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Electrifying Ridehailing: A Cross-sector Research Agenda

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Executive Summary

Electrifying ridehailing services provided by transportation network companies (TNCs; e.g., Uber and Lyft) offers potential benefits to society (reduced climate-altering emissions and air pollution) and TNC drivers (cost savings on vehicle operations with potential for lower total vehicle costs of ownership and thus increased income). Policy levers have emerged to nudge the industry in this direction. California's Senate Bill 1014 establishes a "Clean Miles Standard" requiring an increasing percentage over time of ride-hailing services be provided by zero-emissions vehicles. However, the path to achieving this goal is unclear. This brief presents a research agenda identified by government and industry stakeholders, articulating what they believe are the most important questions to address in order to find the path to TNC electrification. It also highlights which perceived research needs are shared broadly and which differ across government and industry stakeholders to facilitate a shared understanding for better research, policy, and business practices.

Keywords: ZEV (zero emission vehicle), user behaviour, policy, incentive, MaaS (mobility as a service).

1 Introduction

Vehicle electrification is an important strategy in moving toward a more sustainable transportation future, reducing dependence on fossil fuels and reducing greenhouse gas emissions [1-5]. This paper defines electric vehicles (EVs) to include battery electric vehicles (BEVs), powered exclusively by electricity from rechargeable batteries, and plug-in hybrid electric vehicles (PHEVs), which run on gas and/or electricity using a rechargeable battery and an internal combustion engine. Rajagopal and Yang [6] argued that since vehicles used for ridehailing services are driven so many more miles than household vehicles there are commensurately greater social and environmental benefits to reap from transitioning these services to EVs.

Regulations are emerging to shape this transition, such as the 2021 California enacted Senate Bill 1014 [7] to, in part, establish a "clean miles standard" (CMS) requiring an increasing percentage over time of ride-hailing services be provided by zero-emissions vehicles (ZEVs). Though ZEVs include EVs and fuel cell electric vehicles (FCEVs), the focus here is on EVs as there are so few FCEVs on the road in so few places. The CMS set an ambitious goal for TNCs to be operating at 90% electric vehicle miles traveled (eVMT) and 0 g CO_2 per passenger-mile traveled in 2030 (which is essentially 100% eVMT).

Despite emerging regulations nudging the ridehailing industry in this direction, the path to achieving goals for high eVMT is unclear. This brief presents a research agenda identified by government and industry stakeholders, articulating what they believe are the most important questions to address in order to find the

path to TNC electrification. It also highlights which perceived research needs are shared broadly and which differ across government and industry stakeholders to facilitate a shared understanding for better research, policy, and business practices.

2 Literature Review

Achieving TNC electrification is challenging because ridehailing drivers are independent contractors who are responsible for supplying their own vehicle and their uptake of EVs is extremely low. Barriers to EV adoption among TNC drivers include higher EV purchase price relative to comparable internal combustion engine vehicles (ICEVs) and hybrids (HEVs). Prior research has shown that higher-income consumers are more likely to buy EVs [8-10], whereas ridehailing drivers predominantly self-identify as low income [11]. EVs are incentivized by rebates and tax credits at the federal, state, and local levels, although often not at a level that brings them to price parity with comparable gas vehicles, and drivers must still have the capital and/or credit to cover the high upfront costs before applying and waiting to receive rebates and tax credits. Modifications to the federal tax credit made in 2023 and increasing requirements to address equity in ZEV policies may help address this barrier, e.g., the California Clean Vehicle Rebate program now provides higher rebate amounts to low-income households who acquire ZEVs and both it and the revised federal tax credit impose income constraints on eligible households.

From a total costs of ownership (TCO) perspective, high-mileage drivers (like those providing ridehailing services) may reap greater benefits from the lower operating costs of EVs than private vehicle drivers. That is, savings on fuel and maintenance can make up for the higher upfront costs of an EV and enable higher net earnings [12-13]. For example, Taiebat et al. [11] estimated that drivers could achieve a lower TCO with a new BEV with a 250-mile range (BEV250) compared to an ICEV without any subsidy, and all drivers could achieve a lower TCO with a used BEV250. Regarding higher earnings potential, Sanguinett et al. [14] estimated an Uber driver can earn over $10,000 more annually with a Chevy Bolt compared to a Toyota Camry when taking into account operational savings (fuel and maintenance) and the $1 trip bonus Uber is currently offering (assuming about 50,000 annual miles of ridehailing driving, California fuel prices, and home charging). A survey of EV drivers on the Uber platform found that 72% calculated all vehicle costs before acquiring an EV [15]. Taiebat et al. suggested that interventions to inform TNC drivers of the potential TCO savings with EVs will promote a faster transition to TNC electrification.

Driving range, charging infrastructure, and the time it takes to charge may be larger (real and/or perceived) barriers for TNC drivers compared to private vehicle owners because higher mileage means more charging and time away from active driving to charge their EV may erode earnings. Addressing the the issue of range, Taiebat et al. [11] estimated that a fully charged BEV250 could meet the daily driving requirements for more than 86% of Lyft drivers on at least 95% of days. Another recent analysis of TNC trip and public EV charging data in California suggests that TNC-EV drivers in aggregate provide similar numbers of rides over similar distributions of trip distances as drivers of conventional vehicles [16] despite charging their EVs—even multiple times—during a given ride-hailing “shift,” i.e., a single period of driving uninterrupted by an hours-long break to accomplish other activities. The same study found that TNC-EVs are responsible for a disproportionately large share of public DC fast charging infrastructure use, contributing to recommendations for affordable and ubiquitous fast charging infrastructure to support TNC electrification [13, 16].

As this brief literature review demonstrates, research has identified barriers to TNC electrification and proposed solutions. Yet EV uptake among ridehailing drivers remains low. This study asks what further research is needed to understand how policy and business practices can move the needle on TNC electrification. How can we move from theoretical assertions of the potential benefits of electrifying ridehailing to actual awareness, motivation, and ultimately EV uptake among TNC drivers?

3 Methodology

A modified Delphi study was conducted, comprised of two brief online surveys of government and industry stakeholders. Stakeholders were identified through authors’ professional contacts, registration information for attendees at a webinar on the topic of the California Clean Miles Standard, and snowball sampling whereby the initial 59 recruited participants were asked to provide contact information for relevant others at

their respective organizations. For each survey, an initial invitation email was sent followed by up to two reminders targeting individuals who had not completed the survey. Each of the authors handled correspondence with about half of the recruited stakeholders.

The surveys were programmed in Qualtrics software. The first survey consisted of several open-ended questions. The main question asked, "In your professional opinion, what is the most important question that needs to be addressed to facilitate the electrification of TNCs, and why?" In a subsequent question, stakehoders were asked to list any other questions or topics they felt were important. There was also place to enter a website url or description of any relevant organizational resources that articulated research needs for TNC electrification. Finally, stakeholders were asked to describe their organizational role as it related to TNC electrification (e.g., ZEV implementation, emissions modelling).

Open-ended responses about research priorities in the first survey were compiled, thematically organized, and synthesized into a set of broad research questions with examples. Both authors reviewed all data and collaborated on the coding. Only codes appearing in responses to the main survey question ("What is the most important question that needs to be addressed to facilitate the electrification of TNCs, and why?") were used to develop the emergent research priorities. Responses to the follow-up question about other important topics were also coded, but were used to enhance clarity on the topics emergent in response to the main question.

These research questions were presented in the second survey and stakeholders were asked to rank them all from highest to lowest priority to facilitate TNC electrification. The programmed question format allowed respondents to drag and drop the research questions into their ranked order. Each research question was accompanied by an open-ended comment box where respondents were invited to describe what they felt was most important about each question. A subsequent open-ended question asked stakeholders if they felt they were able to accurately articulate what they viewed as the top TNC electrification research priorities through the ranking exercise, and if not, what difficulties or limitations they encountered. Survey programming logic was used to display the question about respondent's organizational role only to those who had not completed the first survey. Analysis of the second Delphi survey focused on stakeholder rankings of the identified questions and then a deeper dive into their comments on the top-ranking questions.

There were 19 respondents to the first survey and 25 to the second; thirteen stakeholders completed both surveys. Among the 31 unique respondents across the two surveys, government organizations represented included: California Air Resources Board (12 respondents), US Environmental Protection Agency (4), California Department of Transportation (3), California regional air quality management districts (2), and a national research laboratory (1). No representatives from city governments participated. Industry organizations represented included Uber and Lyft (4) and three vehicle OEMs (4). One stakeholder from a global non-proft foundation participated in the first survey but not the second.

4 Results and Discussion

This section presents results from the first Delphi survey (synthesis of research questions) followed by results of the second survey (ranking of research questions). As this is a paper about developoing a research agenda, rather than listing ideas for possible further research at the end, we state potential specific research topics flowing from these questions throughout these results and discussion.

4.1 Synthesis of Priority Research Questions

Analysis of responses to the main question in the first Delphi survey yielded six research questions. The six questions and examples synthesized from participant responses were presented in the second survey for the ranking exercise as follows:

- **How can the EV value proposition for TNC drivers be improved to reach (or exceed) cost parity with gasoline vehicles in most circumstances?** For example, what incentive schemes and vehicle acquisition/use models would make EVs the more economic choice for TNC drivers, including those with low income and either poor credit history or lacking sufficient credit history?

- **What are the infrastructure needs to support TNC electrification?** For example, how should supportive infrastructure programs prioritize home v. public charging and geographic distribution/strategic location of public charging? What are potential issues and strategies related to competition between private EV drivers and TNC drivers for shared infrastructure and coordinated use of dedicated infrastructure among TNC drivers? What are the needs and potential solutions for communicating information about charging availability and compensating drivers for charging time?
- **What are TNC drivers' perceived barriers (beyond objective costs and charging availability) to acceptance of EVs and how can they be addressed?** For example, if the value proposition for EVs is made competitive, (how) will drivers become aware of this, since TCO is complex to calculate? What is the prevalence and impact of range anxiety on drivers' propensity to adopt EVs? What is the impact of driver perceptions of charging availability and charging preferences?
- **What will be the impacts of TNC electrification on the landscape of ride-hailing services and what are solutions to address negative impacts?** For example, will there be less availability of services overall (due to fewer drivers, and/or fewer driving hours), different distribution of service availability (in terms of geography and/or time of day), and/or different pricing? What will be the impact on underserved communities (e.g., changes in service availability where EV and/or charging access is more limited) and potential solutions?
- **What role might TNC customers play in the transition to electrification?** For example, to what degree will customers accept EVs for ride-hailing services? What are the barriers (e.g., range anxiety)? Could consumer demand be leveraged to further incentivize TNC electrification?
- **What are the impacts of changing electric vehicle technology?** For example, how would increased EV range, more diverse EV body styles, and lower prices change the impacts of TNC electrification?

There are two important notes about the research priorities identified via analysis of the first Delphi survey. The first is that there was a prevalent theme of equity considerations, which the authors chose to interweave within the six priority research questions rather than making equity a separate topic. The reason for this is that equity was referenced in relation to several of the six identified topics rather than discussed more broadly. However, one stakeholder suggested in the second Delphi survey that the topic may have been underrepresented in the six priorities, "Yes [I was generally able to articulate what I feel are the top research needs], but [I] also wanted to include the importance of disadvantaged and low-income communities and assuring that these communities are benefiting from any TNC electrification."

The other caveat is that, in the second Delphi survey, several stakeholders noted the absence of a question about identifying environmental impacts of TNC electrification. This topic was mentioned several times in the "other important topics" question in the first survey, but nobody mentioned it in the main question asking for the top research priority. Although analyses documenting the potential for reduced greenhouse gas emissions through TNC electrification informed the premise of this research, as one stakeholder summarized, "Those questions and analyses [about energy and emissions implications of electrifying TNCs] remain critical as underpinnings to policy decisions."

4.2 Rankings and Further Analysis of Priority Research Questions

Figure 1 shows the order of priorities for each stakeholder group and the total sample, based on average ranks. Improving the value proposition of EVs for TNC drivers, understanding drivers' perceived barriers, and identifying infrastructure needs were the top three priorities for both groups. Taking another angle of analysis, Figure 2 shows the percentage of each stakeholder group, and of the total sample, that ranked each research question top priority.

Government	Industry	All
Drivers' Perceived Barriers	Value Proposition	Value Proposition

Value Proposition	Infrastructure Needs	Drivers' Perceived Barriers
Infrastructure Needs	Drivers' Perceived Barriers	Infrastructure Needs
Impacts of Evolving Vehicle Technology	Impacts of Evolving Vehicle Technology	Impacts of Evolving Vehicle Technology
Role of TNC Customers	Impacts on TNC Services	Impacts on TNC Services
Impacts on TNC Services	Role of TNC Customers	Role of TNC Customers

Figure 1: Order of research priorities, highest to lowest, for each stakeholder group

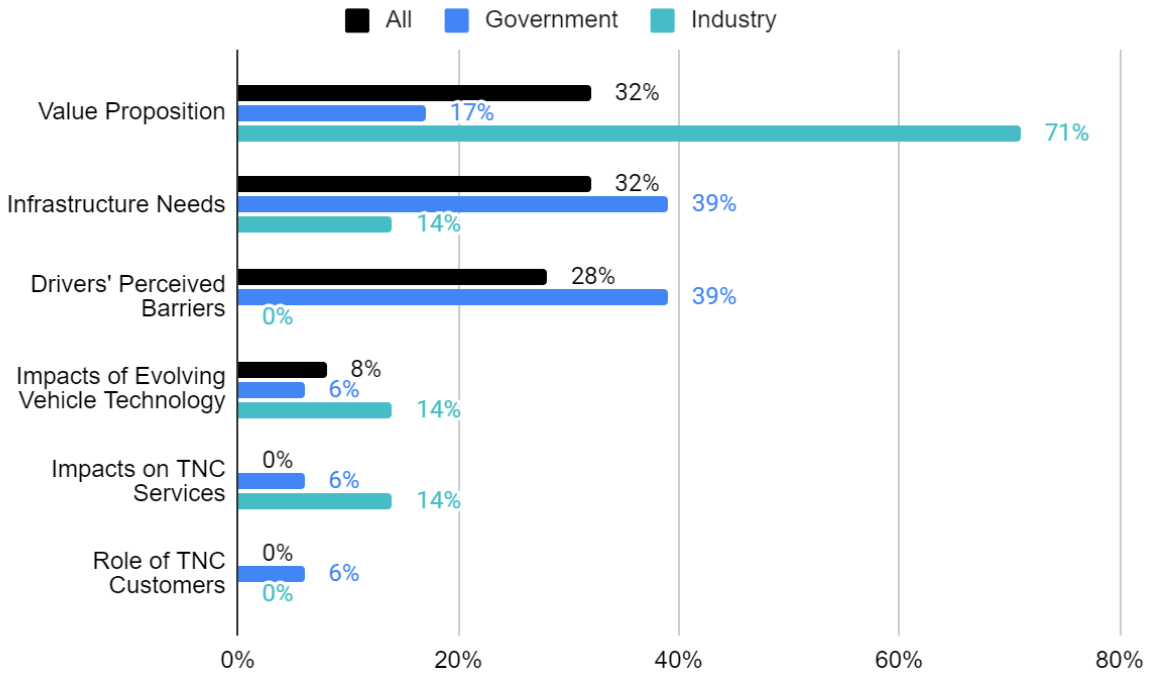

Figure 2: Percentage of each stakeholder group that ranked each research question top priority

Although the same few research priorities rose to the top of the list for both stakeholder groups, there were stark differences in terms of which topics each group selected as the #1 priority. Specifically, industry stakeholders overwhelmingly pushed the importance of improving the value proposition of PEVs for TNC drivers to their highest level of interest and none felt that understanding drivers' *perceived* barriers was the top priority. Perhaps industry representatives feel they already have a reasonable understanding of TNC drivers' needs and perspectives. In contrast, far more government stakeholders ranked driver-perceived barriers or charging infrastructure needs as number one. Perhaps government stakeholders emphasized value proposition less because they already invested heavily in incentive programs and are more interested in other possible strategies. Stakeholder group members also seemed to rank topics that fall more within their organizations' sphere of control as #1. For example, TNCs have some power to alter the value proposition for their drivers to promote EVs (e.g., through driver bonuses and preferential dispatch algorithms), whereas goveremental agencies are in a better position to implement large-scale charging infrastructure solutions.

4.2.1 Improve Value Proposition

The top research priority identified by industry stakeholders (and second priority for government stakeholders) was to investigate how EVs can reach (or exceed) cost parity with gasoline vehicles for TNC drivers, e.g., identify incentive schemes and affordable vehicle acquisition/use models. Open-ended comments about the most important aspects of this research priority included speculations about useful

acquisitions/use models that could be (further) evaluated. For example, one stakeholder observed, “Low cost EV rentals can be a starting point… Used EVs priced at comparable ICE used vehicle prices can also be mechanism for TNC drivers to purchase a used EV rather than a used ICE vehicle.” Another highlighted the need to prioritize potential solutions: “Given the limited incentive budget, what's the best way to use that budget to increase eVMT? For example, higher driver earning (higher $/hr) vs vehicle cost discount vs rental cost discount?” Focus groups and stated preference studies with TNC drivers could be useful in the short-term to help guide programs that could be evaluated and compared.

Several stakeholders explicitly stressed the role of TNCs in improving the value proposition for their drivers; as one government stakeholder noted, “It's difficult to imagine any solution for this that doesn't go through TNCs paying drivers more, although it is unlikely electrification will emerge as a large enough priority to make this happen.” Another advised more specifically to study EV acquisition/use “schemes where the TNC ([working] with vehicle providers) offers EVs to the drivers under a reduced rate rental or purchase program.” Another mentioned the concept of EV driver bonuses: “Drivers operating EVs need to be compensated for taking a risk and operating a new technology. Whether per-ride or per-week, this needs to be enticing.” Research endeavors in partnership with TNCs willing to experiment with such programs could help build best practices.

Some open-ended comments simply conveyed why helping to improve the value proposition was ranked as a top research priority, e.g.: “It's clear that cost is one of the biggest barriers that TNC drivers face”; “Solving the value proposition issue is the most critical issue that must be addressed in order to move from <1% EV penetration among TNC drivers.” However, some also noted important dependencies among this and other (also high-ranking) research priorities. One stakeholder observed, “Though you're rightly separating the value proposition and perceived barriers in your questions, I nevertheless feel like these two questions are important companions.” Others indicated the importance of solving infrastructure challenges and vehicle range limitations first or in tandem with improving value proposition; regarding the former: “Outside of drivers with overnight charging access, EVs do not make financial sense for drivers,” and the latter: “Competition with private ICE vehicles is distorted as long as EVs are more expensive and come with less range.”

Some stakeholders noted that charging costs, both in terms of money and potentially time taken away from shifts, should be factored into considerations of value proposition and cost parity. For example, one observed, “Cost of charging could be a variable depending on region and if driver[s] could charge at home.” Another noted, “A key aspect of [driver bonuses] will need to include some form of compensation to account for recharging time.” Other research needs highlighted under this topic included “understanding effective incentives for various types of TNC drivers (depending on income, location (urban/rural/disadvantaged communities)” (this could also include drivers with v. without overnight charging access).

4.2.2 Understand Drivers’ Perceived Barriers

Understanding TNC drivers’ perceived barriers to EV adoption was the top ranked priority among government stakeholders. Although no industry stakeholders ranked this the number one priority, it came in third in their rankings. Open-ended comments further emphasized that drivers’ perceptions are key considerations beyond the important issues of cost parity and available infrastructure that might be the focus of a strictly economic approach to promoting TNC electrification. One stakeholder explained, “Theoretical adoption at TCO parity is not aligned with real-world adoption” for reasons including the barrier of higher upfront costs even under conditions of favorable TCO. Another stakeholder implied the importance of investigating drivers’ perceptions regarding charging: “Uncertainties around charging availability, access, and consistency (e.g., speed and price) seem like they might be predecessors of range anxiety and the TCO calculation.” In addition to describing these more psychosocial factors, research on this topic can help weigh their relative importance, e.g., “Is affordability more important than range/recharging availability?”

Stakeholders also discussed how research on drivers’ perceived barriers can help inform solutions, e.g., “Perceptions of cost, charging availability and charging preferences are important to understand in order to influence and encourage TNC drivers to accept EVs”. Specific types of strategies suggested included education: “TNC drivers' perceived barriers can be range anxiety, being unfamiliar to the technology, unaware of maintenance issues since ICE vehicles have different maintenance needs, and the ability for the vehicle to accept high power charge to gain the needed range to complete a day as a TNC driver. These can

addressed with driver training in EVs, education and awareness, and technology advancement for vehicles to gain back more range when charging in fewer minutes." These comments suggest a need for applied research and program evaluation to articulate best practices for awareness campaigns and educational programs.

The role of TNCs in implementing solutions was mentioned again under this topic: "I think the TNC companies can be very helpful in providing prospective drivers with TCOs for various models"; "Additional communication could include socializing EV driver incomes (if they are higher)." Partnerships with TNCs could support focus groups and stated preference studies to inform innovative driver awareness and education programs, with applied research to evaluate and compare their effectiveness.

4.2.3 Identify Infrastructure Needs

Industry and government stakeholders ranked identifying infrastructure needs as their second and third most important research priority, respectively, based on average rankings. However, more government (39%) than industry (14%) stakeholders ranked it as the top priority. Most questions raised in the open-ended comments under this topic pertained to shared, public infrastructure. As one stakeholder advocated, "Let's maximize synergies!" This stakeholder also observed, "We may want to prioritize public charging instead of home if the low-VMT future includes shared, autonomous vehicles." This approach is interesting to consider juxtaposed with a comment related to the value proposition priority: "Outside of drivers with overnight charging access, EVs do not make financial sense for drivers." More research investigating the degree to which building up high-speed public charging infrastructure could substitute for the convenience and efficiency of home charging, such as the recent work of Moniot et al. [17], could be valuable.

Questions about shared, public charging included: "What are the needs…level(s), where, how many, etc.?" and, "To what extent might TNC charging needs be different from private EV ownership charging requirements and are infrastructure planners taking these differing needs into account?" "Queue management between TNC drivers and EV drivers in the general public" was also noted as important, but perhaps not a research need: "TNC companies desire limited queues for their drivers while charging companies desire high utilization but limited queues. The private sector is correctly incented to figure this one out." Another mentioned a possible solution involving "reduced charging rates in off-peak hours, not unlike how Tesla manages queueing at Superchargers during peak times."

The idea of dedicated charging for ridehailing vehicles and other high-mileage vehicles (e.g., e-commerce, food delivery) also came up several times. While some posed this as a question [e.g., "Key question: charging location types (distributed? clustered? public? TNC-company-provided?")], one stakeholder declared that "chargepoints should be acessible for all EV users. Dedicated chargepoints are inefficient." Research modelling the utility of dedicated chargepoints v. priority access for ecommerce and gig drivers under various conditions could be helpful.

The importance of understanding drivers' perceived barriers, needs, and differences with regard to infrastructure was another theme in stakeholders' notes, e.g., "[It's] important to understand what will motivate potential TNC drivers to adopt EVs in terms of refueling. It depends on where they live and where they intend to provide TNC service (availability of charging from home base and at general destination) as well as income level and EV range (trade-offs with EV costs, range, charging time)." Regarding the importance of driver perceptions, one stakeholder mentioned that "resolving uncertainty" related to charging infrastructure is an important aspect of this research priority. Relatedly, another wondered, "[Is] high visibility charging a 'need'?" Some assumed it will be necessary to "compensate drivers during charging time or [provide] charging as an amenity and[/or provide] amenities for those who are charging (amenities specific to the needs of drivers)." Relatedly, another stakeholder called for research to understand "overall time to get charged including travel, waiting, and charging." Recent research by Kurani and Sanguinetti [18] addresses some of these issues.

In addition to raising questions, some stakeholders proposed solutions and one who felt this topic was not a high priority mentioned that "much is known already about the type of infrastructure needs for TNC drivers." Proposed solutions included notes on chargepoint locations and density: "Availability of charging infrastructure being comparable to the availability of gas stations can be beneficial to the expansion of EV adoption. Charging stations in rural areas could be more inclusive so drivers do not need to lose there range when going to find charging. Charging hubs in areas where TNC services are high can be useful as drivers

can park, recharge, and get to riders easily." Solutions also advised on optimal chargepoint speeds: "Reliable on-street AC (alternating current); HPDC (high-power direct current) at highly frequented spots"; "Robust expansion of DCFC (direct current fast charging) access for drivers will be needed in all metropolitan areas, even for fleets with overnight charging access. Colder climates will require greater access to DCFC vehicles." Further research on this topic should build on existing knowledge and pinpoint unanswered questions specific to the infrastructure needs of TNC drivers.

Once again, stakeholders explicitly called out the role of TNCs in providing solutions related to this research priority. For example, one called for "strategies/business models to ensure charging availability for drivers, particularly if the TNC is encouraging/incentivizing electrification—how are they supporting its use?" Another considered, with regard to queue management, "TNC's could play a large role if charging is coordinated / if fleets gain access to telematics streams."

4.3 Limitations

The open-ended comments in the second Delphi survey, which formed the basis of much of the analysis presented in this paper, were likely biased toward the government stakeholder perspective. There were only seven industry stakeholders who participated in the second survey, and only three of these were representing TNCs (the other four represented vehicle OEMs). This could partially explain the greater focus on what TNCs need to do to support electrification of ridehailing services, which was a theme across open-ended comments discussing each of the top three research priorities. Future work should be sure that equal attention is given to the role of government in advancing TNC electrification, such as improving incentive schemes given the importance of increasing the value proposition of EVs for TNC drivers.

It is also important to note that the stakeholders contributing to this research agenda may not have access to academic research relevant to these topics. Efforts to further develop this research agenda could include comparing the high priority topics to existing literature to identify specific gaps. Another way of interpreting the findings is that any existing research on the identified high priority topics has not reached these stakeholders or has not been sufficiently applicable. This could suggest the need for better dissemination strategies to make the research more accessible and useful to stakeholders. Another opportunity to build on this research is to include input from additional stakeholder groups, such as advocacy organizations and EV charger companies.

5 Conclusion

The research priorities identified in this study can be integrated into calls for research grant proposals, and the rankings can help grant program administrators determine which topics to include. For example, it could be strategic to prioritize research on the three top-ranking questions: Improving the value proposition of PEVs for TNC drivers, understanding drivers' perceived barriers, and identifying infrastructure needs. Future research on any of these topics should be informed by and build upon existing literature, and outreach efforts to disseminate findings to key stakeholder groups should be a requirement of research grants.

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Presenter Biography

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