shipping or collection preferences accurately. In UFS, outsourcing strategies reduce operational costs and significantly increase emissions and VMT.

By co-locating collection points near significant traffic generators, customers would not have to travel specifically to pick up their packages, reducing their emissions by 1.75% on average. Instead of traditional door-to-door delivery with diesel trucks, splitting service between pickup points and micro-hubs coupled with cargo bikes might present a viable middle ground. Due to their ease of access and parking, cargo bikes are a great choice in the city's dense residential and commercial areas. Transitioning from diesel trucks to cargo bikes for last-mile deliveries results in a reduction of 0.62% in emissions, 0.63% in vehicle miles traveled, and a 0.72% decrease in traffic accidents on average per additional 1% of packages delivered by cargo bikes (*111*), considering about 520 grs of CO2 per package for diesel and about 410 grs of CO2 per package using cargo bikes from micro-hubs as a reference.

Electric vehicles could further reduce local pollution and distribution costs. With a 3-hour time window, the cost per package for delivery by electric vans, electric trucks, and diesel trucks is equal to or even better than for diesel trucks. Battery characteristics, vehicle range, and public charging infrastructure can have significant short-term implications for adopting an all-electric fleet. For example, the analysis indicates that fast-charging economical batteries can reduce distribution costs by up to 25% (*111*). The opportunity cost of owning an electric fleet may diminish as electric trucks steadily improve.

What are the changes in the landscape of warehouses and distribution centers in California?

Spatial analyses for Southern California (i.e., Southern California Association of Governments, SCAG, region) between 1989 and 2016-18, warehouses and distribution centers (W&DCs) patterns were compared with other demographic and environmental factors (*1*). The disaggregated analyses for Southern California markets showed a significant increase in establishments after 2002 (see Figure 10). After 2002, the number of facilities increased, and the jump in 2002 resulted from changes in the classification systems used between the Standard Industry Classification (SIC) system and the North American Industry Classification System (NAICS). In recent years, there has been a decrease in median distances between facilities and downtown areas and a decrease in average facility sizes transacted (16

meters closer to central Los Angeles every year). Similarly, the median distance of sold properties from the Port of Los Angeles decreased by 10.88 meters yearly. There has also been an increase in the number of transactions in the areas close to downtown. The Los Angeles market is responsible for about 30 to 40% of the leases registered in Southern California between 2000 and 2018. Still, when the size perspective is considered, 45.5% were in the Inland Empire, while 27.6% were in Los Angeles. Congestion at W&DCs and emissions from facilities are expected to increase due to the changes in the distribution of W&DCs. Using more and smaller facilities will result in more freight traffic if the amount of cargo is considered constant (though demand for e-commerce is increasing). It is expected that newer and cleaner vehicle technologies will mitigate some of the impacts; however, congestion, energy consumption, and accessibility, particularly at the curb, will be negatively affected by increased traffic. Several factors explain the location of W&DCs, which are characteristic of areas identified as disadvantaged. A positive correlation exists between the number of W&DCs and environmental impact indexes, although not for all criteria pollutants. Planning efforts must consider and explore the dynamic landscape further. Local and regional authorities must evaluate land use, building, and air quality strategies to minimize these impacts.

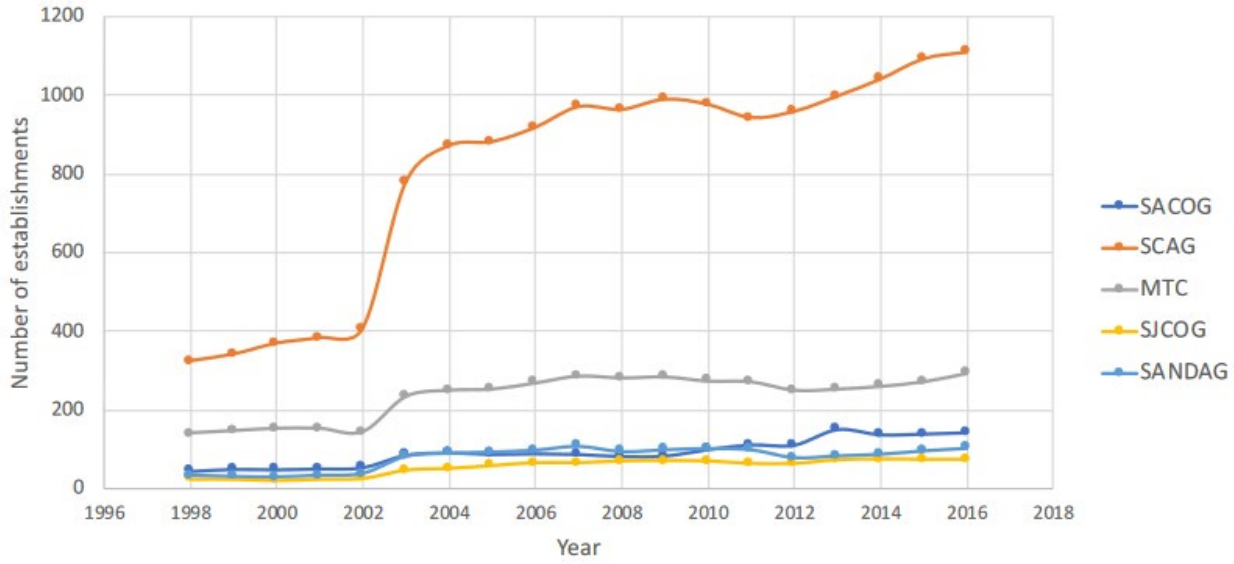

Figure 10. Changes in the number of W&DCs in five MPO regions.
The Southern California Association of Governments (SCAG), Metropolitan Transportation Commission (MTC), Sacramento Area Council of Governments (SACOG), San Joaquin Council of Governments (SJCOG), and San Diego Association of Governments (SANDAG) (1).

What to expect in the future?

Shopping trends have undergone rapid transformations over the past few decades. The advent of e-commerce, the growing demand for expedited deliveries, and the adoption of last-mile delivery strategies, such as crowd-shipping and automation, have revolutionized the operations of UFS. These changes have far-reaching consequences on Vehicle Miles Traveled (VMT), energy consumption, and emissions within these systems. A recent study (*80*) developed a comprehensive modeling framework to quantify the potential impacts of e-commerce, automation, and last-mile delivery strategies on emissions and VMT in

six major metropolitan areas in the United States, including San Francisco, Los Angeles, Dallas, New York City, Washington D.C., and Chicago for the coming decades. This study encompasses an in-depth analysis of shopping behavior, evolving shopping trends, population projections, last-mile delivery operations, and various technology development scenarios to project emissions and VMT by 2050.

Initially, the authors pinpointed key determinants influencing shopping behavior. Age, gender, income, and mobility challenges emerged as the most significant influencers. In Los Angeles, the female population presented a negative correlation with in-store shopping. In contrast, individuals residing in areas with populations less than one million were more inclined toward online shopping. This inclination can be attributed to the distribution of shopping centers, the necessity of traveling longer distances, and the higher likelihood of encountering traffic congestion when shopping in-store. Conversely, the authors assessed the influence of advancements in vehicle technology and efficiency on predicting CO2, NOx, and PM2.5 emissions, considering four distinct vehicle categories: private vehicles, trucks, public transit, and other modes of transportation.

The research findings underscore the role of population growth and demographic shifts in shaping shopping behaviors across various U.S. cities. For instance, SF is anticipated to experience a surge in online shopping, while LA prefers a blend of in-store and online shopping. These distinctive behaviors can be attributed to the demographic makeup of these cities, which includes factors such as gender, income levels, and age. These shopping trends and their forecasted externalities are shown in Figure 11. The results revealed disparities in shopping-related travel behaviors between LA and SF. LA exhibited the longest travel distances and the most extensive reliance on private vehicles, consequently contributing to a notable upsurge in VMT. Meanwhile, SF displays an escalation in shopping-related VMT, which is expected to increase CO2 emissions by 2050.

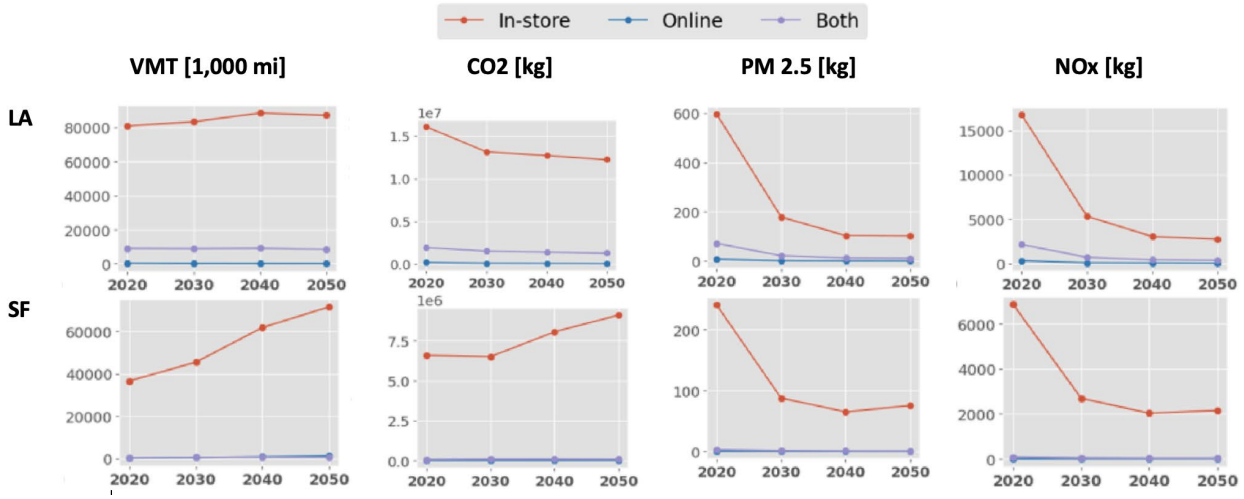

Figure 11. Estimated VMT and emissions from shopping 2020-2050 (adapted from (80))

Additionally, the study examined the impact of three key factors: a. rush deliveries, b. crowd-shipping, and c. automation of last-mile deliveries. The findings for LA are depicted in Figure 12. The findings indicate a substantial impact on VMT and emissions. High- and mid-rush delivery options are associated with an increase of nearly 300% and 200% in both VMT and emissions. Conversely, the study highlights

the positive influence of crowd-shipping when applied at different percentage levels: low (10%), medium (50%), and high (75%). In these scenarios, CO2 emissions from online shipping activities decreased by up to 50%. Furthermore, integrating automation into last-mile delivery operations could potentially reduce externalities of online shopping by up to 25% by 2050.

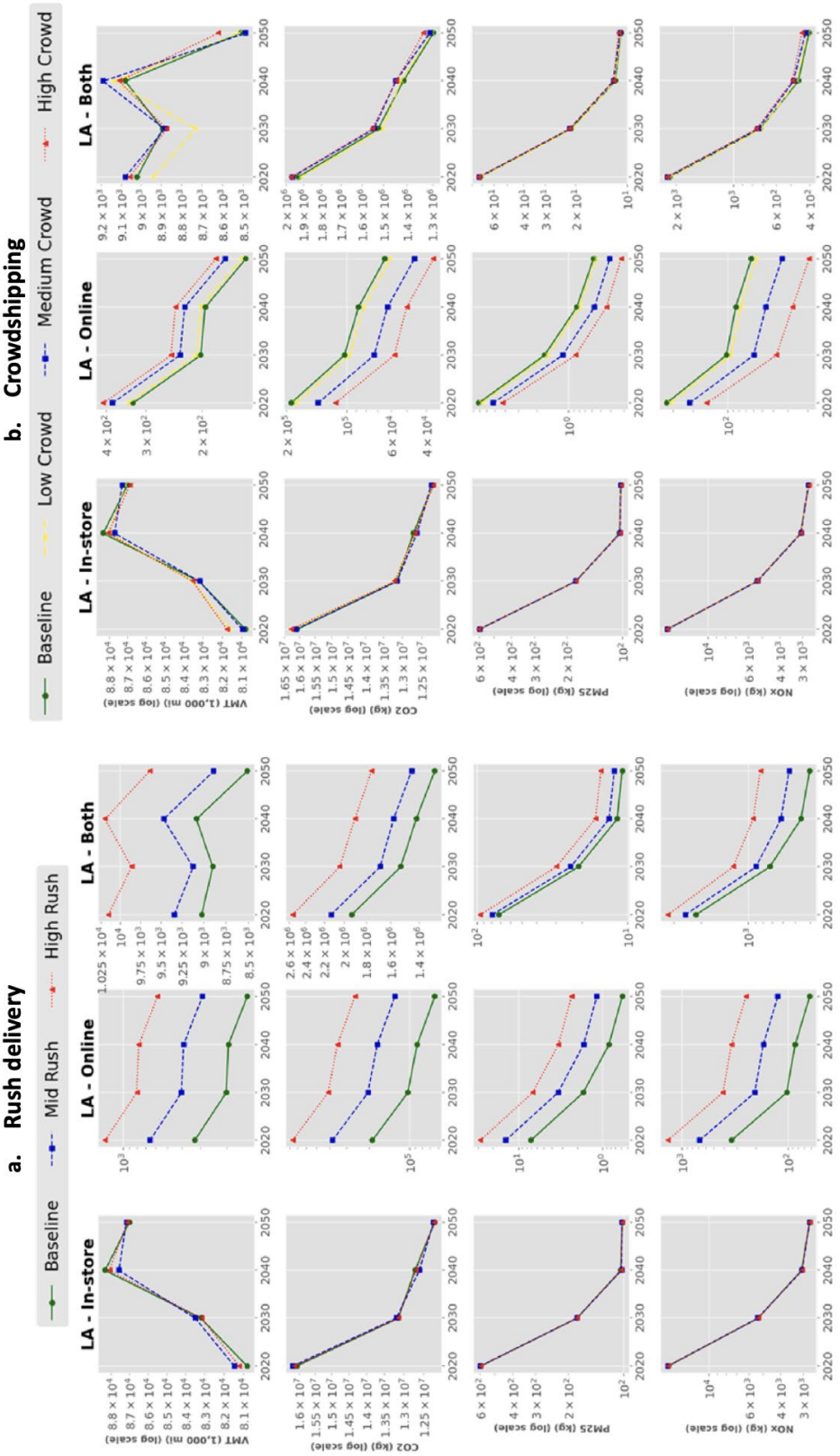

Figure 12. Forecasting emissions and VMT from different last-mile delivery scenarios (adapted from (80))

What are the regional strategies for improving the last mile?

Most transportation plans emphasize traffic and active mobility rather than freight despite its negative externalities. However, new policies are encouraging the inclusion of sustainable strategies in regional planning. Therefore, three regional plans were analyzed to capture feasible and efficient strategies to mitigate the negative impacts associated with this segment of the freight transportation system.

Strategies identified inside those plans were classified according to a set of sustainable and efficient strategies from the literature, as Table 4 shows, and the identification of policies considered in these plans. According to the results of the three plans, the main priorities are reducing emissions and electrifying vehicles. The Bay Area 2050 Plan focuses primarily on traffic and active mobility, whereas the 2020 Long Range Transportation Plan for Southern California gives greater importance to freight transportation. Land use and multimodal logistics are also integrated into the freight transportation planning process in the Bay Area.

On the other hand, the 2021 Regional Plan of San Diego County contains essential strategies relating to e-commerce and last-mile delivery. Sustainable and efficient strategies were considered in the three plans, including improving main freight routes, engaging stakeholders, and sharing information about current local truck routes. Most policies that are considered in these plans relate to the reduction of emissions and the electrification of vehicles.

*Table 4. Sustainable/efficient strategies adopted by regional plans (*118*,* 123*,* 124*).*

Category	Strategies	SANDAG	MTC	SCAG
Strategic planning				
Route optimization	Eco-routing planning for shipment deliveries to reduce cost and emissions			*
	Planning efforts for identifying the types of freight behaviors that need to be fostered or mitigated among the various stakeholders			
Urban consolidation	Logistics consolidation centers planning	*		*
	Implementing design-based guidelines to consolidate deliveries across vendors			
Delivery management	Strategies for reducing the negative impact that the Hours-of-Service rules can have on freight efficiency			
	Efficient vehicle load strategies			
Curbside management	Develop and implement a statewide parking system and increase the truck parking supply.	*		*
Cleaner technologies and materials				
Low and zero-emission technologies	Implementing Green Fuels.	*	*	*
	Recycling, Reuse, and adopting Green Packaging Recycling and Reuse.	*	*	*
Low and zero-emission technologies	ITS vehicles for reducing environmental externalities and road incidents	*	*	*
Best organizational practices				
Tracking of fleets	Provide information on current local truck routes to avoid adverse impacts to communities.	*	*	*
	Develop and implement a freight traffic information system.	*		

Infrastructure intervention and modernization	Develop and implement a statewide freight information platform.			
	Develop and Implement freight-priority traffic management in high-volume truck corridors.			
Sustainability Reporting	Publishing an annual report about the economic, environmental, and social impacts.	*	*	*
Standards & certifications	Assessing national best practices for integrating corridor management, environmental streamlining, and data collection.		*	
Training and Education	Form public-private partnerships to implement public education initiatives that communicate the importance of freight in compelling ways.			
Network collaboration	Participatory stakeholder engagement	*	*	*
	Design a fully transparent tracking system across the supply chain.	*		
	Establish public-private partnerships to integrate and manage freight movement and other data.	*		*
	Strategies for avoiding labor shortages in the trucking industry			*
Governance strategies				
Freight efficient land use practices	Conduct freight planning on urban freight and strategic freight corridors.	*	*	*
	Developing appropriate strategies for analyzing the supply chain operations and patterns.			*
	Strategies that consider the compound effects of urban spatial configuration on passengers and freight transport systems simultaneously			*
	Encouraging the prevalence of intermodal freight facilities.	*		*

California has implemented several programs to promote cleaner freight transportation (*125*) (see Appendix 5. Programs related to freight transportation in California). According to the literature, the primary objective of climate action is to reduce carbon intensity (*115*, *116*). For instance, following the California Air Resources Board's Scoping Plan for Achieving Carbon Neutrality (*116*), the State proposes a sector-by-sector plan to reduce its dependence on petroleum as part of its climate target to attain carbon neutrality by 2045 or earlier. The second goal of policymakers is to align electrification rates with the pace of decarbonization in the power sector (*115*). In response to these policies, industries are taking a more active role in reducing emissions, primarily due to the impact they have been recognized for (*115*). In support of this target, most of the programs identified are vehicle-oriented, such as the Zero-Emission Vehicle Program (*126*), Low Carbon Fuel Standard (*127*), and Clean Vehicle Rebate Project (*128*).

Moreover, some programs consider facility and operational efficiency, such as the California Sustainable Action Plan, which provides guidelines for incorporating freight into the planning process (*129*). Some programs involve community strategies, such as the Community Air Protection Program (*130*) and Local Ordinances to develop and implement new strategies to reduce the health impacts of freight transportation. Further, there have been a few attempts to integrate freight into land use planning, as Assembly Bill 14 requires California to develop a freight plan, updated every four years (*120*).

This regulatory landscape shapes UFS' policies and strives to incentivize and, in certain instances, mandate practices to curb its environmental footprint. While these regulations mark a positive step forward, critical policy frameworks and research gaps demand attention. For instance, although progressive, these regulations and initiatives pose challenges in evaluating and comparing effectiveness. However, the scarcity of detailed data remains a major challenge in developing these evaluations, demanding urgent resolution.

The realm of crowd logistics, despite its potential, remains in its nascent developmental stage. Alongside the regulation of labor platforms, as observed in California's Assembly Bill 5 (*49*), concrete efforts are necessary to mitigate the environmental repercussions of this field. Addressing this goal involves examining the mode choice behavior concerning crowd-shipping deliveries. Understanding how consumers' transportation preferences align with crowd logistics and their impact on the environment is pivotal in shaping effective policies.

Policymakers should also consider implementing freight policy coordination to address the high-level fragmentation across the supply chain. Consequently, an independent policy director for the State could play a crucial role in managing policy issues and facilitating communication between agencies and freight operators. This state-level director would coordinate with state agencies, local offices, and regional and national agencies.

One key policy consideration involves an open digital regional ecosystem. Leveraging digitalization in transport and logistics allows supply chain actors to collaborate effectively, enhance supply chain visibility, manage traffic and cargo flows in real-time, and provide key data for developing urgent analyses that improve the UFS. Simplifying administrative processes and optimizing infrastructure utilization can significantly improve efficiency and reduce costs. To ensure secure and trustworthy networks, it is crucial to integrate stakeholders and regulate data sharing and accessibility. This fosters competition, encourages innovation and ultimately leads to cost reduction. California has different types of cities with distinct UFS; thus, the types of stakeholders to include will vary. For example, cities in Southern California have large populations that require significant local consumption, and at the same time, the cities may serve as international and inter-regional trade gateways, which can affect the types of freight movements and their impacts.

Chapter 6: Recommendations

Based on the synthesis of research, here are a few recommendations for the state of California to minimize the negative externalities of UFS in urban environments, highlighting those presented in Figure 13. Recommendations are linked to the pillars and oriented to change private and user behavior in response to the main challenges considered in Chapter 3.

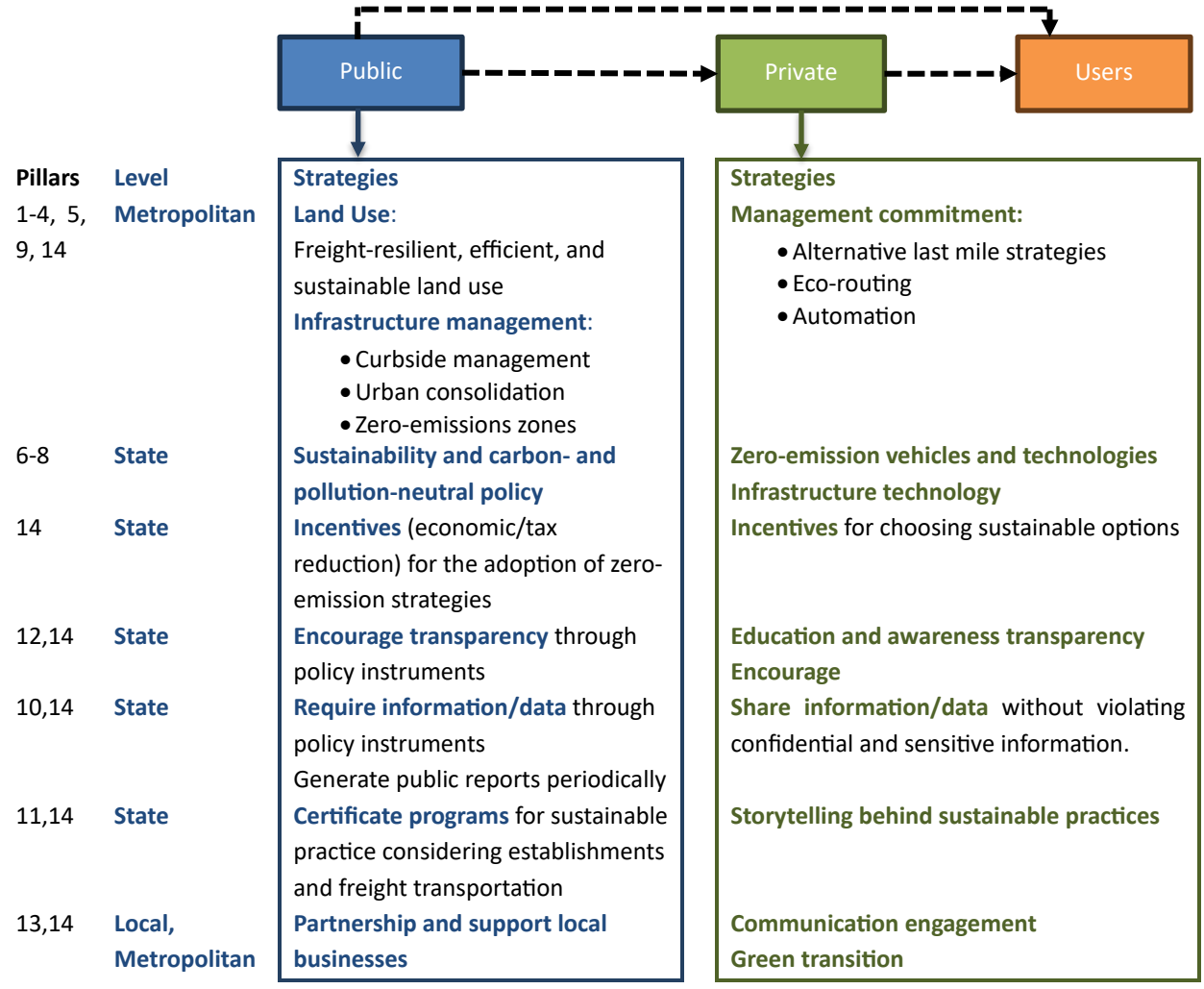

Figure 13. Top strategies as a pathway for sustainable UFS in California

Government agencies have a central role in improving the efficiency and sustainability of the UFS by enhancing land-use practices while monitoring and evaluating their environmental impacts. Five key recommendations are given in these regards: 1) integrating freight into the land use regional plans, considering all the new trends in business and shopping behavior; 2) defining metrics to assess the sustainability dimensions of urban freight; 3) regulation of new vehicle and infrastructure technology; 4) incentives to promote sustainable and good practices; and 5) collaboration and communication between private and public sector.

1. Urban planning agencies should proactively integrate e-commerce into their planning activities. This facet is often overlooked in urban planning discussions at the city and regional level despite its substantial impact on the dynamics of urban life. The tendency of logistics platforms (e.g., dark stores, micro-fulfillment centers) to move near customers to better fulfill time demands increases the negative externalities in urban areas. In addition, there is a disconnection between freight and passenger transportation planning processes, resulting in some efforts in one sector, putting the other at risk. Consequently, **it is crucial for practitioners and planning organizations to pay greater attention to this sector by identifying spatial patterns of logistics, changes in the market, and shifts in consumer shopping behavior that influence the retail and e-retail sector in California for a better planning process.**

   Additionally, planners should regularly evaluate previous policies and sustainable strategies to identify their effectiveness and to adjust them as needed. The planning process also should anticipate green transition shocks in the economic sector. As a result, it is essential to have a deep understanding of the local and operational conditions of UFS, as well as the development of a framework for incorporating freight into the metropolitan planning process to improve the performance of the transportation sector and the economy.
2. **Developing and implementing a harmonized framework is crucial for a comprehensive assessment of UFS sustainability.** While traditionally, sustainability has been analyzed in terms of economic, social, and environmental dimensions, recent research emphasizes the critical role of considering spatial and political dimensions when referring to sustainability in the transportation sector, especially in UFS (*131*). Stakeholders, including private organizations, logistics companies, academic institutions, and policymakers, approach sustainability assessment with diverse interests, insights, and metrics. This diversity highlights the absence of a unified framework for evaluating UFS sustainability (*132*). To address this gap**, it is necessary to define metrics for evaluating all the dimensions of sustainability in UFS**, providing policymakers with a transparent and evidence-based framework for decision-making.
3. Infrastructure management is a crucial trend to intervene from the public sector. Some common strategies identified in the literature include designating specific zones for micro-distribution centers or establishing delivery hubs, curb-side management, and zero-emission zones. Curbside and parking management are well-documented as pillars for improving sustainability. **A multi-pronged approach is required to provide a more efficient method of parking and unloading, educational programs, expansion of loading/unloading bays, parking pricing strategy, public information on parking availability, and freight trip generation analysis**. Similarly, consolidation of last-mile deliveries and increasing stakeholder collaboration could result in systems-level sustainability and customer satisfaction across the urban freight system.

   Technology plays a process's role in achieving sustainability since it provides clean vehicles and efficiency in the transportation process. However, technologies such as autonomous trucks and vans, roadway delivery robots, and drones are currently in their experimental phases, showing potential to improve last-mile deliveries' efficiency, safety, and operational cost-effectiveness. Moreover, the efficiency of the current incentives for purchasing electric vehicles (EVs) needs improvements to encourage their use in the last-mile delivery sector, particularly within parcel fleets. Strategies such

as ZEZ serve as policy instruments to incentivize the production and demand for ZEVs while discouraging the use of fossil-fueled vehicles by making their operation costlier and less convenient. Government policymakers in the freight industry must accelerate funding to create start-up companies that will provide these new technologies at superior quality and lower costs.

4. Similarly, **policies oriented to a management commitment from the private sector are important. Specific actions can be considered, such as eco-routing through economic incentives to alleviate the financial burdens associated with eco-routing; incentivizing and facilitating the installation of standard lockers in large residential or commercial buildings; freight-on-transit operations; crowd-shipping with an appropriate regulatory framework, and micro-mobility**. Some of the main challenges of adopting sustainable methods are the tendency to maintain current practices and the high costs. Therefore, management commitment from the private sector results in a prevalent strategy. A company whose leadership values sustainability and recognizes its long-term benefits is more likely to invest in and successfully execute sustainable strategies. As part of this commitment, the organization may need to set clear sustainability goals, allocate resources for technology adoption, and foster a culture of environmental responsibility. A triple-bottom-line approach in all aspects of the supply chain, multi-stakeholder collaboration, and positive incentives from the government are examples of initiatives that motivate sustainability.

   Offering tax incentives or grants to encourage companies to invest in green delivery practices is a positive strategy for the local government to consider. Most of the incentives in California are oriented to hybrid or electric vehicle adoption. However, the state should also consider other strategies, such as implementing an action plan for circular economic development in the private sector. In this aspect, the California government has made a good effort to motivate retailers to embrace biodegradable and recyclable packaging materials while discouraging double packaging. However, it is crucial to collaborate with customers in a concerted effort to enhance their understanding of the environmental consequences associated with packaging choices, thereby encouraging them to opt for more eco-friendly packaging companies.

   From the private sector, several vital actions are needed to guarantee a transition to sustainable practices. For instance, some strategies can be developing practical certification and other assessment tools, implementing green sourcing practices through circular economics, continuous improvement, and compliance with regulations, and informing consumers about greenwashing, sustainable companies, and practices through government reports. The government should pay special attention to financial and advise support to small companies during the green transition due to their economic disadvantage, setting benchmark targets for local production. It is also essential to avoid coercion by using financial incentives. Support certification programs implementing strategies for quantifying emissions can be useful for guaranteeing the green transition. California has been implementing those programs for the retail sector, but this initiative can also be expanded to the transportation sector.

5. **Cooperation is the most important criterion for improving the efficiency of supply chains. Some key strategies for stakeholders are implementing collaborative transport network systems, building mutual trust, and improving data sharing from different actors.** For instance, fostering partnerships between e-commerce companies and traditional retailers can facilitate package consolidation and reduce delivery trips. However, bringing together representatives from government agencies,

businesses, logistics operators, trucking companies, drivers, and community organizations is the first step required to establish a shared vision and goals for the UFS. This approach ensures that all parties' needs and concerns are known to find and evaluate alternatives to address them effectively. To that end, it is necessary to establish clear communication channels for stakeholders to exchange information and coordinate their activities.

Additionally, data availability is the common denominator in literature because of their absence. **Developing a strategic information system is essential to ensure the availability of solid, comparable, and appropriate data for evaluating the impacts of e-commerce and proposing efficiency and sustainability enhancements for UFS.** This would be a centralized platform for sharing data while maintaining privacy and sensitivity.

Furthermore, this data plays a critical role in **developing models or tools for more effective planning and decision-making of urban cargo at the city level** (*133*)**.** These models can offer quasi-real-time simulation and a virtual representation of UFS to improve operations, reach more efficient routing, optimize the delivery schedule, reduce congestion, and improve sustainability based on diverse scenarios tailored to each region or city's needs. However, integrating large amounts of private and public operational data, including fleet characteristics, GPS tracking, routes, timing, traffic flow sensors, weather forecasts, and travel demand models, is crucial for ensuring the accuracy and usefulness of these models (*134*).

Researchers can bridge existing gaps, enhance comparability, and provide valuable insights to support sustainable and more efficient urban e-commerce strategies by adopting a common data agenda and employing recommended data collection methodologies and sources. Applying these strategies and drawing inspiration from successful pilot projects and policies in the USA and other countries can help California align its sustainability goals and minimize the negative environmental impacts of the UFS.

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Appendices

Appendix 1. Strategic planning

Initiative: Management Commitment

Description: The best strategy to achieve management commitment is the Long-term strategic vision, making sustainability an integral part of the organization. **The vision should include sustainability practices such as a triple bottom line approach in all aspects of the supply chain, multi-stakeholder collaboration, and positive incentives from the government.** The three buttons represent three pillars: environment, society, and economy. Firstly, environmentally friendly supply chain management needs to be integrated into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of final products to consumers, and end-of-life management once the product expires. The second pillar refers to corporate social responsibility, which involves integrating social factors into a typical supply chain and adopting ethical standards to further social justice. Literature offers several innovative strategies to achieve sustainable goals such as reuse, recycling and remanufacturing, green raw materials, quality management, planning and forecasting, and Life Cycle Assessment (LCA). Those strategies could also improve economic performance. However, multi-stakeholder collaboration is the most popular strategy in the literature, with manufacturers' direct involvement with their suppliers and customers, adopting transparent communication and feedback.
Moreover, it is necessary to identify the most prominent practices, particularly those that positively impact other practices. The role of governance in this process is critical because it raises awareness of the benefits and shares successful experiences. It is also essential to avoid coercion by using financial incentives.

Stakeholder: Government, companies, carriers

Pillars: 1-13

Benefits: Reduce operational cost, improve economic performance, positive attitudes from consumer

References: (*124*, *135–139*)

Initiative: Eco-routing planning

Description: Classical routing strategies primarily focus on optimizing the cost of goods distribution from distribution facilities to consumers. However, in recent years, eco-routing has emerged as a promising approach for last-mile delivery. Its primary objective is distributing delivery vehicles and loads along routes that minimize fuel consumption and enhance sustainability. Eco-routing balances travel time/distance and fuel consumption/emissions, leading to potential fuel savings from 12% to 33% compared to traditional routing methods. Unlike adopting new vehicle technologies, implementing eco-routing offers short-term benefits, as it does not require profound technology development and demonstrations, substantial investments, or extended payback periods.
Routing decisions depend on various data inputs, including vehicle types and configurations, operational conditions, driving styles, and delivery/time constraints. Therefore, the success of eco-routing implementation relies on the availability of diverse data sources, including infrastructure

sensors, traffic devices, and freight transportation data encompassing load, demand, familiar routes, and vehicle availability. This data is pivotal for effectively modeling, monitoring, measuring, and forecasting the operational performance of UFS. It also allows the estimation of potential impacts on the urban environment and ultimately enables decision-making to enhance the sustainability of the transportation system. However, this strategy faces two significant challenges: firstly, much of this data is privately held, posing a significant barrier to developing eco-routing solutions. Secondly, as eco-routing's primary goal is energy consumption reduction rather than cost reduction, it often increases carries costs, making it less appealing to UFS operators. **Government initiatives should actively encourage data sharing among UFS stakeholders, including public agencies**, to overcome these obstacles and **promote the widespread adoption of eco-routing.** Furthermore, **they should develop economic incentives to alleviate the financial burdens associated with eco-routing, making it a more attractive and feasible option for all stakeholders.**

Stakeholders: Government, companies, carriers, consumers

Benefits: Fossil fuel use savings, between 12% - 33%, can reduce GHG and urban pollution.

Pillars: 1 - 4, 8, 10

References: (*140–145*)

Initiative: Urban consolidation centers

Description: As an infrastructural and operational solution, consolidation of last-mile deliveries and increasing stakeholder collaboration could result in systems-level sustainability and customer satisfaction across the urban freight system. **This strategy depends on several factors, such as the center's location, the enrollment of low-pollution low-volume vehicles, and the urban planning process.** Several approaches have been formulated to create optimal numbers and locations of micro-consolidation centers (e.g., a mathematical program and developed a time-efficient heuristic solution), combined with an optimally planned delivery system that uses more sustainable travel modes like EVs, cargo bikes, delivery robots, delivery lockers, etc. Micro-consolidation centers can make the last leg of distribution sustainable and dramatically reduce the negative externalities. Additionally, their integration with the current transportation system will require infrastructure and policy alterations. Consolidation centers should be considered during urban planning to guarantee their integration according to land use and socio-economic aspects, minimizing possible side effects.

Stakeholder: Government, companies, carriers

Pillars: 1- 4, 13, 14

Benefits: route length reduction of 15–35%, pollution reduction of 11–21%, resulting cost savings are estimated at between 2 and 24%

References:(*56*, *139*, *146–150*)

Initiative: Parcel self-collection

Description: There is still a relatively low adoption rate for locker delivery options. Due to the possibility of secure delivery, free delivery options, and increasing online shopping behavior, parcel lockers will be more likely to attract consumers. An integrated approach that encompasses operators and consumers is proposed as a strategy for improving last-mile operations. **Essentially, this approach consists of incentivizing and facilitating the installation of standard lockers in large residential or commercial buildings, motivating customers to adopt this strategy, and combining it with other strategies.** If implemented on a large scale, automated parcel lockers in residential buildings can significantly reduce vehicle dwell time and the amount of time delivery couriers spend within buildings. Consumers and the government must work together to implement this strategy through incentives. In addition, there are several approaches to identifying the most suitable locations for parcel lockers as a tool for decision-makers. A collection point's success depends on customers' willingness to pick up their packages. Thus, e-retailers can offer higher wages to encourage collection-point pickup. This is a win-win since this strategy contributes to the efficiency of the operation. It is also possible to increase consumers' willingness to adopt this strategy by providing information about the positive environmental implications of self-collection. Self-service technologies enable the customer to shift from a passive to a proactive consumer by replacing the work previously performed by the employee. Moreover, combining this strategy with others, such as crowd-shipping and electric trucks, can contribute significantly to sustainability.

Stakeholders: Government, companies, carriers, consumers

Pillars: 1- 4, 13, 14

Benefits: 50-60% reduction in average time inside the building, around 33% of dwell time, cost savings of up to 11.0%, and reduction of CO2e emissions by 1.75- 2.5% on average per delivery in urban areas.

References: (*111*, *147*, *151–160*)

Initiative: Sharing economy for freight deliveries

Description: Outsourcing logistics services is now integral to the transportation system. The primary objective of crowd-shipping (CS) should be to take advantage of underutilized crowds and their associated resources to facilitate the delivery of goods while keeping economic, social, and environmental concerns in mind. This topic is an emerging research area, but **current literature sets some strategies to improve these services: appropriate regulation, education, collaboration among competing firms, sharing information, and a platform for humanitarian logistics.** Policymakers must regulate labor conditions, wages, and chain of custody. An appropriate regulatory framework must explicitly define its characteristics to drive the future of crowd-shipping toward more sustainable practices. Conducting training (e.g., loading and unloading of parcels) and mentoring campaigns for untrained crowd workers are other strategies companies incorporate. Training (e.g., loading and unloading packages) and mentoring campaigns for untrained crowd workers could address trust, safety, and security concerns. There may be opportunities for cooperation between competing CS platforms whenever resources are constrained. For instance, competitors can cooperate when a suitable crowd-shipper is unavailable within their network and participate in other on-demand services like the passenger rideshare market.

Furthermore, the uncertainty and risk are not well explored in the literature. New and advanced tools based on machine learning and artificial intelligence could support decision-making. However, CS needs empirical data to contribute to this field. Finally, CS has been proposed as a medium to facilitate humanitarian logistics through the voluntary participation of crowd-shippers or senders.

Stakeholders: Government, business, carriers, researchers

Pillars: 1- 14

Benefits: Cost reduction by 9-37% per detour, travel reduction by 1.6 km, more job opportunities

References: (*161–166*)

Initiative: Alternative delivery strategies for the last mile

Description: **Some strategies for last-mile delivery are identified in the literature, including freight-on-transit operations, autonomous vehicles, and micro-mobility.** Combining goods and passenger movement on public transportation requires some slack capacity already existing in the transit system and complex logistical coordination, significantly when freight and passenger travel destinations operations may differ. Strategies such as combining freight on transit with cargo bikes and other micro-mobility solutions can bypass the need for significant infrastructure operations such as trucks. Of all innovations in transportation, robotics has the maximum potential to alter e-commerce by making urban freight systems cheap, safe, sustainable, and fast. Drones and Autonomous Ground Vehicles can be used for specific last-mile urban freight uses through collaboration between private and public sector stakeholders. However, most operate on small scales with some hesitation due to a lack of certainty regarding future federal and local regulations. New sensor technology and data analytics are required to track drone emissions during last-mile delivery operations and reduce drones' energy consumption. Other challenges and opportunities to improve sustainability in urban last-mile logistics are load weight with human-powered bicycles, legal restrictions for UAVs, fragmentation of orders, and more carbon emissions. Regulations must be in place to manage the risks and vulnerabilities associated with high-volume manufacturing and new technology's environmental and energy costs.

Stakeholders: Government, companies, carriers, consumers

Pillars: 1, 3, 4, 6, 13, 14

Benefits: using drones instead of trucks reduced greenhouse gas (GHG) emissions by 9-30%

References: (*98*, *101*, *167–170*)

Initiative: Curbside Management

Description: Based on the literature findings, **a multi-pronged approach is required to provide a more efficient method of parking and unloading: educational programs, expansion of loading/unloading bays, parking pricing strategy, public information on parking availability, and freight trip generation analysis**. The novelty is the integration of all strategies. Drivers trained in safe behaviors could improve the company's attractiveness to customers and provide public recognition of their efforts. Drivers without fines during a specific period may also be eligible for incentives for good behavior. Providing

loading/unloading bays in areas with more significant freight traffic will help reduce walking time and minimize interaction between commercial vehicles and other road users by adapting parking pricing strategies to increase occupancy and parking availability using current parking spots. Implementing an Intelligent Parking System (IPS) would allow information on the availability of loading zones for commercial vehicles in high-demand areas to reduce the time spent searching for parking there. Finally, the areas with the highest levels of freight trip generation in urban areas will be determined, the trips will be matched to parking availability, and a portion of the deliveries will be moved during non-peak hours if parking is insufficient.

Stakeholder: Government, companies, carriers

Pillars: 1, 4, 12, 14

Benefits: Reduce parking fines, foster safe behavior, reduce search and walking time, improve parking access, Reduce delivery trips, balance supply and demand for parking

References: (*56*, *104*, *135*, *171–174*)

Initiative: Ensure safety

Description:
The rise in companies engaged in goods transportation has heightened concerns regarding traffic safety. UFS demands a focus on safety measures, which have been extensively outlined in the literature. **These include dedicated lanes, route-based strategies, time-sensitive approaches such as off-peak hour delivery, off-peak use of lanes, Intelligent Transportation System (ITS), connected vehicles, and land use policies favoring freight movement.** A key aspect to consider in the public sector is the correct allocation of resources towards safer roads. Developing models based on crash databases is an effective strategy for planners to analyze critical zones based on crash frequency, types, and collision diagrams and propose countermeasures with associated costs and effectiveness, considering their cost/benefit ratio. **Incorporating equity into this process via tools like the Transportation Equity Needs Assessment Toolkit is vital, ensuring disadvantaged communities are prioritized in risk zones.** Additionally, implementing a traffic safety investigation program is valuable for improving road safety. This involves technical safety enhancements, listening to public concerns, and integrating community feedback.
The surge of e-commerce has redirected and increased the freight flow onto local streets and arterials, elevating risks for vulnerable road users. Research focusing on the safety implications of this shift is urgently needed, given the current gap in understanding its effects on urban safety. Moreover, developing driver education campaigns alongside certification programs is a good strategy to ensure safer freight operations. Finally, evaluating the safety and risks associated with unmanned aerial vehicles (UAVs) is an emerging area of research requiring policy attention. Identifying potential hazards in air operations and planning optimal flight routes is essential for UAV operations.

Stakeholders: Government, companies, carriers, users

Pillars: 1, 4, 5, 8, 9, 12, 14

Benefits: reduced fatalities, reduced UFS costs, satisfy the expectations of the public

References: (*135*, *175–179*);

Appendix 2. Cleaner technologies and materials

Initiative: Zero-emission vehicles and automation

Description: In the realm of technology, incorporating automation and electrification stands out as promising strategies to enhance the efficiency of UFS. While automation has found its place in manufacturing, distribution centers, and automated port terminals, it remains relatively uncommon in the last-mile delivery segment. Nevertheless, the emergence of hubs and micro-hubs in the distribution network has opened the door to proximity-based solutions for customers, where using shorter-range and lower load-capacity automated vehicles becomes a promising option. **Technologies such as autonomous trucks and vans, roadway delivery robots, and drones are currently in their experimental phases, showing potential to improve last-mile deliveries' efficiency, safety, and operational cost-effectiveness.** However, these technologies face various challenges and concerns that require resolution and regulation. These encompass issues like the high initial purchase price, infrastructure demands for autonomous loading and unloading, security, labor and social considerations, regulatory obstacles, ecological impacts, and public acceptability.
On the other hand, electrification has made more substantial advances than automation. Its integration into UFS displays a greater degree of market readiness. Research studies have shown the technical feasibility of EVs, including electric trucks and delivery vans, for UFS deliveries, with the added benefit of reducing GHG and pollutant emissions, noise, and maintenance costs. Electric cargo bikes have emerged as competitive alternatives for replacing fossil-fueled vehicles, especially in delivery scenarios that are more time-sensitive than load-sensitive, where they reduce external costs in urban logistics. However, the implementation of EVs faces substantial challenges that must be addressed to facilitate more comprehensive options for ZEVs. These challenges revolve around the availability of charging infrastructure, the high purchase costs of electric trucks and vans, limited cargo capacity, and a shorter range for cargo bikes, alongside other road infrastructure requirements. **Moreover, the efficiency of the current incentives for purchasing EVs needs improvements to encourage their use in the last-mile delivery sector, particularly within parcel fleets**.

Stakeholder: Government, companies, carriers

Pillars: 4 – 6

Benefits: Improvements in efficiency and safety, fuel savings, operational cost reductions, and safety

References: (*9*, *50*, *180*, *181*)

Initiative: Zero-emission zones for freight

Description: Zero-emission zones (ZEZ) for freight designate specific urban areas where only zero-emission freight and delivery vehicles can operate. This innovative approach holds significant promise in comparing air pollution, congestion, GHG emissions, and noise pollution. Several European and U.S. cities have already implemented this initiative to reduce urban pollution. Studies in the literature indicate that ZEZ can lead to a reduction of up to 15% in a city's freight-related emissions. However, air quality improvements may not be substantial in large urban centers due to other PM and NOx emissions sources. **ZEZ also serves as a policy instrument to incentivize the production and demand for ZEVs while discouraging the use of fossil-fueled vehicles by making its operation costlier and less convenient.**

Implementing ZEZ is a complex endeavor requiring extensive coordination and collaboration among various UFS stakeholders, including businesses, vehicle owners and operators, grid operators, and governments at the city, regional, and national levels. Furthermore, ZEZ is not merely a vehicle replacement strategy; it represents a new way of viewing freight as a holistic system, demanding a reevaluating of how goods and services are transported and advocating for reducing freight trips. Currently, there are four modes for implementing ZEZ, each varying in efficacy and complexity: voluntary compliance, micro-hubs, parking and loading zones, and mandatory compliance. Therefore, each city must establish clear and achievable objectives to shape and manage its ZEZs while defining minimum requirements for compliance.

Stakeholders are the government, businesses, carriers, and researchers.

Pillars: 6, 14

Benefits: Up to 15% in urban-freight-related emissions.

References: (*8*, *101*, *182–185*)

Initiative: Green packaging

Description: In recent decades, businesses have faced pressure to curb waste and reduce excessive packaging while boosting recycling efforts. This pressure emanates from customers and governments concerned about the supply chain's environmental footprint. Research studies have shown that consumers' awareness of packaging's environmental impacts influences their purchase decisions. Indeed, these studies have identified that customers are willing to pay more for products packaged in "environmentally friendly materials." Nowadays, packaging has evolved into a strategic asset for companies, fostering customer loyalty and playing a relevant role in product transportation throughout the supply chain. Recognizing this, freight companies are now adopting "green packaging" as an integral marketing strategy.

Green packaging uses recyclable packaging and replaces materials that cause significant environmental harm. This strategy also seeks to reduce packaging usage, reduce waste from transportation and warehousing, and maximize recycling opportunities. Typical materials employed in green packaging encompass paper, glass, metal, ceramics, bamboo, and other compostable and recycling materials, but it also reduces over-packaging. These materials must converge in a shape and design that allows an efficient accommodation of products based on their volume and weight while maintaining storage and handling ease during transportation. Despite the advances made in green packaging, **it remains imperative for both companies and governments to concentrate efforts on educating consumers and promoting the selection of less harmful materials.** With this, UFS can reduce waste and slow the depletion of natural resources while ensuring that green packaging becomes economically competitive.

Stakeholders: Customers, businesses, government

Pillars: 7, 10

Benefits: Waste reduction and increase in reusing packaging materials.

References: (*136*, *186–188*)

Appendix 3. Best organizational practices

Initiative: Adoption of standards, certifications, and sustainability reporting

Description: **For a transition to sustainable practices, several vital actions must take place, such as developing practical certification and other assessment tools, the implementation of green sourcing practices through circular economics, continuous improvement in compliance with regulations, and informing consumers about greenwashing, sustainable companies and practices through government reports.** By implementing certification programs and reporting assessments, it may be possible to prevent greenwashing across the supply chain, enhance supply chain resilience, enhance continuous improvement, and ensure regulatory compliance. Those certification programs implement strategies for quantifying emissions, and circular economics can be implemented to reduce energy consumption and improve economic performance by protecting the environment and reducing resource usage. **However, clear and well-defined metrics for assessing all dimensions of sustainability are still required in UFS.**
Furthermore, communicating sustainable supply chain practices to customers and stakeholders can enhance a company's competitiveness. However, it is necessary to understand the extent to which firms use greenwashing to mislead their supply chain stakeholders. By implementing a labeling and certification program, consumers could be informed about different environmental costs and impacts of different delivery scenarios. Governments should also take action by rewarding behaviors that promote less waste and penalizing those who are more wasteful.

Stakeholder: Government, companies, carriers

Pillars: 1, 6, 7, 10, 11

Benefits: Circular and functional economies could lead to a 2–5% reduction in air pollutant emissions

References: (*180, 189–192*)

Initiative: Horizontal collaboration

Description: A Framework for Horizontal Collaboration in Supply Chain and Transportation Planning has been proposed to decrease the overall cost of transportation and improve environmental and economic sustainability. **Some strategies can be highlighted from this framework: Design collaborative transport network systems (CTNs), build mutual trust, and improve the scalability of sharing information/data on the organization's resources.** A digital ecosystem can be created by constructing a system that shares information, also called a unified, integrated information-sharing system, a collection of logistic information structured in a particular manner, including information about objects, subjects, logistics systems, and processes. Sharing resources between two competing suppliers is necessary to avoid disruption. Increasing commitment to work with competitors to recover from disruption is possible through an agreement based on transparency and mutual benefits. Supply chains can collaborate in real time, improve transparency, and enhance trust by sharing real-time data using blockchains, the Internet of Things, and advanced analytics. The primary objective of a better collaboration strategy is to design larger economies of scale that can reduce distribution costs and improve customer service by increasing flexibility and availability. Also, the consumer has evolved from being a passive purchaser to

an integral part of the product development process, actively contributing to research, development, and innovation by sharing their insights.

Stakeholder: Government, companies, carriers

Pillars: 1, 2, 13

Benefits: reducing distribution costs and improving customer service

References: (*141*, *193*–*197*)

Appendix 4. Governance strategies

Initiative: Freight resilient, efficient, and sustainable land use practices

Description: Freight efficient land use (FELU) strategies are a set of initiatives oriented to minimize the external and private costs related to the production, transportation, and consumption of goods. **Planners can promote those practices by implementing a FELU program with four steps: understanding local conditions of the economic and supply chain, identifying priorities and opportunities, selecting the most effective FELU initiatives, and engaging stakeholders to determine the way forward.** Some of the most strategic initiatives identified in the literature are long-term management, zoning system, site/building design, facility/infrastructure management, parking/loading area management, pricing, incentives, and taxation. Some of them had been previously introduced in this section. Access management strategies may include implementing restrictions or permits for freight vehicle access to specific zones or time windows, establishing dedicated loading and unloading zones, optimizing delivery routes, promoting multimodal logistics, and coordinating with local authorities to enforce compliance.
Additionally, promoting mixed-use development, where residential, commercial, and industrial activities coexist within the same area, can reduce the need for long-distance freight movements. Moreover, by creating safe and convenient walking and cycling networks, land use planning encourages active transportation options for residents and businesses, potentially reducing the need for vehicle trips and improving the efficiency of urban freight operations. Engaging in dialogue and joint decision-making processes can identify sustainable urban freight solutions, such as coordinating delivery time windows, implementing freight-friendly urban design standards, or integrating freight considerations into transportation infrastructure projects. Finally, neutralizing the e-commerce impacts and environmental externalities associated with new business models, such as dark stores and ghost kitchens, requires implementing various strategies and practices from policymakers.

Stakeholders: Government, companies, carriers, consumers

Pillars: 4, 9, 12, 13, 14

Benefits: improving the efficiency of urban freight operations and mitigating environmental and externalities

References: (*122*, *171*, *198*, *199*)

Appendix 5. Programs related to freight transportation in California.

Year	Program	Policies or regulation	Description
1990	Zero-Emission Vehicle Program (*126*)	Zero Emission Vehicle (ZEV) Mandate, Advanced Clean Car Regulations	California's ZEV program requires automakers to produce and deliver an increasing number of zero-emission vehicles (ZEV) to meet specified quotas. This encourages the adoption of cleaner technologies in the automotive industry.
2008	Proposition 1B: Goods Movement Emission Reduction Program (*200*)	Executive Order G-08-011	Local agencies apply to CARB for funding, and then those agencies offer financial incentives to owners of equipment used in freight movement to upgrade to cleaner technologies.
2008	Sustainable Communities & Climate Protection Program (*201*)	California's Sustainable Communities and Climate Protection Act of 2008 (Senate Bill 375)	SB 375 is the land use component of California's wider strategy to reduce greenhouse gas emissions. It also requires California Metropolitan Planning Agencies (MPOs) to create a Sustainable Communities Strategy.
2008	Truck Loan Assistance Program (*202*)	California Alternative and Renewable Fuel, Vehicle Technology, Clean Air, and Carbon Reduction Act of 2007 (AB 118), AB 8 (2015), AB 118 (2024)	The Truck Loan Assistance Program helped provide small-business fleet owners affected by CARB's In-Use Truck and Bus Regulation financing opportunities to upgrade their fleets with newer, compliant trucks.
2009	Low Carbon Fuel Standard (LCFS) (*127*)	Assembly Bill 32	LCFS sets a declining standard for the carbon intensity of transportation fuels. Fuel producers can earn credits by producing low-carbon fuels, encouraging cleaner alternatives, and providing an economic incentive for the industry to reduce carbon emissions.
2009	Advanced Technology Demonstration and Pilot Projects (*203*)	Low Carbon Transportation and AQIP Funding Plans	This initiative aims to help accelerate the next generation of advanced technology vehicles, equipment, or emission controls that are not yet commercialized.
2012	California Climate Investments (*204*)	Cap-and-Trade Auction Proceeds	Revenue generated from the State's cap-and-trade program, which puts a price on carbon emissions, is reinvested into projects that reduce greenhouse gas emissions. This includes funding for public transit, active transportation, and projects that improve air quality.
2015	The California Sustainable	Executive Order B-32-15	California's Sustainable Freight Action Plan aims to transition the freight and delivery industry toward zero-emission technologies. This includes efforts to

	Freight Action Plan (*129*)		accelerate the deployment of low-emission vehicles in freight operations.
2015	Minimizing Community Health Impacts from Freight (*205*)	The California Sustainable Freight Action Plan, Executive Order B-32-15	Staff provides an annual update to the Board on actions to minimize emissions and community health impacts from freight facilities.
2016	Clean Vehicle Rebate Project (CVRP) (*128*)	SB 1275, SB 859, SB 615	The CVRP provides rebates to individuals, businesses, and government entities purchasing or leasing eligible ZEV or plug-in hybrid vehicles. This incentivizes consumers to choose cleaner vehicle technologies.
2017	The California Electric Vehicle Infrastructure Project (CALeVIP) (*206*)	California Energy Commission (Energy Commission) released Grant Funding Opportunity.	California provides funding for developing electric vehicle (EV) charging infrastructure, making it easier for companies and individuals to adopt EVs.
2017	Access Clean California (*207*)	SB 350 Barriers Report	Access Clean California is a multi-faceted outreach effort that helps streamline access to California Climate Investments' consumer-facing, equity-focused clean transportation and clean energy incentive programs for low-income and disadvantaged communities.
2017	Innovative Technology Regulation (*208*)	Title 13 Motor vehicles	The Innovative Technology Regulation provides a more flexible short-term certification pathway for innovative truck and bus technologies to address the high initial certification costs and engineering challenges and encourage additional technology innovation.
2018	Local Ordinances and Zoning Regulations (*8*, *209–211*)	Green Building & Sustainability, Clean Up Green Up (CUGU), Green Zones for Economic and Environmental Sustainability, Zero-Emission Delivery Zones: Decarbonizing Urban Freight and Goods Delivery in U.S. Cities	Some local jurisdictions in California, such as Los Angeles and Santa Monica, have implemented or are considering zoning regulations that encourage or require sustainable practices. This may include restrictions on certain types of vehicles in urban areas and promoting the use of ZEV.
2018	Zero-Emission Airport Ground Support Equipment (*212*)	Mobile Source Strategy, State Implementation Plan, and the Sustainable Freight Action Plan	The zero-emission airport GSE measure will act as a catalyst for further adoption of zero-emission equipment in the off-road sector, facilitate the transfer of technology to suitable heavier duty-cycle applications, and expand the use of zero-emission infrastructure.

2019	Zero-Emission Airport Shuttle (*213*)	Mobile Source Strategy, State Implementation Plan, and Sustainable Freight Action Plan	Vehicles like airport shuttles that operate on fixed routes have stop-and-go operations, maintain low average speeds, and are centrally maintained and fueled, which are ideal candidates for targeting zero-emission electric technologies. CARB is in the process of developing a regulation to accelerate the deployment of zero-emission airport transportation.
2020	Zero-Emission Forklifts (*214*)	CARB's Mobile Source Strategy, State Implementation Plan, and Sustainable Freight Action Plan	CARB staff is developing a measure to drive greater deployment of zero-emission forklifts within fleets throughout the state. This is one of several near-term actions intended to facilitate further zero-emission equipment penetration in the off-road sector.
2020	Advanced Clean Truck Act (ACT) (*215*)	Senate Bill (SB) 350, and Assembly Bill (AB) 32.	The ACT requires original equipment manufacturers (OEMs) of medium- and heavy-duty vehicles to sell ZEVs or near-zero-emissions vehicles (NZEVs) such as plug-in electric hybrids as an increasing percentage of their annual sales from 2024 to 2035.
2020	Clean Truck & Bus Vouchers (HVIP) (*216*)	California Alternative and Renewable Fuel, Vehicle Technology, Clean Air, and Carbon Reduction Act of 2007. Assembly Bill (AB) 118	HVIP continues accelerating market transformation by incentivizing the purchase of zero-emission heavy-duty trucks and buses for California fleets.
2021	Enforcement of Clean Truck Check HD I/M Regulation (*217*)	SB 210 Heavy-Duty Vehicle Inspection and Maintenance Program.	SB210 directed CARB to develop and implement a comprehensive heavy-duty vehicle inspection and maintenance (HD I/M) regulation to ensure that vehicles' emissions control systems are properly functioning when traveling on California's roadways. Starting January 2023
2021	Medium- and Heavy-Duty Fleet Zero-Emission Vehicle Purchasing Support (*218*)	SB 372 Medium- and Heavy-Duty Fleet Zero-Emission Vehicle Purchasing Support	This includes financial support, such as incentive and loan programs, and non-financial support, such as web resources, technical assistance, and training.
2022	Plastic Pollution Prevention and Packaging Producer Responsibility (*219*)	Plastic Pollution Prevention and Packaging Producer Responsibility Act SB 54	SB 54 establishes a new extended producer responsibility (EPR) program to manage packaging and single-use plastic foodware products across every sector of the economy.
2022	On-Road Heavy-Duty Voucher Incentive	Proposed Fiscal Year 2021-22 Funding Plan for Clean Transportation Incentives	VIP provides funding opportunities for fleet owners with ten or fewer vehicles to replace their older heavy-duty diesel or alternative fuel vehicles with ZEV.

	Program (VIP) (*220*)		
2023	Sustainable Freight Transport (*221*)	Funding for Cleaner Freight Equipment: Proposition 1B: Goods Movement Emissions Reduction Program, Carl Moyer Memorial Air Quality Standards Attainment Program, Low Carbon Fuel Standard (LCFS), Electric Utility Transportation Electrification Programs, Clean Diesel and Diesel Emission Reduction Act (DERA) Programs, Clean Off-Road Equipment Voucher Incentive Project (CORE), AB 617 Community Air Protection Incentives	CARB is working with agency partners and stakeholders to implement a broad program that includes regulations, incentives, and policies designed to support the transformation to a more sustainable freight system and reduce community impacts from freight operations in California.
2023	Advanced Clean Fleets Regulation (*222*)	Executive Order R-23-003	Drayage trucks will be required to start transitioning to zero-emission technology beginning in 2024, with full implementation by 2035.