

# Long-Term Impacts of Shared, Connected, Automated, and E-Mobility in New York State: Exploring Hubs of Mobility and Energy Innovation

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# **Long-Term Impacts of Shared, Connected, Automated, and E-Mobility in New York State: Exploring Hubs of Mobility and Energy Innovation**

*Final Report*

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## Notice

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## **Abstract**

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Disruptive changes in mobility services are emerging across the nation and in New York State that have the potential to further enable private car-optional lifestyles and expanded, more flexible and affordable mobility choices. By convening stakeholder engagement roundtables of advanced transportation experts, then utilizing available data for visual and novel analysis methods to explore these transitions and transformations, this report aims to inform a new proactive strategy for reinventing mobility across communities in the State.

This framework focuses on exploring the long-term impacts and strategies for enhancing future positive societal impacts, while reducing potential risks that may be associated with an increasingly shared, connected, automated, and efficient (and/or electrified) mobility system. The report presents a review of rapidly evolving literature, and offers a synthesis and integration of data, analysis, and scenario modeling methods, with key findings aimed at helping to further develop a framework for comparative assessment across a typology of settlement types and mobility technology adoption rates. Through modeling, and data-motivated analytical insights, this report is designed to serve as an interface with and feed into other existing and aligning initiatives, public dialogues, planning, and decision-making environments that are being used to inform the future of efficient transportation and mobility systems.

## **Keywords**

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Integrated Sustainable Mobility and Energy Outcomes, Risks and Benefits, Synergies and Tradeoffs, Automated, connected, electric, and shared mobility.

## **Acknowledgments**

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# Acronyms and Abbreviations

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AAA	American Automobile Association
ACES	automated, connected, efficient (electric), and shared
ACS	American Community Survey
AEV	automated-electric vehicle
APTA	American Public Transit Association
AV	automated vehicle
BMTS	Binghamton Metropolitan Transportation Study
BRT	Bus Rapid Transit
BTS	Bureau of Transportation Statistics
BTU	British thermal unit
CAEV	connected, automated-electric vehicle
CAV	connected and automated vehicle
CLCPA	Climate Leadership and Community Protection Act
CNT	Center for Neighborhood Technology
CUNY	City University of New York
CV	connected vehicle
DOE	United States Department of Energy
DOT	Department of Transportation (refers to any jurisdiction level: national, state, city)
EPA	Environmental Protection Agency
EV	electric vehicle
GBNRTC	Greater Buffalo Niagara Regional Transportation Council
GDP	gross domestic product
GHG	greenhouse gas
ICM	Integrated Corridor Management
IT	information technology
kWH	Kilowatt-Hour
LDV	light duty vehicle
LIDAR	Light Imaging, Detection, and Ranging
MaaS	Mobility as a Service
MPO	Metropolitan Planning Organization
MTA	Metropolitan Transportation Authority
NFTA	Niagara Frontier Transportation Authority
NHTS	National Household Travel Survey
NPMRDS	National Performance Management Research Data Set
NREL	National Renewable Energy Lab
NYC	New York City
NYCDOT	New York City Department of Transportation

NYMTC	New York Metropolitan Transportation Council
NYS	New York State
NYSDOT	New York State Department of Transportation
NYSERDA	New York State Energy Research and Development Authority
OBD	On-board diagnostics
PANYNJ	Port Authority of New York and New Jersey
PMT	passenger miles traveled
PMV	people mover vehicle
PSEG	Public Service Enterprise Group
R&D	research and development
RADAR	Radio Detection and Ranging
SAV	shared automated vehicle
SET	Social Technical and Environmental
SETEG	Socio-demographics, Economy, Technology, Environment, and Governance
SOV	single occupancy vehicle
TCAT	Tompkins Consolidated Area Transit
TLC	Taxi and Limousine Commission
TNC	Transportation Network Companies
TRB	Transportation Research Board
UTRC	University Transportation Research Center
VKT	vehicle kilometers traveled
VMS	variable message sign
VMT	vehicle miles traveled
ZEV	zero emission vehicle

# Summary

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Disruptive changes in mobility services are emerging across the nation and New York State that have potential to further enable private car-optional lifestyles and expanded, more flexible and affordable mobility choices. By convening stakeholder roundtables with advanced transportation experts, and then utilizing available data for visual and novel analysis methods to explore these transitions and transformations, this report aims to inform a new proactive strategy for reinventing mobility across communities in the State.

This framework focuses on exploring the long-term impacts and strategies for enhancing future positive societal impacts while reducing potential risks that may be associated with an increasingly shared, connected, automated, and efficient (and/or electrified) mobility system. This report presents a review of rapidly evolving literature, and offers a synthesis and integration of data, analysis, and scenario modeling methods. Key findings are aimed at helping to further develop a framework for comparative assessment across a typology of settlement types and mobility technology adoption rates. Through modeling, and data-motivated analytical insights, this report is designed to serve as an interface with other existing and aligning initiatives, public dialogues, planning, and decision-making environments that are being used to inform the future of efficient transportation and mobility systems.

Throughout this report, an emphasis is placed on some of the key indicators and metrics that can continue to be explored in ways to help gain insight into and improve system performance. Applying a service user satisfaction lens as a force for change and acknowledging the significant uncertainty that lies ahead, the potential for adoption benefits and risks in increasingly mature markets for connected and automated vehicles (CAVs) is explored to inform infrastructure (re)development, cost analysis, economic, market, and social transformation processes. The initial research shared aims to inform and guide future road-mapping for research, technology integration, and investment decisions associated with emerging mobility, while emphasizing a “systems of systems” philosophy.

Integrated and interdisciplinary approaches have also been developed and implemented to engage State, regional, and local-level research and practitioner communities with automated-connected-electric-shared (ACES) mobility and associated infrastructure systems. Using stakeholder feedback processes, data

integration techniques, visualization, modeling, and analytics, important knowledge gaps and new critical information and metrics are developed and presented in the report.

The following are several high-level findings identified:

- Stakeholder engagement processes led to the identification of several important research questions and inputs to assumptions for scenario modeling, examples of which are shared below.
- Estimates on the bounds of potential impacts of automated and connected vehicles were offered in response to questions such as: (1) What is the highest potential increase in energy and emissions impacts that automated vehicles (that are NOT shared or electric) will have in New York by 2030 (assume a worst-case scenario) and (2) what is the highest potential decrease in energy and emissions impacts that automated vehicles (that ARE shared and electric) will have by 2030 (assume best-case scenario)? Results:
  - NYC (n=21): Best case: 100% of respondents anticipate at least a 10% decrease; with 10% for -75%, 29% for -10%, 29% for -25%, 29% for -50%; Worst case: 71% view +50%; 24% view +150% as possible.
  - Buffalo (n=8): 100% of respondents anticipate up to a 50% increase for worst case; for best case, 38% view -50% as possible, 38% view -50%, and 25% view -10% as possible.
  - Ithaca (n=25): majority (72%) of respondents anticipate up to a 50% decrease; with 25% anticipating 75% or more decrease; in worst case: 32% view no change as possible; 48% for a 50% increase; to 12% anticipating +150%; and 8% anticipating worst case as up to a 250%.
- Models were developed, extended, and refined for advancing estimates of the potential impacts for New York State (building on a methodology applied nationally), with focus on the specific local influences that might also have potential to be key factors affecting mobility and energy: for example, estimates of vehicle miles travelled (VMT) impact lower bounds ranged from -4.8% to -8.5% and upper bounds from 123% to 133%, with transportation energy bounds of (-60%, +240%), (-63%, + 181%) and (-63%, +195%) for NYC, Buffalo, and Ithaca.
- The extent to which emerging mobility technologies will have impact in and across different cities, or different parts of the State, was a key research question and initial analysis results demonstrate the potential range of change: for example, two to four times higher adoption rates for EVs by more highly educated, wealthier, core urban populations relative to other identified rural, suburban, and urban clusters of populations.
- Mode choice is closely linked with population and employment density—more than 90% of core urbanites use transit or active modes, compared with just 22% and 17% of suburban and rural residents, respectively. Household vehicle ownership varies from approximately two vehicles per household in rural areas to only 0.5 in core urban settings.

These high-level analysis insights motivated by public, private, and research community interests will be used to continue to advance technologies, planning, policy, behavior, and finance pathways toward positive real-world implications. Through original research, analysis, and case studies, this report seeks to define the potential for ACES mobility implementation in the State, across several cities, and to

establish improved understanding of risks and benefits in order to ensure success in adapting to new emerging mobility technologies. The report is intended to be a resource for New York State agencies as well as local governments and regional planning agencies looking to further explore ACES mobility innovations as critical to broader strategies for co-designing and building a more efficient, affordable, inclusive, and low-carbon mobility ecosystem.

In summary, the objectives of this study were to estimate the range of outcomes that may be related to new mobility infrastructure, technologies, and behaviors, in order to identify what management strategies may be considered and prioritized for low-carbon mobility system development in communities across New York State. Using New York, Ithaca, and Buffalo as case studies, the research question identified was the following: To what extent does new integrated mobility systems (i.e., including increased automation, connectivity, electrification, sharing, and digital transformation/data-enabled infrastructures) and concerns around environmental factors (e.g., GHG emissions) associated with these mobility systems shape current to future energy outcomes in New York?

The report is divided into two parts: Part I summarizes the workshops and stakeholder engagement conducted by the project team across New York State and Part II presents the analysis framework with preliminary data analysis and impacts assessment. Both efforts are anticipated to serve as enabling the development of more robust knowledge as well as a process of a co-evolving feedback loop between research and practice to help continue exploring long-term implications for the State. The preliminary data analysis included (1) gathering baseline data and (2) survey of local expert opinion on the key relationships of interest and factors to consider for modeling future long-term impacts that may inform how to plan with uncertainty. The report concludes with a discussion of how mobility system research, pilots, programs, and policies can help to shape a more ambitious energy and sustainability agenda. Such analysis and deliberations assist in providing a rationale and pathway for the twin goals of developing more inclusive and low-carbon mobility systems across New York State, a system with cost-, time-, and energy-efficient mobility as well as key aspirations for a safe, productive, and accessible system.

# 1 Introduction

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Today, concerns over congestion, affordable and equitable transportation options, and environmental sustainability (Anas, 2015) have increased interest in exploring alternative ways to manage mobility, reinvent mobility, and take advantage of disruptive impacts associated with the adoption of increasingly connected mobility, automated vehicles, and shared high-capacity, energy-efficient, and low-carbon mobility services in the State of New York. As connected and automated vehicles (CAVs), together with shared and electric mobility transitions, have garnered more attention over the past decade, transportation network companies (TNCs) (e.g., Uber, Lyft, Via) and other micro-mobility services (on-demand transit to car, bike, and scooter shares) are being recognized as some recent forms of new mobility transitions, with the potential to transform energy, mobility, and lifestyles.

New York State, with its unique culture of urban mobility innovation, global interconnectedness, and shifting demographics, offers an important locale for identifying strategies for and barriers to integrated, multimodal system environments that are supportive of connected automated and shared mobility strategies, multiple additional emerging technologies, new policies, and predictive analytics that encompass critical behavioral science insights.

The New York Metropolitan Transportation Council's Plan 2045 section titled Changes Likely to Impact Transportation (NYMTC, 2018) and the New York State's Climate Leadership and Community Protection Act (CLCPA) highlights opportunities and goals for tapping into these new mobility transitions and reaching a net zero carbon economy by 2050 (S6599, 2019):

- Personal mobility is likely to evolve from vehicle ownership to increased use of “car-optional” lifestyles (at least in cities) with more use of and options for shared, on-demand, and possibly automated vehicles that increase economic productivity, road safety, and other potential benefits for system efficiency.
- The availability of new types of data and digital connectivity are already enabling new approaches to provide, operate, and use transportation services. Managing the transportation system with new organizational arrangements for service provision to facility and asset management may reshape financing and governance of built, natural, social, economic, and information infrastructure. Both personal and organizational access to data and services at your fingertips (e.g., with the “push of a button”) is already driving change in many ways.
- Critical forces of change for transportation include advances in information and communication technologies, alternative fuels and vehicle technologies, employment and economic transformation, demographic changes, land development patterns, and responses to extreme events and system resiliency.



A new ecosystem of energy efficient and affordable mobility services and institutions are emerging in diverse hubs across New York State. While very different contexts, each are strategically positioned to take advantage of evolving transformations in energy, mobility, and built environment innovation. There are significant variations expected in the impacts of emerging mobility technologies and services expected across rural, suburban, and urban environments. A high level of unpredictability requires an approach that remains flexible and adaptable to market transformations. This could include factors that may vary depending on the range of operating modes, technology performance, system design decisions, and a wide range of regional factors.

Some of the efforts described in this report combines data integration, visualization, and analytics in a method called “typology” to examine the influence on mobility and energy outcomes of factors associated with socio-demographics, economy, technology, environment, and governance (SETEG), used in this study as independent variables. These variables include indicators on income, age, gender, race, education, home ownership, housing and transportation affordability, employment access, population density, intersection density, particulate matter (PM) concentrations, cancer hazard, and respiratory hazard across all State settlement types ranging from urban to rural settlements.

The goal of both the stakeholder engagement and data analysis components of this project is to explore the options, opportunities, and constraints associated with transforming mobility dynamics in New York State. The interdisciplinary methods used include exposing critical data layers and current outcomes that may inform future system design and management approaches. A highly geographically resolved understanding of the underlying SETEG dynamics is key to explaining these variations and informing effective decision-making.

This early-stage research effort, based on finer-grained spatial data that was available at the time of writing, attempts to explore which mobility energy metrics have greater explanatory power in the variations of social and spatial differences that exist among rural, suburban, and urban communities. It has been widely noted that inequities exist between settlement types, and the growing new mobility literature has generally focused on urban and affluent areas, without considering these to also be important subjects of inquiry for all current social, economic and infrastructure configurations across a region or State. Indeed, a 2017 United States Department of Energy (DOE) report noted: “the ways connected, automated and shared vehicles are integrated in rural areas may differ substantially with how they are integrated into urban areas. So, it is likely that various paradigms will co-exist.” (DOE Office of Energy Efficiency & Renewable Energy, 2015). This project, therefore, builds on these hypotheses

by collecting and integrating data identified across New York City, Ithaca, and Buffalo as well as more rural upstate regions. By analyzing the associations of these dynamics, this effort aims to inform coming transportation transformations and explore how energy-efficient mobility may evolve, based on an envelope of potential outcomes discussed in the literature and evidenced by real world data that is collected, processed, analyzed, and visualized as clusters of diverse settlements to inform context-sensitive efforts in New York State.

This study aims to help develop an overarching research, policy, and feasible pathways roadmap with a scenario modeling framework, which could help in the co-design and co-development of a future data and information warehouse. With some limitations and remaining knowledge gaps, the preliminary analyses are designed with the intention of interfacing with and feeding into other existing and aligning efforts used to inform the emerging body of knowledge on new integrated, efficient, and low-carbon mobility systems and related decision-making challenges and opportunities. While the study of enablers and barriers to further allowing new synergies between Automated, Connected, Efficient (Electric), and Shared (ACES mobility remain nascent, they are identified as emerging dynamics that are critical to shaping the future of mobility, energy, lifestyles (or quality of life), and economic activity/productivity.

The specific goal of the analyses framework in this study is to therefore assess and compare pathways in the context of a broad range of sustainability metrics, with particular focus on regional variability, and with planners, investors, and service consumers as key stakeholders. The development approach includes building on existing indicators (mobility, energy, and productivity metrics) and frameworks that have evolved from the capabilities of systems analysis, examining infrastructure development, cost analysis, energy-economic impacts, and market transformation processes. The proposed framework specifically aims to help inform and guide research, development, deployment, and investment decisions associated with ACES mobility systems, emphasizing the integration of currently disparate transportation and energy literatures and research-practitioner communities for systems integration.

In the first year of the project, the research team interacted with a diverse set of agencies and transportation professionals by conducting two intensive workshops—one in New York City and the second in Ithaca, NY. These workshops involved several panels bringing together experts from public, private, and academic domains. Furthermore, the research team had several stakeholder engagement

meetings from across the State. During the second year of the project, the team formed analyses to estimate current changes in human behaviors to explore the most important decision factors shaping enablers and barriers to adoption as well as the anticipated impacts (both benefits and risks) of new ACES mobility technologies and services emerging as most critical to New York State based on plausible scenarios.

This report is structured in two major parts. The first, Part I, provides a summary of the workshops which includes the motivation and objectives behind the workshops, description of insights derived from expert interaction, and subsequent stakeholder engagement. The first section of Part I presents the kickoff workshop in NYC. It is followed with the discussion of the second workshop at Ithaca and a third section which summarizes various stakeholder engagement meetings.

The second, Part II of the report, presents the formulation analysis framework, methodologies, and metrics employed to estimate the impacts due to ACES mobility in New York State. Also presented are some modeling results estimating the range of impacts due to several different behavioral and vehicular factors influencing ACES mobility. These estimates also contrast the range of impacts across three very different urban centers in the State. The report concludes with a discussion of how alternative interventions can shape mobility, energy, and emissions goals. A limitation or area for future analysis is the critical behavioral insights associated with technology adoption, the possibilities for car-pooling lifestyles with increased use of transit or public-private partnerships for ACES mobility, and an increasingly key area of electric vehicle (EV) to grid impacts interface (which was outside the original scope, yet is clearly emerging as a priority area for New York State). Such analysis and deliberations help to provide a rationale and pathway for the twin goals of developing more inclusive and low-carbon mobility systems across the State. A cost-, time-, and energy-efficient mobility system as well as a safe, productive, and accessible system are key aspirations for a smart(er) New York with improved economic opportunity, environmental sustainability, inclusive access, and quality of life for all.

## 2 Part I: Workshops and Stakeholders Engagement

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### 2.1 New York City Project Kickoff Workshop

#### 2.1.1 Introduction

The University Transportation Research Center (UTRC) and the National Renewable Energy Lab (NREL) convened on May 11, 2018 for a full-day workshop that shared and discussed a pre-workshop survey. The workshop concluded with a “data-thon” roundtable to explore and assess available data and key research questions in exploring the long-term potential impacts of increasingly ACES mobility systems, technologies, and services in New York State. Participants and presenters shared approaches, data, and insights from research and public and private sector perspectives to inform progress for this study.

The focus of the NYC workshop was to examine key data, models, scenarios, and strategies that would enable potential synergies of energy and mobility system goals via increased multimodal and digital connectivity, automation of emerging fleets, vehicle and ride sharing, and transportation electrification. By bringing together mobility experts and leaders, this workshop focused on identifying strategies for and barriers to designing a “reinventing mobility” analysis framework. The framework (1) was designed to characterize, increase observability into, and inform accelerated decision-making and proactive planning for a rapidly evolving technological and service ecosystem and (2) reflected the need for data and adaptive/evolving approaches to maximize public-private benefits.

The key workshop question posed, for shaping new critical research directions, included:

- How can the larger community now advancing transportation and integrated mobility best generate new and enhanced data sets, visualization, and modeling approaches that can encourage energy-efficient, cost-effective and high-performing technologies in the public interest, while also setting new technology-related policies that would not prematurely stifle promising innovations?

Additional key questions, included:

- What strategies will encourage innovation and reinventing of mobility across rural, suburban and urban environments of New York State?
- What will be the future of mobility and where do we need to head for harnessing technology and new services for positive outcomes while reducing risks?

More specifically, some of the provocative discussions and findings included:

- Despite the promise of TNCs for ridesharing, research shows that 90% of TNC trips are single rides. Unless there is widespread adoption of pooling, TNCs may not reduce the carbon footprint of transportation. Furthermore, larger numbers of smaller shared vehicles in big cities could contribute to congestion.
- Even though in the short-term TNCs may detract from public transit, their long-term sustainable impact can only be through enabling a car-free, or car-light lifestyle.
- Survey respondents in NYC who reported having a disability are about twice as likely to use ride-hail applications several times a week as those who did not report a disability.

### **2.1.2 New York City Workshop Synthesis and Survey Summary**

This summary presents a review of the stakeholder engagement workshop to help formulate and develop an overarching research roadmap, informing a future information and knowledge-action warehouse designed to interface with and feed into other aligning efforts used to apprise specific decision-makers. Using expert feedback from the roundtable, knowledge gaps and new critical research, and metrics are proposed in ways that bring together smart and sustainable transportation communities to explore mobility pathways that may have critical real-world impacts.

A project overview and aims of the workshop were introduced by the City University of New York–National Renewable Energy Laboratory (CUNY–NREL) team. The introduction was followed by three panel sessions, identified via literature review and initial stakeholder consultations on pressing topic areas at the Smart Cities New York conference held on May 14-15, 2020 in New York City, including:

- Shared Mobility, Public-Private (Micro)Transit, and Increased Occupancy: Past, Present, and Future
- Vehicle Connectivity and Automation/Plausible Future Scenarios for Cities, Communities and the States of NY/NJ
- Regional Opportunities/Data Considerations Across Scales: District, City, Regional, State Levels

The scope and key points of the panels are described in terms of key messages, challenges and opportunities, and data or knowledge gaps in the following sections.

**Table 1. Summary of Speaker Organizations, Topics, and Other Attending Organizations**

Organization	Topic
TNC	Shared and High-Occupancy Mobility/(Micro)transit
Transit	Connectivity and Automation in Transit
Transit Non-profit	ACES Impacts on Transit
TNC	Shared Mobility
Vehicle sharing	Shared Mobility
Auto manufacturer	Vehicle Automation
Auto manufacturer	Vehicle Automation
UTRC/CCNY	Connectivity, Automation, Sharing, and Local-Regional Insights
NREL	Shared, CAVs, E-Mobility Insights (City-Regional-to-National)
<u>Other Attending Organizations</u>	
Representatives from several government agencies, research faculty from NYS and around the U.S.	

Note: Attendees noted the value of assembling research, data/literature, and public-private advanced mobility experts—each learning from the other, and the groups generated ideas and priority challenge areas to collaboratively inform the design, audience for, and proposed use of a new “reinventing mobility” framework in New York State.

### **2.1.3 Panel 1—Shared Mobility, Public-Private (Micro) Transit, and Increased Occupancy: Past, Present, and Future**

This dynamic panel session brought together shared mobility experts from across the spectrum, from private mobility providers to public transit actors and researchers (NREL). The panelists presented a vision of mobility with sharing at its center, noting that the technology enabling pooled rides was already operational in New York State. A paradigm shift from individual ownership toward access to alternative travel-time and cost-efficient mobility choices were identified as major behavioral factors determining the extent and speed of the adoption of shared mobility. In addition, public transit and truck-sharing were established as long-standing “shared” modes which could also benefit from innovations such as electrification, connectivity, and automation.

**Table 2. Panel 1 Summary**

<b>Panelist</b>	<b>Key Messages</b>	<b>Challenges</b>	<b>Opportunities</b>	<b>Knowledge Gaps</b>
<b>TNC</b>	<ul style="list-style-type: none"> <li>• The future is shared, electric &amp; automated.</li> <li>• Focus on how ride-sharing plugs into multimodal network/facilitating payment/consumers.</li> <li>• Private sector harnessed to support policies.</li> </ul>	<ul style="list-style-type: none"> <li>• Concerned with greening the fleet/AVs.</li> <li>• Need to think on good &amp; bad city impacts.</li> <li>• (-) privately owned/used vehicles.</li> </ul>	<ul style="list-style-type: none"> <li>• How do we utilize vehicles on the roads today better; and improve GHG footprint?</li> <li>• Pooling &amp; vehicle sharing; series of products for commuter and employer benefits.</li> </ul>	<ul style="list-style-type: none"> <li>• Responsibility for thinking more responsibly about “what are impacts and how can we help shape them?”</li> </ul>
<b>NJ Transit</b>	<ul style="list-style-type: none"> <li>• This is the most exciting time for transit: “I’m having more fun now than I’ve ever had.”</li> <li>• Land-use: mixed-use development, shared streets.</li> </ul>	<ul style="list-style-type: none"> <li>• Transit ridership is declining.</li> <li>• Paratransit is incredibly inefficient and poor service.</li> </ul>	<ul style="list-style-type: none"> <li>• Technological response: connected, automated, on-demand, electrified transit.</li> <li>• Institutional response: leverage shared, on-demand vehicles for low-ridership routes.</li> </ul>	<ul style="list-style-type: none"> <li>• Impacts of CAVs on transit ridership.</li> <li>• Unanticipated Consequences.</li> <li>• Future finance of mobility infrastructure.</li> </ul>
<b>Vehicle sharing company</b>	<ul style="list-style-type: none"> <li>• “Mobility is Nobility.”</li> <li>• Shifting from an ownership to an access/service paradigm.</li> </ul>	<ul style="list-style-type: none"> <li>• Access to transit for truly multimodal mobility.</li> <li>• Moving a need in 500+ cities Uhaul services.</li> </ul>	<ul style="list-style-type: none"> <li>• One U-Haul shared truck replaces 19 large private vehicles.</li> <li>• On street shared vehicle parking permits project in City of SF.</li> </ul>	<ul style="list-style-type: none"> <li>• Sharing loading capacity.</li> <li>• Centralized parking vs on street parking for urban core.</li> </ul>
<b>Transit non-profit</b>	<ul style="list-style-type: none"> <li>• International perspective: look beyond U.S. borders.</li> <li>• Human capacity development.</li> </ul>	<ul style="list-style-type: none"> <li>• Changing demographics and mobility needs.</li> <li>• Updates on “state of the art.”</li> </ul>	<ul style="list-style-type: none"> <li>• Tech-enabled first- and last-mile solutions.</li> <li>• Better data-sharing to improve logistics.</li> <li>• First last mile (for suburban/rural).</li> </ul>	<ul style="list-style-type: none"> <li>• Changing demographics.</li> <li>• Financial strains.</li> <li>• Service as cost competitive?</li> </ul>
<b>TNC</b>	<ul style="list-style-type: none"> <li>• Increase PMT/VMT.</li> <li>• “The future is here”: 69% of Via rides are shared.</li> <li>• 40% pooled option in outer boroughs.</li> </ul>	<ul style="list-style-type: none"> <li>• Need more regulatory incentives for people to share.</li> <li>• Staying above &gt; 1 PMT/ VMT and more during peak hours.</li> </ul>	<ul style="list-style-type: none"> <li>• Opportunities for suburban and rural shared mobility.</li> <li>• Freedom of info requests to TLC on shared mobility data.</li> <li>• More efficient routing /pick-up and drop-off.</li> </ul>	<ul style="list-style-type: none"> <li>• Quantifying more \$ for TNC, faster trips (if more share).</li> <li>• Employer provided mobility.</li> </ul>
<b>NREL</b>	<ul style="list-style-type: none"> <li>• Business community starting to engage with public interest.</li> <li>• Watch Columbus Smart City Initiative.</li> <li>• Maximize mobility.</li> </ul>	<ul style="list-style-type: none"> <li>• Car ownership culturally engraine – yet changing w/ millennials.</li> <li>• Freight data.</li> </ul>	<ul style="list-style-type: none"> <li>• Employers providing mobility benefits to attract talent.</li> <li>• \$30k per parking space.</li> <li>• Paratransit/Travel time.</li> </ul>	<ul style="list-style-type: none"> <li>• Quality of mobility /accessibility w/ energy lens.</li> <li>• Developer community.</li> </ul>

### **2.1.3.1 Panel 1 Group Discussion**

When prompted to envision the future of shared mobility, panelists reacted that the future is already here, and mobility sharing is already happening, albeit at a modest scale. Regulations were proposed as a powerful lever to influence consumer, provider, and behavior toward shared rides. The importance of anticipating potential unintended consequences of technological disruptions was emphasized—in terms of urban planning, employment, revenue streams, energy use, etc. Vehicle occupancy was identified as a critical indication of positive or negative energy impacts. Therefore, maximizing vehicle occupancy and understanding the more mature markets for vehicle pooling was established as one priority in the transition to a shared mobility and the rapid on-demand transit paradigm. Finally, questions about the impacts of automation on employment and workforce development were raised, highlighting the need for training opportunities.

Additional questions proposed for further study, included:

- What’s happening in the rest of the world and how that may inform the State and the United States?
- How Mobility-as-a-Service (MaaS) aligns with high-occupancy, affordable, and reliable transit systems?
- How data and information is shared and what is achievable for public and private sectors?
- To what extent are we planning for centralized MaaS and CAV parking; will we dedicate more space for carshare companies, for fast charging hubs, other infrastructure?

### **2.1.4 PANEL 2—Vehicle Connectivity and Automation: Plausible Future Scenarios for Cities, Suburban Areas, and New York State and New Jersey**

This session discussed plausible scenarios for the deployment of vehicles with higher order automation and ways to ensure that connectivity and automation bring positive benefits. The session addressed the potential opportunities and challenges, the infrastructure that will be needed and the level of public acceptance that can be expected, as well as other important issues. For example: How will humans behave? What happens in the future and what is the range of scenarios to consider?



**Table 3. Panel 2 Summary**

Panelist	Key Messages	Challenges	Opportunities	Knowledge Gaps
NYS Govt.	<ul style="list-style-type: none"> <li>• Governor wants state to be a leader in technological innovation.</li> <li>• Promoting R&amp;D of technology by investing in research centers particularly in photonics.</li> <li>• Trying to engage private sector but not as enthusiastic as researchers.</li> </ul>	<ul style="list-style-type: none"> <li>• Safety—asking people to concede responsibility to software but where is responsibility for accidents?</li> <li>• Effect that automation will have on jobs.</li> <li>• Technology must be validated before legislators will enact laws pertaining to AVs.</li> </ul>	<ul style="list-style-type: none"> <li>• Campus shuttles, public transportation efficiency.</li> <li>• People with special needs, or without cars.</li> <li>• Working with private sector to make sure they have what they need.</li> <li>• Equitable distribution of technology and services.</li> </ul>	<ul style="list-style-type: none"> <li>• Policies and actions that will most effectively promote the development and validation of technology and get the private sector engaged in the process.</li> <li>• Jobs of the future</li> <li>• How to be first? with pro-innovation/first in the country's approaches.</li> </ul>
University Research Faculty	<ul style="list-style-type: none"> <li>• Transportation policy and technology are much more volatile than in the past.</li> <li>• Planners will need to act like parents of a teenager—need to nurture but not be overprotective.</li> <li>• Adoption of Shared Automated Vehicle (SAV) technology will change role of public sector from infrastructure and service provision to oversight.</li> </ul>	<ul style="list-style-type: none"> <li>• What if widespread adoption of SAVs clearly contributes to worsening congestion or murky impacts on public safety?</li> <li>• Transportation equity when mobility is allocated preferentially to “5-star” people</li> <li>• Safety vs. efficiency trade-offs are based on physics and will remain with us.</li> </ul>	<ul style="list-style-type: none"> <li>• Improving safety—how much closer to achieving Vision Zero goals, reducing number and severity of accidents.</li> <li>• Increasing efficiency—in terms of capacity, but also fuel consumption and emissions.</li> <li>• Improving mobility especially for people who can't drive.</li> <li>• Public sector oversight.</li> <li>• Parking design(s).</li> </ul>	<ul style="list-style-type: none"> <li>• Data and insights beyond NYC and statewide are key.</li> <li>• Future uncertainty for technologies and services. E.g., a civilian killed (in NYC or upstate) under bad circumstances, and if by that time 1000s of NYers dependent on SAVs for daily mobility.</li> <li>• Evidence: multiple benefits, less risks and negative impacts.</li> </ul>
UTRC	<ul style="list-style-type: none"> <li>• Plausible scenarios for adoption of level 4-5 AVs vary greatly for urban, suburban, rural, and closed communities.</li> <li>• Infrastructure required and public acceptance level depend on environment.</li> </ul>	<ul style="list-style-type: none"> <li>• AVs adoption in urban settings requires vehicles to have same higher automation level and extensive infrastructure changes.</li> <li>• Rural area car culture makes fully automated PMVs unlikely.</li> </ul>	<ul style="list-style-type: none"> <li>• AVs most likely to be accepted in closed communities with low speed multi-passenger micro-transit.</li> <li>• In rural areas, long distance freight and dedicated lanes on highways and in restricted areas.</li> </ul>	<ul style="list-style-type: none"> <li>• Legal aspects</li> <li>• Socio-economic impacts and plausible scenarios for urban, suburban, rural and closed communities.</li> <li>• Public acceptance.</li> <li>• Realistic concepts.</li> <li>• Infrastructure.</li> </ul>

**2.1.4.1 Panel 2 Group Discussion**

Research on networks with both automated vehicles (AV) and regular vehicles indicates that efficiency increases sharply with increasing penetration level, but an issue that needs to be addressed is that the

behavior of an AV in traffic is very different from a vehicle driven by a human, which can irritate the drivers. AVs are being programmed to strictly adhere to traffic or parking rules and speed regulations, offering enhanced safety and less need for rules enforcement, relative to the dynamics for human drivers and the extent to which human speeding and/or parking violations may occur today. An analogy was made between the adoption of AVs and that of Positive Train Control—a system designed to prevent train collisions. This technology has been around for a long time, but many cities haven't been able to implement it for a number of reasons, including the high cost, a problem that applies to AVs as well. One of the main challenges with AV adoption is that driving is something that most people are familiar with—a situation distinct from the introduction of trains or planes—making it difficult to design new AV regulation when there are existing traffic expectations that drivers are accustomed to. Another point made was that what works in older rail-oriented cities is very different from what works in newer cities and suburbs. These differences need to be kept in mind because the study covers New York State, not New York City exclusively. An important trend is building infrastructure with the idea of repurposing space to accommodate new technology, such as converting parking garages in Arizona for new uses (AZ Central, 2018) or the D.C. DOT repurposing street parking to pick-up and drop-off zones. Finally, while in the past rural areas have not been included in the conversation about AVs, these areas have the most to benefit from automation where long drives and low-traffic volumes present relatively simple driving conditions as compared to midtown Manhattan streets, which are considerably more difficult for AVs to negotiate.

### **2.1.5 PANEL 3—Cross-Scale Opportunities and Regional Data Considerations**

This session focused on (1) the “cross-scale” considerations of reinventing mobility, (2) co-creating a refined or new set of questions for data and analytical insights, and (3) sharpening key messages from earlier sessions across different levels—from project scale, to local, regional, and State level.

The three key questions for the panelists, included:

- What's the current status and key issues for integrating shared, connected, automated mobility at the scale in which you're focusing your efforts? (e.g., at State, regional, local, and project-level?)
- What are possible and politically- or market-viable futures to expect and plan ahead for proactively?
- What are the desirable outcomes and key risks? How best to avoid risks and increase the benefits?

Early consensus and agreements of the panelists, building on prior panels, included the following:

- Changes are happening now, and we need to shape the future of mobility in a careful way.
- Behavior, culture, and decisions could all change corresponding to industry/market forces.
- There will always be risks and the role of the public sector is to guide or provide the structure.
- One key goal is the balancing of public-private interests while maximizing public benefit.

**Table 4. Panel 3 Summary**

Panelist	Key Messages	Challenges	Opportunities	Knowledge Gaps
Chief Data Officer from a DOT	<ul style="list-style-type: none"> <li>• Data sharing &amp; interoperability for impact analyses and policy making.</li> <li>• Usage fees and transport finance may be critical to figure out .</li> <li>• Insurance industry may be turned upside down.</li> </ul>	<ul style="list-style-type: none"> <li>• Baseline data: there is need for baselines and historical analyses to inform pathways ahead.</li> <li>• Will data sharing be voluntary or mandated –will there be a trusted broker? Who owns the data?</li> </ul>	<ul style="list-style-type: none"> <li>• Having practical perspective based on data from lots of pilots for analyses.</li> <li>• Lots of newly available data (e.g. NY Open Data platform).</li> <li>• Sharing across jurisdictions.</li> <li>• Safety in forefront.</li> </ul>	<ul style="list-style-type: none"> <li>• Impact of data and technologies for connectivity, via sensors, etc.</li> <li>• Education for a new workforce.</li> <li>• Cross-sector future insights and preparing (the mobility sector is not alone).</li> </ul>
NYMTC	<ul style="list-style-type: none"> <li>• NYMTC’s Plan 2045 provides scenarios in near- &amp; long-term (now-2020, 2020s, 2030s, 2040); Sensitivity analyses; Regional inter-jurisdictional cooperation.</li> </ul>	<ul style="list-style-type: none"> <li>• Impacts are difficult to capture due to lack of current and instantly data.</li> <li>• Balancing public goods versus private interests</li> <li>• Anticipating change in regional plan (Plan 2045).</li> </ul>	<ul style="list-style-type: none"> <li>• Adaptive evolution of policies.</li> <li>• Impacts to clean air funding/ strategy impacted by how we forecast future.</li> <li>• New types of data.</li> </ul>	<ul style="list-style-type: none"> <li>• Vehicle occupancy travel data.</li> <li>• What happens when we have a mixed fleet?</li> <li>• Evolving timeline– mostly still speculations on the road ahead.</li> </ul>
NYCDOT	<ul style="list-style-type: none"> <li>• AV impact/policies could be similar to e-bike legalization; last mile access, equity; Ride hail pricing so transit is not disused; Better network management due to AVs; Freight efficiencies; EV charging station networks.</li> </ul>	<ul style="list-style-type: none"> <li>• Seamless payment options, AVs must follow state/local laws.</li> <li>• Reallocating street space, parking, and land in positive ways that support affordable housing, good urbanism, and shifts to mobility as a service.</li> </ul>	<ul style="list-style-type: none"> <li>• Automation of traffic enforcement, use data from operators; Utilize AV data for public infrastructure policy and maintenance.</li> <li>• Learning from largest corridors/ metro on edge of transformations.</li> </ul>	<ul style="list-style-type: none"> <li>• Obtain data from operators.</li> <li>• How best to achieve the NYCDOT 80 by 50 (NYC Mayor’s Office, 2016) goals with future of mobility technologies and services.</li> <li>• Hypersprawl? ghost vehicles? Vehicles return to suburbs? Collapse of state/local revenues?</li> </ul>
University Research Faculty	<ul style="list-style-type: none"> <li>• Study resilience of infrastructure in AV planning/policies.</li> <li>• Policies to help housing affordability.</li> <li>• Equity of accessibility, e.g., Babcock Ranch, FL; urban districts.</li> </ul>	<ul style="list-style-type: none"> <li>• Vehicles need to be somewhere when not driving.</li> <li>• Building resiliency</li> <li>• How to achieve better, safer mobility.</li> <li>• Achieving net zero energy buildings–yet transportation?</li> </ul>	<ul style="list-style-type: none"> <li>• Research methodologies must adapt &amp; evolve; NY/NJ port to building delivery; Land use changes.</li> <li>• Utility of time.</li> <li>• Transit and urban infrastructure can be redefined.</li> </ul>	<ul style="list-style-type: none"> <li>• Relationship with and impacts on housing.</li> <li>• Approaching parking industry and developer community will be useful to fill gaps.</li> <li>• Interactions with EV and infrastructure investment.</li> </ul>

### **2.1.5.1 Panel 3 General Discussion**

- Public benefits can be realized from Level 2 and Level 3 automation—do not have to wait until Level 4 and Level 5.
- Disruptive changes impact cross-scale funding and strategy and on how to forecast the future.
- How to accommodate and optimize by various jurisdictions? How to balance public good versus private?

An important comment during the panel was that what might work in New York City may not necessarily work in Albany, Buffalo, or Ithaca. It is therefore important not focus only or primarily on NYC, rather to understand the range of challenges and opportunities across urban, suburban, to rural environments in the New York State.

### **2.1.6 Data-thon Roundtable: Informing Analytical Insights Framework for Data and Modeling**

Finally, a “data-thon” focused brainstorm and strategy session for next steps was designed to understand potential changes in behavior and decisions related to mobility; infrastructure, technology integration, and emerging policy concepts; scenarios and analysis to inform pilot ideas; and mobility metrics for rural-suburban-to-urban integration synergies for improving service access.

The overall goal of the roundtable was to objectively assess and provide analytical insights on the impacts of self-driving vehicles within and across the New York State, with emphasis on synergies between automated, connected, electric, and shared vehicle transportation transformations. Participants joined a group discussion session on relevant topics as well as a discussion on the data available and needed for reinventing mobility in the State.

The topics that have been discussed are:

- Understanding behavior and decisions to identify lower to higher bounds of mobility impacts
- Infrastructure, technology integration, and emerging policies
- Scenario and analysis—informed pilot ideas
- Mobility metrics for rural-suburban-to-urban integration synergies
- Improving access and equity

The discussion included perspectives of State government, metropolitan, and regional planning organizations, cities, MaaS providers, businesses, and others relating to these topics. Data on electric utilities was identified to have more presence in future stakeholder engagement.

## 2.1.7 Human Behavior and Mobility Impacts

- Importance of using the appropriate baseline data.
- State and local data that reflects specific origin-destination pairs for taxis and TNCs today.
- Energy impacts of two-way feedback on connected vehicles—e.g., Waze, NYC connected vehicle (CV) pilot demonstration project, etc.
- What is the available behavioral data and what data do we still need? Can Google Maps help?
- Role of partnering with private sector in a number of ways to create new behavioral metrics.
- Targeting new mobility service consumers and factors that affect use of energy for mobility.
- TNCs as the tip of the spear for mobility as a service—accessing revenue data to explore how quickly changes are accelerating, decelerating, and/or plateauing.

### 2.1.7.1 Data Sources

*Mobility:* locational data provided via Google Maps, Streetlight, National Performance Management Research Data Set (NPMRDS) data, New York Thruway, Metropolitan Transportation Authority (MTA) turnstile, cellphone data, On-board diagnostics (OBD) data from insurance or other telematics; Port Authority of New York and New Jersey (PANYNJ) revenue data.

*Inferences on Efficiency:* EV vehicle share, energy investment in electric substations, vehicle occupancy data.

*Key comments:* All the past behavioral surveys—may be useless unless they were designed with specific research questions in mind relevant to future of mobility; Transportation Research Board (TRB) committees and publications that offer a large amount of research; basic data may be used and could be built on for research.

## 2.1.8 Infrastructure, Technology Integration, and Emerging Policies

- Best practices for roadway markings and signage for better AV operation.
- Change in parking space allocation by real-estate developers.
- Mobility options to residents by real-estate developers/employers.
- Technological deployment for CV infrastructure and maintenance.
- Energy—solar power and vehicle charging.

### **2.1.8.1 Data Sources**

*Mobility:* TNCs provide a lot of data to the NYC Taxi Limousine Commission, only a small portion goes on their website; this data can be requested using freedom of information request (since June 2018, TNCs report on the number of trips that are actually shared and on the density of shared trips across NYC metro).

Policies:

- Emergency response and improvement in the ability to deal with disasters using AVs
- Pricing for upkeep of infrastructure
- Peak pricing for EV charging
- Consumer adoption of EVs

### **2.1.9 Scenarios and Analyses**

- Explore modification of travel demand modeling by relaxing the park-and-ride facilities' capacities and study impact of transit use.
- Empty and deadheading miles.
- First mile/last mile integration examples in Long Island Railroad (LIRR) and micro transit in suburban areas.
- Surrogates for potential AV adoption: tech device ownership.
- Value of travel time impact on commuting and regional travel.
- Changes in economic opportunities resulting from spatial redistribution of employment and education.
- Regional electric power models, nature of source of power generation (renewable or not).

*Key Comments:* Equity of public investment? Perhaps more infrastructure investment in suburbs due to more predicted AV usage and lesser investment in cities?

### **2.1.10 Mobility Metrics for Rural-Suburban to Urban-Integration Synergies**

- Passenger miles traveled (PMT)/VMT or PMT/unit of energy (British thermal units, kilowatt-hours, or gallon of gasoline equivalent)
- Quality of mobility versus energy
- Impact on e-commerce

### **2.1.11 Summary of Additional Data Discussions and Key Comments and Questions**

- Some states are on the forefront in terms of best practices—e.g., California has AV cameras, striping, etc.
- How to categorize types of shared, electric, and automated mobility services in vehicle registration databases?
- CV infrastructure—what is being put in and which technologies already exist?
- New parking garages and parking facility adaptability?
- Can we focus on some pilots and data collection from forward looking communities?
- Should we pay closer attention to the developer’s community—statistics on changes in thinking and approaches in real-estate development based on how new mobility technologies change the way they build?
- How many vehicles will be electric, automated, and shared and in how many years?
- Should New York State have aspirational goals?
- How to deal with emergencies for extreme events? When to shift into this new operation? Are we increasing evacuation capacity when everyone needs a shared-ride system?
- What electric power grid considerations to include if transportation electrification is coupled with ACES?
- How will costs and transportation affordability change? How quickly?
- In places outside NYC where the single occupied vehicle is the dominant mode of transportation—what about curbside and parking infrastructure for CAVs? Which parts of the population will still drive? Where does a CAV or fleet go—parking, circling, and/or can rent it out for the day?
- Scenarios may need to be designed based on population cohorts such as fast adopters to late adopters in technology, with separate scenarios and analyses for rural, suburban, urban settings.
- What is most difficult to assess? Travel time utility? Elasticities? Land use changes?
- As a metric on mobility and energy performance—PMT/VMT—can we quantify?
- What are the considerations for freight?
- Do paratransit users and vulnerable populations have increased access?
- Untapped area: How to work with the various data collected to guide investments?

### **2.1.12 Conclusions from Kickoff Workshop**

In sum, the workshop provided several useful insights into research involving shared, connected, automated and efficient mobility. Key takeaways are as follows:

- As automated vehicles and emerging transportation technologies are still in infancy, obtaining relevant data can be critical for analyzing their impact.
- New York State has a wide spectrum of demography and geography. Hence, the estimated impact of technology and needs of the localities and regions are very different. These need to be key considerations in impact assessment and analysis.

- Modeling of impacts for shared, connected, automated and efficient mobility entails several different factors that must all be considered. Adaptation and enhancement of existing tools may be necessary for long-term transportation planning tasks as well as unification of mobility and energy analysis within a common modeling framework associated with shared, connected, automated and efficient mobility.
- Market adoption to user behavior, vehicle efficiency to system operation, user affordability to the impact of government subsidies or new policies—provide examples of the vast number of uncertainties and unknowns.

## **2.2 Upstate New York Workshop**

### **2.2.1 Introduction and Objectives**

Following the successful kickoff workshop in NYC, the study team organized a second workshop in Ithaca, NY on October 5, 2018. This workshop focused on informing an ongoing study on future mobility systems design across diverse contexts, with integrated data and modeling, and applied research to quantify the potential mobility and energy impacts of new technologies and services that can help shape a better future for New Yorkers—this time with focus on impacts in Ithaca, Tompkins County, and Upstate New York.

ACES mobility technologies with on-demand MaaS options are increasingly recognized as having potential to transform energy and mobility dynamics. Ithaca offers another unique locale for identifying strategies toward, and barriers to, integrated, efficient, and affordable multimodal system/service environments.

This interactive workshop emphasized the needed data to understand impacts, and the adaptive and evolving approach to maximizing public benefits. This workshop brought together local transportation experts and leaders to help plan, design, and reinvent mobility in a rapidly evolving technological and service ecosystem. This roundtable was highly interactive and engaging, reflecting the need for data and an adaptive and evolving approach to maximize efficient systems and services with transformational public benefits. Participants together shared inputs to inform strategies that encourage innovation and reinvent mobility across rural, suburban, and urban environments of New York State (with focus primarily on the upstate contexts).

To help seed thoughts and comments, some key questions were considered:

- How can communities/cities generate new and enhanced data sets, visualization, and modeling approaches that can inform the impact of technologies in the public interest?



- What strategy and policy will encourage innovation and reinvent mobility across rural, suburban, and urban environments of New York State?
- What will the future of mobility be and where do we need to head for harnessing technology and new services for positive outcomes while reducing risks?

A summary of stakeholder inputs are provided in the next sections. In addition, notes are included on State to local-level insights on emerging e-mobility, regional opportunities on mobility and energy (informed by exchange with Cornell intelligent campus transportation staff and interdisciplinary researchers working on topics related to the themes of the workshop), and a panel focused on shared, connected, and automated vehicles. A data-thon helped to explore available data for unique pilots, programs, policies, and shaping future modeling scenarios and analyses.

## **2.2.2 Background and Context**

Ithaca and Tompkins County were identified as a ripe location for new forms of transportation (e.g., as demonstrated by LimeBike) with interests to explore creating “connected, efficient/electric, shared mobility” testbeds. Priorities included creating new dynamics in the urban center while not neglecting rural transportation and adaptive approaches to automation. Key interests included identifying how ride pooling and transit can work together as a complementary, unified, affordable, efficient, and accessible system. The findings of workshop stakeholder input and consensus-building exercises and discussions—that built on the panels to inform deliberations—are noted below as useful context/key results:

The items below present a summary based on stakeholder inputs to rank their top priorities in terms of challenges, opportunities, and barriers to reinvent mobility in New York State:

### **2.2.2.1 Challenges**

- Public acceptance, changing behaviors to accept shared electric, automated (identified by multiple participants).
- Reduce the number of vehicles going into employment centers.
- Congestion
- Adopting CAV technologies without increasing car dependency—can we agree about the need to reduce car dependency?
- Providing transportation where it is needed, when it is needed.

### **2.2.2.2 Opportunities**

- Data sharing (identified by multiple participants).

- Improve land use and neighborhood design; build for people and not vehicles (identified by multiple participants).
- Ability to organize trips that are reliable and in real time (MaaS and Hypercommute).
- Much more efficient market in transportation: who gets what service at what price and what terms and conditions (reducing inefficiencies).
- Improve quality of life (e.g., access to transit and services for socially vulnerable).

### 2.2.3 Barriers

- Why would people want to give up their independence and convenience by giving up cars? The mindset is ingrained. Too accustomed to the convenience (identified by multiple participants).
- Data silos.
- Need to know typical daily travel needs of everyone to optimize transit options.
- As long as the U.S. continues to prioritize personal vehicle use, transit will lag.

### 2.2.4 Panel Discussion

The two presenters and panelists included representatives from Tompkins Consolidated Area Transit, Inc (TCAT) and Tompkins County Department of Social Services.

The key points from talk by TCAT (local/regional transit agency) included:

- First-last mile pilots—a focus on Dryden to Ithaca (Route 43) connections.
- Currently, the transit agency is moving 16,000 people on a weekday with 33 routes that include campus circulators and a series of rural routes.
- Challenge identified has been the select trips are economically profitable whereas the rest of the time its subsidized rural services.
- Fixed route and paratransit have both been identified as financially ineffective, due to lost ridership and limited funding for the services.
- Keen interests in new cost-effective MaaS and working with Get About, as the paratransit provider, to move away from requirements of booking 48 hours ahead of time for services, trip routing done manually, and to move towards on-demand spontaneous trips with alerts to dispatchers that interface with drivers for dynamically re-arranging pickups so that drivers can better meet passenger demand in real time.
- Surveys have been conducted to analyze daily trips, different travel times, and how best to avoid incurring additional costs—initial very small sample surveys (n=20, including mobile home parks). Noted results are that nine of 20 participants have a disability, 13 of 20 have interests in new first-last mile services; six of 20 are without smart phones. These surveys are being conducted to explore trip making and coordinating between modes in order to improve connection times, and dynamically arranged pick-ups.
- Census data on income, demographics, and travel data on travel peaks in a.m. and p.m. are utilized to focus on accessibility in the quarter-mile walksheds.

- Interface development with a startup on hypercommute to be included on the same platform as the Get About services (team has been applying for grants in recent years).
- Focus is on a pilot for first-mile and last-mile services as a multimodal, trip-sharing interface that allows integration of fixed-route transit, paratransit and other public or private carriers in areas where nonexistent or inadequate public transportation with fixed-route transit is not viable and where “transportation-insecure citizens” reside.

The key points from the talk by Tompkins County Department of Social Services/Chief of Transportation Planning:

- Regarding MaaS, the focus was on creating a tool for small urban and rural communities.
- Interests in improved mobility for customers by exploring successful deployment of mobility as a service in small urban and rural areas.
- Moving away from venture capital model alone to a customer interface offering taxis, car rentals, intercity bus, bikes, carshare, transit, mobility education and public support, primarily to small-urban, mostly rural areas.
- “One click” center or “inbox” for (1) taxi cabs, (2) fuel vouchers, (3) bus passes (think example of AAA—that helps mitigate “trip failure”).
- Value Propositions: financial transactions, innovation, and adaptation to the future by creating a “concierge service.”
- Moving from everyday options of ride-hailing (where demand is typically highest in the evenings and weekends, and for students) to scooters (soon there will be ~50 e-scooters).
- Bundle the cost of services and explore affordability in areas where walk score is high with bus passengers, carshare, taxi, bike member support to rural areas where walk score is low yet very affordable costs of services (e.g., future vanpool subsidy; discounted carshare; taxi; volunteer driver with revenue).
- Question raised of perhaps a future “feebate” approach with market segments/typology of populations that enables cross-subsidies and fees/revenues in one location to support rebates/subsidies in another.
- Key outcomes of interest: equity, access to job opportunities, collaboration, and not stranding people.
- Ensuring that land use is addressed.
- Exploring interests in mobility anxiety as TNC only a smartphone away—can there be more experimentation around carpooling spontaneously and that’s reliable on, for example, a Saturday morning?
- Only anecdotal data from campus and at the airport on Thursday to Saturday night is highest demands for TNCs (taxis lost ~30% of their nighttime business).
- Specific locations of Dryden corridor to Ithaca, making it easy for students get to and from airport and college town areas.

## 2.3 Stakeholder Engagement

Over the course of the first year of this project, the research team organized several smaller one-on-one stakeholder follow-up meetings to the workshops. The objective of these follow-up meetings was to get a deeper understanding of the data, models, policies, and initiatives taken up by the organizations and private firms that could impact the mobility and energy consumption in their region of operation.

The following is a list of stakeholders with whom meetings were organized:

- A mobility provider/TNC in NYC
- A (now) former microtransit provider in NYC
- Energy provider/distributor and researchers: Ithaca—energy agency, researchers, and firms working towards smart home EV charging initiative in Ithaca, NY area
- Ithaca Carshare and BikeWalk Tompkins—Car and bike share nonprofits in Ithaca area
- Binghamton Metropolitan Transportation Study (BMTS)—Broome County MPO
- Greater Buffalo Niagara Regional Transportation Council (GBNRTC), Go Buffalo Niagara, Niagara Frontier Transit Agency (NFTA)—Erie and Niagara county MPO, shared mobility organization and public transit

A brief summary of the meetings is presented in Table 5.

**Table 5. Stakeholder Meeting Summary**

Stakeholder	Summary
TNC	<p>Operates in NY: NYC (5 boroughs) + Newark. Began service in 2013 - started as commuter - during commute hrs. Expanded to 5 boroughs - Mid-late May 2017</p> <p>Via users have the payment option of using employer commuter benefits.</p> <p>Do not own vehicles but encourage drivers to buy higher capacity vehicles; no particular initiative to encourage EV usage.</p> <p>Users choosing shared option does not always mean all rides are shared. <b>Via users choose as 66% shared option in NYC – relatively higher than other TNCs (yet a smaller coverage area). Average vehicle occupancy is 1.6-1.8.</b></p> <p>TNC tax could help sharing; PMT/VMT can be used to measure performance on levels of “pooling.” The cost of operation is highly variable in NYC but trip and vehicle sharing holds the potential to reduce costs, congestion, and emissions.</p>
Microtransit	<p>Chariot started operations in Oct'17 in NYC. Currently have: in NYC - 4 public routes (Queens, Brooklyn, Manhattan); 3-4 vehicles in each route during peak; 15-20 min headway; with deadheading; 50-60 vehicles; In the next few months: 20-30 vehicles along private/enterprise (employer-based mobility) routes; Chariot later closed its' operations in 2019, offering an example by which new mobility services may not be sustainable or disruptive in the long-term.</p> <p>Focus is more on first mile/last mile connections with public agencies /private firms &amp; business parks / hospitals, colleges / real-estate building owners.</p> <p>Pricing: Trip- &amp; route-based; fixed cost; Enterprise - monthly for a route length; \$ in NYC - &gt; subway, &lt; Uber.</p> <p>Current pooling observation may be hard to project as user group constitutes young and high earners.</p> <p>Vehicles: Fully owned Ford Transit vans and drivers full time employees; PMT/VMT used for sustainability measures.</p>

Table 5. continued

Stakeholder	Summary
Energy provider/distributor and researchers	<p>Implementation of NYSEG Smart Home Rate for EV charging in Ithaca, NY Objective is to encourage energy-efficient mobility (through EVs) by minimizing peak electricity usage to charge EVs. Design pricing strategies to encourage users to charge during off-peak hours; <b>Deadline-motivated pricing and time of use EV rebates are being considered</b>; Data collected will include home/work arrival and departure times; TNC EVs of some interest for data; Power usage will be measured using smart meter installed in selected/participating households for one year.</p>
Ithaca Carshare & BikeWalk Tompkins	<p>26 vehicles within urban core (downtown, college towns, bus stops.) Trip purposes such as shopping, errands, medical appointments, moving cargo are served; Average 3700 miles a year per user. Started in 2008 and membership increased 2013 to ~1500 members. 33% annual membership; 30% students; Cornell staff and students form 60% of members. <b>Service has improved access to disadvantaged population and served dense urban core commuters.</b> Discount for elderly for medical programs; Voluntary driver program for medical appointments; Bike sharing: Low income options - buy rides by cash from Bikeshare office. Vehicle electrification is awaiting grant from NYSERDA.</p>
BMTS	<p>Share of TNCs in BMTS: Uber/Lyft entered similar to July 2017; relatively small % 0.2% in travel behavior survey. Type of regional planning modeling: four step; simple mode choice (auto &amp; transit are significant, walk). <b>Modeling TNCs as feasible/making more sense, if mode share at least 2-3%;</b> Key challenges / opportunities/ barriers in the region: <b>Congestion is not really an issue; Maintenance of infrastructure, pavement, and transit adoption are major challenges.</b> Equity; Mobility management - mobility provision by Lyft in rural areas; ~ cost to taxis; mostly medical appointments; Cayuga, Broome counties.</p>
GBNRTC, Go Buffalo Niagara, NFTA	<p>Modeling - traditional mode share; for shared modes sensitivity analysis is performed. Uber/Lyft started in July 2017. Do not report data; only open data from news articles are used for information on TNC usage. Regional transportation planning models are fairly traditional mode share; using these models for modeling ridesharing and CAVs is difficult given the vast number of unknowns. Ongoing initiatives in Buffalo area: ICM for I90: I-90 junction to Canada border; incidents &amp; other events roadway capacity breakdown; VMS (Variable Message Sign), ramp metering, queue warning, tech; smart parking, smart corridor integration. Promotion of sustainable transportation opportunities with employers and developers (also supported under joint NYSERDA-NYSERDA funding opportunities). MaaS and transit services for employment access in remote areas Buffalo Green Code: started in 2017 for transportation demand management in new real-estate developments: <b>New zoning ordinance: all new developments more than 5,000 sq ft, &amp; office more than 50,000 sq ft must reduce Single Occupancy Vehicle (SOV) trips; offices must accommodate trips to the site; a need to demonstrate plan for a 10% reduction two years after building opens (will there be “carrots (or market-based incentives) and sticks (as new regulations or penalties)”?. There remains very limited data available, as these developments are still under construction.</b> Several other TDM initiatives include credits for developers for car/bike share/pool options, transit pass subsidy, home location choices, flexible work schedules, commuter shuttles, unbundled parking.</p>

The information and data shared during the stakeholder meetings was used to perform data integration into the analysis framework and formulate and analyze scenarios.

## 3 PART II: Analysis Framework, Data, and Impact Analysis

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### 3.1 Introduction and Objectives

Over half of humanity now lives in cities and by 2030, nearly 60% of the world's population will be urban dwellers. Cities are often described as demand centers for employment, markets, and emerging technologies and services. New smart city market opportunities are opening up with the significant need for—and benefits and risks associated with—the delivery of energy, mobility, information and communications technology (ICT), as well as affordable housing. Meanwhile, energy use and associated greenhouse gas emissions are being generated from various infrastructure sectors servicing cities, such as transportation, energy generation/distribution, buildings, water supply, waste/wastewater management, telecommunication, and industrial production (Hillman, 2010).

With transportation as an infrastructure sector that has proven one of the most stubborn in terms of continually rising energy demands, societal externalities (e.g., pollution, congestion, wasted time), and security/resilience concerns (e.g., a continued reliance on foreign oil from geopolitically unstable settings), this section focuses on ideas about reinventing mobility in New York State and understanding critical pathways for achieving promising directions in the future. More specifically, this section addresses the key question: What are some of the critical pathways, and synergies in those pathways, for achieving more promising directions?

The three revolutions (coined in Sperling, 2017), refer to the fundamental changes and innovations in transportation (and energy) systems that may result from an increasingly automated, shared, and electric mobility ecosystem of technologies, plans, and policies. Some of the early forms of these transitions, or transformations, have also been enabled by a foundation of increasing digital connectivity, from smart phone application-enabled, ride-hailing services offered by TNCs (such as Uber, Lyft, Via, and others) to the more recent adoption of dockless bike sharing, e-scooters, micromobility, and microtransit (including first- and last-mile services as to/from transit).

While it is clear that new choices are emerging, the broader ACES mobility megatrends remain uncertain, specifically within the context of adoption-decision processes, through which service users, service providers, cross-scale policy actors and institutions may pass from: (1) First knowledge of the innovations; (2) Forming an attitude towards the innovation; (3) Making the decision to adopt or reject the innovation; and (4) Implementing the innovation and confirming the decision taken (Rogers, 1962).

This analysis section of the report therefore also begins to address the question: If improving personal- and/or systems-level mobility is a primary objective, what configurations of new ACES mobility service adoption may be desirable, and what are energy to greenhouse gas (GHG) mitigation co-benefits?

The objectives of some of the human-centered analyses in this section are to (1) estimate current changes in human travel behaviors around valued services, (2) explore the most important decision (and peer influence) factors shaping enablers and barriers to adoption, and (3) investigate the anticipated impacts (both benefits and risks) emerging as most critical to cities. More specifically, using three city case studies and a typology of rural-suburban-urban settings across New York State, the behavioral science-motivated research question identified here is: To what extent will the confluence of rising demands for and new forms of experimentation with improved mobility services (i.e., safer, more reliable, accessible, convenient, time-, cost-, energy-efficient) shape ACES investments and related outcomes in cities? Data and analyses of New York, in particular, as one of the largest state economies in the U.S. (with a uniquely rich suite of open data assets), is explored within the context of advanced mobility-energy, technology-service markets and opportunities.

Part II of the report is divided into three sections: literature review, preliminary data analysis, and modeling of potential implications of ACES-related mobility technology and services adoption. The preliminary data analysis for comparisons of New York City, Ithaca, and Buffalo includes gathering different types of mobility data and local expert opinion on the relationships of advances in mobility to urban infrastructure changes and transportation-related energy productivity factors. Part II concludes with a preliminary exploration and discussion of how alternative interventions can shape mobility, energy, and emissions goals.

## **3.2 Literature Review**

The literature review summarizes how individual ACES transformations impact cities, regions, and states, examining both the direct and indirect benefits and risks. Table 6 provides a summary of the first approach including thirty publications describing the social, economic, environmental, technological, and governance benefits and risks (both direct and indirect) of ACES mobility technologies and services. Similar approaches have been taken recently by Taiebat et al. (2018), yet with a narrower focus, primarily on CAVs and their associated environmental impacts. The literature identified is fairly strong quantitatively in terms of the energy related impacts of connected-automated vehicles and insubstantial with respect to the observed direct and indirect benefits of synergies between adoption of shared and electric mobility, which will likely diffuse faster than automated vehicles (based on data from state

departments of motor vehicles and cities). The exceptions are the case of transportation electrification studies and automated-electric-shared shuttles that are deployed in smaller, geographically confined districts or neighborhoods (Chen et al., 2016; Garikapati et al., 2017). Measurable improvements from e-mobility, based on new infrastructure modernization upgrades, provide an important evidence base for decision-making, but in many cases the factors driving ACES mobility adoption and related outcomes can be complex, and may be confounded by factors such as socioeconomic status and accessibility to (or affordability of) emerging ACES services.

**Table 6. Literature Review of Benefits and Risks of ACES Mobility Transitions and Transformations**

Transitions	Review of benefits (direct & indirect)	Review of risks (direct & indirect)
Automated:	Unequaled freedom & flexibility (Sperling, Pike, & Chase, 2018); Energy-saving driving behaviors, vehicle design, mobility on-demand systems that change ownership/travel patterns (Brown et al, 2014; Wadud et al 2016); added comfort, convenience, safety; extending services to underserved -e.g. elderly, disabled, unable to drive (NFB, 2010; Harper et al., 2015); land use /parking conversion (McDonald & Rodier, 2015; Zhang et al., 2015); emissions (Greenblatt, 2015).	More travel demand and congestion (Fagnant & Kockelman, 2014) ; mode shifts-transit, passenger train & air travel (Wadud et al. 2016); new safety, security, reliability (Taeihagh, 2019); affordability; zero occupancy; adoption in mixed traffic (of AVs and human-driven vehicles) (Kockelman, 2016); living farther from destinations and more travel/sprawl (Brown, 2014).
Connected	Enables vehicle and ride-sharing Optimal traffic signal phase /timing; safety via detection of nearby vehicles, pedestrians, objects; adaptive cooperative cruise control, lane change /merge operations for smoother traffic flow; platooning; data/analytics for decisions (e.g. informing less hunting for parking) (Hartman & Cronin, 2017).	Cybersecurity (e.g. spoofing, sensor vulnerability, disabling brakes, grid reliability) (Parkinson et al. 2017); procurement costs, licensing, & insurance/liability; regulatory; privacy; human factors-risk perception (Fagnant & Kockelman, 2015).
Electric	Displace the use of petroleum; mitigate pollution, emissions, and energy security issues related to oil extraction, importation, & combustion (Sovacool & Hirsh, 2008); saving money; better for environment; performance (Singer, 2016); improved energy management and storage in electrical energy grid (Pirouzi et al., 2018) ; decarbonization of transportation (Cano et al., 2018); secondary use applications (Neubauer & Pesaran, 2011); more infrastructure development, consumer expenditures & revenues for local economies & utilities (Chen et al., 2016).	Too expensive; not dependable; limited charging access (Singer, 2016); long-range travel; socio-economic issues/ norms; psychological barriers, behavior modifications (Westin, et al. 2018); grid compatibility & security; fast-charging for high utilization (Cano et al., 2018); battery waste/recycling (Zeng, Li & Liu, 2015); full use of charge-depleting range majority of days (Williams et al., 2011); impacts on gas tax revenue; impacts of rate design.
Shared	More affordable, time-efficient, and reliable travel options, including for underserved populations; enabling of further electrification, connectivity, automation, efficiency of under-utilized assets; enable transition to high-utilization, high-mileage, high-occupancy fleets; right-sizing (Alonso et al., 2017); mode replacement (PSB, 2017); lifestyle changes (e.g. car ownership; relocate residence to areas where more choices; ageing in place; less parking; higher residential/commercial land use density, fleet and infrastructure conversion to valued uses (Toor et al., 2018); (Circella, 2019; Henao, 2017); re-inventing transit as on-demand, right-sized services (Taiebat et al., 2018); first-last mile opportunities (Shaheen and Cohen 2018).	Rising traffic; inefficient deadheading; induced travel where chauffeured ride-hailing and not doing the driving makes trips more convenient (Chase, 2014; Schaller, 2018); mode replacement (e.g. less walking, biking, transit); increases in car ownership (for income/ "gig economy" employment); congestion; equity of access; lack of data to explore trends / performance; curb/right-of-way management; industry disruption impacts taxi, parking, grocery, car rental industries (Le Vine et al., 2014; Henao, Sperling et al., 2018).



Sample literature quantifying key impact factors relevant to ACES, by scope of only vehicle, mobility systems, urban systems, and society (using a similar framework to Taiebat et al., 2018) is shown below, and extended to a systems framework, of socioeconomic, technological/built environment, ecological, governance (SETEG) systems (Romero-Lankao and Sperling, 2016) to assess and enable quantitative analysis of co-benefits, risks, and synergies motivating adoption and informing models.

**Table 7. VMUS Framework for Review—Extended via SETEG Systems Framework for Review**

Energy Impacts Study	Vehicle (V)	Mobility System (M)	Urban Infrastructure System (U)	Societal (S)
Mersky, 2016	Fuel economy: +10% gains to -3% losses			
Zhang, 2018 (Case Study: Atlanta)		Pct. AV ownership: est. 9.5% reduction in total pct. vehicles; VMT: 29.8M unoccupied VMT induced per day per the reduced vehicles.		
Fox-Penner, 2018	Platooning: 2.5% reduction by 2030-35; Higher avg. speed: +8% increase; Rightsizing/ Weight Reduction: 50% reduction.	Traffic Smoothing: 15% reduction in energy (as kWh/mile) Intersection Mgmt.: 4% less (kWh/mile).	Electricity Needs for LDVs: 13 to 26% of total U.S. electricity via LDV demand by 2050.	
Bansal, 2017			Rate of Adoption: Level 4 U.S. vehicle fleet: 24% (pessimistic) to 87% (optimistic) by 2045.	Avg willingness to pay (WTP): for connectivity & full automation: \$67 (xx) & \$5857 (xx) (survey of n= 2167 Americans).
	<b>Socio-Economic (SE)</b>	<b>Technological (T)</b>	<b>Ecological (E)</b>	<b>Governance (G)</b>
Harper, 2016	New choices for non-driving, elderly, people with travel-restrictive medical conditions – may increase light-duty VMT up to 14%; Gender impacts also explored.	Assumptions for Road capacity: will increase by 30%, while the value of travel times and parking costs will decrease by 65% and 50%, respectively, resulting in a 20% increase in VMT (Childress et al., 2015).	Environmental benefits-reducing energy use and emissions from the ability to deploy vehicles according to each trip's occupancy (right-sizing) (Greenblatt & Saxena., 2015).	By 2030, roughly 74 million seniors living in the US States (close to 26% of total US population).
Crayton, 2017	Steady employment impacts on physical and mental health: AV driver disruption in key socioeconomic groups.	Road casualty prevention: from 1.2M (2013) to 1.35M (2018).	Ease of access to green spaces and physical activity.	Vehicle emissions to fuel economy standard for AVs: impacts on air quality and health.

**Table 7. continued**

	<b>Socio-Economic (SE)</b>	<b>Technological (T)</b>	<b>Ecological (E)</b>	<b>Governance (G)</b>
Kang, 2017	Assumption on Subscription memberships per vehicle (115:1 for AEV); current car sharing service has 72 memberships per vehicle on average as of January 2014 in the U. S.	Optimized fleet size, vehicle range, and # of charging stations resulted in reasonable wait time (11.9 min) in Automated- EV service.	AEV service is more sustainable than AV in terms of GHG emissions. Gas price and electricity cost are key factors in deciding choice between AEV and AV services.	Scenario: lower charging station cost via subsidy or technology maturity. \$10,000 for installment cost and \$1000 for maintenance cost that is the lowest estimated cost for a level III charger.
Konig, 2017	Findings suggest people are ready and interested in riding with CAVs but not willing to buy one.	Wide-spread acceptance and hence adoption of this new technology is far from certain.	A higher % of “pleasure drivers” who valued the driving task itself more than possible benefits stemming from handing over control to technology.	across all sub-groups, the most pronounced desire of respondents was to have the possibility to manually take over control of the driving task whenever wanted.

\* Only first author is noted; with all publications in peer-reviewed journals

### 3.2.1 Data Framework

Reliable, energy efficient, and affordable mobility systems and services are fundamental to achieving improved quality of life for all—rural, suburban, and urban as well as low to higher income inhabitants alike. While new emerging mobility technologies and services have primarily focused on the larger markets of urban and more affluent populations, officials representing rural regions or statewide improvements are interested in exploring whether additional geographic regions or settlement types may benefit from new cost-effective access opportunities, relative to the choices and services currently available (Rodier and Podolsky, 2017). For example, while a survey recently reported that the use of application-based, ride-hailing services by adult Americans has doubled since 2015, only 19% of Americans in rural areas use these applications, relative to 45% and 40% in urban and suburban areas, respectively (Jiang, 2019). Building on varying levels of adoption, the rationale for this study is integrating current data to further characterize these important distinctions. The team does this by identifying and clustering features of emergent transportation services, travel and vehicle ownership behaviors, and energy use across settlement types, infrastructure systems, and socioeconomic status groups.

New York State—with its culture of urban mobility innovation, data richness, global interconnectedness, income inequalities and shifting demographics—offers an important and unique locale for identifying key factors explaining human settlement, mobility system, and energy use variations. This section combines data integration, visualization, and analytics in a method called “typology” to examine the influence on mobility and energy outcomes of sociodemographic, economy, technology, environment, and governance

(SETEG) variables, used in this study primarily as independent variables. These include indicators on income, age, gender, race, education, home ownership, housing, and transportation affordability, employment access, population density, intersection density, PM concentrations, cancer hazard, and respiratory hazard across the State.

This typology effort sought to establish linkages between adoption and impacts of new mobility technology with a measurable urban-suburban-rural spectrum of characteristics and subgroups that vary by sociodemographic, governance, education, income, and mobility infrastructure characteristics. Initial methodological approaches were applied to the New York State, analyzing the extent to which these subgroups can shape various energy efficient mobility system attributes. The statistical clustering procedures identified four distinct regions, which the researchers labeled suburban, urban, rural, and core urban due to their visual correlation with these geographic areas. Note that these labels are not a result of predefined geographic groupings but are simply labels for the four typologies identified by an algorithm and researcher team consensus as to useful comparative clusters in the data based on multiple independent variables extending beyond geographic and density characteristics to broader socioeconomic, technological, and environmental dimensions (Wilson et al. 2020). The urban typology revealed that the leading adopters of EVs were core urban and suburban residents who have relatively higher levels of income and education than the urban working-class residents. This suggests that EV and other mobility technology adoption may be more closely correlated to socioeconomic than geographical traits.

### **3.2.1.1 Key Typology Literature**

Urban to rural settlements are often defined in the literature as socioecological systems, either in terms of interacting biophysical and socioeconomic components, or social technical and environmental (SET) components (Berkes, 2008; Geels, 2004; Pincetl et al., 2016). With full acknowledgement of the validity of competing definitions, the SET framework is used as a starting point here because it holds the potential to integrate settlements' components, which cannot be analyzed in isolation since their interactions are key determinants of adoption and energy use.

Yet, while the SET concept is useful for understanding settlements and their impacts on energy use, it may be too high of an abstraction to yield an operational understanding of lower level system interactions. Therefore, to guide the selection of input variables, the team suggests a definition of settlements as systems representing five (SETEG) domains: sociodemographic, economy, technology, environment, and governance.

The social domain includes mobility components such as people commuting to their jobs and schools. This domain is important because it determines travel behaviors and preferences or practices that may involve the use of private vehicles, walking, biking, public transit or ride-hailing services. While the economic domain captures the influence of factors such as income and land tenure, the techno-infrastructure domain includes technological development such as EV markets, transportation networks, buildings, and emergent e-technologies (e-vehicles, e-commerce, etc.). The environmental domain entails the elements of nonhuman natural ecosystems that comprise part of the fabric of cities through their effects on energy use (e.g., through energy endowment, average and extreme temperatures, and abrupt changes in temperature and precipitation). Governance refers to key decision-making elements affecting travel behavior through regulations, planning, incentives and other policy instruments that contribute to the layout of transportation infrastructure and services (see also the category Indicators in Table 8 in section 3.3)

### **3.2.2 Inter-city Clusters**

Of the clustering techniques used at the global scale to examine variations in energy use and emissions across urban areas, several example studies are noted here.

Oke et al. (2019) developed a mobility-oriented urban typology that covers 331 cities of 124 countries. For their hierarchical clustering, Ward's method (Murtagh and Legendre, 2014) was used to cluster cities based on the factor score dissimilarities and on factor analysis used to reduce dimensionality. Data comes from 64 indicators and resulted in 12 clusters for their final typology. The main results reveal that auto-centric cities have the highest CO<sub>2</sub> emissions per capita and the lowest pollution index, and that the wealthiest cities contribute most to CO<sub>2</sub> emissions. Similarly, highway proportion is a good indicator of CO<sub>2</sub> emissions (large bike-friendly cities are the exception).

Creutzig et al. (2015) identified eight types of cities classified by gross domestic product (GDP), population density, gas prices, and heating degree days. The analysis shows economic activity, urban form, transport costs, and geographic factors explain 37% of urban direct energy use and 88% of urban transport energy use. The study notes urban energy use could triple from 2005 to 2050 if current urban patterns of development continue, yet urban planning and new transportation management strategies can limit this to approximately a doubling. Gas prices and population density correlated most strongly with transport energy use, GHG emissions, and economic activity. Notably, energy consumption for urban transport shows an inverted U-shape behavior, with increases in energy consumption at low GDP levels but decreases at high GDP levels (Özokcu and Özdemir, 2017).

McIntosh et al. (2014) use the Global Cities Database to look at 26 cities over 40 years to identify association and causation in changes to per capita vehicle kilometers traveled (VKT). Results show it has been growing since 1960 yet increasing urban density or transit kilometers of service by 1% reduce VKT by 0.2% and 0.16% respectively, while increasing road length per capita by 1% increases VKT by 0.02%.

Priester, Kenworthy, and Wulforth (2013) used a robust data set of 59 indicators, covering land use, socioeconomics, and mobility patterns for a hierarchical agglomerative clustering to classify 41 of the world's megacities. Six megacity typologies were ultimately determined (hybrid cities, transit cities, auto cities, non-motorized cities, traffic-saturated cities, and paratransit cities), with Manila as an outlier based on its unique mobility patterns.

In reviewing these example studies, it is clear that cities are in a state of change in their mobility patterns. At the same time, few cities have fundamentally changed when it comes to the comparative characteristics that place them in the clusters described. An exception could be cities such as Paris, where a steep drop in car ownership has been observed, from 60% of households in 2001 to 35% today (Nossiter, 2019).

### **3.2.2.1 Intra-city Clusters**

Five example studies of clustering approaches at the intracity scale are also relevant for the work. Choi (2018) developed a typology classification for Calgary broken out by city areas: center city (e.g., the central business district CBD), inner city, established brownfield areas, and greenfield areas. The outcomes examined whether monocentric versus polycentric urban structure is best for reducing VKT in Calgary. Households tend to drive significantly further when they live farther from a concentration of activity. Inner areas of the city showed decreases in VKT with much more active and transit-based transportation, while auto mode split in all other areas increased or remained the same between 2001 and 2011.

Reznik, Kissinger, and Alfasi (2018) developed a high-resolution analysis of private vehicle travel-related GHG emissions of residents and correlations with socio-spatial factors in Tel Aviv-Jaffa, Israel. A wide range in vehicle miles traveled (VMT) was observed, largely divided along socioeconomic lines. Emissions per vehicle vary by up to a factor of four, but per capita emissions vary by a factor of 19. Additionally, relative CO<sub>2</sub> emissions per capita are higher than relative VMT per capita, because the

higher socioeconomic status owns larger vehicles that consume more fuel on average. Another major finding is that private car use and emissions levels are influenced more by socioeconomic factors than by spatial factors. Emissions increase with income and education and decrease with density in Tel Aviv-Jaffa.

Zahabi et al. (2013) also used cluster analysis. Five settlement clusters were created for Montreal: Rural-Suburban Cluster, with very low density, accessibility and entropy; Outer suburb Cluster; Intermediate neighborhood type; Urban core with high to medium density, accessibility and entropy; and Downtown core with very high density, accessibility and entropy. Zahabi et al. (2017) used a cluster analysis to define technological scenarios to determine potential emissions implications in three Canadian cities. K-means clustering found four or five neighborhood typologies for each of the three cities, and those were divided between 0 car households versus 1+ car households.

Estupiñán and Rodríguez (2008) modeled the interaction between transit supply and transit demand for Bogota's bus rapid transit (BRT) system at the station/stop level. Primary data included dominant land use, ped facilities, obstructions, bike facilities; and secondary data included socioeconomic, crime, and housing. Factor analysis sorted 23 audit questions into four categories: (1) walkability, (2) barriers/deterrents to car use, (3) pedestrian safety and poverty, and (4) connectivity. Walkability and deterrents/barriers to car use along with transit service supply were positively correlated with higher transit use (at least when the transit is BRT in Bogota). Surprisingly, lack of safety is also correlated with higher transit use (context-specific). Factor 4 was also not correlated with transit use, presumably because Bogota has little spatial variation in connectivity.

This literature review highlights one of the gaps that the study is filling, namely that inter- and intra-city clustering analyses have been done, but high-resolution regional analysis, such as at the state level in the U.S., is lacking. There are examples from England of both intra- and inter-city clustering, which look at car usage (Phillips et al., 2017) and motor fuel price vulnerability (Mattioli et al., 2019) at a fine population resolution. However, this work is centered on car and petroleum fuel use and does not investigate vehicle technology advancements or incorporate current statistics on mode use as key variables for energy efficiency and affordability. Similarly, analyses of the multiple aspects shaping adoption and other outcomes have not yet been undertaken of the U.S. to more systematically, and at a higher level of spatial resolution, address the influence of SETEG domain factors within and across a statewide geography as this study of New York State.

### 3.3 Data for Typology Analysis

The thirteen initial independent variables used in this analysis guided by the SETEG approach are: population density, intersection density, employment access, age (% over 65), gender (% female), race (% white), education (% with bachelor’s degree or higher), household income, home tenure (% homeowners), combined housing and transportation costs as a percentage of income (H+T Index), PM2.5 levels, cancer risk from air toxics and respiratory hazard index from air toxics. The four dependent variables included commute mode, vehicles per household, vehicle fuel economy, and prevalence of EVs, (measured as the number of EVs per 1,000 vehicle registrations). For more detail, see Table 8.

**Table 8. SETEG Indicators, Spatial Resolution, and Data Source**

INDICATOR	FRAMEWORK	RESOLUTION	SOURCE
Age (% over 65)	Social (S)	Block group	ACS 5-year data (2012-2016)
Gender (female)	S	Block group	ACS 5-year data (2012-2016)
Education (level)	S	Block group	ACS 5-year data (2012-2016)
Race (% white)	S	Block group	ACS 5-year data (2012-2016)
Household income	Economic (E)	Block group	ACS 5-year data (2012-2016)
House Tenure (% own)	E	Block group	ACS 5-year data (2012-2016)
HTA Index	E	Block group	CNT
Employment Access	Techno-infrastructurel (T)	Block group	CNT
Intersection Density	T	Block group	CNT
Population Density	T	Block group	ACS 5-year data (2012-2016)
Particulate Matter 2.5	Environmental (E)	Block group	EPA EJSCREEN (2017)
Cancer Hazard	E	Block group	EPA EJSCREEN (2017)
Respiratory Hazard	E	Block group	EPA EJSCREEN (2017)
Average fuel economy (mpg)	Outcome (Governance)	County	IHS Markit
EV adoption (%)	Outcome	Zip code	IHS Markit
Alternative commuters (%)	Outcome (Governance)	Block group	ACS 5-year data (2012-2016)
# Vehicles/household	Outcome (Economic)	Block group	CNT

These data sets come from multiple sources, ranging from publicly available data sets from the U.S. Census Bureau to proprietary data sets on vehicle registrations. The American Community Survey (ACS) (United States Census Bureau 2016), was used for many of the sociodemographic variables. To improve data accuracy, five-year ACS data were used from the 2012–2016 period, rather than data from a single year. Population density was calculated as the number of residents in a block group divided by the land area of the block group in square miles (people per square mile). Age, gender, and race were calculated using the percentage of people over 65, percentage female, and percentage of white residents in the total population, respectively. Household income was calculated using the median income for a given block

group. Housing ownership was calculated as the percentage of property owners in the block group. Education level was calculated as the proportion of the block group population with a bachelor's degree or higher. Commute choice (referred to as "alternative commuters") was defined as the proportion of commuters in the block group who do not commute by single occupancy vehicle to work relative to the total number of commuters. These alternative commuters could be pedestrians, carpoolers, transit riders, bicycle riders, or work from home individuals—the variable is measured as percent of commuters not driving alone.

Data from the Center for Neighborhood Technology's (CNT) Housing + Transportation Index (H+T Index) (CNT 2019) were used for variables relating to economic and technological or built environment factors relevant to transportation. The H+T Index is a publicly available data set that measures the affordability of living in different census block groups across the country, taking housing and transportation costs as a percentage of average income (within the block group) into account. The team also used the H+T Index's employment access figure, which CNT defines as the sum of the number of jobs divided by the square of the distance to those jobs. The number of vehicles per household was calculated as the average number of vehicles per household within each block group. Intersection density is the sum of all intersections in the block group (including those on the borders) divided by the land area of the block group.

The Environmental Protection Agency's EJSCREEN tool (U.S. EPA 2017), a data set combining environmental and demographic information aimed at furthering environmental justice goals, was used as a source for the environmental indicators. PM 2.5 was calculated as the particulate matter levels in the air in micrograms per cubic meter, averaged annually. Cancer hazard was calculated as the lifetime cancer risk from inhalation of air toxics, as risk per lifetime per million people. The respiratory hazard variable was calculated as the sum of hazard indices for those air toxics with reference concentrations based on respiratory endpoints, where each hazard index is the ratio of exposure concentration in the air to the health-based reference concentration set by the United States Environmental Protection Agency (EPA).

Vehicle registration data from IHS Markit (formerly Polk) (IHS Markit 2017) is a proprietary data set which the team used to calculate two of the four dependent variables: the number of EVs (including both Battery Electric Vehicles and Plug-in Hybrid Electric Vehicles) as a proportion of the total number of registered vehicles in each zip code and the fleet average fuel economy. In order to compute the average fuel economy by zip code, a vehicle fuel economy database from the EPA's fueleconomy.



gov was joined with the vehicle registration data. The zip code average fuel economy was computed as the vehicle count-weighted average of EPA combined cycle fuel economy. Since both variables were available at the zip code level, these figures were assigned to block groups via a spatial join.

### 3.4 Methods

Overall, data is collected for informing ACES in New York State, and for purposes of benchmarking comparative case studies across New York City, Ithaca, and Buffalo. These three cities were selected as representative of smaller/midsized to larger urban areas. They serve as use cases to begin to explore the extent to which current mobility technology adoption across these environments may shape planning for mobility in each of these changing innovation ecosystems. The baseline data from multiple data sets are proposed as a framework. Next, associations are identified between the future of transportation and energy through a combination of literature review and local expert surveys on rates of change in observed services to rates of adoption emerging in these diverse city-regions. Third, estimates of future mobility technology and service adoption are explored and compared in terms of anticipated effects on energy, “smart city” dynamics, research, and investments.

#### 3.4.1 Variable Scaling

The panel data described above encompasses very diverse data sources with large variance within and between variables. For factor and cluster analyses, and in order to make results easier to interpret and visualize, all variables were scaled on a 0 to 100 range, using scikitlearn’s pre-processing MinMaxScaler method in Python, as follows:

**Equation 1.** 
$$X_{scaled} = \frac{X - X_{min}}{X_{max} - X_{min}}$$

The three variables representing density (population density, employment density, and intersection density) have very large dynamic ranges (up to five orders of magnitude). Hence, for visualization purposes only, they were log-transformed.

#### 3.4.2 Factor Analysis

Consisting of 13 distinct SETEG variables, the team’s input data set is highly dimensional. In order to cluster these variables effectively, it is necessary to reduce the dimensionality of this data set. Factor Analysis identifies latent variables underlying the observed variables in the data set, thereby reducing dimensionality. Kaiser-Meyer-Olkin (KMO measure of sampling adequacy = 0.855) and Bartlett’s

( $p$ -value = 0.0) tests were performed to confirm the appropriateness of the data set for factor analysis. Factor analysis was conducted using the FactorAnalyzer package in Python and resulted in three factors being used as input to the clustering.

### **3.4.3 Hierarchical Clustering**

Agglomerative (i.e., bottom up) hierarchical clustering was selected as the approach to identify census block groups with maximum similarities across the three previously derived factors, per the methods of Oke et al. (2019). This clustering algorithm proceeds as follows. First, an  $n$  by  $n$  euclidean distance matrix is computed between each block group (where  $n$  is the number of block groups in the New York State). Then, a dendrogram or linkage tree is built, where each leaf represents one block group. These are then sequentially grouped together using Ward's criterion, which aims to minimize the variance of the clusters being merged. Finally, the linkage tree is cut at a certain height to determine the number of clusters, typically at the top of the longest vertical segment.

### **3.4.4 Data and Methodological Limitations**

The detailed block group resolution of the team's analysis allows for a more detailed examination of geographic clustering than typically offered by typologies conducted at coarser resolutions. However, the approach does come with some important caveats. Because two of the team's dependent variables (EVs per household and vehicle fuel economy) were not all available at the block group level, these variables needed to be assigned to block groups from the less-refined zip code geography. Thus, the results are not as robust as they could have been if such variables had also been available at the block group level. However, the spatial resolution of the results, even with the zip code level data limitations, is still much finer than what would be available using a city or county for analysis.

### 3.4.5 Results

**Table 9. Correlation Matrix of Zip Code Level SETEG Indicators in New York State**

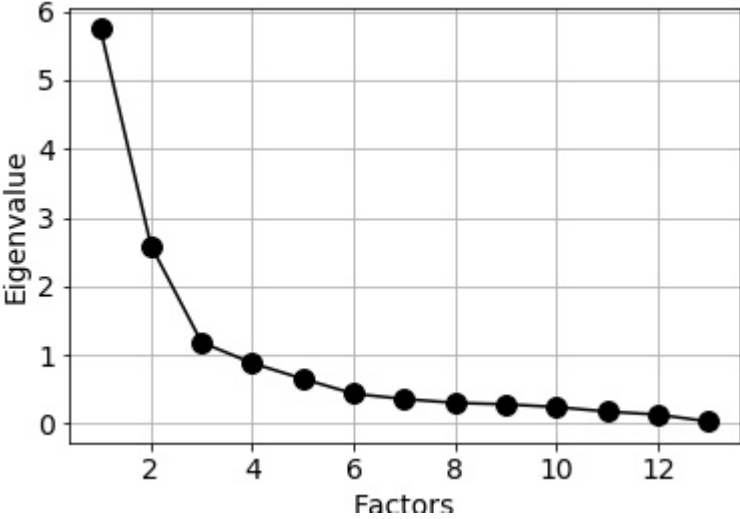
	Density	Income	VMT/ household	GHG/ household	Age dependency	Unemployment	Public transit	EV chargers	EV adoption
Density		-0.30	-0.66	-0.51	-0.12	0.23	0.79	0.24	-0.05
Income	-0.30		0.72	0.87	0.12	-0.54	-0.29	-0.03	0.29
VMT/ household	-0.66	0.72		0.93	0.13	-0.44	-0.72	-0.27	0.06
GHG/ household	-0.51	0.87	0.93		0.12	-0.45	-0.52	-0.23	0.13
Age dependency	-0.12	0.12	0.13	0.12		-0.12	-0.11	-0.13	-0.04
Unemployment	0.23	-0.54	-0.44	-0.45	-0.12		0.33	-0.08	-0.26
Public transit	0.79	-0.29	-0.72	-0.52	-0.11	0.33		0.10	0.04
EV chargers	0.24	-0.03	-0.27	-0.23	-0.13	-0.08	0.10		0.16
EV adoption	-0.05	0.29	0.06	0.13	-0.04	-0.26	0.04	0.16	

Table 9 presents correlations between the different SETEG indicators outlined above. Note the strong negative correlation between public transit use and VMT and GHG emissions per household.

### 3.4.6 Factors

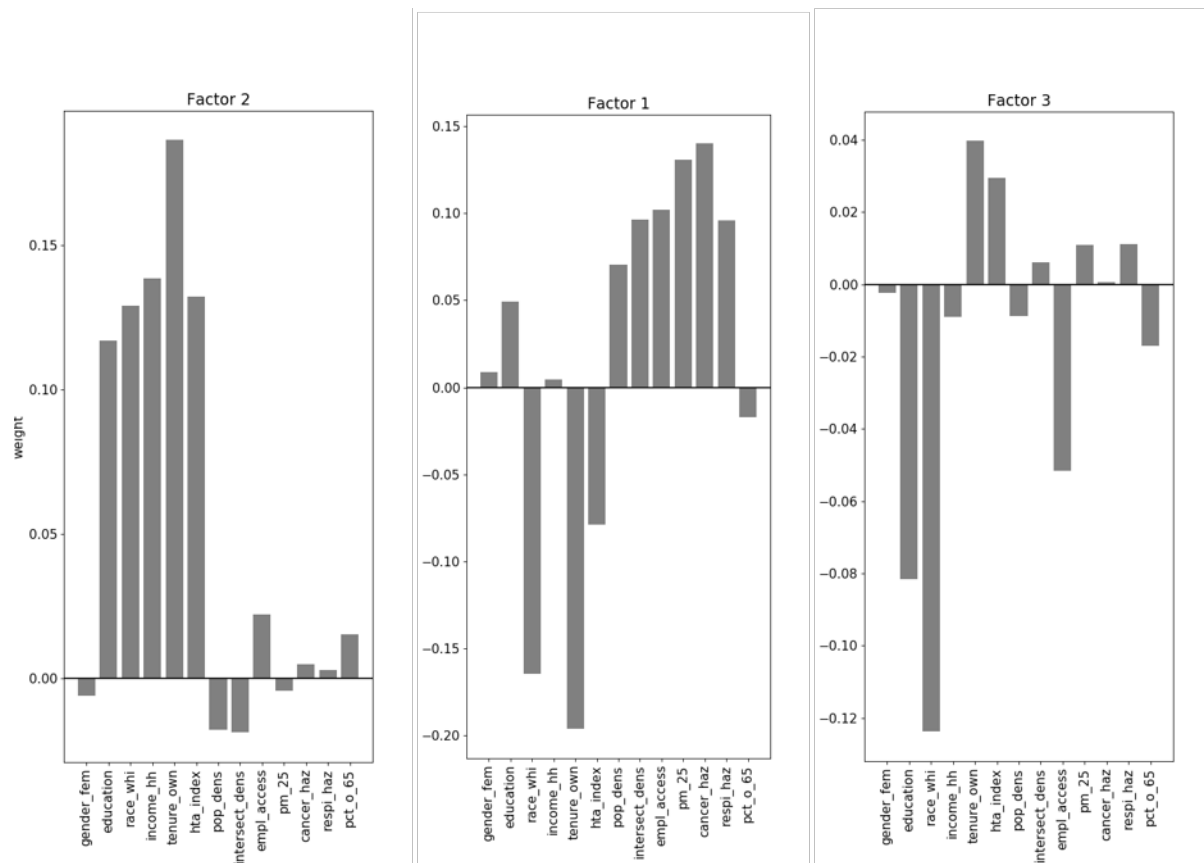
The eigenvector scree plot from the factor analysis shows that three factors have eigenvalues greater than one, and the distinct breakpoint in eigenvalues after three shows subsequent factors add little additional explanatory power (Figure 1). Thus, the dimensionality of the data set was reduced from 13 SETEG variables to three factors.

Figure 1. Factor Analysis Scree Plot



The factor loadings for the three retained factors are shown in Figure 2. These three factors broadly capture the following dynamics as can be seen in Figure 2: urban form (Factor 1), economic (Factor 2), and social (Factor 3).

**Figure 2. Factor Loadings from Factor Analysis**

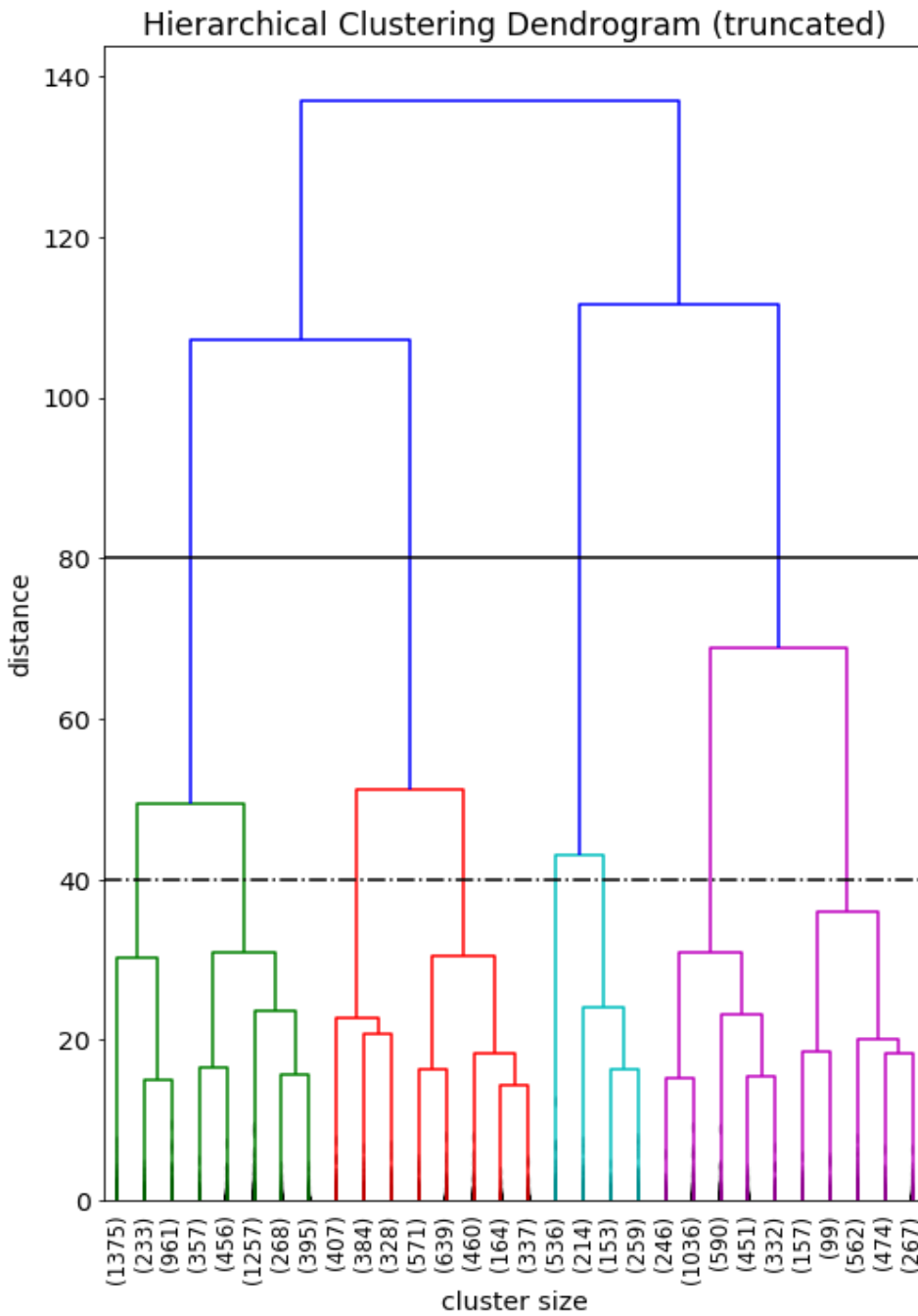


### 3.4.7 The Four Clusters and Their Primary Differences

The dendrogram of census block groups (Figure 3), using the output from the three factors, has a maximum vertical leg that indicates two clusters are the most mathematically distinct. However, the team used the second longest leg to generate four clusters, which more robustly represent the variability of sociodemographic, economic, techno-infrastructure, environmental, and governance indicators at the block group level in New York State (dendrogram distance of 80). As a sensitivity analysis, the team also explored results with greater granularity for a dendrogram distance of 40 (third longest dendrogram leg), producing eight clusters.

The results demonstrate how these four clusters offer an interesting level of variation between sociodemographic, economic, techno-infrastructure, environmental, and governance indicators.

**Figure 3. Dendrogram of Four Clusters Selected for Results**



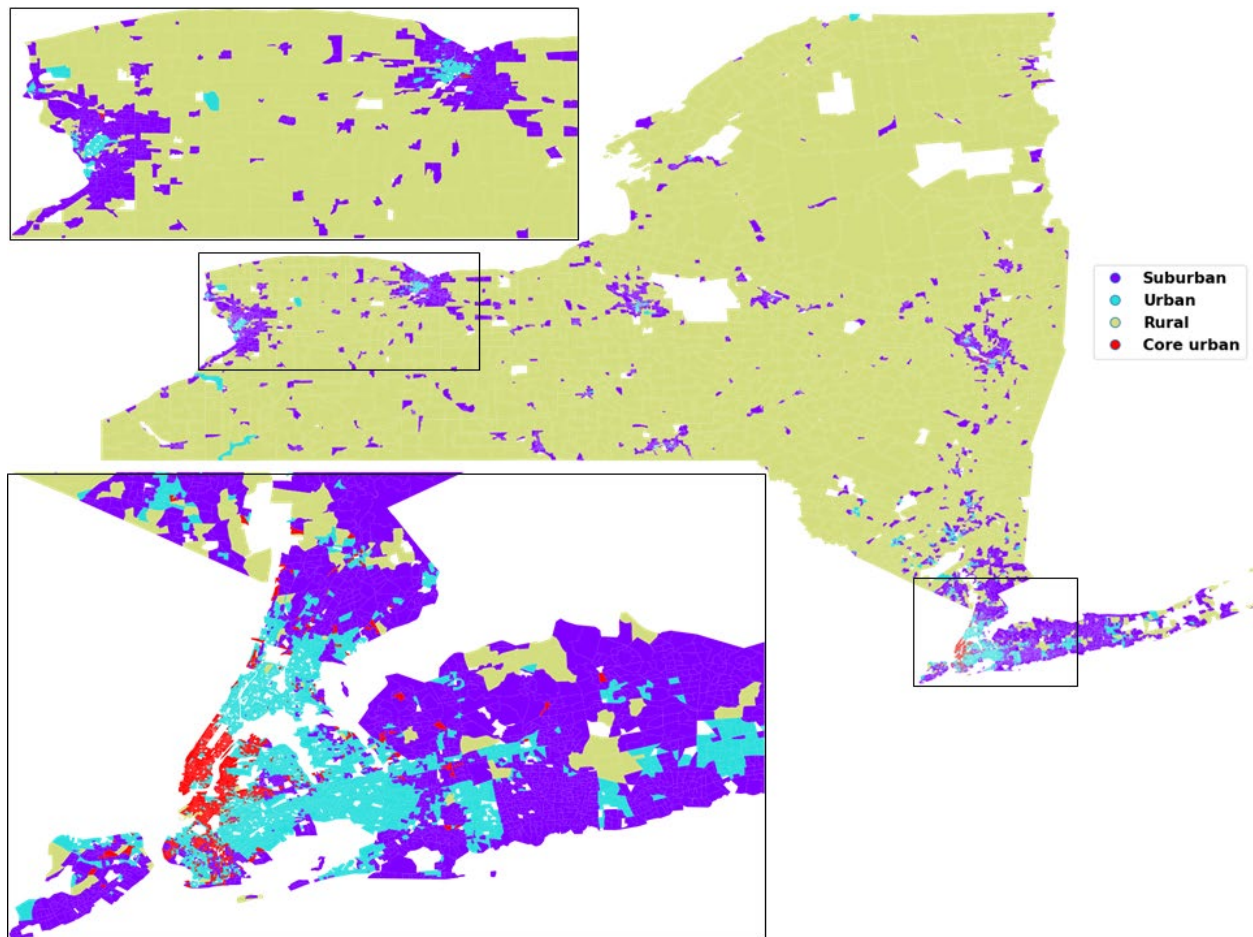
The four typologies produced by the agglomerative clustering approach on the data set are interpreted as core urban, urban, suburban, and rural. These names represent settlement types rather than being tied to any particular SETEG variable. The majority of the State is split evenly between the urban and suburban typologies, each with 37% of the total population. The rural typology makes up 15% of the total population, while only 11% of New Yorkers live in a core urban typology. Further description

of the variables used to identify and compare each typology—that define the cluster beyond using rural to urban data alone—is provided in the appendix in Tables A1 and A2. The resulting dependent variables are presented in Table A3.

While Upstate New York is dominated geographically by the rural typology, suburban and urban typologies are found in or near every major upstate city (Figure 4). Suburban typologies surround Albany, Schenectady, Utica, Syracuse, Rochester, Buffalo, and Binghamton, and they appear around many other smaller upstate cities. Urban typologies are visible in each of the major upstate cities. Interestingly, the Tonawanda, Cattaraugus, and Allegany reservations were also classified as urban typology. There are small pockets of core urban typologies in the cities of Buffalo, Rochester, and Albany. Some block groups, missing data, and thus excluded from the clustering, yielded blank areas on the map.

Each of the four typologies also appear in New York City. The core urban typology is concentrated in Manhattan south of Harlem and in pockets of Queens and Brooklyn closer to Manhattan. The urban typology comprises the majority of Brooklyn, Queens, Harlem, and the Bronx, with pockets on Staten Island and Long Island. The suburban typology dominates areas outside of the city limits and the majority of Staten Island. Uninhabited areas, such as shipyards or waste facilities, are classified as part of the rural typology.

**Figure 4. Map of New York State Clustering Results**



### **3.4.8 Comparative Benchmarking of Independent Variables**

The spider plots below highlight the different indicators across which each of the typologies vary (Figure 5). Urban and core urban typologies unsurprisingly rank high on density and job access measures. They also see higher air pollution (PM 2.5 concentrations, cancer, and air toxics risk) than suburban and rural areas. Homeowners comprise the vast majority of the population in suburban and rural typologies but are largely absent in urban and core urban areas. Education levels are comparable across all typologies, except for the core urban, where education levels are far higher. Whites constitute majorities in all typologies, except the urban, in which they comprise less than a quarter of the population.

Household income disparities between the typologies highlight the socioeconomic segregation of the State, with affluent suburbs standing in stark contrast with working class inner cities and rural areas. However, the Housing and Transportation Affordability (HTA) index offers some nuance. Indeed,



both rural and suburban populations spend a disproportionate amount of their income—59% and 56%, respectively—on housing and transportation combined. Somewhat counter-intuitively, housing and transportation are more affordable for urban dwellers, with 39% and 44% for poor and wealthy urbanites, respectively.

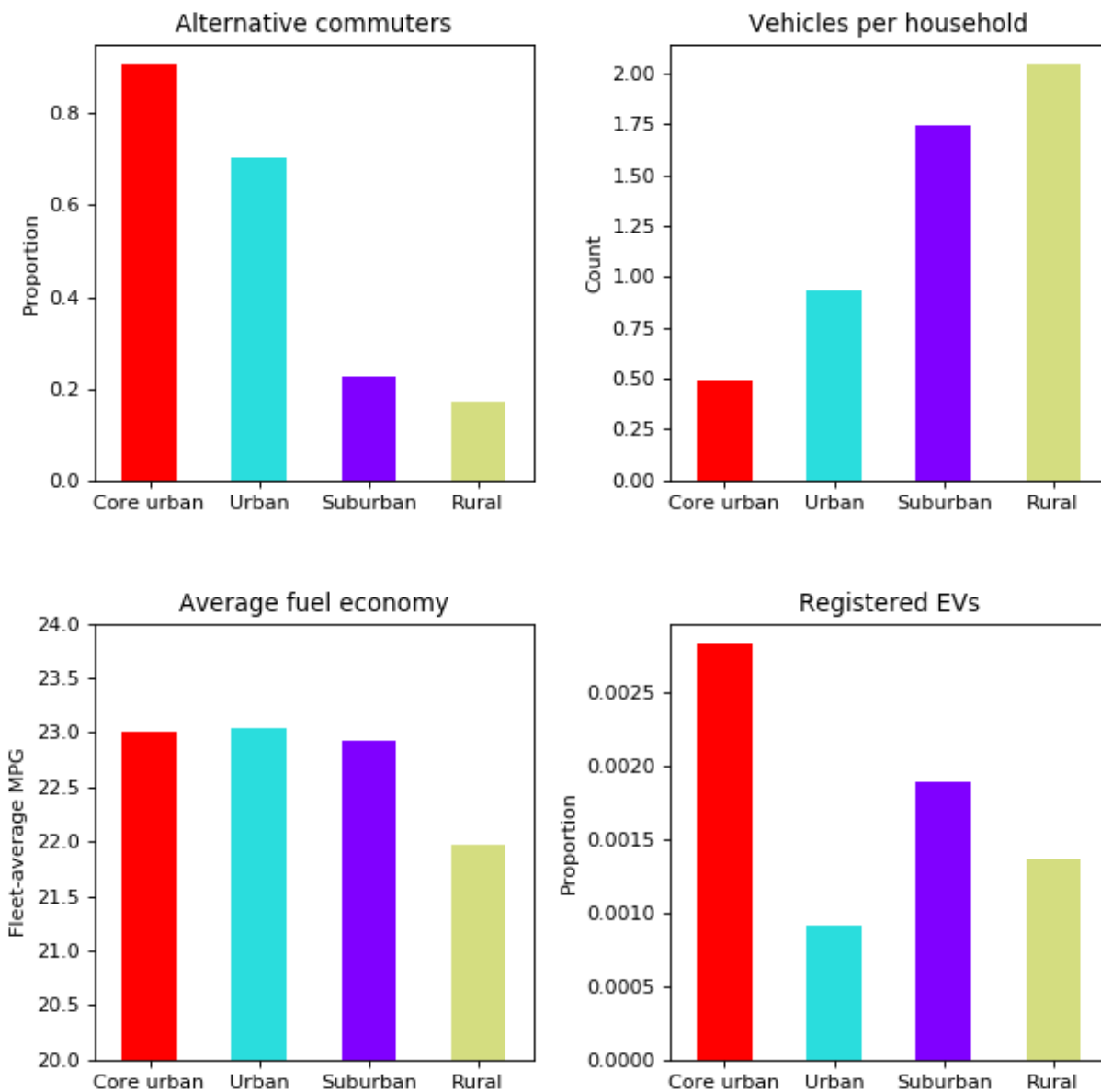
**Figure 5. Spider Plots Showing SETEG Indicators (Independent Variables) in Scaled Relation to Each Other for Each of the Four Cluster Settlement Types**



### **3.4.9 Comparative Benchmarking of Mobility Outcomes**

Alternative commuters comprised the largest share of commuters in core urban areas, followed by urban, suburban, and rural areas (Figure 6). Correspondingly, the number of vehicles owned per household increases from the core urban to the rural typology. Average fuel economy holds fairly constant across all typologies, except for rural, which has lower median fuel economy. The number of registered EVs exhibits its own pattern, with the highest proportion of EVs in the core urban typology, followed by the suburban, the rural, and the urban typologies. This order mirrors the median income for each typology, suggesting that EV adoption appears to be more significantly correlated with income than urban form. This aligns with knowledge of 45,000 EVs statewide currently, of which 13,000 are located in The Public Service Enterprise Group (PSEG) Long Island utility service territory (Somers, 2019).

**Figure 6. Mobility and Energy Outcomes by Typology**



### 3.5 Discussion of Typology Analysis

SETEG factors related to EV adoption and other outcomes vary across settlement types in New York State. Currently, EV adoption is geographically concentrated in core urban settlements inhabited by highly educated and wealthy early adopters—three out of every 1000 of their vehicles were electric in 2017—and similar associations have been shown in the UK (Morton et al., 2017). In contrast, people in rural typology areas drive longer daily distances and lack access to charging infrastructure, which may

explain the lower rate of adoption. Lower EV adoption among urban populations may be because this typology is less able to afford the higher upfront cost of EVs, which points to the relevance of both spatial and socioeconomic factors. Interestingly, fuel economy remains constant at 23 miles per gallon (mpg) across all typologies, except the rural typology, with a 22-mpg average. This is likely a combination of older and larger vehicles in rural areas, as has also been shown in Australia (Li et al., 2015).

However, existing literature finds that EV adoption dynamics in New York State are more complex, and likely follow socioeconomic factors such as income and education rather than only urban category. In addition, Narassimhan and Johnson (2018) find that tax incentives and charging infrastructure significantly influence EV adoption. While these indicators were not included in this study, future work is needed to examine these links.

These socio-spatial patterns reflect the history of unequal urban development in the U.S., with urban typologies having much lower incomes and higher nonwhite populations than each of the three other typologies. Much of this is the result of decades of redlining and other discriminatory housing practices that allowed whiter, more prosperous families to move to the newer, now suburban typologies, while leaving concentrated poverty and struggling urban neighborhoods behind (Frey 1979; Gotham 1998; Zenou and Boccoard 2000; Hernandez 2009). Native American reservations were also categorized as urban typologies, often with the same concentrated poverty mechanisms as are operating in inner cities (Snipp 2005; Sarche and Spicer 2008). The core urban typology, clustered primarily in Manhattan but also evident in some other places, reflects a more recent urban trend in the U.S.: whiter, wealthier, more educated populations opting to live near the city center (Hackworth 2002; Lees 2003; Freeman and Braconi 2004). These more prosperous neighborhoods are often directly adjacent to less prosperous locations, which can ignite social tensions over issues relating to affordable housing and gentrification.

Vehicle ownership rates also vary significantly across the four typologies, with half as many vehicles per household in urban typologies compared to rural and suburban, and again half as many in core urban compared to urban. The findings fall in line with existing research, according to which rural areas are predominantly car dependent with a lack of viable alternatives. According to the most recently available National Household Travel Survey (NHTS), 68% of households in areas with less than 2,000 people per square mile (their definition of “low density”) had two or more vehicles available compared to just 31% in areas with 10,000 people or more per square mile (their definition of “high density”). Similarly, the NHTS reports that only 4% of “low density” households have no vehicle available compared to 27% of the “high density” households (NHTS 2017).

The inverse trend observed in Figure 7 between vehicle ownership per household and use of alternative commuting modes is attributable to the high-employment density, lower socioeconomic status, and the abundance of transit options and infrastructure for active modes, leading to very high (91%) use of alternative modes (i.e., transit, walking, and biking) for populations in core urban areas (Boulangé et al., 2017). Suburban and rural areas have four- and five-times lower use of alternative modes, respectively.

While the team's analysis did not include any indicator of VMT or household trips, data from the 2017 NHTS show that more income is correlated with more travel. Households in the highest income group (>\$100k) took 80% more person trips than those in the lowest income group (<\$15k). Thus, the median income of the four clusters could be used as a somewhat reasonable proxy for trips taken.

Air pollution and exposure to public health hazards are also closely linked to density. Indeed, the urban core typology has the highest exposure while rural areas exhibit the lowest. The average annual PM 2.5 concentration of 10  $\mu\text{g}/\text{m}^3$  in urban areas upstate and in New York City is close to the EPA's Air Quality Standard limit of 12  $\mu\text{g}/\text{m}^3$ , while rural and suburban populations enjoy lower rates of exposure. Similarly, lifetime exposure to cancer risk from inhalation of air toxics and respiratory hazard index vary by a factor of 3 and 6, respectively, between rural and core urban typologies.

The four dependent variables presented were selected because of their immediate relevance to energy consumption. Additional variables, such as annual VMT, public transit ridership, and gallons of gasoline sold were explored for this analysis but were only available at spatial resolutions too coarse to disaggregate to the block group level. In addition, data on long-distance travel—such as air and rail—would paint a fuller picture of the SETEG factors related to transportation energy use (Czepkiewicz, Heinonen, and Ottelin, 2018).

The long-distance travel surveys and approaches to typology methods differs from other typologies largely due to the more detailed geographic resolution of its analysis. While other recent typology projects have used the city as their unit of comparison (Oke et al. 2019; Creutzig et al. 2015; McIntosh et al. 2014), the typology's use of census block groups as a level of analysis allows for comparisons of sub-city level dynamics that are not possible with city-level typologies. Incentive programs from local government entities and other targeted initiatives may find this higher resolution data more useful for their purposes. For example, services aimed at reducing the need for individual car ownership, such as car-pooling, might be prioritized in rural areas. Likewise, the availability of second-hand EVs may be key to EV adoption in modest urban households.

### 3.6 Engaging Local Experts—Results Using Delphi Method

While it is clear that new choices are emerging, the broader ACES mobility megatrends remain uncertain, specifically within the context of adoption-decision processes, through which service users, service providers, cross-scale policy actors and institutions may pass from (1) first-hand knowledge of the innovations, (2) forming an attitude towards the innovation, (3) making the decision to adopt or reject the innovation, and (4) implementing the innovation and confirming the decision taken (Rogers, 1962). This portion of the study therefore asks the question “if improving human-level and systems-level mobility is a primary objective, which new ACES mobility technologies and services adoption to energy and GHG mitigation may be achieved (or not) as a co-benefit?”

The objectives of this section of the study are to (1) explore potential human behaviors and decisions across three different urban settlements in New York State, (2) explore the most important decision factors shaping enablers and barriers to adoption, and (3) investigate the anticipated impacts (both benefits and risks) emerging as most critical to practitioners in New York City, Ithaca, and Buffalo. Using the city case studies, the research question identified here is “to what extent will the confluence of rising demands for and new forms of experimentation with “better” or “smarter” mobility services (e.g., safer, more reliable, accessible, convenient, time-, cost-, energy-efficient) shape ACES-related outcomes in cities?” Data and analyses of New York City, in particular, as one of the largest state economies in the U.S., is explored in the context of new advanced mobility-energy technology-service markets and opportunities.

Overall, data is collected for informing ACES in New York State, and for purposes of comparing the case studies of the three cities. The cities were selected as representative of the smaller, midsize, and larger urban areas. They serve as examples to begin to explore the extent to which current mobility-technology adoption across these environments may vary as well as look into the key dynamics for planning on advanced mobility-energy transitions in these ecosystems.

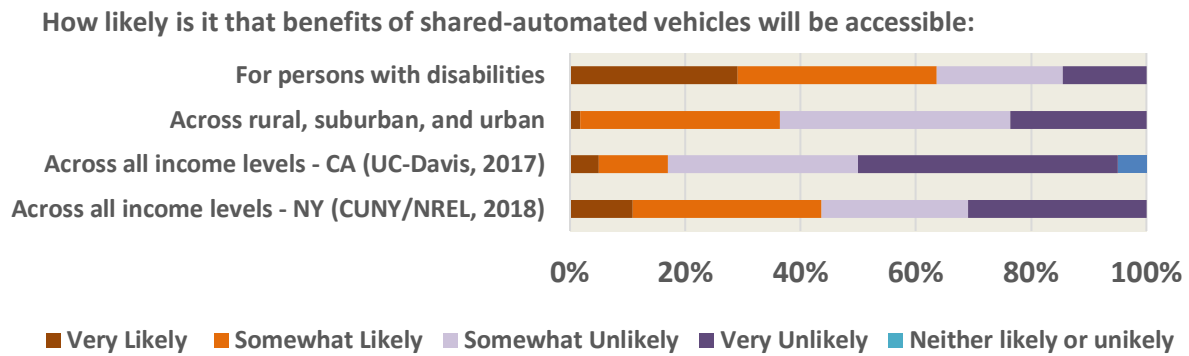
Interactive sessions were held across the three cities to support new data-motivated insights and comparisons via (1) literature review, (2) expert surveys, and (3) data collection and analyses. These approaches have been used to support ongoing analyses, two-way (and multi-directional) information flows, and modeling of scenarios to explore outcomes of alternative “reinventing mobility” solutions enabled by integrating automated, connected, electric, shared (ACES) mobility. These surveys aim to inform early-stage research needed to fill critical gaps, identify tradeoffs, and develop new synergies for enhancing mobility systems in the contexts of NYC, Ithaca, and Buffalo.

Results here focus on professionals with experience in transportation, and their interpretation of where trends are going based on their familiarity with the area and subject matter through the survey conducted as a part of the two workshops and subsequent stakeholder outreach. These survey responses were collected using workshops in New York City (n=22) and Ithaca (n=25) as well as survey responses after a transportation symposium in Buffalo (n=8), with support from local transportation leaders. These efforts were made to engage a wide spectrum of those familiar with the area and these topics.

Results indicate a larger impact of emerging mobility technologies and services on urban areas, and potentially smaller, less well-known impacts in rural areas or smaller cities and towns. Even with the advent of technology, it may also be difficult to interpret what may change, with uncertainty and wide-ranging projections emerging as to rates of adoption—especially for shared and automated vehicles and mobility systems that may or may not be part of MaaS options.

Despite this uncertainty, consistency exists on benefits across all income levels, at least between recent surveys of California (by UC-Davis, 2017) and New York (by NREL/UTRC, 2018).

**Figure 7. Comparing Responses on Accessibility of New Shared-Automated Mobility Service**



**Figure 8. Survey Results on Estimated Rates of Adoption**

Informing Analyses, Scenarios and Potential Impacts of Connected-Automated Vehicles (CAVs), Shared, and Electric Mobility

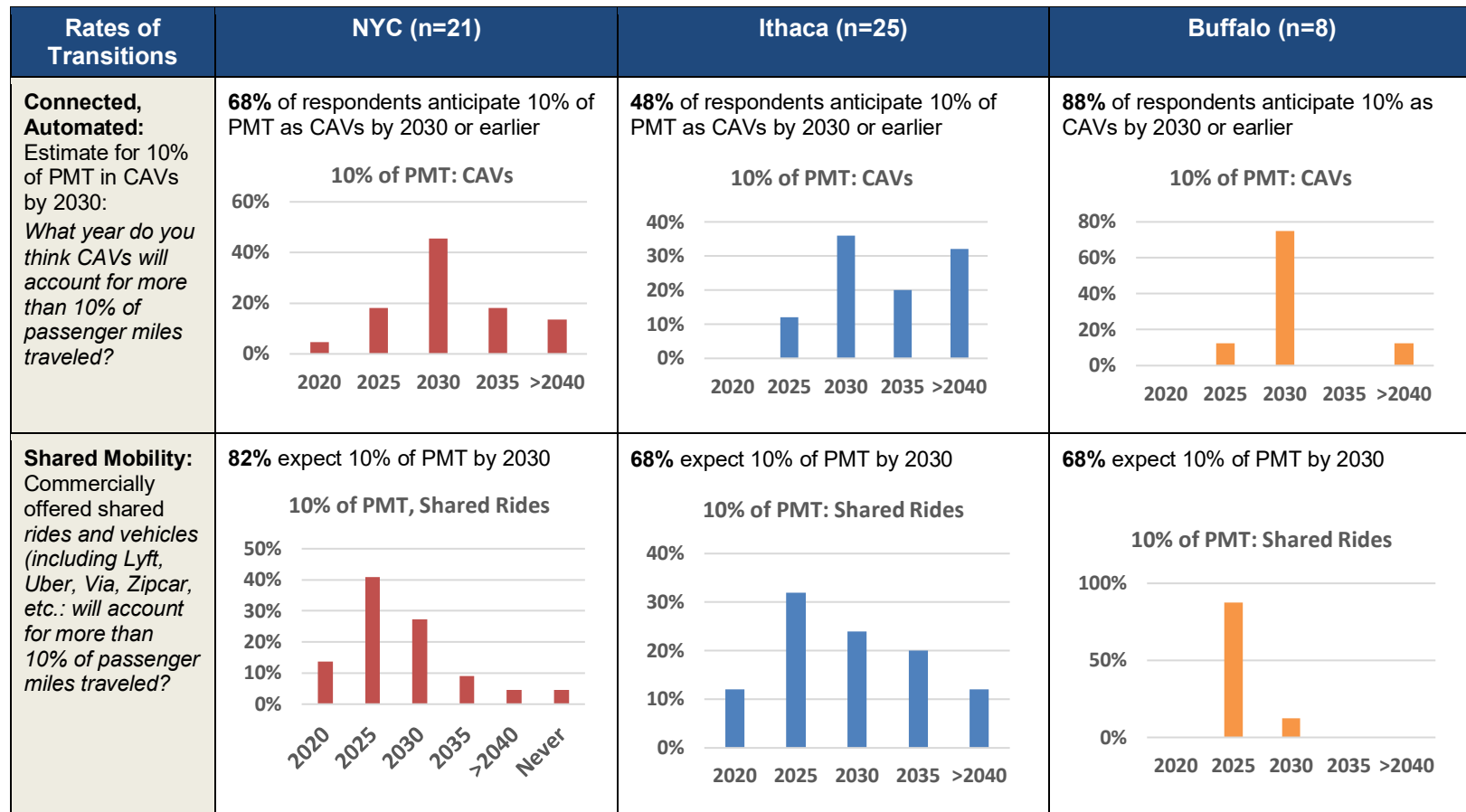
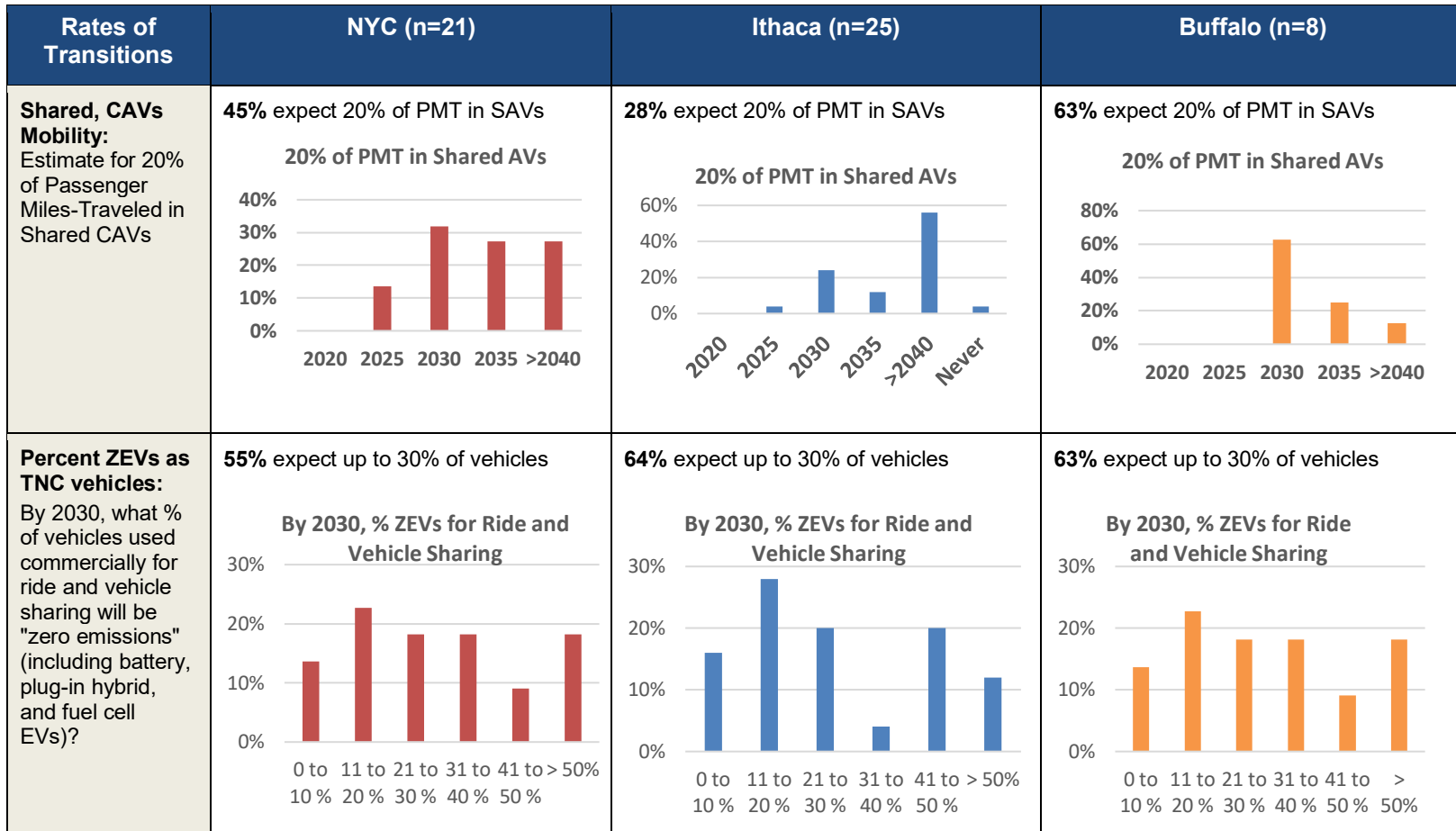


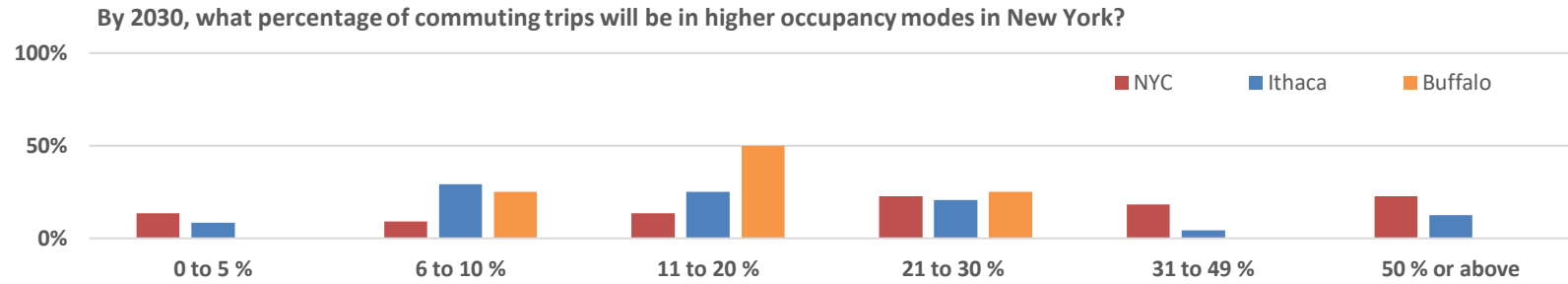


Figure 8. continued



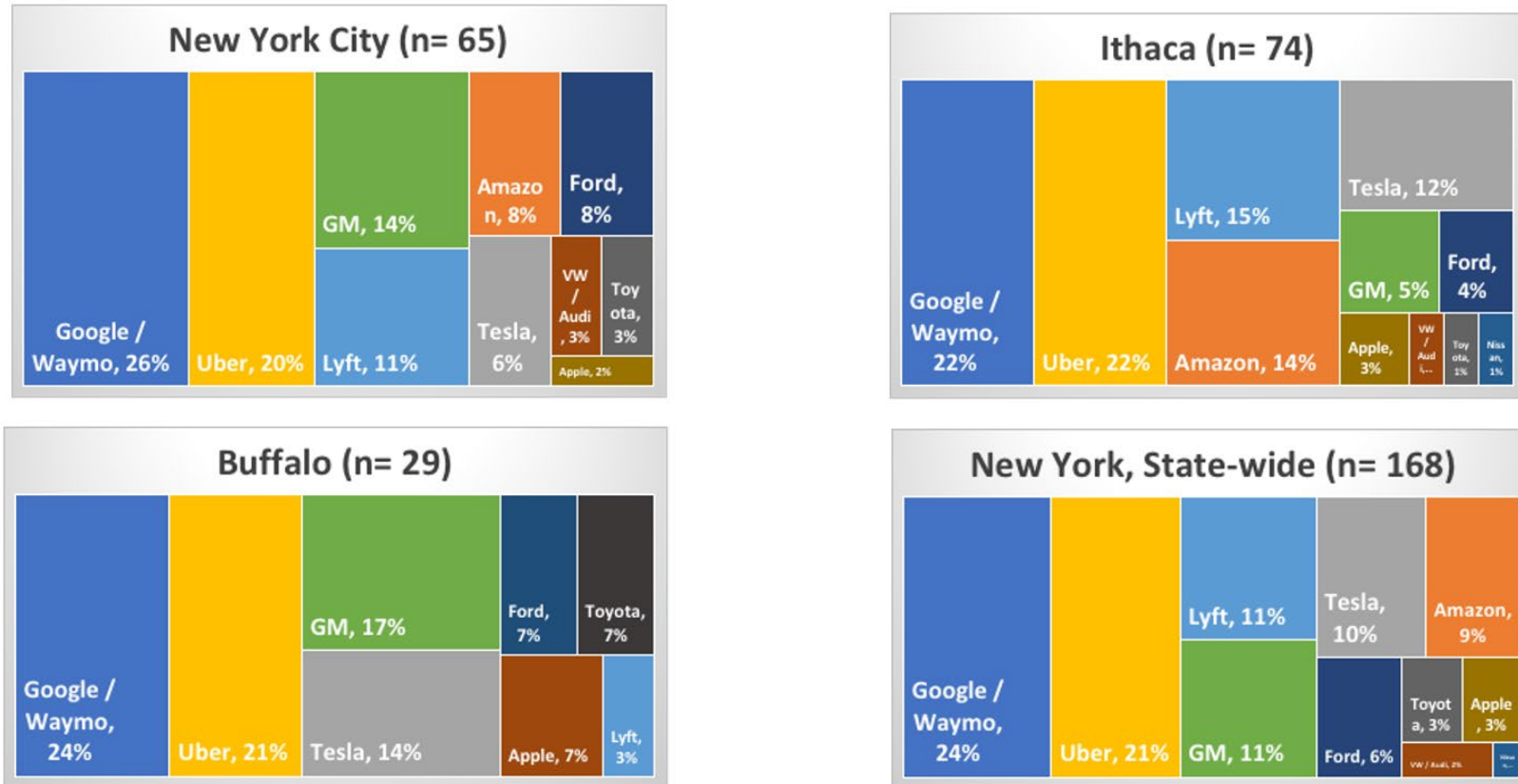
### Figure 9. High-Occupancy Commuting

Below summarizes estimated percentage of trips in modes that include 2+ passengers, as ride-hailing, micro-mobility, transit, and/or carpooling.



**Figure 10. IT Companies, Automobile Companies, and Future Mobility Service Companies**

Which companies are best positioned to capitalize on shared mobility, CAVs, and electric mobility services? (Select three.)\*



**Key Findings:**

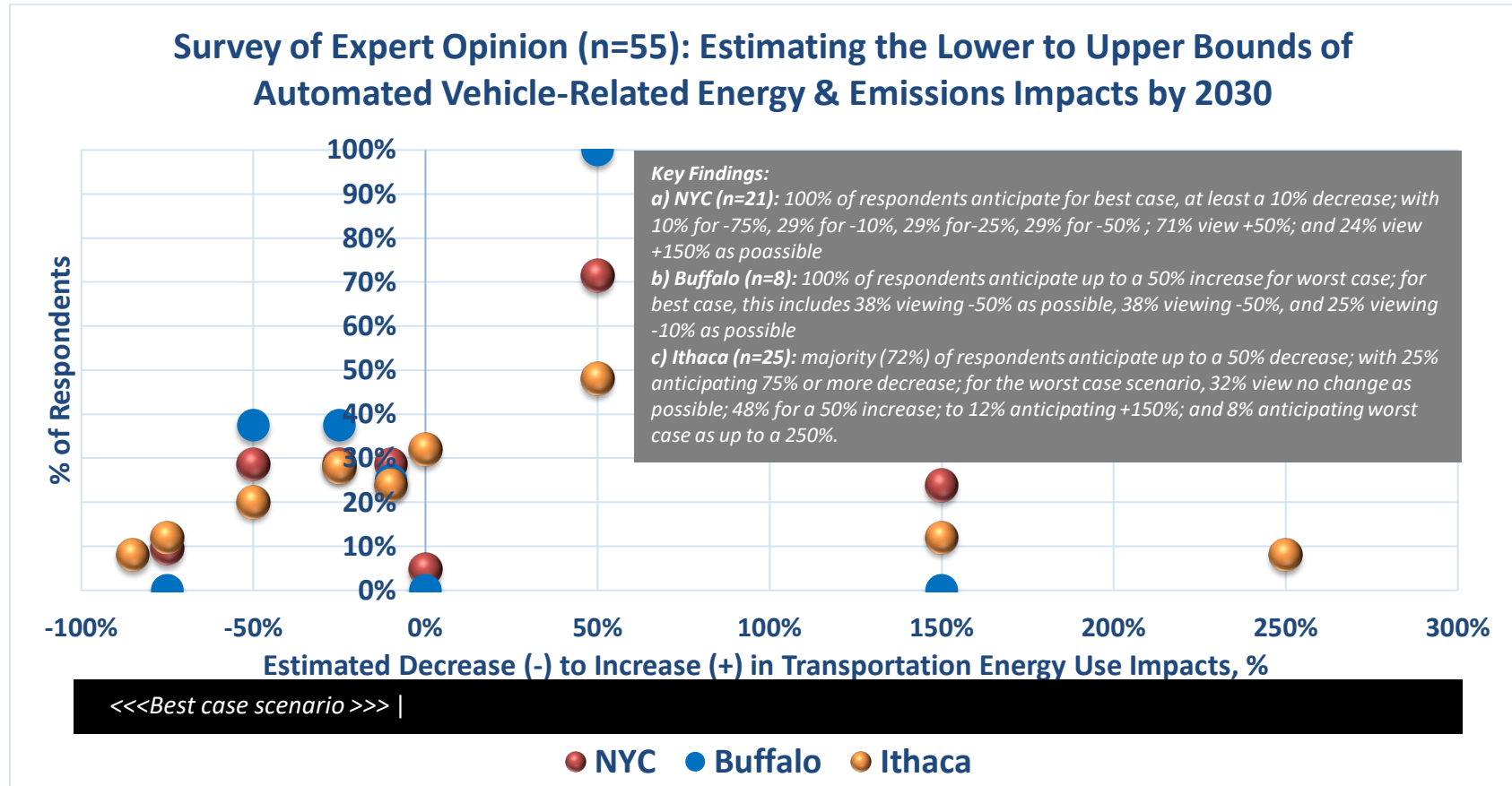
- The respondents thought of IT companies as more flexible, and perhaps having competitive advantage.
- Respondents also noted that auto-manufacturers may need to increasingly partner with these more flexible, MaaS companies.
- Consistency in responses on Google/Waymo and Uber as the current front-runners to capitalize on shared CAVs, electric mobility.

Note: The New York statewide results represent inputs across settings of survey participants invited from New York City, Ithaca, and Buffalo.

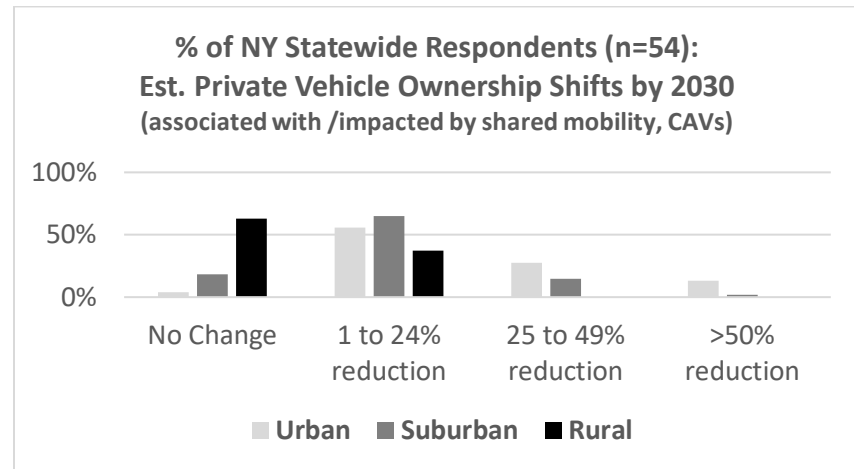
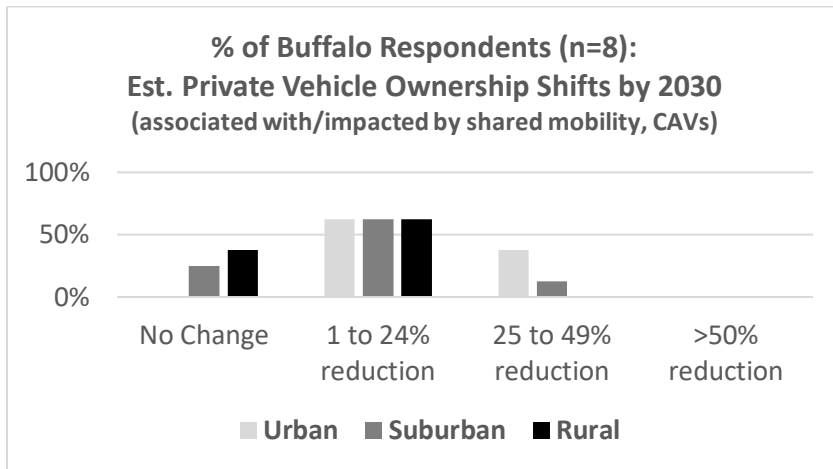
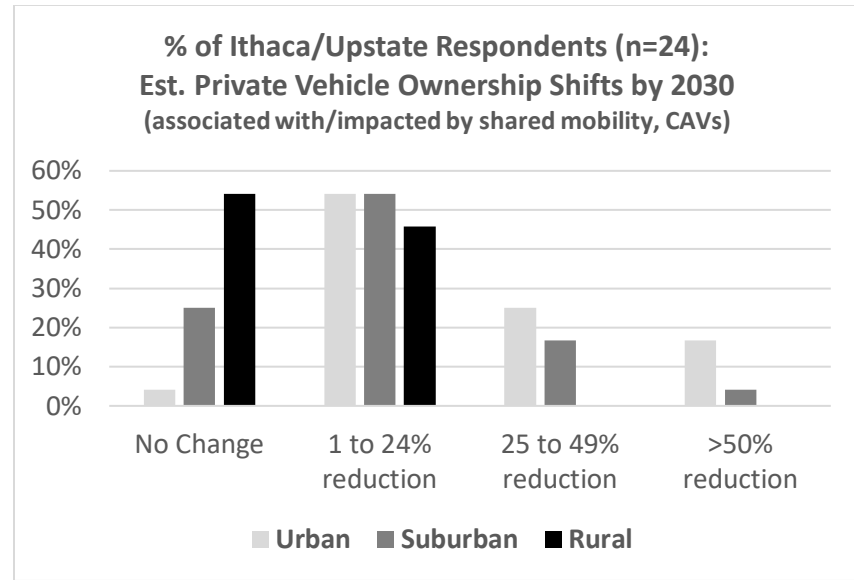
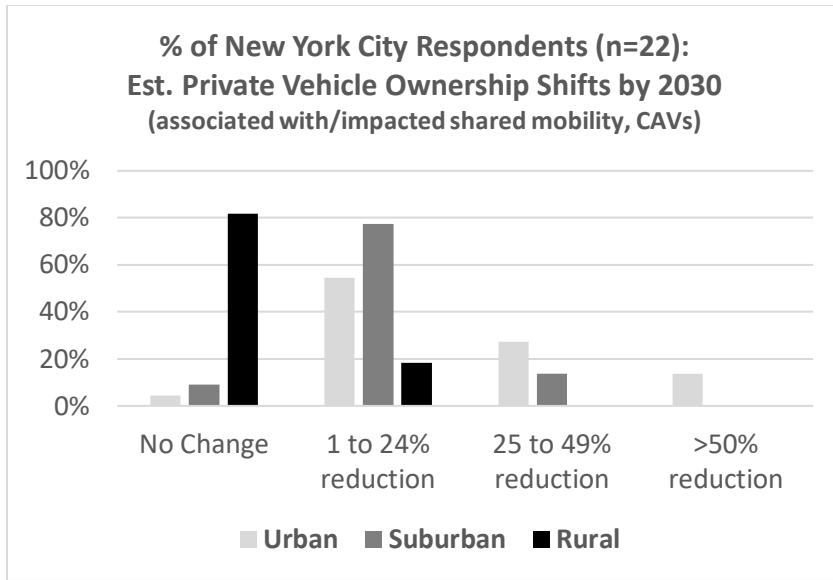
\*Note: some participants selected four.

**Figure 11. Energy Impacts of Automated Vehicles**

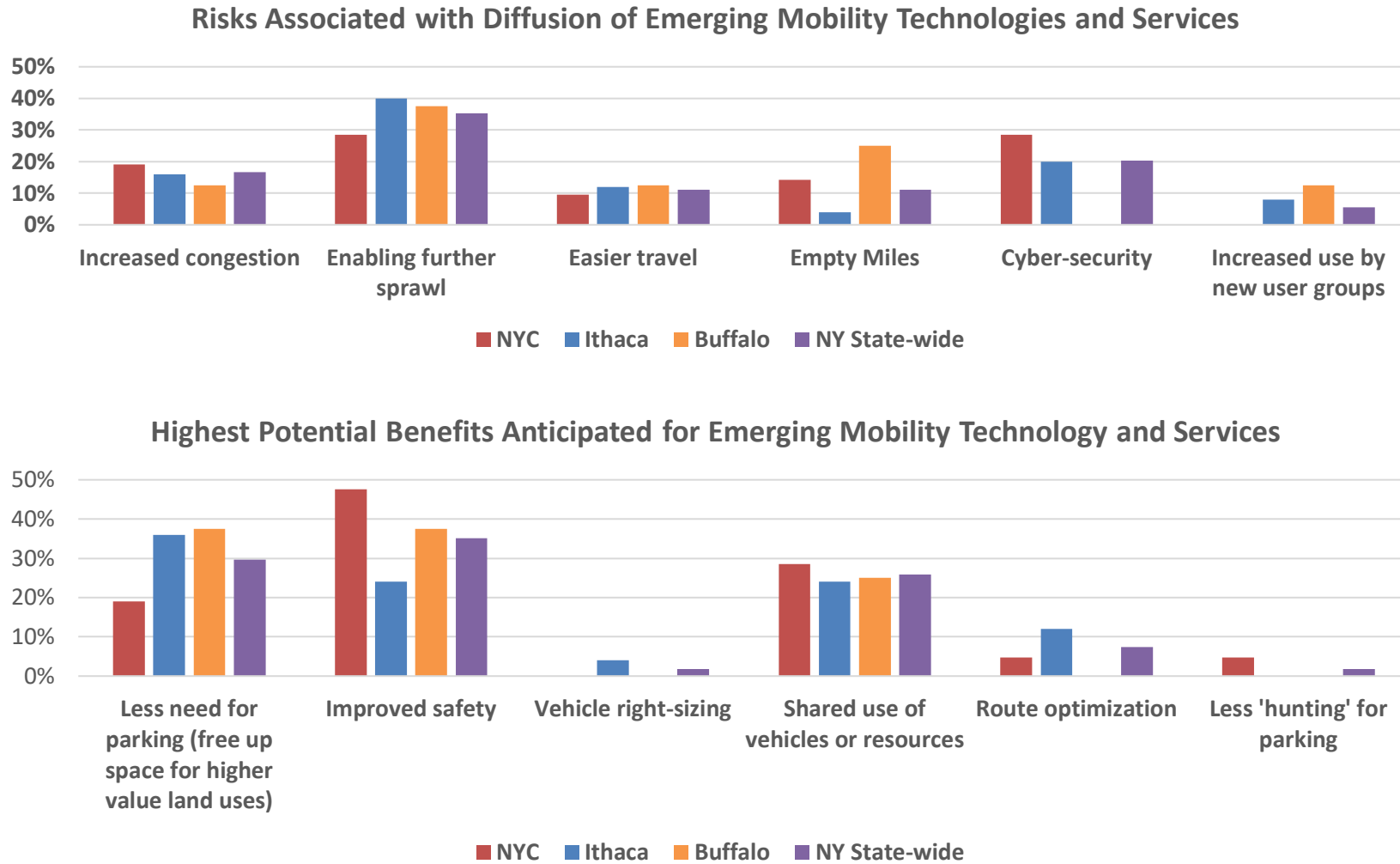
Estimates were offered in response to (1) What is the highest potential increase in energy and emissions impacts that the sale of automated vehicles (that are NOT shared or electric) will have in New York State by 2030? (Assume a worst-case scenario.) and (2) What is the highest potential decrease in energy and emissions impacts that the sale of automated vehicles (that ARE shared and electric) will have in New York State by 2030? (Assume a best-case scenario.)



**Figure 12. Future of Private Vehicle Ownership versus Shared Fleets**



**Figure 13. Future of Perceived Risks and Benefits Associated with Emerging ACES Mobility Technologies and Services**



### 3.6.1 Discussion on Delphi Study

The results in these surveys focus on the anticipated diffusion of transportation technologies in three New York cities. Although the surveys collected a limited number of responses, those who responded are transportation sector professionals who are highly attuned to the transportation landscape of their respective cities and in New York State overall. From a statistical standpoint, it may be difficult to draw strong conclusions, but the respondents provide an experienced and thoughtful perspective on the anticipated near- to mid-future trajectory of transportation technologies and insight into related potential impacts.

In examining the responses from New York City, Ithaca, and Buffalo, there are both similarities and differences across the three cities. Concentrating first on the similarities the following statements can be made:

- Comparable portions of respondents in each city expect: shared mobility options to reach 10% of PMT by 2030 and zero emission vehicles (ZEV) to comprise 30% of the TNC fleet by 2030. Taken together, these findings suggest that the respondents view a fairly strong future for shared, electrified mobility within the coming decade.
- The cities each have pessimism as to whether shared mobility options will reduce private vehicle ownership in rural areas, coupled with mild optimism that urban and suburban car ownership will reduce by up to 24%. Perhaps unsurprisingly, NYC respondents were most pessimistic about the potential reduction in car ownership among rural populations. Across the three cities, the biggest risks associated with ACES technologies was the potential to promote increased sprawl. On the flip side, all respondents tended to see potential benefits in ACES technology regarding improved safety and reduced parking needs.

As to the key differences:

- Perceptions of when CAV technologies would become prevalent: Ithaca tended to be somewhat more pessimistic that CAVs would reach 10% of PMT by 2030. Likewise, there was considerable variation in predictions of shared CAVs implementation. These findings suggest that there is yet to be a consensus on the impact and timing of substantial CAV operations within the next decade.
- Anticipating the portion of commuting trips that would be made via higher occupancy modes of more than two passengers: NYC respondents tended to envision higher percentages of commutes would be made via modes carrying two or more passengers, perhaps a reflection of pragmatism in space and resource constrained NYC. However, sizeable portions of Ithaca and Buffalo respondents also anticipated higher occupancy commuting, though at somewhat lower rates than their colleagues in the City.

Taken as a whole, there appears to be agreement among the survey respondents that some combination of shared and electric mobility is on the near horizon, and that the timing and potential impacts of the connected and automated components of future mobility are less clear. It is also apparent that the transportation experts surveyed are in consensus that transportation technology advances will affect areas of different geographic densities differently. Underscoring this is the contextual and cultural differences between locations. Dense urban areas may, for the sake of practicality, be more willing to adopt post-vehicle ownership models of mobility, depending increasingly on shared options and embracing mobility as a service. Suburban areas may have a more muted interest in shared mobility but may also see AV technologies as enabling them to live more distant from the urban core without sacrificing travel time unproductively—new technologies may actually foster long commutes and increase sprawl. At the far end of the spectrum, rural areas may not anticipate much benefit from shared mobility, at least in its current incarnation.

Interestingly, the respondents seem to point to the potential of shared vehicles and resources as most pragmatic within the range of emerging technologies, followed by zero emission vehicles and somewhat more distantly by connected and automated technologies. This may reflect the current state of advancement of these options, as the capacity to develop tools to share mobility are more accessible than more mature connected and automated technologies, which remain out of reach. The responses are encouraging in that if people are receptive to shared mobility, as is apparent with the success and rapid proliferation of mobility on demand services, the potential to achieve improved energy efficiency and productivity of mobility are viable in a near timeframe. This will allow time to shift toward more advanced technologies as they become available; however, the survey results point to the need to develop approaches tailored to the variations in local geography, culture, and context.

### **3.7 Estimating and Modeling Future Impacts**

New York, as one of the largest State economies, is facing several challenges where the future “reinventing or reimagining of mobility” may play a critical role to transformative rather than incremental progress forward. Based on recent statewide transportation trends, the State is ranked first in excess fuel consumed per auto commuter (Schrank, et al., 2015), VMT has risen consistently (and GHG due to transportation amounts to about 33% of the total emissions (NYSERDA, 2018)). Among several urban innovations, transportation is undergoing transformative transitions in the form of sharing, electrification and automation—the Three Revolutions (Sperling et al., 2018)—most of which will be further enabled by digital connectivity of mobility options, increases in electrified drivetrain efficiency, higher capacity batteries, and early-stage research, development, demonstration, and larger-scale



deployment of increasingly automated vehicles. While the long-term impacts of ACES mobility remain uncertain, a United States Department of Energy (DOE) study estimated that the impact of ACES technology could reduce energy consumption by 60% or increase by 200% depending on a number of variables. (Stephens et al., 2016). These “bounding” analyses have been updated here using recent literature.

Uncertainty and sensitivity to several regional and local factors can help offer more nuanced understanding or identification of knowledge gaps for technology adoption and user behavior. It is necessary to capture these factors when aiming for cross-scale comparable analyses on ACES impacts for State- and local-levels. In this study, a first-order emerging mobility impact study of ACES and associated risks and benefits for mobility, energy, and emissions across New York State are estimated. In moving to the State-level context from the national-level approach, several factors are considered in more detail for impacting mobility in the context of ACES based on a review of current literature addressing ease of travel, shift in mode of transportation, ridesharing, empty vehicle miles, smoother traffic flow, better information access, vehicle and power train resizing, enhanced safety, and additional automated vehicle energy needs.

Various mobility and energy consumption and GHG data at different geographic scales in the State were employed in the study to evaluate the lower and upper bound of impacts due to ACES. Next, ACES is analyzed across the three cities, New York City, Buffalo and Ithaca, to represent varying degrees of urbanization, technology adoption, demographics, and human travel choices. Factors specific to these cities that may play a comparatively more prominent role, while the ACES mobility comes to fruition (e.g., the potential for more long-distance travel including weekend travel in and out of the City and as weekday work travel opportunities, specific to upstate), are considered. Finally, based on the several factors considered in the bounding analysis, key factors that may influence ACES impacts more significantly are explored via scenarios. The three scenarios for plausible futures of ACES adoption offer an early modeling framework analyzing impacts on mobility, energy consumption, and emissions.

### **3.7.1 ACES Impact Methodology**

Vehicle miles traveled (VMT) by roadway functional class and county and light duty vehicle (LDV) energy consumption in New York State is used as a baseline for mobility and energy impacts derived from State and city sources and reports. Freight travel is not considered in this study due to the need for additional data that is not publicly available, and the larger additional scope and resources this would require. Other mobility data such as share of walk, transit, air travel and occupancies are derived

from American Public Transit Association (APTA), Bureau of Transportation Statistics (BTS) and National Household Travel Survey (NHTS) data. Baseline energy and GHG emissions is used for LDV for New York State and New York City were obtained from the corresponding GHG inventory report.

Due to several uncertainties and a wide range of predicted outcome due to ACES, the impacts are estimated as lower and upper bounds for mobility, energy, and GHG following the approach taken by studies such as Stephens et al. (2016), Brown et al. (2014), Wadud et al. (2016), and Chen et al. (2017). For the purpose of brevity of this extended abstract, the team only mentions the outline of their approach. The methodology is based on a kaya identity framework considering VMT by roadway functional class ( $V_i$ ), energy consumption rate ( $E_i$ ), human behavior and technology impact ( $p_t$ ) as shown:

**Equation 2.** 
$$\sum_i V_i * E_i * \prod_t p_t$$

Some of the bounds of impacts of different human behavioral aspects and technological impacts are listed in Table 6. However, some of the bounds for impacts are updated via findings in the latest literature, as well as customized to New York State as data allows. In addition to the factors considered in the above cited studies, the following were added:

- The need for charging stations for electric CAVs (Chen et al., 2016).
- The reduced need for parking infrastructure, wider lanes, etc. the residual built space reutilization could result in reduction in VMT of 2% (Fox-Penner et al., 2018, and Outwater et al., 2014).
- Energy needs of sensing and computing hardware components in CAVs impacted energy consumption by 50–30% (Hamza et al., 2019). However, Lin et al., 2019 in their analysis of various computing configurations, camera-based sensing, storage, and cooling systems show that the driving range reduction went from 2% to 13%. In the study the team uses an upper bound of 20% as a conservative estimate to include other redundant sensors such as LiDAR, RADAR and a lower bound of 2% representing a much higher efficiency expected in the future.

Some of the factors influencing ACES impact are modified to reflect the city-level characteristics.

The changes in human demand for mobility to the bounds of following factors:

- Parking—2–11% of VMT is spent on searching for parking (Shoup, 2006). New York City has a very high demand for parking spaces. Despite the relative ease in access to parking information with CAVs, as a lower bound of VMT saved with lesser hunting for parking is considered as only 2% (compared to 5% for the State).

- Mode shift—In the methodology for the national-level study Stephens et al. (2016), for the upper bound of impact due to modal shift to CAVs, the authors considered a 100% shift from transit, walk, and air to CAVs. However, there are some significant regional and local behaviors that need to be considered in the study. In case of New York State, and much more in New York City, there is very good transit infrastructure. The City has extensive public transit usage constituting more than 60% commuting trips. Hence, for the study, for the upper bound modal shift from transit to CAVs, the team considers only 50% of passenger miles travelled by transit users will shift to CAVs for the State and only 25% shift for New York City.
- Rideshare—The propensity for ridesharing, compared to other New York State locations, is in the City much greater given the availability of the shared ride option provided by TNCs. Up to 20% of Uber/Lyft and 58% Via rides are shared during certain times of the day (NYCTLIC). Hence, the upper bound of VMT reduction due to ridesharing in the City is set as 20% (12% for NYS). Ithaca, a college town, has 22.4% of the population involved in the education sector. This could result in seasonality in travel volume resulting in lesser vehicle occupancies during the off-season. However, when colleges are in session, vehicle occupancies could increase due to higher household density. Therefore, the upper bound for VMT reduction for rideshare was considered as 15%.
- Empty miles—In New York City, currently, the rapid rise of TNCs has resulted in extra VMT—600 million extra miles (Schaller, 2017). Hence, the upper bound for increase in empty VMT for the City is set at 20%.

Table 10 shows the different factors for ACES impact on behavioral choices and vehicle efficiency used in the study.

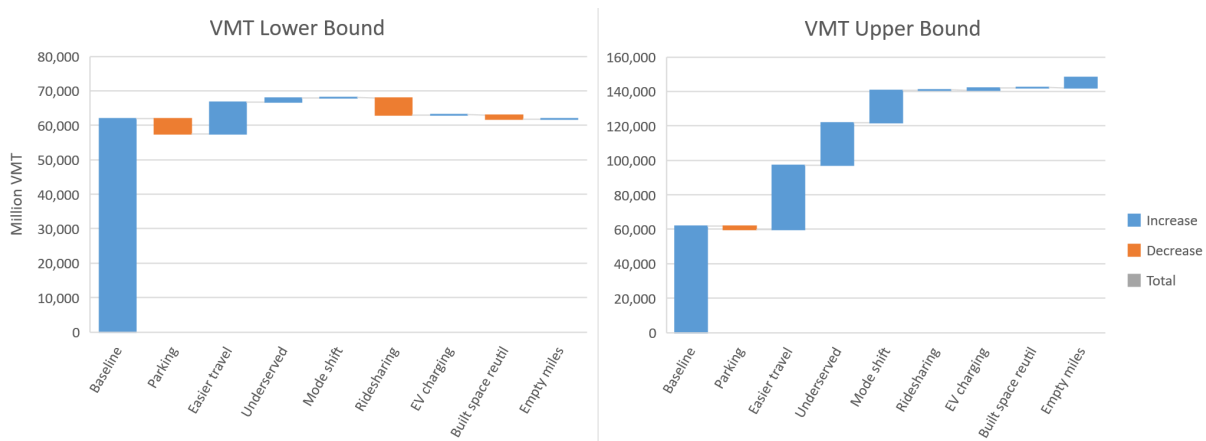
**Table 10. Various Factors Used to Model ACES Impact**

Factor	Range of Impact & Source (-) indicates reduction
Demand / Behavior	
Less hunting for parking	(-)5-11% Full AV (Brown et al., 2014) (-)2-11% NYC
Easier travel	15% (Gucwa (2014) – 60% (Wadud et al., 2016))
Underserved population	2-12% (MacKenzie et al. 2014), Harper et al., 2015)
Mode shift	Walk, Transit (City VMT), Air (BTS) Lower bound – no shift; Upper bound: $q$ % modes shift to CAVs $q$ : 100% for NYS; 50% NYC; 100% Buffalo & Ithaca <u>Scenario Analysis</u> : $q$ : 50% for NYS; 25% NYC; 100% Buffalo & Ithaca
Ridesharing	(-)12%-0% (City VMT), (-)0-20% NYC (-)0-15% Ithaca
Empty miles	0%–15% increase (City VMT) (Fagnant and Kockelman (2014), Fagnant and Kockelman (2015b), Zhang et al., 2018)) – lower bound represent best case ridesharing. 0-20% increase for NYC
EV charging	0-3.5% (City VMT) (Chen et al., 2016) – as a lower bound the team considers CAVs are not electric.
Built space reutilization	(-)0-2% (Outwater et al., 2014, Fox-Penner et al., 2018)
Efficiency	
Smoother flow	(-)7%–15% fuel savings on highway (-)10%–15% fuel savings on city driving (Barth and Boriboonsomsin (2009), Barth (2013), Stephens et al., 2016).
Faster travel	10%–40% fuel increase for highway driving (Brown et al., 2014, Wadud et al., 2016)
CV communication	2%–6% fuel savings for city driving (Yelchuru et al. 2014, Yelchuru and Waller 2014)
Safety (Collision avoidance)	(-)0%–1.9% fuel savings Moore and Zuby (2013)
Platooning	(-)12.5%–25% fuel savings on highway driving during non-peak hours (Schito and Braghin, 2012)
Vehicle resizing	(-)0-50% (Brown et al (2014)
AV hardware energy	2-20% (Hamza et al., 2019)
GHG	
Assumption: The factors from “Smoother flow” to “Electrification” influencing <i>Efficiency</i> are assumed to have similar proportional impact on GHG	
Electrification of CAV powertrain	(-)0-80% more efficient compared to gasoline-powered vehicles (USCSA (2018), Hamza et al. (2019)) For 2030, CAEV penetration: (8%, 20%) of CAVs for all cases
CAV market adoption	For 2030, NYS (10%,35%); NYC (5%, 20%)

Each of the lower and upper bounds of factors listed in Table 6 are used in the kaya identity shown above to estimate the bounds of the VMT and energy impacts of ACES mobility in New York State.

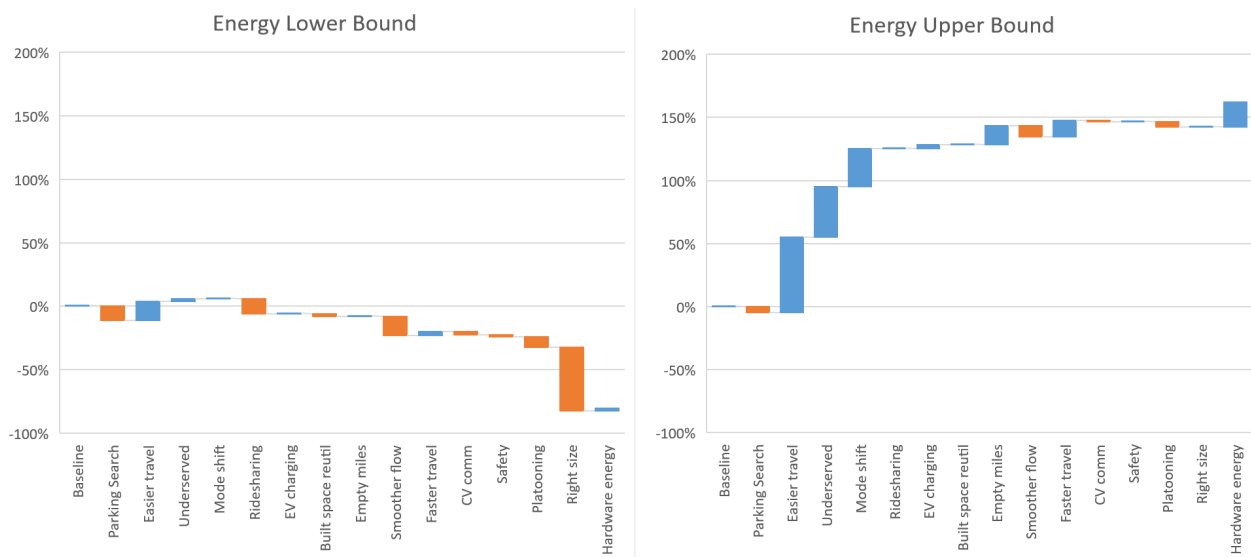
The analysis showed that in the State, VMT could decrease to 5% and increase by 125% due to various factors of ACES influencing travel demand. For New York City, Buffalo, and Ithaca, the VMT decrease and increase are 8.5%, 133% and 4.8% (decreased) and 124%, and 6.6%, 123% (increased), respectively.

**Figure 14. Upper and Lower Bounds of Vehicle Miles Traveled Changes due to ACES Mobility in New York State**



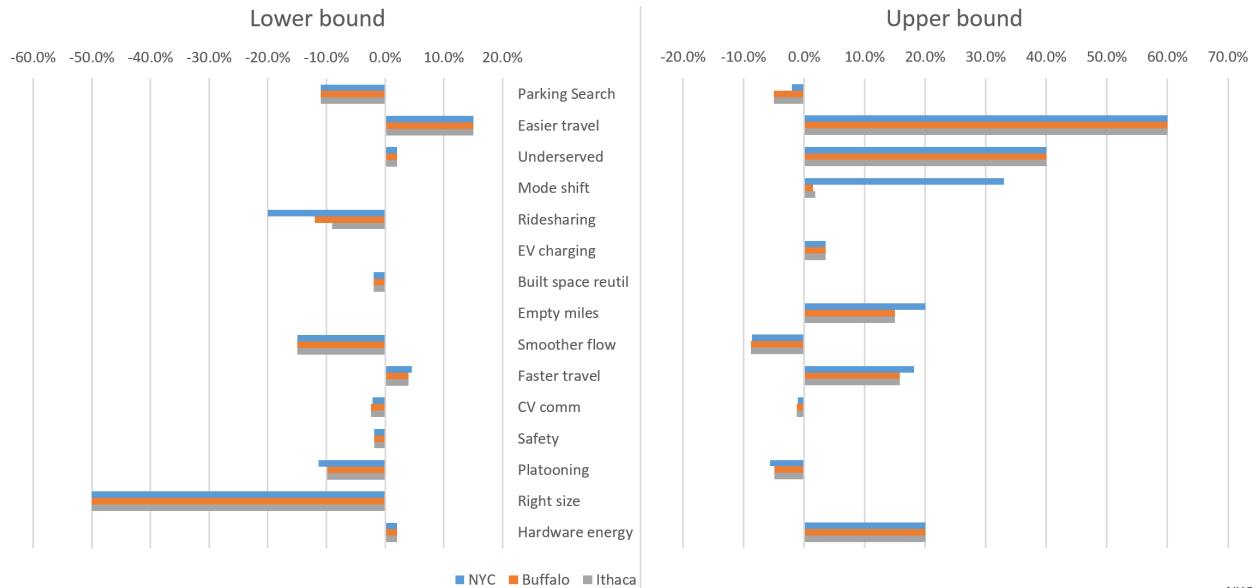
Energy consumption in the State could be reduced by 58% and increased by 215% due to ACES.

**Figure 15. Relative Scale of Upper and Lower Bounds of Energy Consumption due to ACES Mobility in New York State**



For New York City, the energy consumption bounds were estimated as (-60%, +240%). For Buffalo and Ithaca these are (-63%, +181%) and (-63%, +195%), respectively, due to ACES.

**Figure 16. Comparison of Bounds across New York City, Buffalo, and Ithaca among Various Factors**



### 3.7.2 Discussion on Bounding Analysis

The lower bound for energy consumption due to ACES in New York State, New York City, Buffalo, and Ithaca remained in the range of 60%. However, the upper bound for NYS, NYC, Buffalo and Ithaca ranged from 181% to 240%. The significant positive impact on reducing energy consumption and VMT is due to ridesharing. On the upper bound of impacts, ease in travel, greater availability of mobility options for underserved populations and modal shift of transit users may all lead to significant increases in VMT and energy consumption.

Among the three factors that increase energy use, the single factor influencing uncertainty (181% to 240% upper bound energy consumption) across cities is the modal shift of transit users to CAVs. This is despite the fact that, for the upper bound of energy consumption in this study, only 25–50% modal shift from transit to CAVs was considered; a 100% shift was assumed in Stephens et al. (2016). A large proportion of current-day commuters in New York States choose transit and a significant proportion of commuters traveling into the City use transit. If the demand for travel due to the introduction of ACES significantly influences travelers to shift away from transit and shared mobility to private vehicle or single occupancy vehicle travel, then this could lead to a very high transportation-related energy consumption.

Among vehicle-specific factors vehicle/powertrain right-sizing and smoother flow reduce energy consumption significantly. CAV hardware components and faster travel speed of CAVs increase energy consumed. Faster travel speed has less influence because it affects only highway VMT, which is much lower for cities.

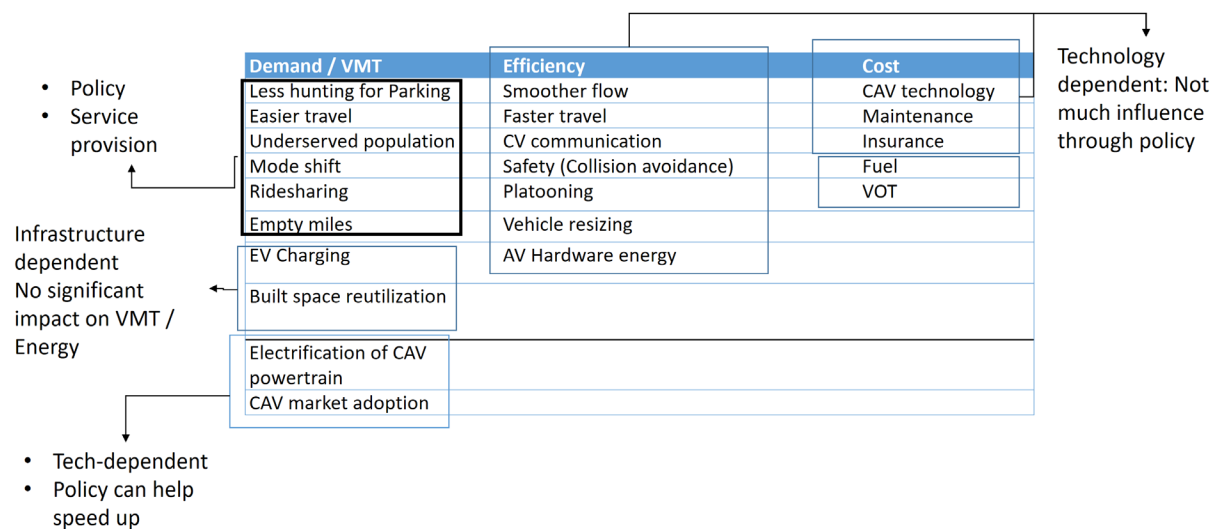
### 3.7.3 Scenario Analysis

The bounding analysis included several factors that could influence the energy and mobility impact of ACES. However, the impact of different factors has differing levels of uncertainty as shown in Figure 16.

### 3.7.4 Scenario Development

The focus was to select factors that result in greater uncertainty in terms of user behavior that influence demand for travel. It is assumed that the factors influencing efficiency (Table 9) are dependent on technological evolution. Changes to policy could, potentially, indirectly speed up the adoption and influence efficiency, but policy could have a direct impact on user demand. Figure 17 delineates factors considered in this study into those that are influenced by technology, infrastructure, and policies. The model of the scenarios is based on factors that, according to the above discussion, influence user demand (shown in the black box in Figure 17). Considerations of ridesharing, mode shift, underserved populations, and electrification and CAV market adoption were accounted for as the factors when designing the scenarios.

**Figure 17. Factors Considered for Scenario Modeling**



The target year for the analysis is 2030. It is assumed that it is unlikely that by 2030 fully automated vehicles will be widely adopted. However, due to the highly nascent nature of ACES, it would be much harder to assess the projection further than 2030. It is expected that by the target year there will be several changes to the baseline data such as modal split, response of certain age groups, and other user behavior due to different emerging and future modes of mobility and adoption of new technology and other factors.

Millennials are associated with choosing more shared and active modes of transportation, postponing car ownership, choosing denser urban centers for housing and also higher rates of adoption of emerging technology and modes of transportation. (Circella, et al., 2016) Due to all these reasons, the team designs the first scenario where commuters in the age range of 21–35 choose a shared mode of travel. Other studies on behavior of travelers using application-based or e-hail services suggest that one consequence of e-hail services is reduction in transit usage (Schaller, 2017). Hence, the team also considers the consequence of mode shift in the 21–35 age group from transit to shared mode such as e-hail. This group is called the pro-sharing age group and it is assumed that all users who are 35 years and younger as of 2020 will be a part of this group.

The first scenario with commuters in the age (in the target year) range of 21–44 (pro-sharing age group) choose a shared mode of travel, which could result in fewer users of SOV. Since the pro-sharing behavior starts in users below 35 years of age as of 2020, the team considers that the oldest among pro-sharing group would be 44 years old—hence the 21–44 age group selection. However, fewer SOV users, in the context on new e-hail services, could also result in lowered transit usage. Thus, in this scenario the team considered three cases: (a) SOV users in pro-sharing age group shift to shared CAV mode by 50%, (b) all users of non-SOV modes shift to CAVs by 50%, and (c) combination of case a and b. These cases, for this scenario, represent the best case, worse case, and middle ground, respectively, in terms of increase in energy consumption.

The second scenario focuses on the impact of ACES on currently underserved populations. Underserved population is defined based on income of the passengers. Population in the low-income group (annual income < \$15,000) benefit from ACES mobility. This scenario captures an increase in VMT due to new groups getting access to mobility, however, also benefit with access to economic opportunities. In this scenario, the team assumes that the VMT for the portion of the underserved population that have access to ACES is similar to VMT of the population with access to mobility in the current day.



In the second scenario, population in the low-income group (annual income < \$15,000) is considered as the cohort. The team considers three cases under each cohort, namely, transit users among the income underserved population shift to CAVs (a) without any ridesharing, (b) with 50% sharing, (c) with 100% sharing.

Given that electrification is a key component of the three revolutions, an important driver will be adoption of EVs along with automation. The team considers a third scenario for the year of 2030 for which an estimate was made for the bounds of energy consumption and GHG emissions based on evolution of adoption of electrification. In 2017, EVs constituted less than 1% of the vehicle fleet in New York State. However, there are several uncertainties in EV adoption and electrification of CAVs such as range anxiety, charging station and fast charging availability, geographical skewness of adoption rates, introduction/penetration of shared automated electric shuttles, etc.

Based on the adoption model developed by Bansal and Kockelman (2017), for the third scenario, the team uses the bounds for rate of adoption for CAVs in the State as (10%,35%) of total fleet. For the lower bound 10% CAVs, it is assumed that 8% (0.8% of total) are electric (CAEVs); for upper bound, 20% (7% of total) are assumed to be CAEVs (Fox-Penner et al., 2018). Among non-CAVs, EV adoption is assumed to be following the current projections (AEO Outlook, 2019). Respective bounds for CAV/gas and CAV/EV are 28%, 7% and 9.2%, 0.8% of total fleet. To account for the likely slower introduction of CAVs in large cities, for NYC's bounds on adoption, the team uses 5%, 20% of total fleet as CAVs. Respective NYC bounds for CAV/gas, CAV/EV are 16%, 4% and 4.6%, 0.4% (assuming same proportion of electrification as NYS). From an energy consumption perspective, a higher proportion of electrification leads to lower energy. Therefore, a case with higher proportion of CAEVs is considered as a lower bound. The team assumes that the VMT distribution on roadway function class to remain the same across different types of vehicles (non-CAVs, CAVs, CAEVs).

### **3.7.5 VMT and Energy Estimates for Scenarios**

Data and Assumptions: For the first and second scenarios, the data from census projection for 2017 (U.S. Census, 2019) is used to obtain the trip rates, proportion of commuters by age group, mode of transportation and income for each of the three cities. Assumptions in the scenario analysis are as follows:

- Assumptions are made that the VMT proportion (of the total VMT in each city) among different population groups in the target year, 2030, will remain same as 2017. Thus, the team projects the trip rates from 2017 to 2030 using population growth rates (NYC, 2017; U.S. Census, 2019) and estimate the VMT for 2030.

- It is also assumed that the occupancy of all shared rides is 2.0.
- For the second scenario, it is assumed that the VMT per capita of the underserved population will be the same as the regular population due to the availability of CAVs.
- In the third—electrification—scenario, the team does not compare VMT as it is assumed that electrification does not impact VMT significantly—particularly given that additional VMT for charging is only estimated to increase VMT by a maximum of 3.5% (from Table 9).

The evaluation of the impact on each of these cases on the annual VMT and energy consumption for each of the three cities is performed. The impact is presented as a percentage change from target year 2030. In addition, due to the introduction of CAVs the VMT and energy consumption would also be scaled according to several factors presented in Table 9. These factors are used to estimate the bounds of impacts in each scenario.

The results for scenario 1 for each of the cities are shown in Table 11. For each of the cities case (a) results in highest decrease in VMT and energy, since it represents where all SOV users in the pro-sharing group switch to a shared CAV mode. Case (b) involves a modal shift from transit to CAVs and hence has the highest energy increase. Case (c) energy savings are in between (a) and (b) as it involves energy savings through ridesharing from pro-sharing group and an energy increase from mode shift away from transit. It must be noted here that as NYC has a significant number of transit users, case (b) energy increase is much higher as compared to Buffalo or Ithaca.

For each of the cities shown in Table 11, the city case (a) results in the highest decrease in VMT and energy, since it represents all SOV users in the pro-sharing group that switched to a shared CAV mode. Case (b) involves a modal shift from transit to CAVs and hence has the highest energy increase. Case (c) energy savings are in between (a) and (b) as it involves energy savings through ridesharing from pro-sharing group and an energy increase from a mode shift away from transit. It must be noted here that as NYC has a significant number of transit users, case (b) energy increase is much higher as compared to Buffalo or Ithaca.

**Table 11. Vehicle Miles Traveled and Energy Savings for First ACES Scenario**

Scenario 1		NYC Impact [Bounds]	Buffalo Impact [Bounds]	Ithaca Impact [Bounds]
Case (a)	VMT	-10% [-4%, +155%]	-26% [-29%, +69%]	-10% [-15%, +104%]
	Energy	-9.5% [-71%, +156%]	-25% [-77%, +76%]	-9% [-73%, +113%]
Case (b)	VMT	+27% [+10%, + 195%]	+4% [-1%, +136%]	+6% [+1%, + 141%]
	Energy	+25% [-65%, +196%]	+3% [-68%, +147%]	-5.5% [-68%, +151%]
Case (c)	VMT	-15% [-0.1%, +166%]	-23% [-26%, +76%]	-5% [-10%, +115%]
	Energy	-15% [-69%, +177%]	-24% [-76%, +83%]	-5% [-71%, +125%]

Results of second scenario are in Table 12. This scenario, unsurprisingly, shows an increase in VMT and energy as an underserved population moves from transit to CAVs. However, this scenario need not be considered as a negative consequence or risk of CAV mobility. CAV mobility in this case provides employment opportunities and increased access.

**Table 12. Vehicle Miles Traveled and Energy Savings for Second ACES Scenario**

Scenario 2		NYC	Buffalo	Ithaca
Case (a)	VMT	+26%	4%	7.7%
	Energy	+26%	4%	7.7%
Case (b)	VMT	+17%	4.4%	8.3%
	Energy	+17%	4.4%	8.3%
Case (c)	VMT	+7%	5%	8.9%
	Energy	+7%	5%	8.9%

Energy consumption and GHG for the third scenario, designed based on literature to show the adoption of CAVs and their electrification, is shown in Table 13. For the third scenario, since Ithaca and Buffalo represent similar VMT and energy per capita characteristics, the figures for energy savings due to electrification is corresponds to that of NYS.

**Table 13. Vehicle Miles Traveled and Energy Savings for Third ACES Scenario**

	Energy (MMBTU)	GHG (MMtCO2e)	Change under Scenario
NYS Baseline 2030 Projection	486.7	50.14	
NYS Scenario Bounds	[425.2, 458.2]	[43.8, 47.2]	[-12.6%, -5.8%]
NYC Baseline 2030 Projection	145.6	12.46	
NYC Scenario Bounds	[120.7, 139.1]	[10.3, 11.9]	[-17.1%, -4.4%]

Based on the scenario analysis, the team can infer that ridesharing can have a significant impact on VMT and transportation energy consumption. With growth in a younger population moving into denser, urban centers for employment and access, ACES mobility can provide environmental benefits via ridesharing. CAVs can also offer benefits through providing new employment opportunities and accessibility for underserved populations, albeit through an increase in VMT and energy consumption. However, it is very critical to balance encouragement of new and emerging modes of transportation such as CAV without losing the benefits offered by traditional transit such as high occupancy, lower per passenger energy, and VMT. Thus, it is critical for cities to straddle new emerging modes with existing modes towards heralding sustainable transportation.

In addition to the impacts and significant influencing factors, one of the most significant uncertainties for ACES regarding mobility, energy, and environment is the rate of adoption. Electrification of CAVs has significant efficiency improvement, GHG reduction, and cost savings. However, the charging infrastructure installation will determine the adoption rates significantly. The rate of adoption of CAVs in cities is also expected to lag that in highway and suburban settings due to the complexity of urban driving environment. This could also have impacts on energy and GHG in the short- and near-term.

### **3.8 Conclusions**

Cities and states are on the leading edge of economic activity and technological innovation—particularly in the mobility space. Transitions and transformations toward increasingly Automated-Connected-Efficient/Electric-Shared (ACES) transportation services has significant potential for shaping future mobility, energy, and emissions impacts. New York State, with its varied social, economic, technological/infrastructural, and environmental and governance characteristics can experience impacts from these transitions to varying degrees.

In this project, the team aimed to bring together stakeholders from various agencies across the states through two workshops, in NYC and upstate—Ithaca, NY. Several stakeholders' inputs helped formulate some research questions and shape analyses framework and scenario modeling. Through a detailed data analysis framework that brings out important typologies, the research team estimated key attributes of NYS for technological adoption. Using stakeholder opinions and building on an initial national-level ACES impact bounding analysis study, the team estimates the range of impacts and model more plausible scenarios.

Exploring multi-dimensional aspects of differences in technology adoption, travel, and vehicle ownership across settlement types can help inform energy efficient and affordable mobility system goals. At the same time, mapping key enablers, barriers, and risks for successfully meeting ambitious goals and targets (e.g., by geography, age, income, education, population density) offers important explanatory power as to context-specific challenges and opportunities. The typological analysis portion of this report explores how a highly geographically-resolved understanding of social, economic, techno-infrastructure, environmental, and governance (SETEG) systems shape variations in technology adoption and associated mobility, and energy outcomes in diverse communities of New York State, in terms of EV adoption rates, alternative commute mode choices, vehicles per household, and vehicle fuel economy.

EV adoption is geographically concentrated in core urban settlements inhabited by highly educated and wealthy early adopters—three out of every 1000 vehicles in this group were electric in 2017. In contrast, people in the rural typology areas drive longer daily distances and lack access to charging infrastructure, which may explain the lower rate of adoption. Lower EV adoption among the urban populations may be due to an inability to pay the higher upfront cost, which points to the relevance of both spatial and socioeconomic factors.

Vehicle ownership rates also vary significantly across the four typologies, with half as many vehicles per household in urban typologies compared to rural and suburban, and again half as many in core urban compared to urban—mainly due to lack of viable alternatives in rural typologies. The inverse trend is observed between vehicle ownership per household and use of alternative commuting modes, which is attributable to the high employment density, lower socio-economic status, and abundance of transit options and infrastructure for active modes, leading to a high (91%) use of alternative modes (i.e., transit, walking, and biking) for populations in core urban areas (Boulange et al. 2017). Suburban and rural areas have four- and five-times lower use of alternative modes, respectively.

The Delphi method analysis portion of this study focused on the anticipated diffusion of transportation technologies in three cities of New York. Although the surveys collected a limited number of responses, those who responded were transportation sector professionals who are highly attuned to the transportation landscape of their respective cities and in New York State overall. From a statistical standpoint, it may be difficult to draw strong conclusions, but the respondents provide an experienced and thoughtful perspective on the anticipated near- to mid-future trajectory of transportation technologies and insight into related potential impacts.

In examining the responses from New York City, Ithaca, and Buffalo, there are both similarities and differences across the three cities. Concentrating first on the similarities, comparable portions of respondents in each city expect shared mobility options to reach 10% of PMT by 2030. Respondents from each city also expect ZEVs to comprise 30% of the TNC fleet by 2030. Taken together, these findings suggest that the respondents view a strong future for shared, electrified mobility within the coming decade. In addition, they tend to see technology-motivated companies, such as Google/Waymo, Uber, and Lyft, with comparatively recent entry into the transportation sector as having advantages over vehicle manufacturing companies in offering mobility services. This is an acknowledgement that the function and dependability of the software behind emerging mobility services is paramount to success in recruiting users more so than the physical hardware that users encounter. This also provides further evidence for a continuing state of disruption, as the business of transportation continues to undergo rearrangement.

Other similarities across the cities include pessimism as to whether shared mobility options will reduce private vehicle ownership in rural areas, coupled with mild optimism that urban and suburban car ownership will be reduced by up to 24%. Perhaps unsurprisingly, New York City respondents were most pessimistic about the potential reduction in car ownership among rural populations. Across the three cities, the biggest risks associated with ACES technologies was the potential to promote increased sprawl. On the flip side, all respondents tended to see potential benefits in ACES technology with regard to improved safety and reduced parking needs.

Some of the key differences between respondents from different cities included perceptions of when CAV technologies would become prevalent. Ithaca tended to be somewhat more pessimistic that CAVs would reach 10% of PMT by 2030. Likewise, there was considerable variation in predictions of shared CAVs implementation. These findings suggest that there is yet to be a consensus on the impact and timing of substantial CAV operations within the next decade.

Another area where the views of respondents differed was in anticipating the portion of commuting trips that would be made via higher occupancy modes of more than two passengers. New York City respondents tended to envision that higher percentages of commutes would be made via modes carrying two or more passengers, perhaps a reflection of pragmatism in space and resource constrained in NYC. However, sizeable portions of Ithaca and Buffalo respondents also anticipated higher occupancy commuting, though at somewhat lower rates than their colleagues in the City.

Using myriad studies from literature, the team considers several factors influencing human demand for mobility, vehicle efficiency, and rate of adoption of ACES mobility to model the impacts as a range with lower and upper bounds. Following this bounding analysis, the team further analyzed the impacts of energy and VMT for three cities, NYC, Buffalo and Ithaca, which portray contrasting degrees of urbanization, technology adoption, demographics, and human travel choices. For each of these cities, any specific local influences that can shift factors affecting ACES mobility are further included in the analysis. VMT lower bounds ranged from -4.8% to -8.5% and upper bounds from 123% to 133%. Energy bounds of -60%, +240% and -63%, + 181% and -63%, +195% were obtained for NYC, Buffalo, and Ithaca. ACES factors, mainly for NYC, are modified to reflect local trends and behavior.

To contrast the expert opinion and literature- and modeling-based impact analysis, the team compares the results of survey questions (Figure 5) and the energy impact analysis presented in the previous section. For NYC, 100% of the experts opine there will at least be a 10% decrease in energy impacts due to ACES mobility and 58% said at least a 25% reduction with a range of change as -80% to +150%. For NYC, the energy consumption bounds were estimated as -60%, +240%. For Buffalo, experts stated the impacts could range between 75% reduction to 150% increase in energy consumption due to ACES with 38% experts viewing a 50% decrease. The modeling analysis showed the range of impacts for Buffalo to be -63%, + 181%. For Ithaca, the of majority experts anticipated a 50% decrease in energy and a range of -75% to 250% increase in energy consumption due to ACES mobility. Modeling results estimated a range of -63%, +195% in energy consumption due to ACES for Ithaca.

Based on the analysis, the team identified significant factors such as modal shift, ridesharing, and underserved population use of CAVs, as well as electrification and CAV market adoption—affecting VMT and energy consumption in the three cities. By down-selecting impacting factors, the team designed three specific scenarios to reflect the likely impact of ACES.

The team performed scenario analysis for the target year of 2030 with three scenarios, (1) ridesharing and modal shift, (2) underserved population, and (3) electrification and CAV market adoption. The market adoption variability of CAVs and electric CAVs were estimated based on literature. Ridesharing could save 10–25% energy, but modal shift away from transit can increase energy usage by up to 25%. CAV mobility to an underserved population can result in 4–26% increase in energy across cities; however, increased employment could power economic activity. Third scenario showed that 5–12% reduction for NYS and 4–17% for NYC in energy consumption.

Modal shift away from transit is the most important behavioral parameter that propels the uncertainty in energy and VMT. However, it is very critical to balance encouragement of new and emerging modes of transportation such as CAV without losing the benefits offered by traditional transit such as high-occupancy, lower per passenger energy and VMT. Thus, it is critical for cities to straddle new emerging modes with existing modes towards heralding sustainable transportation.

Overall, there appears to be agreement among the stakeholders that some combination of shared and electric mobility is on the near horizon, and that the timing and potential impacts of the connected and automated components of future mobility involve uncertainties. Furthermore, transportation technology advances will affect typologies of geographic densities differently. Underscoring this is the contextual and cultural differences between locations. Dense urban areas may, for the sake of practicality, be more willing to adopt post-vehicle ownership models of mobility, depending increasingly on shared options and embracing mobility as a service. However, existing high-capacity public transit modes need to be sufficiently used to avoid the increase of energy consumption. Suburban areas may have a more muted interest in shared mobility but may also see AV technologies as enabling them to live more distant from the urban core without sacrificing travel time unproductively; new technologies may actually foster long commutes and increase sprawl. At the far end of the spectrum, rural areas may not anticipate much benefit from shared mobility, at least in its current incarnation. The urban approach to shared mobility doesn't appear to enable reduced private car ownership in the estimation of respondents. However, CAVs may most benefit rural residents, who must more frequently travel greater distances than those in urban or suburban settings.

Due to the current state of advanced technology and mode options, shared mobility followed by zero emission vehicles and connected and automated technologies is the likely sequence of emergence based on surveys and literature from this study. Similarly, people are receptive to shared mobility, as is apparent with the success and rapid proliferation of mobility on-demand services, the potential to achieve improved energy efficiency and productivity of mobility are viable in a near timeframe, allowing time to shift toward more advanced technologies as they become available. However, shared mode occupancy is a key determinant of energy efficiency and traffic congestion that requires data to evaluate the impact of shared modes' proliferation. Also, there is a need to develop approaches tailored to the specifics of geography, location, and culture that differs across the cities included in this research and beyond, and a necessity to acknowledge that one size does not fit all. Other gaps and data requirements may include energy and service utilization data from future CAV pilots from across the State, surveys or interviews with service users, service designers, operators and cross-scale systems planners interested in harnessing



additional data specific to shared, electric, connected, and automated mobility. These data can provide essential behavioral insights into technology and service adoptions for analyzing future pathways to ACES mobility. This feedback could also inform understandings of service adoptions as synergistic and/or conflicting with transit, based on variable densities and other factors. ACES pilots can also explore and provide information on possibilities of public-private partnerships for service deployments, governance, and financial structures that may need to be established for successful scaling up of services.

Building on information about technology adoption and built infrastructure dynamics that are currently measured using readily available data on EV adoption and intersection density, future analyses could further explore correlations in levels of EV ownership with electric utility service areas, municipal policies and investments, and housing and transportation affordability. These factors are likely to continue to strongly influence EV adoption going forward and can be leveraged at many scales to advance energy efficiency and affordability goals.

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# Appendix

**Table A1. Median Socioeconomic Indicators by Typology, Results for Eight Clusters**

Cluster	Household income	Home ownership (%)	HTA index	Age (% over 65)	Gender (% female)	Race (% white)	Education (% college)
A	\$65,491	55%	51	13%	52%	30%	18%
B	\$40,899	18%	31	12%	53%	34%	16%
C	\$43,147	50%	44	16%	52%	74%	16%
D	\$87,640	77%	62	16%	51%	77%	25%
E	\$119,989	32%	45	16%	53%	78%	64%
F	\$142,154	92%	82	17%	51%	83%	40%
G	\$67,594	82%	59	19%	50%	94%	23%
H	\$86,693	36%	43	14%	52%	73%	50%

**Table A2. Median Environmental and Urban form Indicators by Typology, Results for Eight Clusters**

Cluster	Population density	Intersection density	Employment access	PM 2.5 level	Cancer hazard	Respiratory hazard
A	14,992	418	122,786	9.6	57.9	4
B	29,107	500	197,614	9.8	59.7	3.5
C	2,378	184	23,272	8.6	32.5	1.4
D	3,985	227	53,985	9	40.1	2
E	44,278	599	958,897	10	85	5.3
F	2,034	203	48,896	9.1	41.5	2.1
G	390	45	7,537	8.1	24	0.8
H	18,711	438	331,234	9.9	59.5	3.4

**Table A3. Median Mobility and Energy Metrics by Typology, Results for Eight Clusters**

Cluster	Alternative commuters	Vehicles per household	Average fuel economy	EVs/1000 vehicles
A	61%	1.2	23.2	1.4
B	80%	0.7	23.1	1.7
C	27%	1.6	22.7	1.6
D	31%	1.7	23	2.3
E	94%	0.2	22.5	6.6
F	32%	1.9	23	4.3
G	17%	2	22.2	1.9
H	79%	0.7	23.5	2.8

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