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On-demand automotive fleet electrification can catalyze global transportation decarbonization and smart urban mobility

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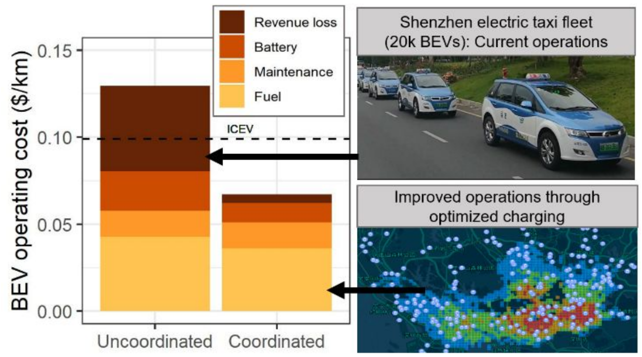
Abstract: Mobility on-demand vehicle (MODV) services have grown explosively in recent years, threatening targets for local air pollution and global carbon emissions. Despite evidence that on-demand automotive fleets are ripe for electrification, adoption of battery electric vehicles (BEVs) in fleet applications has been hindered by lack of charging infrastructure and long charging times. Recent research on electrification programs in Chinese megacities suggests that top-down policy targets can spur investment in charging infrastructure, while intelligent charging coordination can greatly reduce requirements for battery range and infrastructure, as well as revenue losses due to time spent charging. Such capability may require labor policy reform to allow fleet operators to manage their drivers' charging behavior, along with collection and integration of several key datasets including: 1) vehicle trajectories and energy consumption, 2) charging infrastructure installation costs, and 3) real-time charging station availability. In turn, digitization enabled by fleet electrification holds the potential to enable a host of smart urban mobility strategies, including integration of public transit with innovative transportation systems and emission-based pricing policies.



Main text: With the advent of smartphone-based transportation network companies (TNCs, also known as ridesourcing and ridehailing),[i] e-Hail for taxis, and microtransit,[ii,1] mobility on-demand vehicle (MODV) services have become an important component of urban transportation, resulting in decreased public transit ridership, increased vehicle kilometers traveled (VKT), and increased greenhouse gas emissions.[2,3] Although MODV fleets currently represent only a few percent of passenger travel worldwide, the sector has experienced explosive growth in recent years;[4] in some emerging economies with low labor costs such as India and South Africa, these services already represent over 10% of VKT. In several megacities in emerging economies, MODV services represent over one third of VKT (see supporting information for sources and calculations). With urban areas expected to add 2.5 billion people by 2050, urban sustainability will be a defining challenge of the 21st century, and MODV services will represent a key element.[5] A growing number of forecasts predict the global market for MODV services will increase dramatically, in some estimates three-fold by 2030,[6] while others argue that the advent of automated vehicles (AVs) will lead these services to dominate the global transportation market.[7,8] While the ongoing COVID-19 pandemic has drastically reduced MODV ridership, this trend has been partially offset by increases in demand for delivery services,[9] and ridership will likely rebound as the pandemic subsides. Without rapid decarbonization, the corresponding growth in transportation emissions could easily offset carbon reductions in other sectors, putting the Paris Climate Agreement's 2°C and 1.5°C targets[10] out of reach.[11]

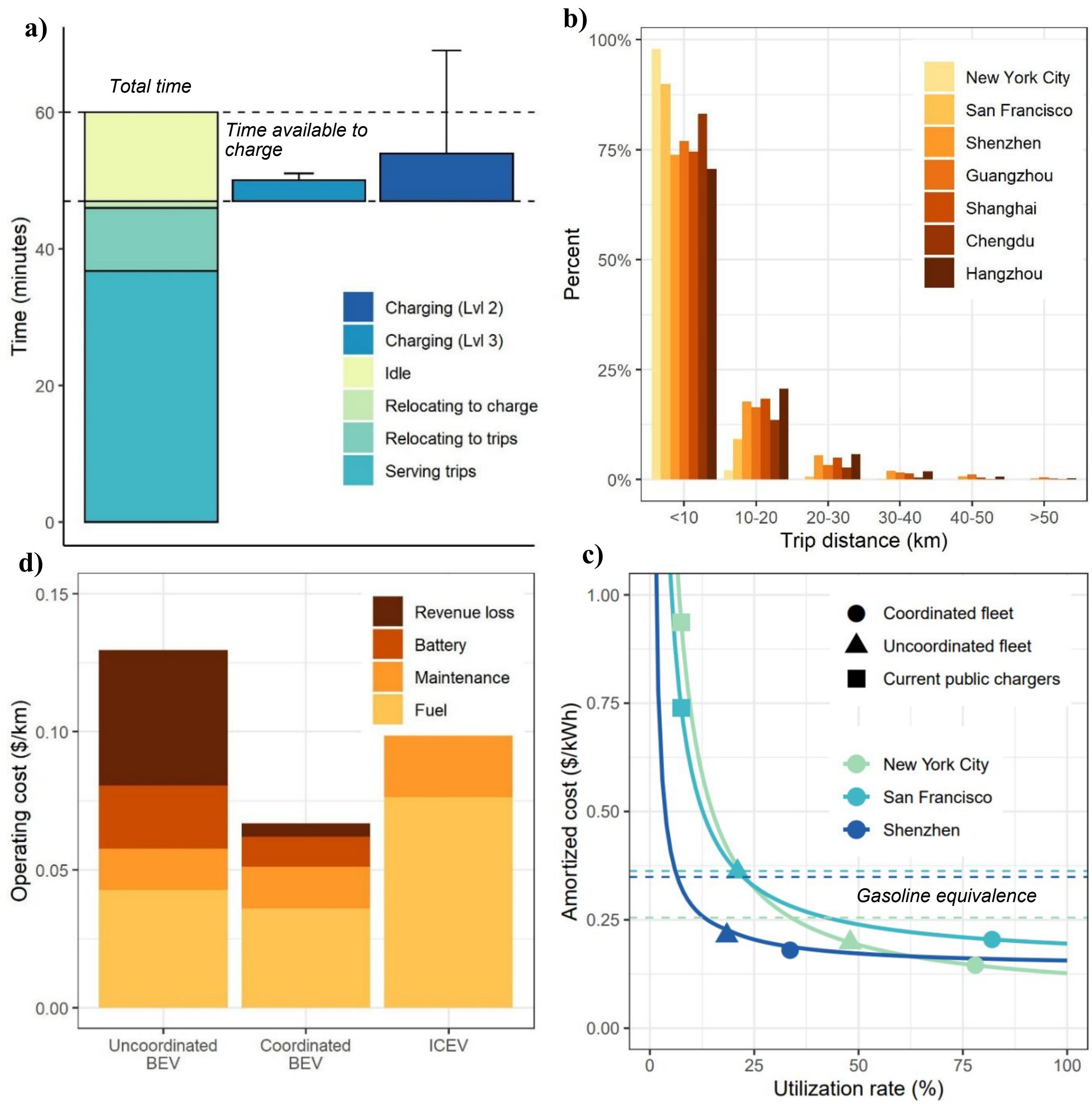


Figure 1. Clockwise from top left: a) distribution of time spent by an average New York City (NYC) ridesourcing driver.[12,13] We assume a vehicle energy consumption of 0.17 kWh/km, equivalent to the performance of the 2018 Chevrolet Bolt.[14] For relocating to charge, we assume one charging session per eight-hour shift and an average relocation distance of 4 km at a speed of 16 km/hour. b) Distribution of taxi trip distances in cities in the United States (U.S.) and China (data provided to authors by city governments of respective cities). c) Relationship between the total cost of charging infrastructure (capital cost, electricity, and demand charges) and percent utilization by time, along with the impact of fleet coordination.[12,15,16] Note that these costs only include the cost of electricity and charger installation, not the opportunity cost of queuing and charging; the reduction of the cost of charging with coordination is due to the reduced quantity of chargers needed. d) Operating cost by vehicle type and fleet coordination based on cost estimates in Shenzhen. We use cost parameters from Bauer et al. (2018),[17] and we assume battery lifetime of 1,500 cycles when uncoordinated, and 3,750 cycles when coordinated, based on authors' review of battery degradation literature. We assume that vehicles must be replaced at 80% of original capacity when uncoordinated, and at 50% when coordinated, as found in Bauer et al. (2018).[17] Revenue lost due to charging is based on Bauer et al. (2020), and includes the opportunity cost from time spent both queuing and charging.[18,19] In both c) and d), we assume an annual discount rate of 5%. See supporting materials for more details on calculations and assumptions.

Previous studies have suggested that MODVs represent a ripe market for the adoption of battery electric vehicles (BEVs). Vehicles used for commercial mobility services accumulate VKT more quickly than vehicles used for personal purposes only, resulting in larger potential operational cost savings, while providing faster reductions in carbon emissions.[20,21] Range anxiety and slow charging speeds have hindered BEV adoption in the personal vehicle market,[22,23] but these barriers can be overcome more easily in commercial sectors.

As shown in Figure 1b, less than 0.5% of taxi trips are over 50 km in a variety of cities, and previous studies have shown that BEV fleets could serve present-day mobility demand in dense urban areas with less than 160 km of battery range.[17] As shown in Figure 1a, MODVs often spend over 25% of their time idle while waiting for trips,[12] suggesting that if this downtime could be harnessed effectively, drivers would have plenty of time to charge. Given that these vehicles are typically driven in urban cores, BEV fleets could also more effectively reduce air pollution, especially in lower-income communities where private BEVs may remain prohibitively expensive for many years.[24]

One factor that complicates MODV electrification is that some companies – mainly TNCs – do not own and operate their vehicles but rather operate a software-based marketplace where drivers working as independent contractors provide mobility services to consumers requesting rides. However, as we discuss below, many of the same opportunities, barriers, and policy needs apply to TNCs as well.

Electrification of the MODV sector also presents an opportunity for large potential spill-over benefits for other areas of sustainability. MODV electrification would expose many consumers to BEV technology and spur investment in charging infrastructure for those without access to home charging (especially common in low-income areas), both of which would likely broaden the market for private BEVs.[25,26] While MODV charging could exacerbate peak electricity loads, coordinated charging could eliminate peak-load growth, spreading charging to hours of the day when electricity is cheaper and/or underused.[27,28] Individual charging stations can also moderate power supply to vehicles to align with grid capacity. Furthermore, as we describe in detail below, MODV electrification can facilitate the collection and analysis of vehicle trajectory data to inform the design, integration and operation of innovative mobility services, including bus rapid transit, shared micromobility (bike and scooter sharing platforms), and partnerships between MODVs and existing public transit service. Beyond its application to transportation innovation and policy, this vehicle trajectory data may also become an important tool to enable contact tracing in the fight against the COVID-19 pandemic.

MODV electrification lacks adequate policy support

Despite such high stakes and promising opportunities, in most areas MODV electrification lags even the slow pace of private-vehicle electrification. While many major TNC companies have announced initiatives to promote electrification, most goals amount to electrifying less than 5% of operations.[29] In addition, several previous efforts at electrification have returned poor results, often citing lack of high-voltage charging infrastructure (also known as Level 3 or DC Fast Charge) as a major barrier. In a London pilot project, Uber found that over 80% of BEV drivers lacked access to home charging, and insufficient public infrastructure prevented drivers from serving as many rides as they could with internal combustion engine vehicles (ICEVs).[30] In India, the TNC company Ola launched a highly publicized pilot with BEVs in the city of Nagpur but ended the project prematurely due to driver strikes arising from long queues at charging stations and lost revenue.[31] In both Stockholm[32] and San Francisco,[33] drivers have reported declining rides because their vehicles lacked sufficient charge as well as revenue losses owing to time spent charging and looking for charging stations.

Current understanding is that fast-charging infrastructure is prohibitively expensive to build and operate without high levels of public subsidy, but the truth is more complex. Because cost is dominated by installation and demand charges, it is highly dependent on usage rates: as usage increases, the per-energy cost decreases exponentially. As shown in Figure 1c, the amortized cost of charging at public fast-charging stations in the U.S. costs over twice as much as gasoline because usage rates are very low; private BEV owners typically charge at home and only use fast-charging stations in emergency situations or on rare long-distance trips. In contrast, BEV fleets need to use fast chargers in urban areas daily and are available to charge in between trips throughout the day. Studies have shown that even use by unmanaged fleets could drive costs below that of gasoline;[34,35] coordinated charging could reduce costs even further.[12]

Even with sufficient charging infrastructure, MODV services may not electrify without additional policy support. Drivers are typically responsible for fuel expenses, leading to a principal-agent problem (i.e., the actor able to solve a problem and the actor affected by the problem are separate entities)[36] as the service operator is much better equipped to facilitate electrification. In many places, fuel costs represent less than 10% of driver earnings, and studies have shown that consumers tend to undervalue savings from efficiency,[37] such that drivers may not prioritize efficiency over other factors (e.g., comfort and style) when choosing a vehicle. Prior to updated regulation in 2009, NYC taxis had an average gasoline fuel economy of 15 miles per gallon (16 L/100 km), much lower than the nationwide average. Even today, though the total cost of ownership of hybrid vehicles is lower than that for gasoline vehicles, only 60% of the taxi fleet in NYC is hybrid, and less than 20% of TNC vehicles.[38]

Both these trends point to the need for policymakers to set firm targets for MODV electrification. Without BEV demand for fast chargers in the urban core, it is not surprising that a lack of infrastructure remains a problem. But if charging operators have confidence in high levels of demand, private companies will invest in infrastructure, resulting in sufficient supply. As shown in Figure 1, high levels of usage from BEV fleets enables charging operators to make a return on their investment, spurring further investment.

Electrification trends in China provide a model for how this can work in practice. Mandates on bus and taxi fleet electrification in Shenzhen, China spurred heavy investment in charging infrastructure, resulting in over 12,000 fast-charge points spread across the city within five years, owned and operated by over 10 different private companies.[15] Electrification mandates for buses and taxis in several Chinese cities have already electrified billions of kilometers, suggesting such policy represents a viable pathway to rapid electrification at scale (see supporting information for more details).

Incentives and pricing play an important role in accelerating adoption of BEVs and installation of charging infrastructure. The city government in Shenzhen and the Chinese national government provided subsidies for charging stations amounting to 30% of installation cost.[15] However, subsidies for charging stations and vehicles do not guarantee adoption, and no level of subsidy is sufficient without demand. For example, analysis of current incentives in the U.S. showed that every US$1,000 of monetary incentive has increased BEV sales by less than 3%, equivalent to a cost of over US$30,000 per additional sale.[39] While incentives will likely be necessary to reward early actors and compensate them for risk, they cannot replace firm electrification targets. One possible strategy would be to combine incentives with targets through a credit-trading scheme, as employed with fuel economy standards for private vehicles in the U.S. and elsewhere.

Cities in other regions have now also set electrification targets, including London, Amsterdam, and Oslo. California has set a timeline to set target reductions in TNC emission intensity,[40] and India has announced a ban on sales of new fossil-fuel vehicles for use in commercial fleets after 2026 (see supporting information for a summary of MODV electrification policies in place worldwide).[41] These governments should look to China for lessons on how to electrify quickly, as well as learn from past mistakes.

The Chinese political context enables rapid policy implementation, and electrification will likely proceed more slowly in other regions. Most of the same challenges and policy recommendations still apply, but a more gradual transition introduces another barrier related to driver equity. When all vehicles are electric, they will need the same amount of downtime to charge, and so have the same opportunity to earn revenue. In contrast, while there are some ICEVs remaining, they may earn more revenue than BEVs that must go to charge. As such, it is likely that TNC companies will need to cross-subsidize BEV vehicles, or schedule charging sessions more carefully.

On the other hand, a more gradual electrification timeline offers the advantage of allowing drivers to opt in based on how amenable their driving habits are to electrification; e.g., those who drive full-time and those who lease vehicles specifically for TNC driving will be likely to adopt a BEV before part-time drivers and those who use their own vehicle. Furthermore, while TNC driving is largely concentrated in urban areas, there are also TNC operations in lower density areas, which may prove more difficult to electrify due to the larger requirement for charging infrastructure; these operations can be given lower priority.

Figure 2. Taxis waiting to charge at Minle station in Shenzhen on July 30, 2019. As shown in the inset, at the same time there were over 100 taxis waiting to charge, a popular charging app by automaker BYD showed 49 available charging ports, suggesting that vehicle data may be necessary to provide real-time charging availability. Minle station is the largest charging station in the world, with over 500 fast chargers,[42] and drivers see it as more reliable than other smaller stations, leading to disparities in usage rates and long queuing times.

Coordinated charging enables effective electrification

While important, adequate infrastructure supply does not ensure efficient charging operations. As shown in Figure 2, taxis in Shenzhen often wait over 30 minutes to enter charging stations, despite real-time charging apps that show plenty of availability. Downtime for charging currently costs drivers US$15/day, more than the cost of electricity itself. A few large charging stations receive a disproportionate share of charging demand, while most other charging stations are not economically viable.

Bauer et al. (2020)[18,19] showed that this inefficiency is largely due to a lack of data: without proper information on the best places and times to charge, drivers tend to charge at large stations right before they end their shifts, during afternoon peak demand. The authors found that providing drivers with complete information including forecasts of trip demand could reduce revenue losses by up to 90%, and even just providing accurate information on queues at each charging station could reduce overall queuing time by half. As shown in Figure 1d, the combined cost reductions of fleet management in Shenzhen could reduce operating costs by almost 50%, from 130% of the cost of ICEVs to 66%. See supporting information for more details.

Whether to coordinate shift changes and minimize downtime for charging, or to minimize battery range requirements, data are essential. To ensure electrification programs succeed, governments need to start building public data platforms to host several critical datasets, including vehicle trajectories, charging station availability and location, and potential charging location costs.

In the planning stage, charging companies should have access to aggregated vehicle trajectory data and grid capacity availability data from power grid operators to predict optimal station locations. Charging companies currently waste significant resources searching for the best sites for charging stations; many studies have developed methods to optimize the siting of charging stations,[43–46] but all require data for proper implementation. In the operational stage, charging station status (i.e., number of plugs available and occupied and estimated time until free) should be aggregated across operators and integrated with vehicle trajectories to provide drivers with an accurate measure of expected wait time at each charging station. Public agencies should also actively monitor charging behavior to identify context-dependent barriers, such as those found in Shenzhen. In the longer term, such data can enable MODV service operators to provide drivers with recommendations for where and when to charge, minimizing electricity prices and grid capacity constraints, downtime for charging, and requirements for battery range. Note that coordinated charging does not require the fleet to be operated by a single company with monopoly power; as long as all operators and drivers have the data necessary to forecast total trip demand and charging availability, several operators working independently could still conduct their own operations more efficiently.

MODV service operators rarely give up data easily,[47] but electrification targets provide a powerful justification for data transparency. In Shenzhen, BEV incentives were tied to providing vehicle trajectory data as part of a broader modernization effort, and in California, the state government successfully requested vehicle trajectory and trip data from TNCs to establish a carbon footprint baseline.[48] These strategies suggest that not only can smart data policy enable electrification, but electrification policy may facilitate mobility data collection as well. Another option could include offering subsidized BEV leases for vehicles equipped to transmit data.

But acquiring data is not enough; policy must also ensure that this data is accessible to key stakeholders, including charging infrastructure developers and operators, along with third-party software developers providing services for efficient fleet operation. While real privacy concerns exist, fleet data is also much less sensitive than data from personal vehicles, and data can be aggregated to the intersection or census tract level to ensure anonymity without reducing benefits. Another possibility would be increasing consumers' access to their data and notification of data collection, as mandated by the European Union's General Data Protection Regulation.[49] Several cities around the globe already collect TNC trip data (e.g., Toronto, Mexico City, Sao Paolo), in some cases also publishing parts of it publicly (e.g., Chicago, NYC);[50] it is not hard to imagine expanding these existing regulations to aid charging infrastructure development and operation.

Labor regulation must incentivize efficient operation

MODV companies have increasingly relied on treating their drivers as independent contractors to minimize labor costs, which means they have a strong incentive to refrain from interfering with how their drivers perform their work.[51] For example, directing drivers to charge at times with relatively low trip demand or collecting data on vehicle state of charge could violate the independent contractor relationship, exposing service operators to legal action. Depending on the implementation strategy, there could be ways to circumvent these risks (e.g., only providing drivers with information on charger availability and forecasted demand), but such complications add another barrier to effective MODV electrification.

Policymakers should reform these policies to increase certainty in the relationship between MODV companies and their drivers. In September 2019, California passed a law[52] that requires TNC and taxi drivers to be treated as standard employees, thus eliminating any uncertainty. An under-appreciated consequence of the law (still under dispute) is that TNCs will now be allowed to direct drivers in between trips, as well as own and maintain vehicles in the same way as other fleet operators. While other strategies exist, this law could serve as a template for other governments around the world seeking to promote both labor equity and MODV decarbonization.

Leveraging fleet electrification for smart urban mobility

Once real-time MODV data become available, its value extends far beyond electrification itself. By shedding light on where people want to go, vehicle trajectory data can enable cities to start integrating MODV operations with innovative mobility services, such as bus rapid transit, bikesharing, and scooter sharing. Present-day public transit systems are designed to provide access to passengers arriving by foot or bike, making it challenging to integrate with vehicle fleets, but future systems could locate stations near highway on-ramps and parking lots to optimize such integration. Areas with a high density of on-demand trips may be better-served by vanpools, while areas with many short trips would be ideal for bike and scooter placement. Private companies have access to such data but have little incentive to reduce energy consumption or congestion. Figure 3 summarizes the linkages among policy levers, direct and indirect impacts, and outcomes.

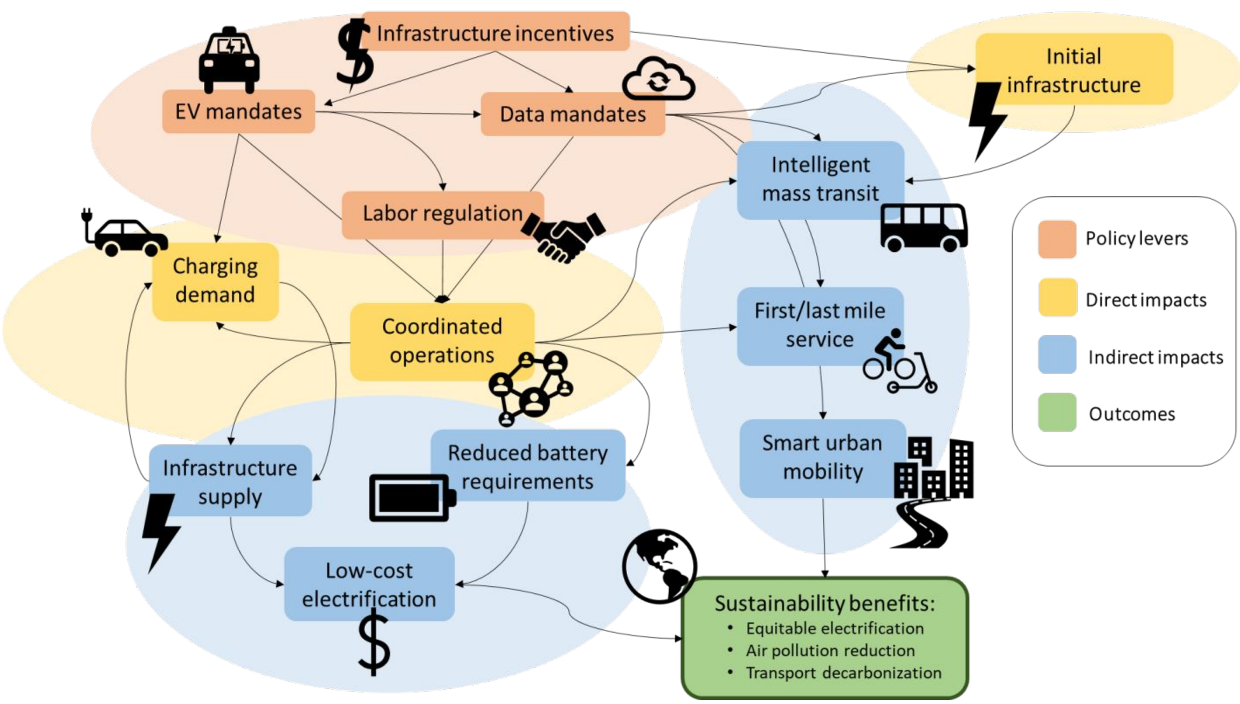


Figure 3. Flow chart depicting the impact of proposed policies to support fleet electrification.

More broadly, open data platforms with vehicle trajectory data encourage a wide swath of smart urban mobility strategies. For example, as more cities move to establish low-emissions zones (emulating London),[53] they will need to understand how much pollution and congestion is caused by each vehicle type across space and time. Data analysis could also inform policies designed to incentivize higher vehicle occupancy, for example through dynamic ride pooling. Ultimately with AVs, all these issues will become magnified, but much harder to regulate once a constituency becomes entrenched. Recently, cities have also started using taxi data to inform contact tracing and isolation efforts to help fight the COVID-19 pandemic; this public health feature will become increasingly important as the globe prepares for future waves of the novel coronavirus or other pandemics.[54]

Conclusion

Urban mobility has entered a period of rapid change, and MODV services may come to dominate the sector over the next several decades. This development carries the risk of increased congestion, pollution, unequal access, and increased carbon emissions. However, it also presents a massive opportunity for both decarbonization and smart urban mobility. When managed properly, BEVs can serve on-demand mobility at lower cost than fossil fuel vehicles with today's technology and provide grid benefits with coordinated charging. Strong political will targeted at MODV electrification can produce a cascade of positive spillover effects, but it will require carefully designed policies targeting both data and labor regulation to succeed.

Supporting Information: Additional information on relevant electrification policies by region; details for calculations of demand for on-demand mobility services by region; current state of electrification of bus and taxi fleets in largest Chinese cities; details on calculations and assumptions for Figure 1; key results from Bauer et al. (2020).[19]

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Definitions by Society of Automobile Engineers (SAE), originally from [1]:
[i] Transportation network companies (TNCs) provide prearranged and on-demand transportation services for compensation mediated by a digital application.
[ii] Microtransit is a technology-enabled transit service that typically uses shuttles or vans to provide on-demand or fixed-schedule service with either dynamic or fixed routing.