Chapter

Electrification of High-Mileage Mobility Services in Cities and at Airports

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Abstract

High-mileage vehicles serving airports offer significant potential for the electrification of transportation, in ways that enhance the affordability and sustainability of mobility for people and electric vehicle infrastructure development. As one example, by mid-2018, transportation network company (TNC) electric vehicles (EVs) in California—as a high-mileage mobility-as-a-service (MaaS) vehicle platform—was estimated to represent 30% of total non-Tesla EV charging demand, despite being only 0.5% of EVs in the State, and having sixty times higher levels of charging energy demand relative to the other EVs. This chapter explores the potential importance of this phenomena, the emergence of urban electric mobility developments and the co-benefits for economic, environment and equity. Through focus on the synergies of electrification with shared-use vehicles and trips, and with mobility options that include higher mileage, utilization, and occupancy, this chapter identifies emerging concepts that will have potential for impacting adoption rates, management, modeling and control for urban electric mobility systems. More specifically, this chapter explores emerging trends at and adaptations for airports. City airports, as critical hubs for TNC trip demand, and engines of regional economic growth, may be a critical locale for siting fast-charging infrastructure and planning new urban electric mobility operations across many metropolitan areas and cities of the United States and globally.

Keywords: new mobility choices, efficient and electric mobility infrastructure systems, airports and urban infrastructure modernization, shared-smart e-mobility, electrification and urbanization dynamics

1. Introduction: a convergence of megatrends for U.S. airports and roles in advancing smart, resilient urban electrification

The focus of this chapter is on the convergence of advanced electric mobility technologies and mobility services that are in use today. This focus has the potential to inform futures of connected and automated vehicles, to fueling/charging of electric mobility systems, to planning and designing for new choices, passenger travel behaviors, and infrastructure-related design and operations decisions. While research has lagged behind the rapid pace of disruption in the mobility marketplace, research has clearly identified urban contexts as where most disruption has happened so far– and where experimentations with new forms of integration of transportation, electricity, and other built systems have the potential to enhance access to economic EV pathways and other sustainability opportunities (across cities and rural communities alike). As an important hub for travel, airports are identified as often being the "front doors" for accessing most cities, and with these hubs helping connect the city to the world. The impacts of these systems are important for understanding the opportunities associated with electrification of high-mileage, shared mobility services, that are increasingly available at airports or within/across cities.

We start with a recent finding: that by mid-2018, high-mileage, transportation network company (TNC) electric vehicles in California were estimated to account for over 35% of total non-Tesla EV charging demand, despite being only 0.5% of EVs in the State [1]. While the use of TNCs at pickup and dropoff points within cities and airports have become increasingly observable, and creating new challenges for curbside management—this initial finding on the key EV charging aspects (that will relate to future curb uses) offers a useful overall chapter rationale and motivation. Similar to TNC fees and revenues, to parking and car rental revenues being of primary interest to airports, the electrification of high-mileage urban mobility services such as TNCs are of prime interest to electric power utilities and cities. Its within this context that we explore related and interdependent questions for informing future e-mobility and energy efficient management of mobility, with new data-driven discovery, behavioral models, and control techniques (e.g., of curb management, fee structures, vehicle caps, and other incentives) that are emerging in cities and especially at airports with TNCs. Aligning with the scope of the book, this chapter focuses on synergies of EV shared mobility inclusive of hybrid and EV technology for intelligent, efficient transport, especially within contexts of developing energy efficient mobility management, modeling, and control techniques. The need for examining energy-efficient, smart cities, and mobility systems innovations—defined by cities that harness and validate using data, new technology, and governance strategies—and related future grid/infrastructure impacts, is based a priority of improving the efficient, affordable, and reliable movement of people, while reducing costs, environmental impacts, congestion, and enhancing infrastructure modernization.

The three key questions posed in this chapter to inform future modeling is around urban electrification priorities at airports and emerging sustainability goals, and include the following:

1. How does research and data-driven insights on EV-shared mobility or new MaaS/TNC choices (by consumers, systems designers/operators, to diverse system management actors) support understanding of urban electrification, electric vehicle (EV) grid impacts, EV-shared mobility infrastructure, behavior change, and technology adoption for future mobility systems?

2. How do new mobility choices, energy-efficient or intelligent transportation system management strategies, infrastructure modernization, and new business models help inform the research, development, demonstration (R2D) and commercialization of (hybrid) electrified urban transport and mobility systems, and within the context of utility industry-led business models?

3. How does R2D approaches on new mobility choices, infrastructure, to new revenue, finance and business models support development of transport system modeling, management and control—inclusive of new disruptions of transportation network company vehicle electrification?

Trends from January 2016 to 2018 show that the company Uber has seen growth from 1 billion to over 10 billion trips, with Lyft seeing an uptick from 100 million to 1 billion rides. In fact, latest figures have revealed that almost 15% of all rides are trips to and from airports and almost 10% of total city vehicle miles traveled (VMT) can be to and from an airport. This chapter explores the rapid growth and initial impact dynamics of Uber, Lyft, and other forms of transportation network companies (TNCs) at airports and in cities, and related megatrends that might shape the electrification of high-mileage mobility services in cities and at airports [1]. The four primary megatrends described in this chapter, include: (1) new mobility as a service (MaaS) transitions (led by the proliferation of on-demand ride-hailing services and TNCs), (2) the integration of new mobility and energy (or electrification) choices, (3) investments in increasingly electrified, intelligent, and energy-efficient mobility infrastructure modernization, and (4) revenue diversification, enabled by adaptations by airports to TNCs, and that may also help to inform future mobility electrification strategies by utilities, drivers, and cities. As new mode choices and comparative insights emerge, this chapter builds on initial quantification of shifts in ground transportation at airports, to identify ways in which adaptations to new mobility as a service (MaaS) options may offer opportunities to significantly disrupt decade old patterns of private gas vehicle ownership, as well as accessibility to or affordability of EV-shared mobility. By exploring key destinations and hubs for these new mobility options (e.g., airports, cities), this chapter aims to learn from emerging trends by integrating data, literature and analytical insights. The trends identified motivate further exploring and modeling of emerging impacts at airports and cities, and so to inform the enabling of hybrids (HEVs), plug-in hybrid (PHEV), and battery electric vehicles (BEVs) and varying urban electrification future at multiple rapidly growing airports. The future research directions and questions identified in this chapter offer initial lessons and knowledge to shape the future of harnessing urban systems data integration for modeling, energy-efficient management and new control algorithms for ride-hailing fleets of automated vehicles that are both electric and shared (by multiple travelers).

1.1 Chapter rationale

The US and global urban transport and mobility system is experiencing significant disruptions, starting over the last two decades in areas of car/bike sharing (e.g., ZipCar, Capital bike share, Divvy, CitiBike, Bixi, Mobike; [2]) and now increasingly in peer-to-peer vehicle and ride-sharing (e.g., Waze Carpool, GetAround; [3]), on-demand ride-hailing services as transportation network companies (TNCs—e.g., Uber, Lyft, Via, Didi, Grab, Ola, 99; [4]), micro-transit, micro-mobility as dockless e-scooters and bikes (e.g., Lime, Jump, Ofo), and as shared EV mobility services. For EV-shared mobility (see EVsharedmobility.org), the trends emerging are clear: new uses of smart-phones and app-based approaches to ride-hailing is enabling entirely new mobility choices (especially observable at airport), EV charging infrastructure is enabling EV adoption (e.g., EVGo, a smartphone app for locating more than 1200 fast-chargers in 66 metropolitan markets and is now charging its network with 100% renewable energy); to TNC drivers using EVs or plug-in and hybrid EVs for saving on fuel costs and maintenance over time. In fact, investments by many automotives such as BMW-Daimler's ShareNow, Ford's Office Ride or GM's MavenGig, have been some of the first to offer EVs for rent to TNC ride-hailing drivers. This is coupled with EV battery prices of more than $1200 per kWh in 2005 dropping to be as low as $200 (or even $125) per kWh for some suppliers in 2020–2025 [5]. All these trends are leading to whole new models and possibilities for daily driver and passenger choices around both mobility and energy.

At the same time, air transportation is among the fastest growing modes (in terms of passenger miles traveled) within the transportation sector, with TNC demand rising at airports, and global air traffic over past 20 years increasing at a rate of 5–6% annually (indicating a doubling time of every 12–14 years) [6]. In the U.S., airports have been vital national resources—enabling movement of people and goods to regional, national and international commerce—yet have also faced significant and growing congestion problems, particularly with increased curb demand and competing uses for right of way within major areas with continued population, economic growth [7], and several new mobility choices.

As regional examples, aviation demand in the southern California region, including San Diego, Tijuana, and five airports in the Los Angeles area, is projected to increase 50% between 2009 and 2030, from 48 to 80 million passenger enplanements [8]. In the New York City metro region, served by JFK, La Guardia and Newark airports, limited efforts have been made to create multi-airport regional demand modeling forecasts and perhaps due to growing concerns on the ability of traditional demand modeling techniques (including multinomial logit formulations for examining airport choice) to produce reliable air traffic and airport-level demand forecasts (especially with uncertainty due to multiple factors, e.g., fuel prices) [9]. Meanwhile, and as of December 2016, new transportation network companies (TNCs—e.g., Uber, Lyft) have been permitted to operate at more than 90 U.S. airports, with some airport data on effects and new strategies—e.g., TNC service revenues (87% of surveyed airports requiring a per-trip service fee), public parking and rental car revenues [10], to terminal building roadway operation design focused on allocating curb space to use of high-occupancy or the most-efficient services [11], and managing traffic volume increases associated with new TNC travel mode shifts [12]. More recently, LAX airport has decided to end their airport curbside pickup of travelers for Uber and Lyft, and instead have passengers travel by shuttle to a nearby parking lot with less congestion, noting "the decision is in response to worsening congestion at the airport, which is undergoing a $14 billion overhaul of its aging road network and terminals." [13]. Similar changes have occurred for San Francisco Airport and will soon take place for Boston's airport as well; opening up new economic questions of airport curbs as low supply, with high demand (enabling additional new revenue opportunities), with research now exploring intelligent, efficient control options such as premium, regular, and budget access for ride-hailing with different fees based on more or less convenient access (including perhaps for vehicles that are higher occupancy, so less congestion; and with higher fuel economy or clean energy electric vehicles, so less air pollution).

Furthermore, airports are increasingly becoming the primary driver determining mobility and economic development trends, particularly in vibrant urban areas. Just as coastlines, river travel, railroads, and highways greatly influenced the design and landscape topology of cities and urban mobility networks, air travel is now exerting its influence in urban development. Mid-size cities such as Denver see a large percentage of development focused on air-front access, while large mega cities (Chicago, New York, LA) are turning their attention on connecting their multiple airports as efficiently as possible to the urban core. Indeed, TNC/taxi drivers are also seeing highest revenues and passenger trip demand within cities being at their airports [14].

1.2 Four megatrends: rapid changes in mobility, energy, infrastructure and finance

Within this context, this paper explores four inter-related megatrends at airports as changing multiple industries (especially parking and curbs—as noted in the airport case study review section). **Figure 1** illustrates a summary of the key

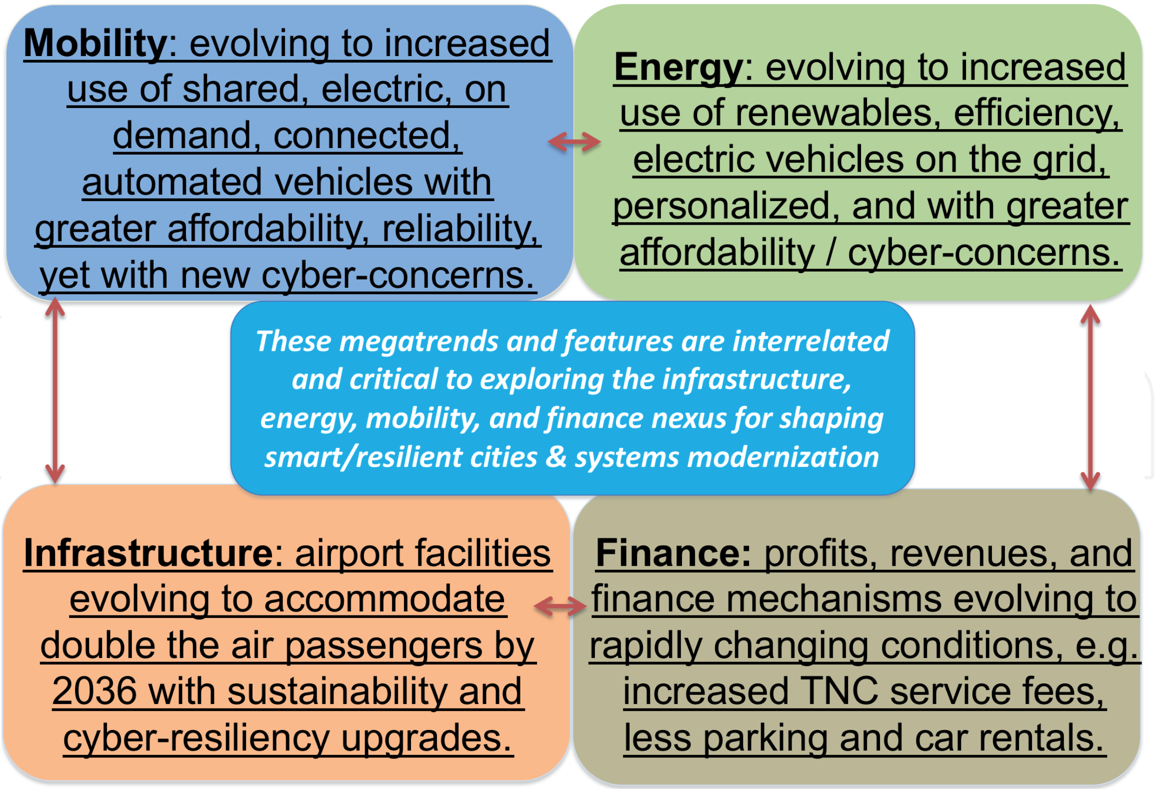

Figure 1.
Interdependencies of mobility, energy/e-mobility, infrastructure, and finance for airports.

interactions, interdependencies, and synergies of these important trends as new urban mobility, energy (including electric utility revenues associated with increasing electric mobility), infrastructure, and finance/revenue pathways unfold, with the learning from data-driven discovery of insights at airports as trends that could inevitably impact cities too. The contexts of global, national, and city levels—based on literature, data, and analytical insights—is shared next for enabling smart cities and urban systems modernization that focus on harnessing high-mileage, ride-hailing MaaS or TNC electric vehicles and shared mobility for enabling accelerated urban electrification, defined in this chapter as:

> *the process of powering [transportation systems] by electricity and, particularly in cities in advanced economies, the introduction of such power by changing over from an earlier power source(see [15]).*

1.2.1 Key message up front: a smart mobility "leapfrog" is a move beyond privately owned EVs to shared e-mobility in urban and airport areas

The term "leapfrogging" has been applied to cities and nations that have adopted a new form of infrastructure by bypassing the traditional progression of development, e.g., from no phones to cell phones—bypassing landlines all together. For the first time in history, similar transformations (perhaps even "leapfrogging" opportunities) may exist for shared, energy-efficient, and e-mobility services in cities that can reduce congestion and pollution while increasing service affordability and "private car-optional" multi-modal accessibility.

According to recent analyses, travel facilities are expected to host 7.8 billion air passengers by 2036, up from 4 billion air travelers today [16]. According to Airports Council International-North America, Airports in the United States are anticipated to have a collective funding need of more than $75 billion over the period of 2015–2019, or $15 billion per year to successfully complete infrastructure projects accommodating facility upgrade needs and high growth in passenger and freight activity-inducing many new congestion and air pollution issues [17, 18]. These funding needs are much higher if there is a need to build out more parking, roadway, and electric mobility infrastructure, and this is where a focus on shared EV mobility may be critical towards cost savings and as high priority measures for reducing pollution for airports and cities.

According to the American Society of Civil Engineers, a two trillion-dollar investment gap exists for the period of 2015–2025 for maintaining our existing infrastructure systems, including a $42 billion funding gap between 2016 and 2025 for aviation. This also comes at a time when 24 of the top 30 major U.S. airports are expected to soon experience "Thanksgiving-peak traffic volume" at least 1 day every week. Similarly, 1 out of every 5 miles of highway pavement is already in poor condition and our roads have a significant and increasing backlog of rehabilitation needs. With aviation industry leaders seeing record $29.3 billion net profits (in 2015), up from $16.4 billion in 2014 (with many North American carriers responsible for over half these profits), leadership is also viewing new infrastructure upgrades as a key need to accommodate rising demands. US and global airports are continuing to focus on harnessing emerging technology services, infrastructure (re)development and investments that can advance local smart cities efforts too, in response to rapid urbanization (growth in urban populations) and motorization (growth in motor vehicle ownership—especially in Asia and Africa).

Integrating EV with shared mobility, as well as with high capacity and high-frequency transit, will enable the benefits of both less air pollution and congestion, creating win-win airport and city opportunities—as well as benefits towards affordability for travelers. With new mobility choices that are increasingly cost and time-efficient, as well as more comfortable services (perhaps relative to transit), energy-efficient or intelligent transportation system management strategies, infrastructure modernization, and new business models are needed that enable acceleration of higher occupancy and multi-passenger forms of (hybrid) electrified urban transport and mobility systems. Leading utilities, such as the New York Power Authority (NYPA), have identified airports (both JFK, and La Guardia; [19]) as primary locations for investment in high-speed electric vehicle charging infrastructure, specifically for Uber and Lyft (TNC) vehicles waiting to pick up passengers. LAX airport in Los Angeles has taken on similar procurement with high mileage bus fleets for airside operations, while recently removing access to the overcrowded curbside to reduce congestion around the terminals [20]. Such approaches have the potential to demonstrate how airports, as major traffic corridors with large fleets can play a leading role in enabling less congestion, and perhaps further incentivizing electrified shared mobility and public transit (allowing those modes easier, lower-cost access to the 'front-door or front curbside') rather than privately-owned gas vehicles or even private electric vehicles. Such considerations might send the right signals for transformation and catalyze new market investments and industry-led business models, initially through 'fast-charging' infrastructure deployments and appropriate utility rate structures to enable accelerated deployment and demonstration of high-mileage, and high-utilization vehicles with easy access to fast-charging infrastructure at airports. Using this model, cities may learn lessons as to best areas for siting charging infrastructure to accommodate similar forms of new on-demand EV mobility services.

While profits are up for airports—with the Federal Aviation Administration in 2016 estimating that $3.5 billion were collected in parking and ground transportation fees, representing 41% of the $8.5 billion in U.S. airport revenue not related to airlines—changes away from parking and car rentals at airports, partially due to TNCs, are motivating new revenue collection approaches as curb pickup-dropoff fees, and perhaps even EV fast-charging infrastructure for TNC drivers.

Some of these initial concepts are further outlined later in this chapter, as new business and finance models for airports, cities, electric utilities and states (ACES) to collect new revenues, reduce congestion, pollution and sustainable infrastructure investment opportunities with high-utilization EV charging infrastructure and electrification/incentivized charging of high-mileage TNC vehicles in cities. This may also help to inform transitions and transformations towards increasingly automated, connected, efficient/electric and shared mobility systems (ACES2).

1.2.2 City-level context

Growing cities and airports are facing complex challenges, ranging from a need to respond to growth in air travel, varied stresses and shocks (e.g., cybersecurity, natural hazards, aging infrastructure) to new disruptive advances in mobility, energy, and revenue mechanisms [21]. Technological disruption is especially true with respect to airport access and egress, where TNCs are making inroads in the percentage of airport passengers served, creating new curb demands and impacting traditional parking and car rental demands. Whereas tracing mode choices for the daily routine of commute to work is often governed by factors that need to be accounted for in a holistic approach to lifestyle and affordability, the access and egress trip to the airport and its associated mode can typically be determined on a per trip basis, taking into account factors such as the economic, efficiency, reliability, and convenience for only that trip (rather than a decision to invest multiple years in a vehicle mortgage). As such, airports offer initial front lines of observing new mobility trends, changes in access and egress patterns, both of which in turn are impacting revenue streams. If these indications foreshadow broader urban mobility trends, airports can be seen as the 'canary in the coal mine' with respect to larger urban scale impacts. A new critical question is with respect to the TNC rate of impacts for the airport versus the city. Currently, and as shown in the results of this chapter, available data still only exists for airports due to charging fees and public records requests. In the near future, anticipated pickup/drop-off (PUDO) or occupancy fee structures implemented across a few cities (e.g., as indicated by regulations emerging in New York, Chicago, Sao Paolo and other cities) may offer new insight.

At the same time, and with the rapidly growing demand for travel in cities, smart city leaders can learn from airports that are already facing significant difficulties keeping pace with technology and market disruptions and responding to unique new pressures and risks to their revenue growth, infrastructure investments and service user satisfaction. While airports in major U.S. cities already struggle to supply reliable access to terminals and manage impacts from private mobility service providers, increases in the types of stresses (e.g., rapid growth in demand for new private mobility services) and shocks (e.g., weather-related airport and power outages in Houston and Atlanta; to cybersecurity attacks on Atlanta's city departments) are also posing new challenges—that may be exacerbated by the surface of potential future cyber-attacks that may become available via an increasingly connected transportation and electric power grid system.

Cities often view their airports as critical and interdependent infrastructure systems for the regional economy, and therefore resilient airport operations—including maintaining quality of and reliability of services is a paramount concern—whether that's Atlanta, Georgia during and after airport power outages; Houston, Texas in recovering from flooding; Los Angeles, California in preparation for a large population influx for the upcoming 2028 Olympic Games.

These challenges identified, may also offer opportunities for airports to perhaps succeed where cities and others have not been proactive, especially in developing longer-term strategies. These responses can therefore offer lessons for city management in how best to respond to industry changes (e.g., decreasing parking revenues cities are also dependent on) to new approaches to finance modernization of aging infrastructure assets or upgrading of urban systems and facilities.

As to new decision environments or responses, the literature review presents a summary of megatrend evolutions and responses at 10 U.S. city airports, based on recent events and related technology services emerging. The diverse range of investment actions identified is discussed as having implications for smart and resilient urban environments, and city-level responses. Key factors and drivers are noted from data and literature-review of these city airports, their metro areas, and noting these EV-related disruption concerns or challenges. The chapter concludes with exploring the need for new predictive capabilities for forecasting EV demand, measuring effectiveness of strategies, and more integrated approaches across the four megatrends of: (1) business model disruption as new affordable, shared, electric, to automated mobility; (2) new cost-effective, distributed, and resilient energy for EVs; (3) airport-related economic opportunity driving infrastructure modernization; (4) revenue diversification and new finance demands.

2. Methods

This paper takes a two-pronged approach. First, a review of literature is conducted to inform analyses and structure the paper in terms of relevant EV mobility, energy or grid impacts, infrastructure and finance priorities. Second, initial data on TNCs at airports is discussed for exploring potential parallel and synergistic efforts for shaping futures of urban electrification.

2.1 An integrated systems review: definitions and assessments relevant to megatrends

Table 1 provides definitions *of* and key drivers of change *for* systems trends identified within the emerging literature and with airports and cities increasingly recognizing the need for building more integrated and resilient systems, that have the *ability to recover from or adjust easily to change*. These changes include adapting to and siting electric mobility infrastructure to support services.

Systems definitions	Airport systems	Urban systems
Transport/E-mobility: ***The quality or state of e-mobility system supporting efficient movement of people and goods and access; the ability/capacity to move in a system***	The Federal Aviation Administration (FAA) launched NextGen, **to modernize** the nation's air transportation and mobility system to increase safety, efficiency, capacity, predictability and resiliency of American aviation [22]. $478 million in airport infrastructure grants to 232 airports in 43 states, as the fourth allotment of the total $3.18 billion in FAA Airport Improvement Program (AIP) funding for airports across the United States is now underway.	The Department of Transportation focus on smart cities is in context of **how best to: move people and goods by supporting affordable, sustainable, safe, efficient mobility; adapt/be resilient to change** (e.g., TNCs, automation); **grow opportunity for all; and align decisions/investments** [23]. To enhance affordability of EV/EVSE adoption, introduction to EVs as part of vehicle/ride sharing may enable greater population accessibility and affordability, relative to private vehicle ownership [24]. ~Half the costs for fueling an EV compared to conventional internal combustion vehicle

Systems definitions	Airport systems	Urban systems
Energy systems*: usable power from resources transferred in production/ distribution systems for doing work*	A rise in energy to transport electrification needs and needs **to satisfy energy demands from: moving passengers and cargo; building, terminal and parking facilities; ensuring energy resilience perspectives; cost savings opportunities** via new forms of energy generation [25]	Urbanization and electrification has clear links to energy consumption, emissions and **key challenges include reducing peak demand power interruptions, ensuring energy security and resilience, and meeting rising demand for affordable, reliable, clean energy** [26]
Infrastructure systems (IS): *underlying foundation, as of a system of public works of a country or region*	Over next 5 years, US airports may undergo $100s of billions in **infrastructure projects to accommodate growth in passenger and cargo activity, rehabilitate existing facilities and to support innovation**; airport access capacity in many areas may limit further airport growth without new solutions.	America's urban areas are often congested and traffic delays cost the country $billions in wasted time and fuel; **in urban settings, service disruption in one infrastructure system will almost always disrupt one or more other infrastructure systems** [27]. New infrastructure investments for electric mobility are now a priority.
Finance systems: *the management of funds and systems for making/ aggregating investments*	"Although nearly all U.S. airports are owned by state of local governments, **airports are required to be as self-sustaining as possible, and receive little to no taxpayer support**" [28]; much of airport revenue is predicated on existing access/egress modes—namely all requiring parking.	"Urbanization is one of the most important potential drivers of productivity and growth in the global economy…**what's invested in today could lock in economic benefits or costs for decades to come**" [29]. Competitive advantage in attracting investment among cities is enabled by ambitious EV targets and goals.

Table 1.
Systems definitions/assessment of megatrends at airports and broader urban systems.

2.2 Airport and city reviews: disruptive shifts informing smart airport, city and urban systems modernization

By bringing together an understanding of intelligent mobility within context of shared use vehicles and rides, together with diffusion of EVs, cities and airports globally are beginning to respond and adapt to new shifts and opportunities for modernization. Examples include:

- Sao Paolo, where the city's new regulatory framework taxes ride hailing services at a lower rate for shared rides and electric cars, and for trips to parts of the city that have limited transport options;

- NYC is also considering a similar approach, $2.50 per trip for taxis, $2.75 for for-hire, $0.75 shared for-hire (note: this was recently updated to $2.50 for private ride-hail trips, and shared rides at $1.25 that will tentatively start in October, 2020), yet this is just for shared/higher occupancy (not incentivizing EVs), and with some pushback: e.g., "While the Albany plan will charge pooled passengers a smaller surcharge ($0.75), it doesn't go far enough to recognize the enormous benefits of ride-sharing and microtransit. In fact, on a percent-age basis, riders in shared-trip vehicles will be paying a higher tax than those who choose to ride alone, and in some cases the total tax per vehicle will be higher too. During morning and evening commutes, Via transports six people per vehicle; the collective surcharge on those vehicles will be $4.50, larger than for lone riders in other for-hire vehicles and infinitely more than for the person driving his or her own car without charge." This is now being extended to the three major airports, Newark, LaGuardia and John F. Kennedy Airports for the Port Authority of New York and New Jersey, where approval has been made of La Guardia also offering a $15 flat fee LGA Connect service with Via (as another emerging ride-hailing operator) from LGA to most New York City boroughs, and farther trips as $20.

- Seattle Airport: "To meet environmental goals, the Port of Seattle only allows Uber vehicles with a blended MPG rating of 45 or higher to wait for airport requests at the waiting area" (where many TNC drivers are using vehicles of this nature that are hybrid electric vehicles such as Priuses).

Many forms of city experimentation to behavior change case study examples are emerging in this area. This will include a need to explore some of the unanticipated effects too—e.g., consumers choosing shared rides when they anticipate no one will actually share (or 'match').

For purposes of this next section of the review, urban systems modernization is now defined in the context of mobility, energy, infrastructure, and financial/economic systems (that include above examples of fee structures). For financial systems and key business shifts, this review includes emphasis on disruptions to parking demand and opportunities for land use conversion of a 2017 US$6 billion annual parking and car rental revenue industry. These cases are used to explore the emerging or potential performance metrics that might help to define key challenges, opportunities, and trends for informing decisions. Finally, the review notes and identifies key contexts, focused on enabling more resilient systems.

1. San Francisco International Airport (SFO)

    - *Mobility*: From 2015 to 2016, airport ride-hail trips increased 75% while airport BART ridership and parking demand decreased, leading to significant reduction in transit and parking fare recovery [30]. Nationally, in 2017, 68% of business travelers chose Uber or Lyft, while only 25% chose rental cars [31]. Since 2009, the city installed over 200 EV charging stations including at municipal garages and SFO airport, with anticipation of EV and gas-powered car prices being comparable as early as 2025 (for light weight, high-mileage vehicles). In the city, trips made by TNCs doubled from 2016 to 2017; and by the end of 2016, TNC vehicles were making over 170,000 trips within San Francisco per day, estimated as ~15% of all intra San Francisco trips, about 20% of VMT, and with ~1% of California TNC vehicles being EVs.

    - *Energy*: SFO consumes 440 GWh of energy each year and is one of the Bay Area region's largest energy consumers; SFO has the goal of achieving a zero net energy campus by 2021 and has decreased energy use by 1.5 GWh from a 2013 baseline despite expanding infrastructure/increasing passenger traffic; a 5% energy use reduction is estimated to save the airport $2.1 million per year [32]; "with air travel expected to double over next 20 years, many airports foresee future power supply constraints as they build new terminals and increase electric load. Due to location, SFO has limited options to bring in additional electric feeders and is exploring how on-site generation may help meet expected need" [33].

- *Infrastructure*: SFO has 5171 acres of land; 14.5 million square feet of space; 135 buildings; and over 200 plug-in electric vehicle parking stall locations, with free charging. For citywide infrastructure, the city currently accommodates over 413,000 registered vehicles, and this includes only 128,551 that are parked in single family home units (that have the most flexibility and lowest investment costs for EV charging installations); and a significant proportion as multi-unit dwellings without easy access to at-home or on-street charging.

- *Finance*: curb-side pickups/drop-offs for Uber, Lyft and Wingz increased from $3.80 to $5 on July 1, 2018 [34]; in Oct 2017, SFO TNC service fee monthly revenue: ~$3 million ($2,941,538), parking revenue: ~$9 million ($9,093,988) [10].

- *Resilience*: as part of the airport development plan utility projects, SFO is adding shoreline and sea wall protection for flood control and sea level rise; as well as new fuel storage tanks for extended outages and as contingency for fuel supply interruptions [32].

2. Denver International Airport (DIA)

- *Mobility*: to keep up with growing traffic, DIA has made significant investments including a $78.9 M purchase, that added 26 more cars (retiring 16 from airport opening in 1995) and increased reliability to a 23-year old automated guideway transit system connecting the terminal to all three concourses [35]. To address emerging pollution concerns city-wide, and as related to electrifying VMT for ride-hailing, the company, Lyft, launched the Express Drive rental program for TNC drivers, deploying 200 long-range EVs in this initial fleet (all of which, as part of this new rideshare rental program, received up to $5000 as an EV tax credit) and with plans to reach a 100% EV network.

- *Energy*: Denver also has over 300 electric vehicle charging ports and has been at the forefront of developing on-airport solar PV facilities, with four projects over 55 acres totaling 10 MW, with design generating capacity at 16.1 M kWh—enough electricity to power roughly 2580 Denver residences (owned/operated by a third party; power purchase agreement; excess power is sold to Xcel Energy) [36]. Falling costs have also motivated a new 1.6 MW PV carport on DIA 800-space parking lot and as a multi-stakeholder microgrid financed between Panasonic, Xcel Energy and DIA [37]. Total 2015 baseline energy use (1,250,801 MMBtu): 59% electricity; 41% natural gas; 18% terminal building; 15% Concourse B; 9% Concourse A; 7% Concourse C; 28% Central Plant; Other: 23% (e.g., 4% Cargo buildings; 4% parking; 3% train; 2% infrastructure) [38].

- *Infrastructure*: DIA identified as a "city within a city"—thousands of employees, 50 million-plus passengers annually; and a $544M South Terminal Redevelopment has included a public plaza, hotel/conference center (opened in 2015), and public transit center (opened in 2016). The city housing infrastructure conditions consists of 44% of residents living in multi-family housing; and just recently, plug-in electric vehicle ready building codes are expected to help address this challenge of increasing the availability and enabling of charging in multi-family buildings.

- *Finance*: In 2016, public parking provided $160 M in revenues; ground transport: $11 M; employee parking: $6 M [39]; TNCs: $3.2 M [38]. For EV charging, the Charge Ahead Colorado program has provides grant funding that covers up to 80% (up to $6260) of the cost of a Level 2 multi-port charging station. At the same time, the capital costs for DCFC stations in the Denver urban areas could be approximately $170,000, and with new funding sources needed to offset the high current operating costs of DCFC stations. The most economical prospects, due to high utilization, could prove to be for TNCs and the fleet of 200 EVs in the Lyft Express Drive fleet, that could more frequently utilize DCFC at airport facilities.

- *Resilience*: this was a criterion for evaluation for the airport energy master plan, referring to an ability of DIA energy systems to adapt to changing conditions, withstand disruption or recover quickly. Power failure metrics have included increasing reliability and resilience in ways that bring benefits for cost effectiveness and carbon reduction (e.g., microgrid/storage opportunities-harnessing renewables, off-peak utility rates, and increasing outage response capability) [38].

3. Kansas City International Airport (KCI)

- *Mobility*: the first 6 months of 2018 saw a 1–5% increase in total passengers over the same month in previous year. There were 11.5 M total travelers in 2017 and already 5.7 M travelers as of June 2018. For freight mobility, growth is even faster with 198,491, 890 lbs. of air freight moved through KCI in 2017 [40]. If to combine freight and mail transported by air, KCI experienced a 11.4% increase for year end 2016 versus 2015 [41].

- *Energy*: KCI became a first U.S. airport to integrate fully electric shuttles for passenger service with four BYD 30-foot coaches and the new KCI terminal has a goal of 100% renewable energy. In addition, the city—with Kansas City Power and Light—has invested in over 1100 charging stations.

- *Infrastructure*: 551 acres of pavement (as equivalent: 2125 road miles); another 52 miles of actual roads; 189 miles of airfield lighting wire; 23,000 parking spaces [42]; new $100 million KCI terminal (opening 2022) to replace the three existing terminals [43].

- *Financial/economic impact*: airport activity estimated in FY2015 contributed to 41,625 jobs; $1.41 billion in earnings; $5.02 billion in economic output to the 17-county primary service area; representing $2.79 billion value add to area's GDP (2.4% of area GDP) [44].

- *Resilience*: few details for airport; yet their DOT smart city vision Element #11: low-cost, efficient, secure, and resilient information and communications technology (ICT) [45].

4. Portland

- *Mobility*: in 1998, public transit made up 10% of access to the airport [11]; more recently, in 2017, and 2–3 years after transportation network companies have been serving PDX, TNC services make up over an estimated 10% of access to the airport for passengers [10]. As shown in **Figure 2** from 2017 City of

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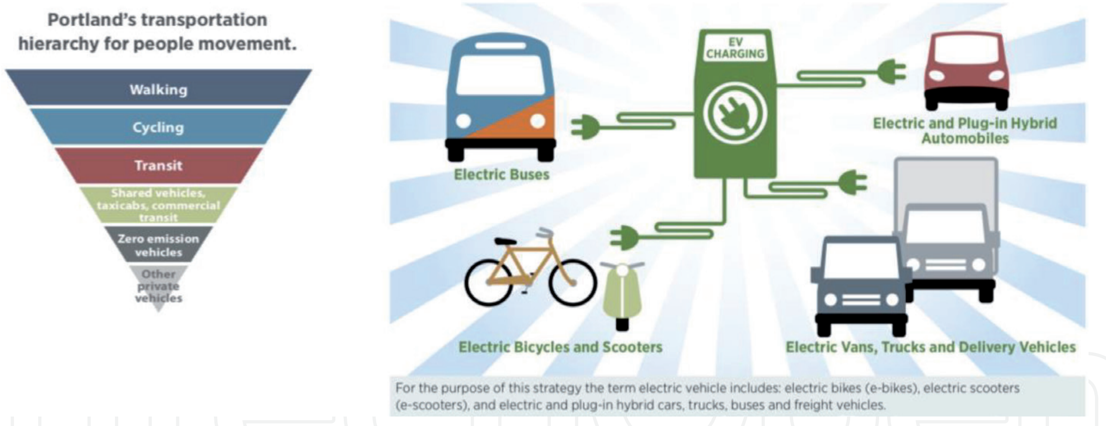

Figure 2.
Portland's prioritizing of people first for EVs (source: City of Portland [46]).

Portland Electric Vehicle strategy, the city aims to prioritize people movement over car movement, and so that includes focusing on electrification of the public transit system as a first priority, then shared vehicles and then private automobiles that remain in use—while also seeking to maximize benefits to air quality and affordability for low-income residents and parts of the city that are most dependent on private vehicles. Similarly, Portland became one of the first cities for Lyft to offer the option of 'Green Mode', with consumers being given the option to request EV rides. This is a significant step, yet with careful planning in entering additional city markets due to the limited supply of EVs in TNC fleets, and therefore the potential for longer consumer wait-time.

- *Energy*: Currently, and due to the low cost of electricity, an EV in Portland can travel a mile with electricity for about one third the price of gasoline [47]. In 2015, PDX had the largest installation of commercial electric vehicle chargers of any U.S. airport with 42 EV charging stations and is continuously expanding related infrastructure based on demand. By 2035, PDX aims to obtain 100% of operating power for PDX-controlled facilities from renewables and have in-building energy efficiency levels of 45 W/M2 [48]. By 2020, the City also has goals to increase access to EV charging infrastructure by doubling the number of Level 2 and DC Fast Chargers (DCFC) available to the public.

- *Infrastructure*: PDX now has a $1.3 billion plan to modernize the terminal core of the airport, based on serving 35 million passengers annually by about 2035, up from 23 million passengers each year today [49]; Portland's Jetport expecting $312 M upgrade too;

- *Finance*: TNC service fee monthly revenues for the airport has increased from $22,122 in May, 2015 to $318,966 in October, 2017. Unlike other cities, monthly parking revenue has also increased—roughly doubling from October 2010 ($3,645,956) to October 2017 ($6,222,862)—this is over a period of 140% growth in passenger volumes. However, on a parking revenue per passenger basis, parking revenues have declined ~8% over the 24 months after TNCs entered the market at PBX (as shown in results, **Figure 2**).

- *Resilience*: The City of Portland was proactive in collaborating on data with TNCs as related to change in TNC and taxi trips by zip code, with large TNC trip increases seen at the airport and average TNC ride duration being highest by the airport as originating zip code [50].

5. Dallas

- *Mobility*: World's 10th busiest airport in 2015 (64.1 M travelers); 4th busiest US commercial airport, with a projected doubling of future freight by 2040 and passenger travel will increase by >50% too; a key sustainability goal includes optimizing efficiency of fleet operations;

- *Energy*: 26 EV charging stations and goals of decreasing energy/fuel use, to conversion of vehicles as increasing alternative energy portfolio; aims of carbon neutrality; leadership has noted that utility owns/operates the transmission/distribution systems and have not yet embraced the electric vehicle (and are perhaps not sure how it will impact the system); announcements of UberElevate's first electric flying shuttles at both DFW and LAX, offer unique areas for analyses.

- *Infrastructure*: airport encompasses ~18,000 acres, making it second largest in the US in terms of land area; $1.9 billion renovation and expansions including building a 6th terminal; and new considerations emerging when developing parking garages; thinking is changing due to new rail and TNCs—questions on future demand for parking, roadways, fueling infrastructure and energy infrastructure? 'Will we have 1000s of cars parked in garage and as EVs with an extension cord? Is airport ready for new loads of EVs and how will infrastructure be put in place to attract business? A need to understand how advances in transportation/mobility systems impact airport as automated vehicles/buses?'

- *Finance*: airport chief financial officer estimated that the airport lost somewhere between $10 million to $20 million in revenue to Uber and Lyft [51]; airports concerned on capacities to dynamically set TNC service fees to raise revenues; also exploring ways to make parking products attractive (e.g., valet services) rather than empty spaces or high curbside demand with limited supply getting zero revenue, despite potential for willingness to pay for easier access.

- *Resilience*: A desire to build infrastructure that is flexible and can adapt to new demands; to ensure resilience strategy also helps address water-scarce region, droughts, and high water demands (e.g., for DFW central utilities plant cooling towers, irrigation of open space, and gas drilling operations on airport property) via reclaimed water strategy with City of Fort Worth.

These snapshot examples of airports and cities offer a diverse range of the sets of challenges, priorities and trends emerging. An important comparison, in the context of emissions benefits of EV adoption in urban areas and for airports aiming towards ambitious climate action goals, is shown in **Figure 3** of the States of Texas

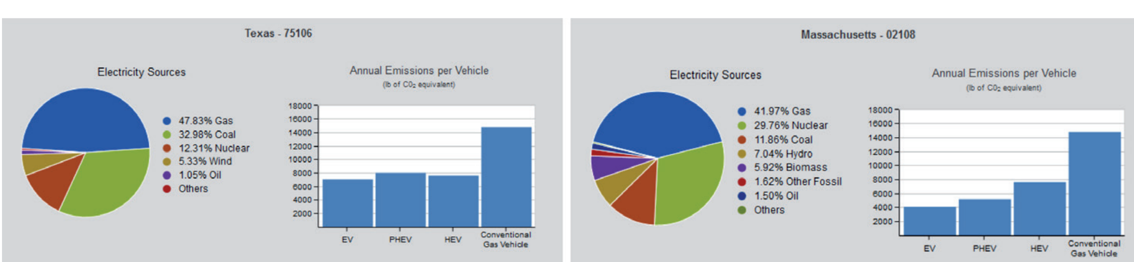

Figure 3.
Texas versus Massachusetts grid mix: associated annual emissions per vehicle (source: To and Linnewiel [52]).

versus Massachusetts, in terms of the overall life-cycle well-to-wheels emissions benefits for EVs, that vary by grid mix. For example, the annual EV emissions is almost double in Texas.

Table 2 offers another literature and data review approach, comparing Pittsburgh, Columbus, Austin, Atlanta and Houston airports, on emerging investments and recent disruptions that may inform future intelligent transportation management, modeling and control in the context of electrification dynamics.

These reviews motivate several questions for on-going research, development, demonstration, and long-term planning, using data to generate understanding on how best to help reduce costs, improve mobility, save energy, modernize infrastructure assets, build resilience and ensure sustainable revenue models. Some of these questions associated with data and assessment methods are described in **Box 1**.

2.3 Exploring impacts of new technology services and extreme events: a case study review

In 2011, when Tropical Storm Irene arrived, all major New York airports were closed. Although not a hurricane, the storm resulted in 5–8 in. of rain, and generated news that certain categories of hurricanes would put JFK International Airport under more than 15 ft. of water. This very substantial risk is known and now very well understood by the airport, metro region, and whole Northeast mega-region after Hurricane Sandy hit in 2013—as this event cost US airlines an estimated US$250 million in revenue due to ~20,000 flight cancelations on the eastern seaboard of the US from DC to Boston. These disruptive events, as well as disruptions associated with new technology services, offers new opportunities to explore the range of impacts to e-mobility, energy/grid and infrastructure impacts. A consequence of not exploring risks and vulnerabilities includes developing a reputation of mishandling disruption. The long-term business impacts from passengers who might make other travel choices could be substantial. Therefore, improved understanding of impacts can inform new EV planning, decisions, to future optimal responses for efficient, affordable EV systems and long-term resilience (e.g., managing risks/recovery).

Approach. Different strands of scholarship and practice provide context on the important impacts relevant to the design and upgrading of airports and urban systems as they transition. This review includes literature on impact assessment, including benefits of and risks to airport and urban transitions and transformations. This then informs a quadrant-based framework (**Figure 2**) that aims to further explore the synergies and trade-offs between these risks and benefits. For example, advances in energy efficient mobility and infrastructure may not necessarily lead to sustainable revenue and finance models for sustainable and resilient upgrades that will be able to account for future stresses, shocks and potential disruptions (that may not yet be identified, similar to airport planning, and investment decision-making prior to the arrival of transportation network companies such as Uber and Lyft). Similarly, growing revenue bases and finance may not necessarily enable moving towards more efficient resource utilization in terms of mobility, energy, or infrastructure systems and services.

This literature review takes two approaches. First, potential impacts are reviewed. Second, review of how shared mobility, electric mobility, and connected and automated vehicles (CAVs) may disrupt airports is reviewed. Progress at both airports and in urban areas is explored, in order to identify knowledge and scenario modeling gaps to be filled and opportunities for energy efficient systems that reduce costs, improve operations, economic prosperity, and resilience.

Airport	Mobility	Energy	Infrastructure	Finance	Resilience
Pittsburgh	~9 M annual passengers and 75 k tons of freight; ~8% growth rate for both from 2016 to 2017	9000 acres of airport leased for natural gas drilling ($50 M signing and ~$16 M/yr. in royalty)	25 years old; $1.1B renovation by 2023; new 4500-space parking garage at a cost of $258 M	Saving $23 M/yr. via upgrades and financing via 20- to 30-year bonds, grants, passenger facility charges, natural gas drilling revenue.	Airport viewed as essential to regional economy/in times of emergency; aging infr/power outages motivate dev of smart transport system and airport microgrid
Columbus	Estimate: ~9 M passengers annually by mid-2020s; Columbus Regional Airport Authority as also a transit authority (plus COTA); city future pilots of AV shuttles	Goal of continuous pursuit of energy conservation, efficiency and innovation for moving both people and cargo—e.g., efficient trucks—test of platooning	$2B for new terminal, parking garage, rental car facility, utility upgrades—addressing overcrowded facilities, 1950s-built airport (Note: an $80 M 2016 renovation)	Revenue records not yet available—parking, car rental, TNC, taxi and ground transportation data still being collected. With 2% of total trips by transit, most revenue loss may be for parking and car rentals	Smart city aware helping to address underdeveloped bus system and minimal public transit network (largest US metro with no passenger rail or light rail), leaving city almost entirely (89%) reliant on private cars for travel
Austin-Bergstrom	13.9 M airport passengers, ('17), 12% increase ('16) as 8 year in a row of growth; 48% less passengers in 1999 (when opened); 500% increase in MetroRail ridership from 2008 to 2014.	Municipally owned utility, Austin Energy, enabling state-of-the-art transport electrification strategy for the airport and city-wide	Two new parking garages, 9-gate expansion, and project on airport boulevard corridor to better accommodate safe, multimodal connectivity	Use of a public-private partnership to build a 1.6 M SF CONRAC rental car facility; 2016 mobility bond; according to 2015 poll, 63% would favor an increase in taxes to construct above ground rail	Focus on airport security and continuity of operations; ASOCS is their web-based operational and communications management system that helps manage and reports all incidents and activities at the airport.
Atlanta	>250,000 passengers daily;	Recent 11 h power outage led to cancelation of over 1000 flights	$6B capital improvement plan: CONRAC rental car center, a fifth runway, int'l terminal	InterContinental Hotel as one key opportunity to diversifying revenue [9]	Reliable, redundant and resilient energy supply for airport-critical facilities via district-scale energy solutions
Houston	53 M passengers annually, with more than 10 million as international travelers	Focused on reduced energy costs (e.g., chiller plant); responding to issues with sensors; and reconfiguring water treatment schedule to reduce pumping	$1.5B expansion and renovation including $244 M for new Terminal C North concourse; airport sits on more than 11,000 acres; airport system as three airports;	Projected 18 month payback through energy infrastructure upgrades and $1 M in annual savings; airport system fund from the city of Houston; FEMA funding of $114 M for overall Houston flood recovery	Airport emergency operations center tested by Hurricane Harvey, along with security of passengers and employees; flights were canceled, roads were flooded, and some passengers were stranded and employees were not able to leave after normal shifts

Table 2.
Comparisons of city airports, unfolding megatrends, and resilience priorities.

Data

- How can the larger intelligent, smart cities and e-mobility research community advance data-driven discovery, planning and decision-making—what EV strategies, enhanced data and modeling can best inform responses to rising airport passenger/GHG levels?
- What strategies will encourage innovation and reinventing of U.S. airport ground transportation across emerging mobility-energy-infrastructure service environments?
- What will be the future of parking revenue, land and infrastructure (re)development, and in what direction to we need to move to harness technology and new services for positive economic/business model outcomes while reducing financial or other risks?

Assessment Methods

- What are key priorities, modernization definitions, and related metrics for reporting?
- What EV mobility input data, models, and information resources can be drawn upon?
- How best to integrate sustainable and resilient infrastructure assessment tools for increasingly shared, electric mobility and related infrastructure at airports/in cities?

Box 1. *Key questions for exploring long-term impacts from airport transformations.*

Potential impacts of four mega-trends. First-in-history megatrends, described below, touches on emerging themes of EV technology, market growth, and new consumer demands for better services motivated by economics, time, convenience, socio-demographics, and so on. Cities, their airports and broader transportation systems that are ever-increasingly connected.

From review, impacts can be largely categorized into the megatrends of changes in:

- *Mobility efficiency and costs:* electric vehicle (EV) battery prices of more than $1200 per kWh in 2005 are soon to be as low as $200 per kWh for some suppliers in 2020 [5]; shared mobility and mobility as a service (MaaS) choices are expected to continue dropping in costs as urban and airport markets continue to emerge and capture larger market shares, with more optimal matching of supply and demand, lower costs through 'pooling', and future automation. The current global sharing economy market estimated at over US$250bn (led by Uber) (US$68bn, #1 global ride-sharing); Didi Chuxing (US$50bn, #1 China ride-sharing) and including Airbnb, WeWork and others could soon reach an estimated US$2 trillion globally [53]

- *Energy efficiency and new generation costs enabling distributed energy resources as PV, EV, and storage:* solar photovoltaic prices declined almost 75% from 2010 to 2017 and onshore wind electricity by 25% to $0.06USD/kWh in 2017 [54]. Bids for solar plus storage or wind plus storage are now cost-competitive with almost all other options, leading to new emerging markets for distributed energy resources, especially at airports where microgrids provide operational flexibility, cost savings, and new redundancies in offering reliable EV fueling options for groundside to airside transportation.

- *Infrastructure efficiency and integration:* some of the largest investments in infrastructure today are being made in strengthening, retooling and integrating new technologies and cyber-physical services at airports (and in cities). There is significant potential for maturity in the use of more intelligent, dynamic management and control of energy, mobility, building, to communications infrastructure. This includes improved supply chains and distribution systems for services, to integrated utility/grid/network management, mobility systems integration to achieve future visions [55]

- *Finance/revenues* unique opportunities are emerging to increase revenue and financing (e.g., utilities via transportation electrification; airports via TNC service fees and/or future EV incentives). Attracting new finance, enabling of public-private partnerships, or new business models can sustainably enable more market-based and self-sustaining airport capital improvement, EV infrastructure upgrades, and operational resilience strategies—where airports often are the innovators, cities could be considered early adopters, with other actors as later adopters or laggards, in less mature markets for adapting and learning from new approaches to rate/fee structures within context of new services being adopted in the public 'right of way' [56, 57].

There are more specific details that can be inferred under this framework for the type of impacts associated with these megatrends, yet this articulation provides an area for high-level modeling analysis opportunities on potential risks and benefits. As noted in **Figure 4**, a synergistic effect could take place in the upper right category, where more efficient, cost-effective, and satisfactory services for customers may provide a virtuous cycle with revenue growth associated with continued investments in modernization towards efficient e-mobility, energy and infrastructure with enhanced resilience and vice versa as leading to sustainable revenue growth, finance, and increased economic prosperity/competitiveness of the region.

2.4 Preparing: mobility disruptions of shared, electric, connected to automated systems.

While studies being performed analyzing the impact of shared and electric mobility, to the potential future impacts of CAVs, few have explored impacts directly at airports and/or specifically as focusing EV adoption first on high-mileage, high utilization, and high occupancy assets. Significant opportunities may exist by enabling this emphasis, with focus on data with TNC drivers to site fast-charging infrastructure, or incentives to enable changes associated with EVs waiting in airport queues, to other equity focus areas for airports, cities, and electric utilities to consider—that could emerge by efficiently moving TNC EVs through queues or passengers having use of curb and a more affordable trip, if requesting an EV and/or higher occupancy ride-hail option for their ride in a TNC or public transit vehicle.

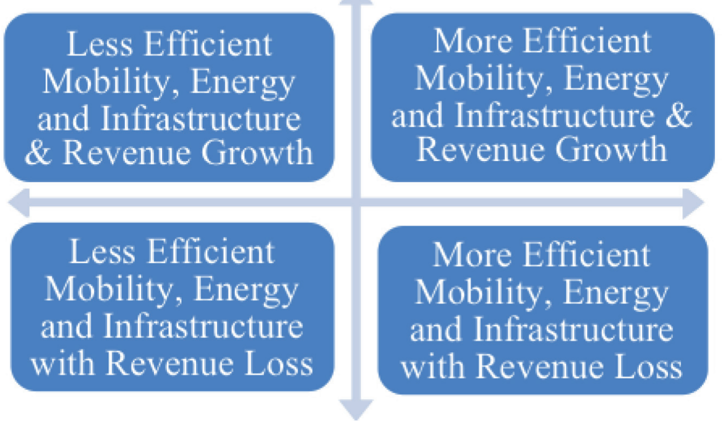

Figure 4.
Mapping impacts as synergies and tradeoffs between goals and financial health.

With human behavior, future factors to consider and collect data, generate modeling and control approaches on could include examining e-mobility dynamics through perspective of key use cases, e.g.,

- Prioritizing low and moderate income (e.g., accessibility, equity, and potential for a used EV market)

- Prioritizing high-mileage vehicles (e.g., to accelerate decarbonization pathways)—including with transit, ridehailing (TNC), and Taxi—as prior to privately owned vehicles.

- Broader equity contexts in terms of affordable housing, transportation and EVs—e.g., emphasis on multi-unit dwelling (garage orphans that lack charging at home and those who spend over X% of their income on energy and housing).

- Utility planning—with emphasis on grid impacts/management, incentives for diverse customers, and generating new revenues.

Additional considerations could include:

- easier or inhibited travel (e.g., free and/or easier access to curbside or door-to-door travel if higher occupancy, electrified vehicles; or up to $10 service fees added or less convenient parking garage pickup and drop-off zones for single occupancy, and gas vehicles),

- Variations in travel by higher income or working populations (at home or away airports),

- Potential for short-haul air travel as modal shifts to increasingly affordable AV-driven e-mobility,

- Shared-automated vehicle ride-hailing, to empty miles/deadheading, and shifting parking demands.

Introduction of electrified MaaS and CAVs may also result in changes to costs, and financing via per-mileage usage fees rather than prior gas tax revenue. Increases in costs may be due to: deploying new technology in airport vehicle fleets, higher maintenance and repair costs as larger infrastructure footprints emerge, service fees, and demand growth. Reductions in cost may be due to: insurance premiums, less damage due to power outages, or other operational costs. Predicted impacts of shared, e-mobility including vis-à-vis automation continues to have high levels of uncertainty in terms of rates of adoption, willingness and ability to share, and access/egress constraints or enablers for higher levels of energy efficient mobility.

3. Results

The results described below include an emphasis on managing growth in passengers, as well as shifts in TNC service fees and parking revenues—which touch on most aspects of the systems and megatrends described. For simplicity purposes, we zoom in specifically on integrating a few datasets. This includes an emphasis on

TNC data inputs and new service fee analyses with potential to inform new mobility and energy efficient mobility system scenarios, case studies for new strategies, and/or improved investments.

For example, based on the trends shown in the latest cross-city airports analysis below, it is expected that many of the airports identified will need to devise new finance models that may include monetizing ground access, for example by introducing a per-person access fee or occupancy-based fee. With high uncertainty as to the future of parking demand decreases and to what threshold will trends hold consistent, there will likely need to be a reconsideration of whether investments in enormous new parking garages/infrastructure, as well as CONRAC facilities are needed. At the same time, this may also be less of a challenge for airports that have historically limited parking due to land and geographic constraints (e.g., Boston Logan Airport).

While many new structures will not be ready until the mid-2020s, it is very possible that with up to a 50% (or even a more conservative 20%) drop in parking demand, some investments may quickly become obsolete. Instead, successful airports may develop scenarios for multimodal ground transportation that can flexibly accommodate a variety of access modes, identify explanatory or predictive factors for new mode choices, and anticipate the different needs of passengers traveling on each of them. In addition, strategies for adaptive investments in new affordable and cost-saving travel and energy systems, that enable higher occupancy, electric mobility systems and more reliable airport travel facilities could also be in high demand. This is demonstrated by adaptive responses such as a recent Boston airport decision to set up designated ride-hailing pickups from a centralized garage site; LAX airport banning Uber, Lyft, or taxi pickups on the curbside and instead requiring passengers to use shuttles to transport from farther away land over to terminals; and the Port Authority of New York New Jersey now defining a pathway to implement occupancy-based pickup and drop-off fees to incentivize less congestion to and from the airport and enable more efficient groundside airport operations.

3.1 Cross-city airport trends based upon latest revenue data integration and analysis

As noted, airports are experiencing increases in air travel, and with an ever faster increase in ride-hailing travel demands to and from airports. The analyses presented below focused on gaining observability into mode choice trends, quantifying changes using airport data (via public information on passengers, revenue data) to transit data (that has been made available initially for both the Denver and Seattle airports) [10, 58] (**Figure 5**).

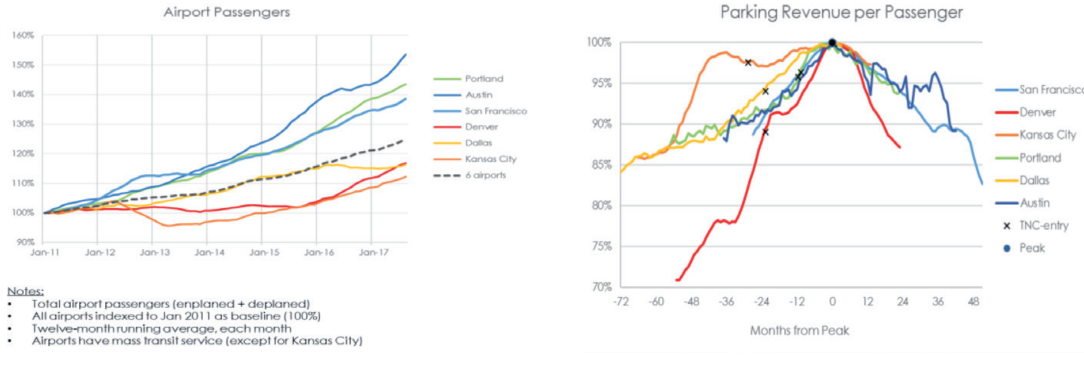

Figure 5.
Integrated analyses of airports on growth in airport passengers while observing declines in parking revenues (similar data has been analyzed indicating similar trends for car rentals).

A refined analysis approach is now emerging focused on transactions per air passenger, shown below for Denver and Seattle. For this specific approach, we gathered monthly transactions from January 2010 to December 2018 with the following data via public requests:

- Airport passengers (enplaned and deplaned) collected by airports
- Ground transportation transactions: parking, car rental, taxis, TNCs (source: airports)
- Transit transactions collected by the corresponding public transportation authority (Sound Transit for Seattle-Tacoma and the Regional Transit District for Denver)

Using transaction data, and based on the number of transactions per mode after ride-hailing introduction, the following are key mode replacement findings:

- Seattle (SEA-TAC) airport: for every 100 new TNC transactions for ground transportation, ~27% replaced transit, 35% replaced parking, 17% replaced car rentals, and 21% replaced taxis
- Similarly, at Denver International (DEN), ride-hailing transactions replaced transit, parking, car rental and taxis at a rate of 34.7, 39.0, 16.6, and 9.7%, respectively.
- Note: Ride-hailing is currently 25–40% cheaper than taxis.

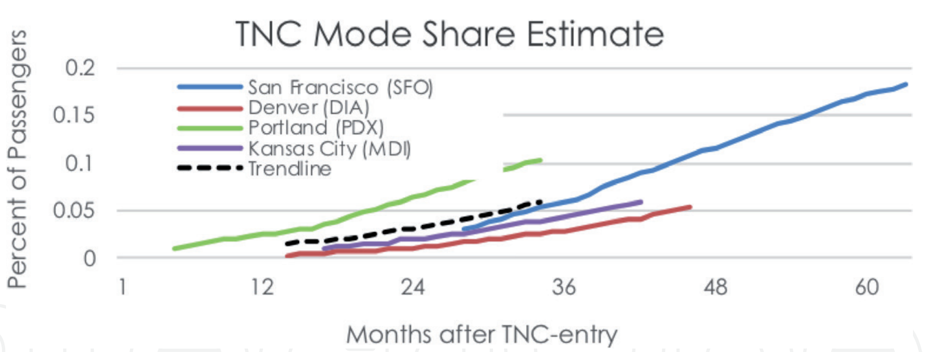

Figure 6.
Integrated analyses of six airports showing how the steady decline in airport parking revenue per passenger is associated with the TNC mode share growth at many airports.

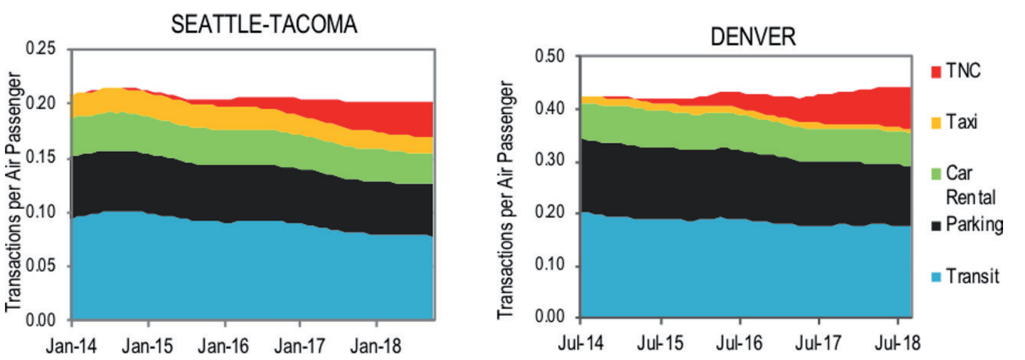

Figure 7.
Transaction data per air passenger and airport mode choice changes.

Figure 6 is a map of fees assessed by airports on TNC companies for ride pickups and/or drop-offs. High charges include Orlando ($5.80), to $5.00 charges in Seattle, San Francisco, Chicago, and Detroit. SFO has been charging this amount since July 1 as per trip (increased from $3.80 to $5 on July 1, 2018, with exceptions made for certain airport access points); in addition, it's worth noting the lack of fees charged by airports in the New York region (**Figure** 7).

4. Discussion: key messages from airports for informing cities

The future of energy-efficient, intelligent mobility systems, will likely include focus on harnessing the potential of electrification of high-mileage, higher-occupancy vehicles across ride-hailing, taxi, to public transit or airport shuttle operations. Thematic areas for future research include:

Exploring human behavior and mobility impacts: What can other areas (e.g., cities, regions) that currently lack TNC- or other private mobility data learn from airports, that may be more data-rich in understanding changes in travel behavior, due to policy and fee-based responses? Will this data inform advanced energy management, modeling and control for hybrid to fully electric vehicles and can ridehailing research inform how connected-automated vehicles are deployed in the contexts of cities and with initial use cases being developed at airports (e.g., EasyMile EZ10 automated-electric shuttle to soon be deployed at Dallas-Fort Worth Airport)?

Exploring new EV infrastructure, technology integration and emerging policies: Can we identify data-driven insights that improve energy-efficiency and financing of multi-modal right-sized electric transportation starting at airports, where incentives for higher vehicle occupancy, electric transit, and infrastructure, coupled with energy (e.g., distributed energy resources, microgrids), and other forms of infrastructure upgrades and modernization could move in more agile ways to accelerate the electrification of transportation, as starting with high-mileage TNCs?

Future of mode choice modeling, scenarios and analyses: Can research explore the modification of airport mode choice and energy modeling by identifying key factors shaping personal versus business traveler, to airport employee, individual versus family travel decisions? What is the appropriate balance to strike in the right-sizing of multiple systems—e.g., parking facilities, curbs, vehicle fleets, to distributed energy resources—and for down-sizing, decommissioning or repurposing certain land uses and infrastructure assets? What are the strategic capacities for changes at airports versus within cities and metro regions? Additional exploring via analyses of new mobility shifts, and building on additional studies will be critical [10]. How different will impacts, priorities, to models of transactions, revenue and financing strategies look across airports and between airports and their respective cities?

5. Conclusions

With airports and cities hosting significant critical infrastructure systems and operations, and air travel today representing over 9% of total U.S. transportation energy use [59], what will the future hold as energy impacts from new mode choices and utility demands for e-mobility? With $3.5 billion in parking and ground transportation fees representing 41% of the $8.5 billion in U.S. airport revenue not related to airlines, according to the Federal Aviation Administration, what will be the future of revenues as TNC fees to utility revenues from e-mobility business models? What is the long-term viability of a nearly US$6B airport parking/car rental industry? Case study airports and their adoption of strategies in increasingly mature markets for on-demand, high-mileage mobility services are expected to offer insights into future opportunities for electric vehicles, shared mobility electrification, finance, and infrastructure (re)development. Future research could focus on integrating public and private community interests for advancing technologies and modernization strategies that have positive real-world implications and upscaling potential for future city systems integration, accelerated planning and decision-making.

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