WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

Industry Agenda

Electric Vehicles for Smarter Cities: The Future of Energy and Mobility

In collaboration with Bain & Company

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Preface

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By 2050, about 70% of the world's population will live, commute and work in urban areas. Between now and then, cities and suburbs will undergo significant transformations to create sustainable living conditions for their residents. Mobility and energy are the twin pillars of these transformations, and both will require radical adaptation to meet demographic and economic growth without increasing congestion and pollution. Cities will require mobility and energy solutions that are sustainable, affordable, secure and inclusive, and integrated with customer-centric infrastructure and services. Thus, the convergence of energy and mobility is critical.

These are exciting times in which new technologies allow people to rethink the way they live in a more sustainable and efficient manner. Smart mobility. Smart water. Smart grid. Smart integration. These are the foundations of tomorrow's cities, which are being realized today.

Following the World Economic Forum's previous work on the future of electricity and the digital transformation of industries, this report examines the major trends affecting the transformation of energy and mobility systems, with a special focus on cities: electrification, decentralization and digitalization of the energy system, along with the shift towards shared mobility and autonomous driving.

The recommendations provided aim to accelerate these transformations, in ways that will magnify the economic and societal benefits they could bring. While suggesting a comprehensive approach and broadly applicable principles, this report also shows how to tailor each electrification strategy to specific markets: energy, mobility and urban infrastructure patterns will affect how the countries and cities decide their own priorities. Furthermore, the report also showcases examples of transformational public and private initiatives to drive greater collaboration.

The vision and framework proposed in this report will support policy-makers and urban planners, as well as private investors and businesses to undertake the critical actions required to accelerate electric mobility where energy, mobility and urban transformations converge.

Overview

Mobility is going to change rapidly in the coming years as electric vehicles (EV) proliferate, ride sharing continues to grow, and eventually autonomous vehicles (AV) enter urban fleets. This is especially true in cities where new forms of mobility are concentrated and where investment in supporting infrastructure is needed to accommodate this growth. These changes coincide with the evolution towards cleaner, more decentralized and digitalized energy systems and services, and increasing electrification.

Today, public- and private-sector stakeholders deploy policy, infrastructure and business models based largely on current patterns of mobility and vehicle ownership. The uptake of privately owned EVs is encouraged, while business models for charging stations vary, as they are deployed or operated by a range of players – public agencies, car manufacturers, energy companies and pure players. Limited interoperability and digitalization of infrastructure can make broad customer engagement challenging. Outside the energy sector, awareness of energy-related issues is low. Mobility integration with electricity system and grid edge technologies is emerging. As a consequence, EV charging could create local constraints and stability problems on power networks and reduce the environmental benefits of electrification.

There is an opportunity to design a different future, and reap both environmental and economic benefits with a call to action around the following three principles to be acted upon:

1. Take a multistakeholder and market-specific approach: First and foremost, a market-specific approach that considers all relevant stakeholders should be applied to new mobility patterns with smarter and cleaner energy systems (see Figure 1). Energy, mobility and infrastructure enterprises, along with policy-makers, regulators and urban planners, can collectively define a new paradigm for cities. The paradigm would go beyond today's industry divisions in search of complementary municipal, regional and national policies.

The investment and infrastructure to support electric mobility will vary significantly from one place to another, thus any approach needs to be market specific. Local stakeholders should plan for electrification while taking into account local characteristics, especially: urban infrastructure and design, the energy system and the culture and patterns of mobility.

2. Prioritize high-use vehicles. The focus should be on electrifying fleets, taxis, mobility-as-a-service vehicles and public transport, which will have a greater impact as these represent a higher volume of miles travelled. Although personal-use vehicles will likely remain a significant portion of the vehicle stock for many years, they are on the road less than 5% of the time, representing a low volume of overall miles driven.

3. Deploy critical charging infrastructure today while anticipating the transformation of mobility. To keep pace with growing demand and to address range-anxiety issues, charging infrastructure is needed, especially along highways, at destination points, and close to public transport hubs. To minimize the risk of stranded investments, future mobility and vehicle ownership patterns should be considered, as some current charging locations (i.e. in apartment buildings, at parking meters along city streets) may not be needed in the future. The infrastructure should be deployed in combination with grid edge technologies – such as decentralized generation, storage, microgrids and smart buildings – and integrated into smart grids, to fully exploit the flexibility of EVs while enabling the stability of the energy system. Digitalization would help simplify and enhance the customer experience, support efficient infrastructure deployment and management as well as enable new services associated with electric, shared and autonomous mobility. Charging stations can become hubs for smart-city services.

Figure 1: The convergence of mobility and energy futures

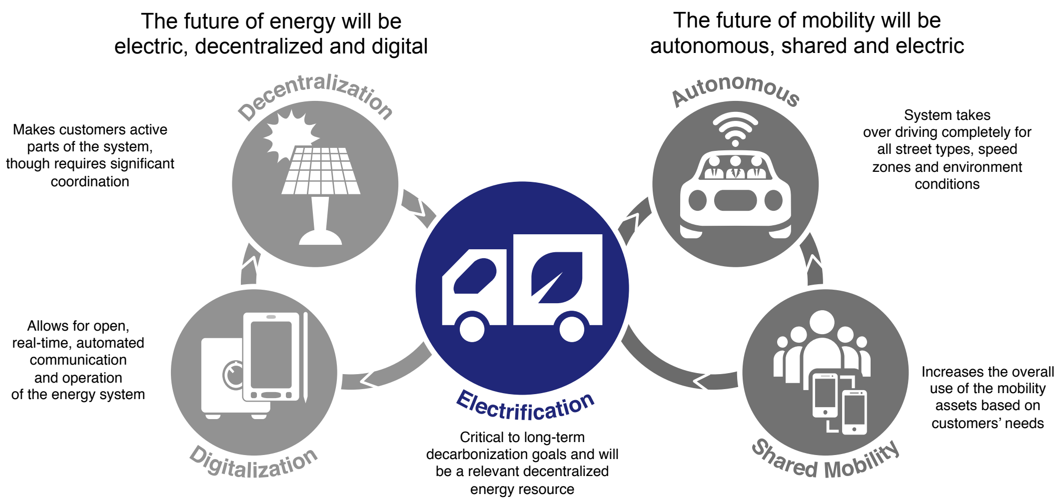
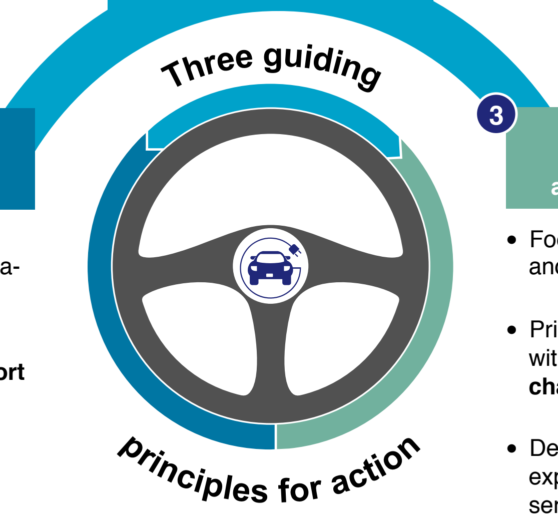


Figure 2: Three principles for action on electric mobility

1 Take multistakeholder & market-specific approach



2 Prioritize high-use vehicles

- Focus on electrifying **public and commercial fleets**, including mobility-as-a-service
- Complete electrification of **public transport** system
- Enable the integration of **autonomous vehicles** (AV)

3 Deploy critical charging infrastructure today while anticipating mobility transformation

- Focus on reducing **range anxiety** and promoting **interoperability**
- Prioritize energy-efficient **charging hubs** with **grid edge technologies** and **smart charging**
- Develop **digital end-to-end** customer experience to **enhance access** to charging services

These recommendations (see Figure 2) will create value in three dimensions:

– **Environment.** As the share of miles driven by EVs increases, urban mobility emissions will decrease progressively; electrification combined with a clean energy mix and optimized charging patterns will further reduce emissions, improving air quality and benefiting human health, with a much-decreased ecological footprint.

– **Energy.** EVs are a relevant decentralized energy resource (DER), providing a new controllable electricity demand, storage capacity and electricity supply when fully integrated with grid edge technologies and smart grids. Smart charging will create more flexibility in the energy system, improving stability and optimizing peak-capacity investments. Fleets of electric and, later, AVs can amplify the potential of smart charging, through the aggregation of multiple vehicles and higher control of load profiles. This will also open the door to broader energy efficiency services.

– **Mobility.** EVs will become more affordable than vehicles powered by internal combustion engines (ICEs) as the cost of batteries declines. Smart-charging services will reduce charging costs (for example, by charging when energy prices are low, if dynamic pricing is implemented), and new revenue streams for fleet operators, who will be able to provide ancillary services to energy markets. In the future, AVs will also cost significantly less per mile than personal-use ICEs, by as much as 40% (see Figure 13) and could also reduce congestion and traffic incidents.

This report provides recommendations based on case studies and interviews with a wide range of leaders and experts from energy and mobility industries, civil society, academia, city councils and national governments.

Working together, public and private stakeholders can adapt these principles to optimally converge mobility and energy, and to enable cities to better meet climate goals, support energy efficiency, foster innovation of services and infrastructure, and generate economic growth, ultimately providing great benefits to citizens.

The vision

Urban mobility and infrastructure are evolving to incorporate more EVs. Today, however, public- and private-sector stakeholders develop policies, deploy charging infrastructure and follow business models based on current mobility patterns and vehicle-ownership norms, with limited consideration of energy implications. There is no common or clear vision for how the design and deployment of the required infrastructure would be affected by changes in mobility patterns, vehicle technology or energy systems.

This report aims to identify a shared vision for the future – an evolution of the current trajectory of EV proliferation for cleaner mobility to a designed future, the transformation.

This transformation would accelerate the ability of cities to meet climate goals, optimize grid infrastructure investments, enable innovation of services and infrastructure, dramatically increase productivity and generate economic growth, ultimately providing great benefits to citizens.

The differences between the current EV proliferation phase and a more extensive transformation to be designed, in terms of policy, infrastructure development and mobility culture and patterns, are described within this section (for a summary, see Figure 3).

a. Policy approach

Status quo – proliferation

The electrification of transport is the main pillar of national and local policies for cleaner mobility, through the substitution of ICEs with EVs. Many current regulations encourage the proliferation of privately owned EVs by offering financial and/ or non-financial incentives, including tax rebates, access to priority lanes, free parking or free electricity, and penalizing vehicles with emissions (see Figure 4).

These incentives are motivated by the potential of zero-emission vehicles to significantly reduce greenhouse gases such as carbon dioxide (CO_2), nitrous oxide (N_2O) and nitrous dioxide (NO_2). In fact, electrifying light-duty vehicles (LDV), even with the current energy mix, would decrease CO_2 emissions by 60% per mile driven (see Figure 10).

Climate goals

Following the 2015 United Nations Climate Change Conference (COP21) agreement in Paris, many countries and cities have announced goals to eventually ban internal combustion engines. The European Commission also released the Clean Mobility Package in November 2017 to set new CO_2 emission standards and guidance for cleaner mobility.

Norway, the Netherlands, France, Germany, the UK, China and India have all made announcements indicating their intentions to eventually ban the production and sale of cars that run on fossil fuels. Cities including Athens, Madrid, Mexico City, Paris and Stuttgart have announced plans to ban diesel cars by 2030 or earlier.

Car manufacturers followed these regulatory commitments with their own pledges to move away from the production of ICEs. BMW plans to mass-produce EVs by 2020, offering 12 models by 2025. Renault plans to produce 20 electrified models by 2022, including 8 pure EVs. Volkswagen will invest up to $84 billion in battery and EV technology to electrify all 300 of its models by 2030. Volvo has committed to fit every car it produces by 2019 with electric or hybrid engines.

China set a timeline of peaking its CO_2 emissions around 2030, and has indicated it plans to ban the production and sale of fossil fuel cars in the near future. Increased electrification of mobility coupled with more renewables in the energy generation mix have become a crucial part of the solution.

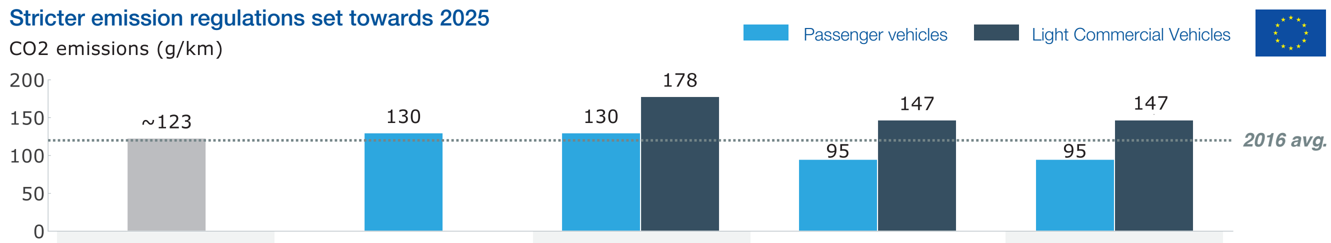
The opportunity – transformation

A more extensive transformation will require policy and regulatory reforms to support the electrification of transport that goes beyond decarbonization goals. Policy and regulatory objectives can aim to achieve smarter cities, aggregated efficiency and productivity, and broader economic development. These will rely on the convergence of energy, mobility and infrastructural planning objectives and complementary municipal, regional and national policies.

Figure 3: Proliferation and transformation

	Proliferation ongoing globally	Transformation to be designed
Policy approach to electrification	**Driven by national and local objectives for cleaner mobility**, through substitution of personal use **ICEs** with **EVs**	Driven by **local objectives** to achieve **smarter cities** and broader **economic development**
Charging infrastructure development	**Home**, **destination and highways** with low **integration** with **energy systems** and **uncertain business models**	**Fully connected** and **shared**, supporting **flexible charging**, integrated with **clean energy systems**, through a **fully digital experience**
Urban mobility culture and patterns	Focused on traditional **individual ownership** model	New **mobility patterns** such as **fleets**, **shared** and **autonomous electric vehicles**

Figure 4: European emission regulations are set to become stricter through 2025



Current average
- Current average emissions in Europe for passenger vehicles

2014
- Max CO2 threshold 130g/km for all passenger cars
- Costly NOx reduction for diesel (0.08 g/km)*

2017
- Stricter particle number (PN) regulations for gasoline engines
- Real driving emissions (RDE) test set to begin (monitoring emissions live on cars)

2021
- Challenges for OEMs as worldwide harmonized light vehicle test cycles (WLTC) for pollution and fuel efficiency go into place

2025
- Ambitious target set for passenger cars - innovation needed from OEMs to live up to targets

Increasing penalties to auto makers for excess emission per vehicle

- **Before 2019:** 1st gram of excess emission €5, 2nd gram €15, 3rd gram €25, subsequent gram €95
- **From 2019[1]:** €95 for each gram of excess emission per registered vehicle

Note: [1]EU6 regulations on emissions; RDE: Real-Driving Emissions
Sources: IHS Automotive Conference 2016, European Commission

The focus should be on electrifying the vehicles with the highest use rates, such as public transport or mobility-as-a-service fleets, which represent a higher volume of miles travelled. This approach also helps to avoid the main barriers to adoption by individual customers (concerns about vehicle range and charging) and long vehicle-replacement cycles.

b. Mobility patterns

Status quo – proliferation

Mobility culture, such as the influence of society and age on vehicle ownership, and mobility patterns vary across countries and cities. In general, traditional vehicle-ownership models still play a central role in individuals' commuting patterns, complemented by partially electrified public transport networks.

The opportunity – transformation

The growth of mobility-as-a-service and an increase in the number of AVs will significantly alter urban mobility patterns, with the opportunity to reduce transport costs, improve traffic congestion and safety, and repurpose urban spaces currently used for parking.

The ease of mobility-as-a-service and shared mobility solutions may reduce the number of vehicles on the road as urban and suburban commuters use their personal vehicles less. This trend could be accelerated by AVs in the future, especially as the perception of customers evolves. In this scenario, the cost per mile of a shared AV is significantly lower than a self-driven, personal-use ICE vehicle, creating a compelling value proposition for the customer (see Figure 13).

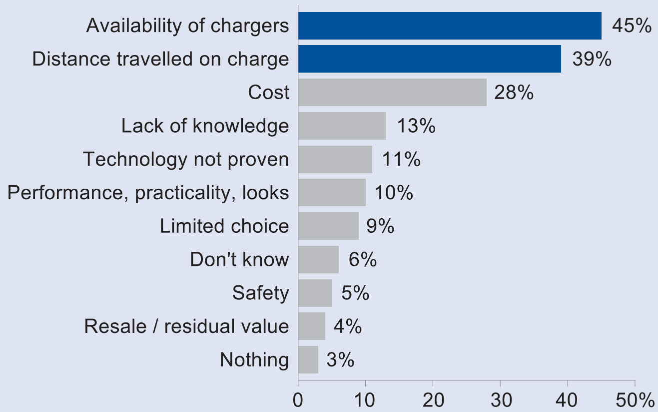
Customers' concerns about EVs

As the cost of batteries goes down, EVs will become more affordable than ICEs. Combined with the lower costs of EV maintenance and repair, and assuming the cost of electricity remains competitive compared to the fossil fuel equivalent, customers will benefit from a significant decline in the operating cost per mile from driving EVs. Overall, by 2020, the total cost of a personal-use EV could be about the same as an ICE, aside from any incentives, in some markets.

As cost becomes a less relevant concern, many customers are still worried about depleting their battery's charge before reaching their destination or waiting for their EVs to charge, as shown in a recent survey among UK drivers. The availability of chargers and the distance that can be travelled on charge become the main barriers to EV adoption.

Figure 5: Lack of charger availability is the main barrier to EV adoption

Reason for not purchasing an EV
(multiple selections possible)



Source: UK Department for Transport (2016), N=649 licence holders

c. Charging infrastructure development

Status quo – proliferation

Charging infrastructure is mainly deployed to meet the needs of personal-use vehicles. Customers charge their vehicles when it is most convenient, either at home in the evening or in business districts during the working day, at destination points such as car parks, shopping centres or hotels, as well as in public parking spaces.

Business models for charging stations vary widely, with stations owned and operated by a range of players including public agencies, car manufacturers, energy companies and pure charging infrastructure players. They are deployed under three main schemes: either as a marketing investment (for example, by car manufacturers to support sales of EVs), through public-private partnerships (such as a free concession of public land or cost and revenue sharing) or as part of the regulated asset base of electricity network operators.

Charging station business models

The municipality of Oslo (Norway) owns and operates a charging infrastructure on public land and also supports publicly accessible, privately owned and operated infrastructures in partnership with private real-estate entities. The city rents out the parking slots at night and offers free charging to EV owners.

In Hong Kong SAR, the local government encourages developers to scale up the EV charging infrastructure, including solutions integrated with the smart payment system Octopus, which is also used to access the public transport network.

In Stockholm (Sweden), energy technology and energy utility companies own and operate charging stations, while the city provides public land as a free concession for a certain number of years and under specific service level agreements.

In 2011, the state of California (USA) restricted utilities from investing in public EV charging due to concerns that it could limit the participation of other players. In 2014, the ban was lifted to encourage investments where the business case is uncertain, such as in low-income communities, resulting in about $500 million invested from major utilities. Utility-funded programmes help reduce the costs of expansion while improving the market perspectives.

Some car manufacturers have deployed fast-charging networks, with a focus on highways and points of interest such as hotels and malls.

Oil and gas companies are also entering the fast-charging market to attract and retain customers to their existing service stations.

Pure charging infrastructure players sell charging stations, as well as charging, financing services and maintenance services.

Battery swapping is another potential model. In India, Sun Mobility is developing a service for swapping electric bus batteries, as well as smaller two- and three-wheel vehicles. In China, the province of Zhejiang is developing a network of fast-charging and battery-swapping stations.

Slow charging outside the home is often associated with offers of free electricity to attract customers (a model used by many retailers) or as part of a subscription service. Networks of fast and ultra-fast charging stations become more profitable as customers show a willingness to pay a premium for rapid charging – such as along highways connecting cities.

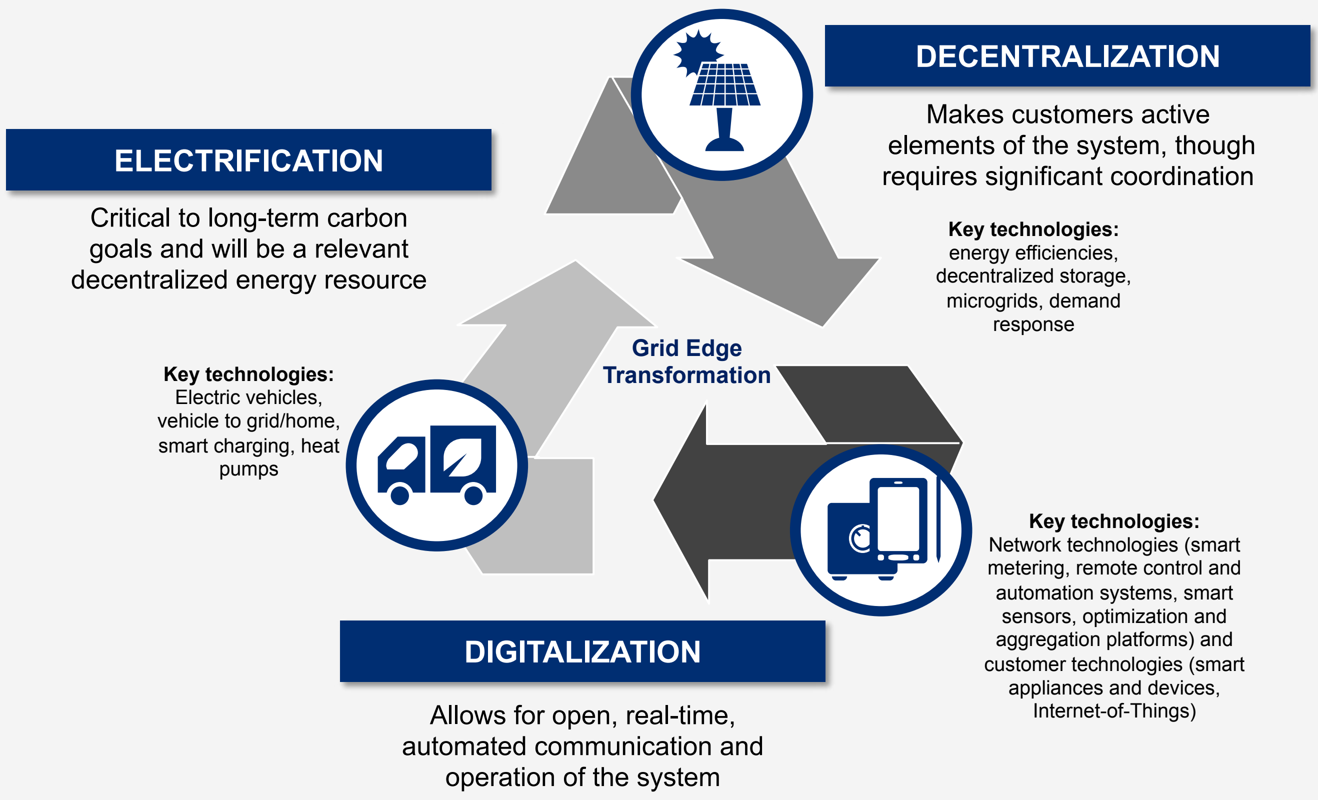
However, limited interoperability and weak digitalization of the systems – which could make customer access easier and provide useful data to relevant stakeholders – put customer engagement at risk by complicating their experience.

Outside the energy sector, awareness of energy-related issues is low and, as a consequence, integration of the charging infrastructure with the energy system and other grid edge technologies is nascent. A common question raised by the public sector and other stakeholders is: can the electricity system handle the future growth of EVs? The answer to this question varies by market, depending on the evolution of regulatory standards as described in the Grid Edge Transformation framework (see Figure 15), and levels of digitalization. These factors contribute to a market's ability to optimally manage additional peak electricity demand from EVs and could lead to local capacity constraints and grid stability issues.

The opportunity – transformation

As the energy system gets cleaner and increasingly digitalized, accommodating a move to decentralized energy generation, storage and smart buildings (see Figure 6), several new energy related services will become possible due to the charging infrastructure. As shown in the box "Integration with grid edge technologies and smart grids", these services will create new sources of value for the customers as well as for energy and mobility service providers.

Figure 6: Three trends of the grid edge transformation



Sources: World Economic Forum

Electrification, decentralization and digitalization act in a virtuous cycle, enabling, amplifying and reinforcing developments beyond their individual contribution. Their integrated deployment could generate more than $2.4 trillion of value globally for society and industry by 2025 by increasing the efficiency of the overall system, optimizing capital allocation and creating new services for customers. (For more, read The Future of Electricity: New Technologies Transforming the Grid Edge, published by the World Economic Forum in March 2017.)

At the same time, as mobility patterns and culture evolve towards increased shared and automated vehicles, and the performance of batteries improves, the optimal location for the charging infrastructure will change.

As cities continue to restrict city-centre access for personal-use vehicles, and the distance EVs can travel increases, home, local and destination charging stations will primarily be needed to meet on-the-spot demands from the last-mile delivery sector – movement of people and goods from a transport hub to a final destination in the home – or shared mobility services. The highest demand for EV charging will be located close to the main public transport nodes, in public- and private-fleet depots or hubs in the outskirts of cities offering a variety of other services (such as vehicle maintenance, car sharing and shopping centres). These locations will therefore become more profitable, while others may become stranded assets (see Figure 7). Business models will still vary in different markets and cities, as no single solution will work everywhere.

Integration with grid edge technologies and smart grids

The rapid growth of renewable energy sources, especially solar and wind power, introduces increasing amounts of non-dispatchable (sources that can be turned on and off or can adjust their power output on demand) sources of power generation into the energy system. Renewable energy introduces more intermittency to the electricity grid. Electricity system operators will need to build greater flexibility into the electricity system to maintain a constant frequency, through the digital management of demand, supply and storage. EVs could be used as decentralized energy resources (DERs), given their controllable electricity demand (through smart charging), capabilities for decentralized energy storage (batteries) and potential as a source of power, such as vehicle to everything (V2x) - relevant sources of flexibility for energy systems.

– Smart charging. Smart charging is controlling the power of charge to match with network capacity (avoiding peak demand), renewable energy (maximizing use of renewable power) and customer's needs (time and costs). Dynamic electricity prices and integration with smart grids are necessary to manage and control this process. Integration with other grid edge technologies (such as solar panels) will offer more flexibility. Digitalization supports customer interactions, such as their participation to the programme and charging preferences. Customers, including fleet operators, can benefit from such programmes through reduced costs by charging at the best price or other additional revenues from energy services.

– V2x. EV owners, especially EV fleet operators with predictable capacity, could provide ancillary services by supplying the excess electricity stored in the EV batteries to buildings or the electricity grid. Vehicle-to-grid (V2G) trials are ongoing, with encouraging results. For example, in Denmark, V2G provides frequency regulation services to the electricity grid and generates revenues. However, in most countries, regulation and energy markets are not yet ready for this service and the commercial and technical feasibility is being tested. The support of the automotive industry is required for both, and in particular to design and commercialize V2x batteries.

– Integration with decentralized storage. EV charging hubs would benefit from the integration with decentralized generation and storage to reduce the impact on the local network, optimizing the load profile. Use of second-life batteries in decentralized storage systems could reduce the cost of decentralized storage and contribute to circular economy objectives.

– Integration with smart buildings. A smart building's digitalized microgrid could incorporate charging stations, along with renewable energy sources such as rooftop solar panels, to improve a building's energy efficiency. For instance, in a supermarket, assuming the power generated by rooftop panels would be used primarily for the store's cooling systems, any surplus power could be used to charge customers' vehicles onsite. With a digitalized energy management system, the store would be able to optimize its energy use based on real-time energy prices, external temperatures and electricity grid demands.

Figure 7: Current deployment strategies for charging stations may leave some as stranded assets

	PROLIFERATION	TRANSFORMATION
HOME	**Slow charging** At home or residential streets, covers most journeys	✗ Potential for stranded /underused assets
LOCAL	**Slow to fast charging** Implemented in urban and suburban areas to reduce range anxiety (for example, along the streets or in urban service station)	✗ Potential for stranded /underused assets
DESTINATION	**Slow to fast charging** Whilst parked at venues, such as shopping or working. Match charge time to time spent at destination (for example, 1-hour charging at the supermarket vs. 8-hour charging at work)	✗ Potential for stranded /underused assets
FLEET	**Slow to ultra-fast charging** At depot or hub for fleets, including autonomous vehicles Depots could be in urban car parks or just outside urban areas, integrated with a city's public transport strategy	
HIGHWAY	**Fast to ultra fast charging** At service stations, along highways to enable charging on long journeys, with less than 15 minutes charge time possible. Tackles range anxiety; gives confidence and convenience	

Source: Bain analysis

The value of the transformation

Both the proliferation and transformation models of EV adoption provide positive impacts for environment, energy and mobility systems and create value for industries and society. However, moving from the proliferation to the transformation approach will prompt a significant increase in the value generated. For example, in the US, a full transformation generates nearly four times the value of the proliferation (see Figure 8).

A key reason for the value generation is that more miles would be driven by EVs, as shown in the sidebar (see Figure 9).

a. Environment

Status quo – proliferation

The proliferation of EVs, with their more efficient engines, certainly contributes to a limit in urban mobility emissions, along with stricter emissions regulations on ICEs. However, focusing strictly on personal-use EVs will not help to achieve the current climate goals. For example, in the US, cutting vehicle emissions by half would require 40% of light-duty vehicle stock[1] to be electrified, or 95 million vehicles. Current forecasts predict this percentage will not be reached until 2042.

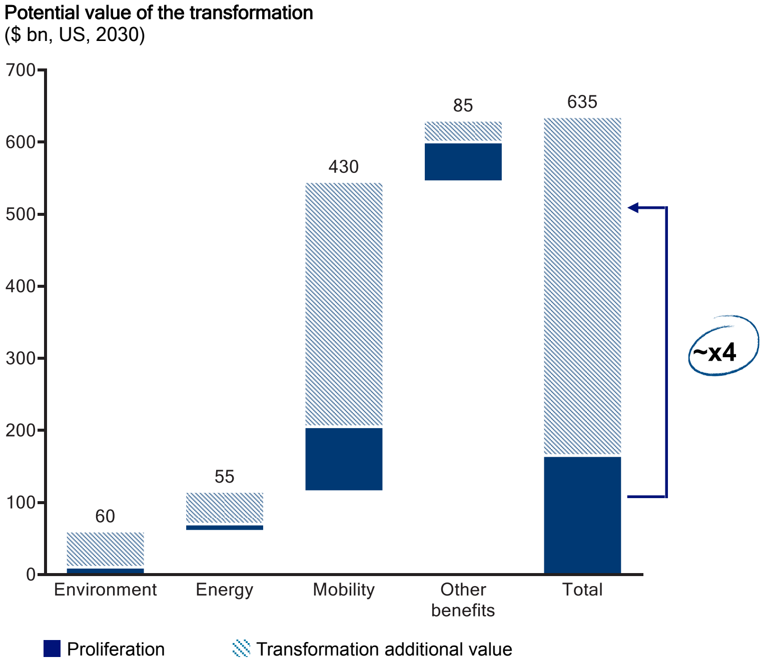
The opportunity – transformation

The transformation would instead focus on electrifying high-use vehicles, such as shared AVs, public transport and commercial fleets. Instead of relying on individual customers to replace their ICE with EVs, the transformation relies on companies making capital investment decisions based on a compelling business case for EVs that operate at a lower cost per mile than ICEs at a high rate of use.

More miles powered by electricity, combined with smart charging in a clean energy system based on renewable or other carbon-free energy sources, would bring full-cycle emissions down to 24 CO_2 grams per mile and marginal emissions close to zero (see Figure 10).

This transformation would increase the positive impacts of EVs on the environment compared to the current model, representing up to $60 billion by 2030 for the US alone (see Figure 8).

Figure 8: Shifting from the proliferation to transformation approach could quadruple the value generated in the US by 2030



Note: Assuming all AV are EV; calculation methodology in Appendix d; rounded numbers
Source: Bain analysis

- Transformation leads to an increase in the share of miles driven by EVs, quadrupling the potential value by 2030 through a push for fleet and mobility-as-a-service electrification as well as new forms of mobility
- Sizeable value from generation capacity and ancillary services savings, most coming from smart charging and reduction in curtailment of renewables
- Most value for society coming from mobility savings, such as decreased cost per mile

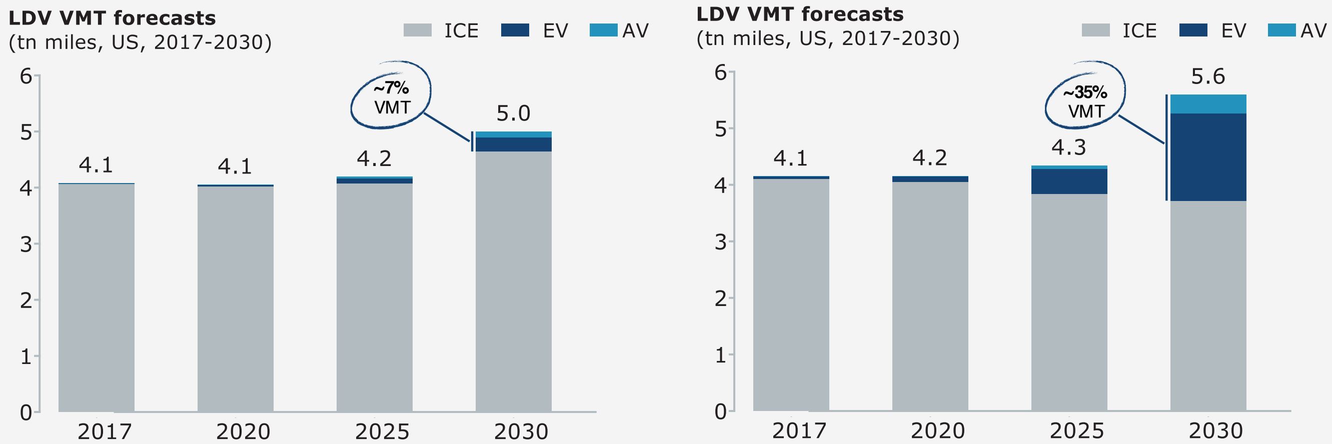
1. Assuming that 47% of the current LDV stock is vehicles for personal use, they contribute to 36% of the emissions.

Proliferation vs transformation – projection of electric miles in the US

In the US, the transformation would electrify around 35% of vehicle miles travelled by 2030, even while the vehicle stock would remain about 85% ICE. This is compared to less than 10% of miles being electrified if public policies keep focusing on traditional ownership models by prioritizing personal-use EVs.

Figure 9: EVs could represent up to 35% of LDV miles travelled by 2030

Status Quo - proliferation | Opportunity - transformation



- Public policies continue to focus on traditional ownership models, incentivizing personal-use EVs
- Limited penetration of EVs, mobility-as-a-service and AVs
- While the ICE stock decreases, EV and AV share of miles remains limited

- Strong regulatory push for EVs reduces total cost of ownership down and raises EV competitiveness
- EV and AV account for a growing share of miles pushed by electrification of commercial, public and mobility-as-a-service fleets with higher rate of use
- ICE LDVs decrease, but remain the majority of vehicles. Mobility-as-a-service and AVs help increase the EV mileage

Note: LDV= Light Duty Vehicle (like cars and small trucks); VMT = Vehicle Miles Traveled

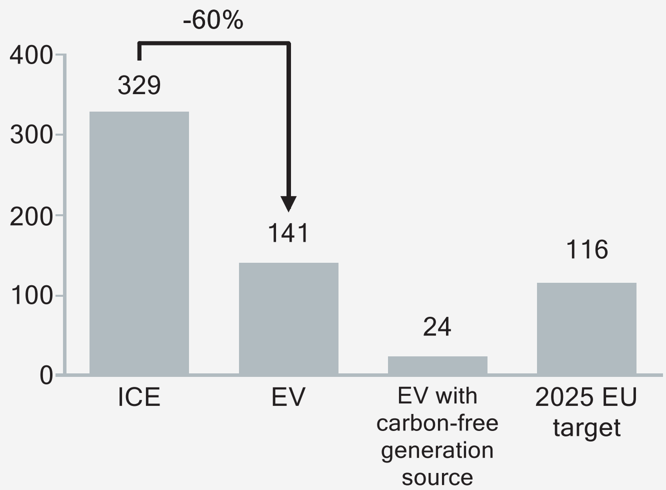
Sources: Bureau of transport Statistics; IEA; Morgan Stanley; Euromonitor; Bain analysis

EVs for cleaner mobility

In the US, 1,100 trillion tons of CO_2 were generated by LDVs in 2016, costing $470 billion in lost wages and healthcare costs.[2] Based on the US energy mix for electricity generation, EVs currently release around 140 grams of CO_2 per mile compared to 330 grams per mile for an ICE, a 60%.

Figure 10: Full-cycle CO_2 emissions from EVs are at least 60% lower than those from ICEs

(g CO2/mile, US, 2016)



Note: CO2 emissions include tailpipe and full cycle

Source: EPA; US Department of Energy; EIA; Bain analysis

2. CO2 emissions are from the IEA; costs are from the World Bank and Institute for Health Metrics and Evaluation, “The Cost of Air Pollution: Strengthening the Economic Case for Action”. Washington, DC: World Bank, 2016.

Environmental benefits of smart charging with different energy mixes

In cities such as Oslo and Montreal where hydropower generates more than 95% of the electricity, with no emissions and no intermittency, EV charging would be continuously clean. Smart charging would still be useful to deal with any local constraints on the power grid, for example, to reduce the need for grid reinforcements or to shave peaks in demand.

In cities like Richmond, Virginia, in the eastern US, which is supplied by a mix of wind and conventional coal generation, charging could be timed to match the windiest times.

Cities that derive an increasing share of their electricity supply from renewable energies, for instance, San Francisco or Houston in the US, could avoid curtailing renewables by adjusting optimal charging times and charging station locations.

b. Energy

Status quo – proliferation

In the current proliferation model, EVs are seen primarily as a means of transport; their use as DERs remains at a very preliminary stage.

The integration of the charging infrastructure with grid edge technologies, such as decentralized generation, storage, smart buildings and smart grids, is limited. Policy support in the form of dynamic pricing and other regulatory aids that could accelerate electrification is also limited.

While the potential global additional demand generated by EVs will be relatively small (see Figure 11), locally it could create challenges, leading to the need for additional investments in grid peak capacity and grid reinforcements.

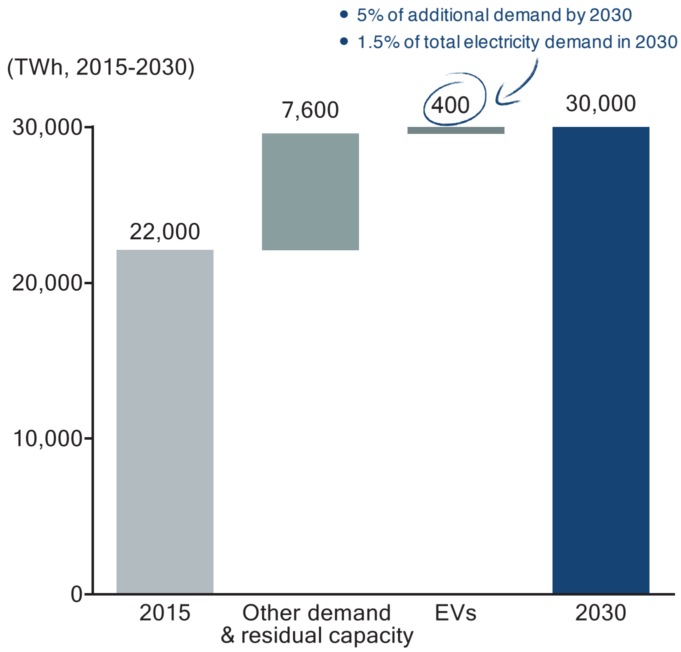
The opportunity – transformation

The integration of mobility patterns with electricity systems and grid edge technologies could bring more than five times the value of the status quo, representing up to $55 billion of value in the US alone in 2030 (see Figure 8). Most of this value will come from the smart management of electricity demand.

In fact, charging EVs at the right time and in the right location can increase the consumption of renewable energy, reduce the need for additional peak capacity investment and improve the stability of the grid (see Figure 12). With well-designed pricing and rate structures, customers could benefit from charging at lower rates that reflect the cost of electricity production at a given time and location.

The use and benefits of smart charging can be accelerated through a digitalized power system, dynamic pricing and grid edge technologies, combined with new mobility patterns (see Figure 15).

Figure 11: Forecasted EV demand as per worldwide additional power generation



Note: Excluding electricity production loss

Sources: IEA; European Environment Agency; OECD; Bain analysis

c. Mobility

Status quo – proliferation

Under the proliferation model, most policies focus on encouraging the adoption of EVs for personal use and individual vehicle owners will benefit from the potential savings on the cost per mile (see Figure 13). However, given the low use rate of personal-use vehicles (especially in terms of miles driven) the overall benefit to society is minimal.

The opportunity – transformation

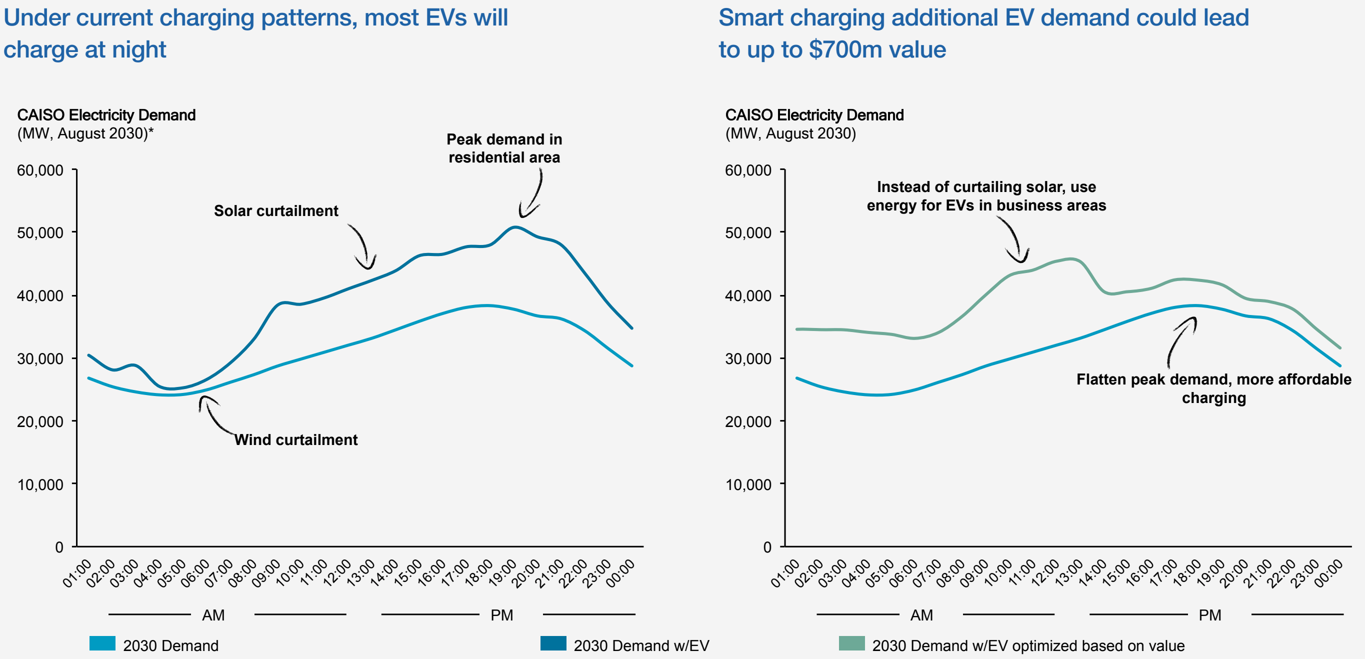
The value of EVs over ICEs increases with the use rate of the vehicle. For this reason, focusing on shared EVs and AVs could generate nearly five times more value in mobility than with the proliferation scenario, representing up to $430 billion in the US in 2030 (see Figure 8).

In particular, the penetration of AVs will have a significant impact in the future given their high use rates while shuttling multiple people at once.

Smart charging benefits for the energy system

In California, where cities increasingly rely on solar generation, by 2030 there could be as many as 4 million EVs on the roads. In that scenario, smart charging could represent up to $700 million savings for customers of California Independent System Operator (CAISO) by 2030. While most of the current charging patterns show that privately owned EVs charge in residential areas when the prices are high, the transformation paradigm would push for charging during the day or overnight to reduce charging costs.

Figure 12: Smart loading value potential for CAISO

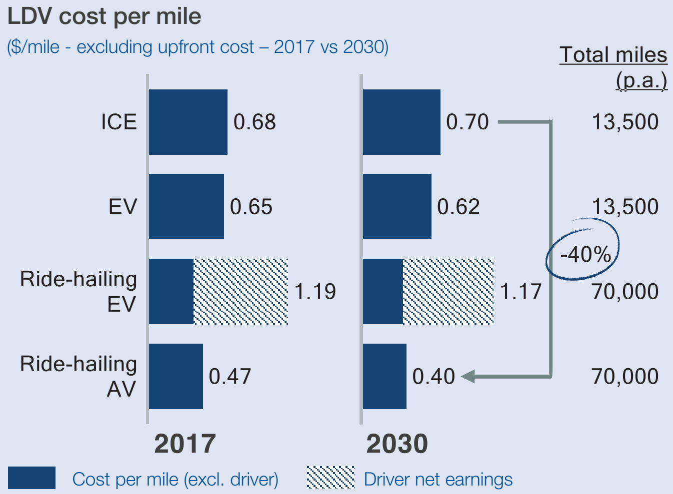


Sources: CAISO Renewables Watch; NREL; Californian Energy Commission; RMI; EIA; Bain analysis

Influence of new mobility patterns on cost per mile

Public and private fleets, mobility-as-a-service and later AVs will exhibit a decreasing cost per mile when going electric. Driving down the cost to around $0.40 per mile by 2030, AVs will be the real breakthrough for urban mobility patterns. This new mobility cost benchmark will challenge traditional self-ownership models and will affect customers' choices.

Figure 13: Mobility-as-a-service AVs are set to revolutionize LDV costs per mile



Note: Cost per mile comparison based on compact car ICE and compact car EV in the US; Cost varies by vehicle, market and use

Source: Bain analysis

Recommendations for action

The recommendations below are derived from research into practical examples and case studies, as well as interviews and workshops with experts and leaders from the private and public sectors, academia and civil society.

They are compiled into a framework structured into three main principles. This framework complements the national-level recommendations in the World Economic Forum's "The Future of Electricity: New Technologies Transforming the Grid Edge" to accelerate electrification, decentralization and digitalization.

Principle 1 – Take multistakeholder and market-specific approach

A comprehensive approach to electrification of transport will require engagement of stakeholders from different industries and sectors and may vary significantly across different markets.

The key recommendations are the following:

– Develop a multistakeholder approach in electrification strategy

– Ensure city, regional, and national policies support and reinforce each other

– Assess local characteristics to inform action

Develop a multistakeholder approach in electrification strategy

– Design internal organizations to ensure convergence of energy, urban and mobility planning objectives

The energy, mobility and infrastructure sectors, along with policy-makers, regulators and urban planners, can collectively define a new paradigm for cities. For example, at a practical level, an electric mobility programme can bring together human and financial resources from urban energy and mobility planning departments to ensure adoption of a comprehensive approach to the electrification of mobility.

Ensure city, regional, national policies support and reinforce each other

– Build a national platform for electric mobility with city representation

Coordination among the local, regional and national levels will be necessary to anticipate and enable the integration of the grid edge and mobility transformations. For example, public bus systems can be operated by federal or provincial governments, depending on circumstance. Certain policies and regulations, for example, dynamic pricing, may fall under the domain of national policy-makers. A national platform for electric mobility with city representation can facilitate cooperation among different regulatory and policy-based entities.

Figure 14: Recommendations for electrifying mobility

Take multistakeholder and market-specific approach	• **Develop a multi-stakeholder approach in electrification strategy** - Design internal organizations to ensure convergence of energy, urban and mobility planning objectives • **Ensure city, regional, national policies support and reinforce each other** - Build a national platform for electric mobility with city representation • **Assess local characteristics to inform action** - Assess current and projected local characteristics in terms of city infrastructure and design, energy system, and mobility culture and patterns.
Prioritize high- use vehicles	• **Focus on electrifying public and commercial fleets, including mobility-as-a-service** - Introduce financial and/or non-financial incentives for high utilization vehicles • **Complete electrification of public transport system** - Secure funding for electric buses and infrastructure, and renew the fleet gradually through public procurement - Collaborate with the public transport operator(s) to define the fleet electrification targets - Involve electricity network operators and electricity suppliers to enable smart charging and ancillary services at bus depots • **Enable the integration of AVs** - Develop national regulatory frameworks that allow regions and cities to begin testing and introducing AVs - Investigate the impact of AVs on urban spatial and infrastructure planning
Deploy critical charging infrastructure today while anticipating the transformation of mobility	• **Focus on reducing range anxiety and promoting interoperability** - Develop fast-charging network through public-private funding to connect different cities - Include standardization and interoperability in minimum requirements • **Prioritize energy-efficient charging hubs with grid edge technologies and smart charging** - Locate charging hubs on the outskirts of cities, connected with public transport systems and alternative mobility means - Support the evolution of regulatory paradigms to enable new energy-related services - Decide on the approach to charging mobility hubs: public, private or public and private cooperation • **Develop digitalized end-to-end customer experience to enhance access to charging services** - Create a national database of public charging points through public-private partnership - Standardize and simplify the payment of the charging services

Source: World Economic Forum

Integrated approaches for electric mobility with city, national and regional cooperation

The city of Montreal (Canada) has created a multi-disciplinary internal committee for electrification of transport with the directorates of environment, transport, urban planning, economic development, municipal properties and rolling stock management and the Montréal Transit Authority.

The German National Platform for Electric Mobility platform was created in 2010 and led to the introduction of legislation meant to support electric mobility in cities, such as the authorization of free parking, use of bus lanes and special access rights for EVs. However, only a few cities adopted these policies due to the lack of city representation in the national platform. The platform is currently integrating cities in the working groups and in the law-making process.

Assess local characteristics to inform action

Assess current and projected local characteristics in terms of city infrastructure and design, energy system, and mobility culture and patterns.

The investment and infrastructure necessary to support electric mobility will vary significantly from one place to another, so any approach needs to be market specific. City infrastructure and design, energy systems, mobility culture and patterns were identified as the critical factors to consider when prioritizing actions:

- **City infrastructure and design**. Advanced critical infrastructures, like electricity and telecommunication networks, as well as the digitalization of city information services define the potential for innovative mobility and energy services such as smart charging. In dense cities, congestion and limited available space call for the deprioritization of personal-use vehicles.
- **Energy system**. The carbon intensity of the energy generation mix correlates to the potential emissions of electrified mobility. The prevalence of non-dispatchable energy sources, such as solar and wind, can determine optimal charging locations and timeframes. The level of decentralization of the energy system affects the level of autonomy the city has in designing regulatory frameworks for the supply of energy to charging stations. Cities should also assess their regulatory readiness to adopt electrification, digitalization and decentralization (see Figure 15).
- **Mobility culture and patterns**. Vehicle-ownership culture influences the potential penetration of mobility-as-a-service. The AV penetration potential indicates the city's level of AV adoption maturity. Finally, the public transport system's coverage is a vital indicator of its actual contribution to mobility patterns. These factors are all relevant to defining the best strategy and priorities to accelerate and maximize the electrification of travelled miles – for example, the relevance of electrification of personal-use vehicles in regards to other mobility services.

To gain a better understanding of how these local factors would affect a city's priorities in terms of the electrification of transport, some examples of assessing local factors and defining tailored recommendations are provided in the appendix. These examples are demonstrated by three representative urban areas: Paris, San Francisco Bay Area and Mexico City.

Principle 2 – Prioritize high-use vehicles

Transform the approach to transport electrification, advancing and reforming regulation, prioritizing high-use vehicles. The goal is to accelerate the electrification of miles to maximize value creation.

Important dimensions to be addressed when encouraging mobility electrification:

- Focus on electrifying public and private fleets, including mobility-as-a-service
- Complete electrification of the public transport system
- Enable the integration of AVs

Focus on electrifying public and private fleets, including mobility-as-a-service

- Introduce financial and/or non-financial incentives for high-use vehicles

This approach will accelerate the benefits of electrification, maximizing the amount of miles that will be run on electricity, and eventually reducing congestion.

Local authorities could take the responsibility to lead this change through financial and non-financial incentives that target public and private fleets, taxis, mobility-as-a-service operators or logistics companies. Bonus-malus systems to redirect investments from ICEs to EVs, granting shared electric vehicles access to selected areas of the cities or to high-occupancy lanes exclusively, are examples of policies to consider.

Examples of financial and non-financial incentives in the transformation approach

- Oslo is gradually introducing restrictions on cars entering its city center. It also grants access to priority lanes for shared EVs only. Initially, access was granted to any EV, but this resulted in congestion of priority lanes as soon as EVs proliferated.
- The Massachusetts Electric Vehicle Incentive Program incentivizes (up to $ 7,500 for purchase and $ 5,000 for lease) municipalities, universities, colleges and state agencies to electrify their fleets and deploy charging stations.

Public agencies could also partner with private companies to electrify alternative urban mobility, such as car sharing. Fleet operators should be encouraged to electrify their fleets to benefit from reduced operating costs.

Examples of efforts to encourage electrifying fleets, car sharing and other mobility services

Public fleets: Stockholm is progressively renewing public fleet vehicles with EVs. Oslo (Norway) plans to have all 1,200 public vehicles using electricity by 2020, and to increase their usage by sharing them between city-hall employees and citizens.

Police fleets: As part of a sustainability plan, the Los Angeles Police Department (LAPD) decided to switch 260 fleet vehicles of its fleet to EVs. Charging infrastructure development is also under way and being integrated with decentralized solar power generation. By leasing rather than buying vehicles, the LAPD can invest in charging stations, including fast-charging stations in city-centre car parks.

Taxis: In London (UK), the Transport for London office will require all new black cabs to be electric or emission free by January 2018, and diesel vehicles will not be permitted in London by 2032. Eighty charging points will be dedicated to black cabs, with plans to implement 150 by the end of 2018 and 300 by 2020.

Car sharing: In Paris (France), the region of Ile-de-France and Bolloré Group, a transport company, developed Autolib, an electric car sharing service with 4,000 EVs and 1,100 charging stations with more than 6,200 charging points across the region, accessible to service users and other EV owners. In Bangkok (Thailand), a consortium of companies, including BMW and Schneider Electric, is collaborating with the King Mongkut's University of Technology Thonburi to encourage EV use across Thailand, initially through car sharing and a campus-based electric bus.

Mobility-as-a-service: Lyft, a mobility-as-a-service operator, offers incentives to drive EVs. DiDi Chuxing, the main Chinese mobility-as-a-service operator, operates the largest fleet of EVs (about 260,000 with a target of a million by 2020). With Global Energy Interconnection Development and Cooperation Organization, DiDi is building its own charging station network primarily for its drivers before making them publicly available.

Last-mile delivery services: The city of Dortmund (Germany) is developing non-financial incentives for last-mile delivery companies to electrify their fleets: EVs receive permission for extended access to the city centre. DHL, a logistics operator, designed and manufactured an electric delivery van to electrify its last-mile delivery vehicle fleet.

Complete electrification of the public transport system

- Secure funding for electric buses and infrastructure, and renew the fleet gradually through public procurement
- Collaborate with public transport operator(s) to define fleet electrification targets
- Involve electricity network operators and electricity suppliers to enable smart charging and ancillary services at bus depots

Local authorities should complement the electrification of LDV miles by focusing on the electrification of public transport systems, especially in large cities with fully developed rail and bus networks.

The electrification of public transport systems should be undertaken systematically with the renewal of bus fleets. Authorities should collaborate with public transport operators to define a target for the completion of fleet electrification. The involvement of local electricity network operators is critical to enable smart charging and ancillary services, optimizing the charging profile of bus fleets at depots.

Electrification of public transport systems

In the Ile-de-France region around Paris, RATP, the main public transport operator, wants to electrify up to 80% of its bus fleet (around 3,600 units) by 2025, with a public investment of around €2 billion, which will also stimulate bus manufacturers to develop new solutions.

Buenos Aires (Argentina), Montreal, Oslo, Stockholm and Santiago (Chile) also prioritize the electrification of public transport through public procurement of electric buses.

China has prioritized the electrification of city public transport. According to the International Energy Agency, China's stock of electric buses exceeds 300,000 units. Shenzhen is one of the most ambitious cities, with hundreds of electric buses already in operation and a goal of having a completely electric bus fleet. Guangzhou Municipal Government, for example, plans to speed up bus electrification and aims to reach 200,000 new units by 2018.

Enable the integration of AVs

- Develop national regulatory frameworks that allow regions and cities to begin testing and introducing AVs
- Investigate the impact of AVs on urban spatial and infrastructure planning

AVs can play a major role in the future of urban mobility by reducing congestion in city centres, decreasing the number of accidents and significantly reducing mobility costs. Electrified and shared AVs could represent a significant portion of travelled miles since they could be on the road almost all the time. Their charging patterns are also controllable and provide additional flexibility to the electricity network.

National regulatory frameworks can enable regions and cities to begin their own local trials with AVs in partnership with private companies. In most European countries, regulations currently require a driver to be in control of any moving vehicle: such rules may have to be modified to accommodate AV trials. Moreover, increasing the number of AVs on city streets will require changes in the design of the urban environment as well as in customers' mobility behaviour. Pilots should include investigations into how AVs could be integrated into traditional urban spatial planning and what influence their use will have on urban infrastructures; 3D models of urban development may be considered to support this analysis.

Examples of efforts to integrate AVs

In early 2018, the city of Rouen, Region of Normandie and Renault (France) plan to launch a mobility-as-a-service pilot on open roads with five AVs for public use. Initially with human drivers' supervision, they have the potential to be driverless once the technology has been proven and regulations permit.

General Motors is developing a 24/7 free AV mobility service, initially for their employees in the US.

Volkswagen and the city of Hamburg (Germany) are working together to promote autonomous driving as part of the city's intermodal, traffic management, congestion and air-quality strategies. Projects include experimental applications of AVs for passengers and city freight, along with the expansion of electric mobility.

California Department of Motor Vehicles provides licences to test driverless cars on public roads in the Silicon Valley as part of an experimental programme.

China's government has announced it will develop national regulations for testing AV on public roads in China.

Singapore and Ann Arbor (USA) are piloting full automation. A study conducted in Ann Arbor, a mid-size US city, by the Columbia University Earth Institute showed that 18,000 shared and driverless vehicles could provide the same mobility service within the city as 120,000 vehicles for personal use, at lower cost and higher productivity.

Principle 3 – Deploy critical charging infrastructure today while anticipating the transformation of mobility

In the context of mobility and energy systems transformation, planning charging infrastructures is critical in order to cope with the risk of stranded assets.

Recommendations to optimize investments in charging infrastructures include:

- Focus on reducing range anxiety and promoting interoperability
- Prioritize energy-efficient charging hubs with grid edge technologies and smart charging
- Develop digitalized end-to-end customer experience to improve access to charging services

Figure 15: Redesigning the regulatory paradigm

Redesign regulatory paradigm
Change the rules of the game, enabling new roles for network operators, innovation and full integration of decentralized energy resources

- **Evolve the revenue model**
  - Promote innovation & efficiency through outcome-based regulation
  - Remove bias towards capital expenditures by allowing non-wire alternatives to compete
- **Integrate DERs into markets and monetize their services**
  - Clearly define role, asset type, and ownership of DERs
  - Enable adequate market design, allowing independent aggregation and location-based valuing of DERs
- **Modernize system planning**
  - Shift from distribution network operators to distribution service platform providers
  - Break regulatory silos (geographies, industries, sectors) through integrated plans
  - Reassure investors by clarifying the transition path and regulatory timeline
- **Use price signals by redesigning rate structures**
  - Introduce dynamic prices and assess efficacy of flexible demand charges

In order to deploy critical charging infrastructure now while anticipating the future of mobility, the redesign of the regulatory paradigm for the energy system is needed. Also see The Future of Electricity: New Technologies Transforming the Grid Edge, published by the World Economic Forum.

Focus on reducing range anxiety and promoting interoperability

- Develop fast-charging networks through public-private funding to connect different cities
- Include standardization and interoperability in minimum requirements

Range anxiety remains a major barrier to EV adoption by public- and private-fleet operators as well as individuals. It should therefore be a priority to implement a national and transnational network of interoperable fast-charging stations at highways and to provide charging services at commuting hubs.

Networks of fast-charging stations could be developed through public-private funding to connect cities. These charging stations are not only investments for the future but can be profitable using the correct business models. In the future, new services could be developed as additional sources of revenue.

Standardization and interoperability of infrastructures are critical to ensure that a variety of service providers can enter the market and customer experience is as smooth as possible. This is a specific issue where a multistakeholder approach will accelerate achievement of results and help define a minimum requirement for infrastructure development.

Focus on reducing range anxiety and encouraging interoperability

Enova SF, the Norwegian energy and climate change fund, has been investing in a network of fast-charging stations connecting Norway's southern main cities and ensuring a charging station every 30 miles.

Similar initiatives are ongoing along the main corridors in Europe, such as the CIRVE (Iberian Corridors of Rapid Recharging Infrastructure for Electric Vehicles) project deploying multi-standard quick-charging points on the highways connecting France, Spain and Portugal, supported by European Commission funds.

MIT is proving the value of mobile phone data records to estimate EV mobility demand and optimize the location of charging stations. The resulting optimized deployment could reduce the distance driven to reach the closest charging station by more than 50%. Mobility data analysis and deployment optimization can substantially improve accessibility of charging stations.

The smart charging pilot run by Southern California Edison and Autogrid addressed the challenges associated to the proliferation of charging stations and EVs from several vendors, adopting a variety of technical protocols, and supporting the widest variety of use-cases. The pilot proved the suitability of adopting a unified cloud-based application using open standard protocols like OpenADR2.0 and SEP 2.0. In addition the pilot also studied the response of EV drivers to price fluctuations and electronic requests to curtail charging (demand response), and the impacts of EV charging on power systems.

Prioritize energy-efficient charging hubs with grid edge technologies and smart charging

– Locate charging hubs on the outskirts of cities, connected with public transport systems and alternative mobility means
– Support the evolution of regulatory paradigms to enable new energy-related services
– Decide on the approach to charging mobility hubs: public, private or public and private cooperation

Cities will also require networks of publicly accessible charging stations for urban traffic. Planned as hubs, offering mobility and energy services, they will complement existing private charging stations. These hubs should be designed with the long-term transformation of mobility in mind, so they do not become stranded assets as mobility patterns change.

Located in the outskirts of the cities and connected with the public transport system and alternative mobility means (such as car sharing and other mobility services), they should accommodate enough traffic from both personal-use vehicles and fleets to provide revenue to the operators, either directly by selling electricity and subscriptions, or indirectly through additional mobility- and energy-related services.

The involvement of electricity network operators will facilitate the integration with the energy system. Supporting the evolution of the regulatory paradigm (see Figure 15), for example through the introduction of dynamic pricing, will enable additional energy-related services (see the text box titled "Integration with grid edge technologies and smart grids").

The development of these charging mobility hubs could take different approaches, such as using public, private or public-private cooperation, depending on the local market maturity.

Examples of smart charging hubs

Oslo's Vulkan project to develop an EV charging facility on the city's outskirts demonstrates a public-private cooperation model between the city, a utility company and a real-estate firm. Equipped with about 100 multi-speed charging stations and offering smart charging, battery reserve and vehicle-to-grid technologies, it is fully digitalized with pre-booking for fleet operators and car sharing services. Vulkan could be a model for future charging hubs.

The EUREF Campus, in the outskirts of Berlin (Germany), hosts international technology companies and research institutions. It offers normal and fast-charging stations for EVs and alternative mobility means, such as bikes. The campus is also equipped with inductive charging for fleet operation. The stations are V2G-ready, integrated in the local micro smart grid with solar and wind generation and enabling smart charging solutions. The microgrid uses artificial intelligence with machine-to-machine learning capacity to optimize EV charging and send energy surplus back to the grid, based on dynamic pricing.

Develop digitalized end-to-end customer experience to enhance access to charging services

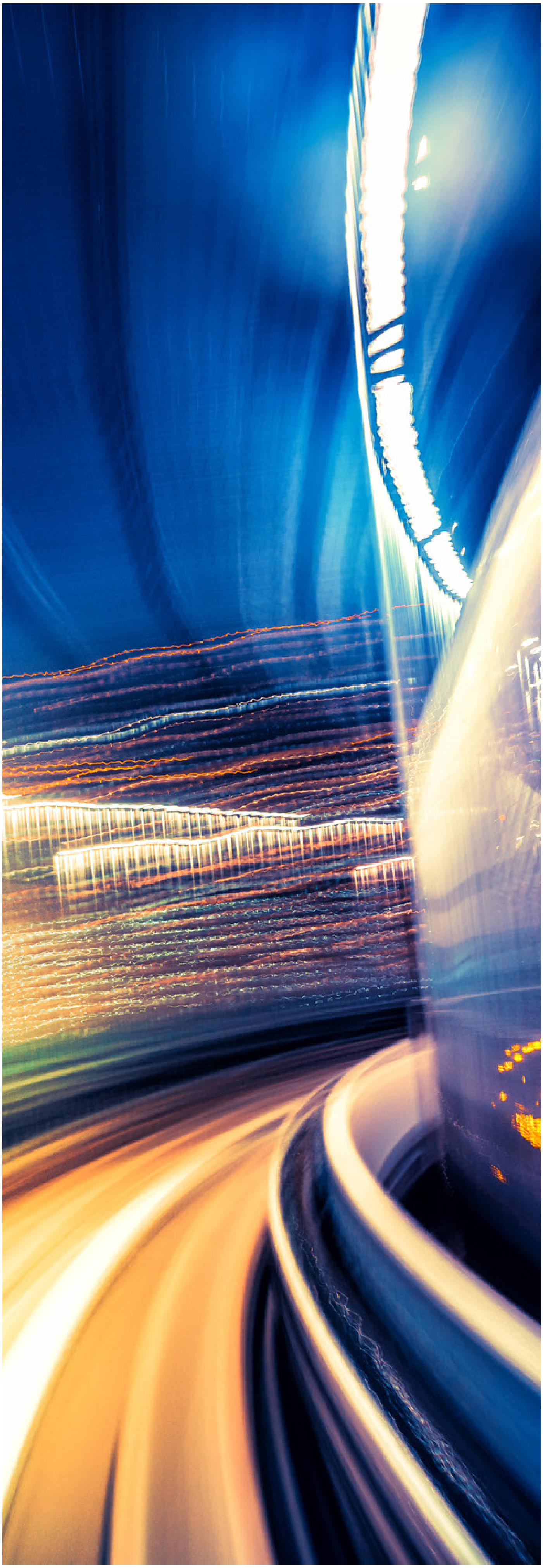
- Create a national database of public charging stations through public-private partnerships
- Standardize and simplify the payment of charging services

Customer's engagement with the new energy and mobility services will be accelerated by creating a seamless experience.

Ensuring data access and sharing, while safeguarding privacy and cybersecurity, is critical. Public and private stakeholders should partner to create interoperable databases of charging points, so that customers can move across cities and countries with real-time visibility of available stations. Operational data from the infrastructure should be collected, elaborated and shared with all relevant stakeholders to continuously improve services, and plan infrastructure development. Services would be managed through digital interfaces, and payment processes standardized and simplified.

Example of a national database of public charging points

The Norwegian government is cooperating with the Norwegian Electric Vehicle Association and the private sector to develop NOBIL, an open, publicly owned database available to everybody for the development of new services, such as real-time location of available and accessible charging stations.



Conclusions

EVs are proliferating globally at a rapid pace due to decarbonization policies and the draw of improving EV costs and performance for customers. However, the current trajectories, with an emphasis on vehicles for personal-use vehicles and non-integrated strategies for the deployment of charging stations, could limit the benefits that can be generated by electrification of transport.

By anticipating the transformation of mobility and energy systems, a more comprehensive approach can be designed to meet climate goals, optimize investments, enable innovation of services and infrastructure while dramatically increasing productivity and generating economic growth.

Policy-makers will have to advocate for the convergence of local energy, urban and mobility patterns in regards to electrification strategies. They should also ensure that city, national and regional policies support and reinforce each other.

The energy sector will have to accelerate the path towards a cleaner, more digitalized and decentralized system, yet one that is more connected and customer centric. Enabling dynamic pricing and creating new roles for network operators by redesigning the regulatory paradigm will be vital to this strategy.

The mobility sector will have to be at the forefront of the transformation of mobility patterns, developing new business models based on service and sharing models, rather than ownership and personal use of vehicles. At the same time, mobility players will have to consider the opportunities created by new uses and services associated with EVs as decentralized energy resources.

Urban planners will have to involve energy and mobility-relevant stakeholders to define the optimal location of the publicly accessible charging infrastructure. They will also have to support investigations of how traditional urban spatial planning will support the adoption of AVs and its potential influence on the design of the urban environment.

All stakeholders must cooperate to ensure a seamless customer experience, by supporting the deployment of a flexible, open and multiservice infrastructure. The creation of multistakeholder public-private working groups at the early stages of the journey will maximize potential value and favour the emergence of effective partnerships to support the initial development of the market, including infrastructure.

The World Economic Forum encourages the implementation of this report's recommendations to accelerate the transformation of energy and mobility systems.

Appendix

a. Paris

Figure 16: Synthesis of Paris' local factors

		Level	Rationales	Example of tailored recommendations
Infrastructure & design	Smarter cities maturity	Low – High	• Amongst top 5 smartest cities in the world • Clichy-Batignolles (54ha Paris neighborhood) largest scale smart grid initiative	• Electrify new forms of mobility (mobility-as-a-service, AV) and public transport fleets (bus) • Develop a framework for AV integrated with the public transport system for outskirt commuting • Build charging hubs through public and private partnerships with real-estate companies and parking operators by public transport nodes in city outskirts • Capitalize on existing smart grids to integrate new charging hubs into the energy systems and enable dynamic pricing
	City density	Low – High	• High density; 9th most congested city worldwide	
Energy System	Carbon intensity	Low – High	• Low carbon emission in France due to energy mix (72% nuclear, 19% renewables), towards 37% of renewables in 2030	
	Dispatchability	Non dispatchable – Dispatchable	• High dispatchability due to decrease in 2030 through solar and wind push • 5% of needs produced in Paris; consumption to increase by 13% with the Greater Paris' project (including fuel efficiency)	
	Level of decentralization	Centralized – Decentralized	• Grid operated by regulated company Enedis with multiple operators	
Mobility culture and patterns	LDV ownership culture	Owned – Shared	• Average ownership culture with 0.3 car per inhabitant and 0.86 private parking space per car • Push for shared mobility through Autolib' service	
	AV penetration potential	Low – High	• AV experimentations authorized since 2016 and ongoing pilots with autonomous shuttles	
	Public transport system coverage	Limited – Excellent	• Amongst top 5 cities for its public transport system (46% of motorized commuting)	

In Paris, the deployment of new technologies is rapidly growing in order to provide additional services to a dense population. Smart meters are being deployed extensively and a 4G network is fully deployed. The level of congestion is among the highest in the world and the city is facing a scarcity of space in its central and business districts. The city council has already taken measures to reduce the number of personal-use vehicles.

Electrify new forms of mobility and public-transport fleets

The extended public transport system accommodates half of Parisian commutes. Mobility-as-a-service companies are increasingly used in the city centre. Therefore, rather than focusing on the electrification of personal-use vehicles, the city should exploit the quality of its public transport system and encourage the electrification of the bus fleet, in addition to last-mile delivery services, taxis and alternative means of mobility.

Develop a framework for AVs integrated with the public transport system

AVs may also help to reduce congestion and ease connections between the main public transport hubs. In cooperation with the French government, the development of a framework for AV pilot schemes and deployment should prioritize public transport and shared mobility. RATP, the city's public transport company, is piloting electric autonomous buses around the city in order to develop an integrated solution for unmet mobility needs, such as those of non-connected areas.

Build charging stations at public transport hubs in city outskirts

The acceleration of electrification calls for infrastructure development to charge buses, public and private fleets, as well as personal-use vehicles when mass transit is not an option. The charging stations should primarily be located in the city outskirts, to avoid stranded assets in the centre as the city rids itself of personal-use vehicles; stations should connected to the main public transport hubs to ease commuting. Developed through public and private partnerships with real-estate companies or parking operators, they should provide additional services such as parking places, vehicle cleaning, maintenance and repair or shopping centres.

Capitalize on smart grids and enable dynamic pricing

These charging hubs will benefit from Paris and its surrounding region's carbon-free energy system (France's centralized energy generation mix is 72% nuclear) if connected to the grid or incorporated in the region's transition plan towards increased use of renewables. Cooperation with electricity network operators is essential to take advantage of the deployment of smart grids and enable smart charging in hubs and at bus depots. The city should cooperate with the national regulator to anticipate management of additional non-dispatchable energy sources by enabling dynamic pricing to encourage off-peak charging.

b. San Francisco Bay Area

California's San Francisco Bay Area profile has high levels of personal-use vehicles and an energy mix with considerable solar generation.

Develop charging stations integrated into the local energy system with dynamic pricing

Renewables represent about a third of the electricity generated in the state of California and are set to increase in the future, primarily through solar and wind generation. The electrification of transport could add existing challenges to the "duck curve" (the temporary imbalance between peak demand and renewable energy production, for instance, the peak generation is in the middle of the day in California while the peak demand occurs after sunset) as current charging patterns would create an additional disconnection between electricity supply and demand. Clear, automatic and real-time pricing signals are critical so customers charge at the optimal time, flattening the load curve. It would also help reducing the curtailment of renewables by encouraging charging in the middle of the day to capture excess solar production.

Build mobility charging hubs where there is low demand during the day

The region should work with electricity network operators to identify locations with a low load during the day in addition to available circuit and substation capacity, to plan and deploy mobility hubs. These should be located primarily at the outskirts of cities, in parking stations at destination points and along highways. Planning should anticipate the evolution of mobility patterns to avoid potential stranded stations in downtown streets, for instance.

Prioritizing public and private fleets while accelerating AV integration

Because most of the commuting in the San Francisco Bay Area takes place in private vehicles, electrification should prioritize public and private fleets through financial incentives and public-sector procurement. Mobility patterns are evolving with the development of mobility-as-a-service. Creating incentives for shared AVs would help decrease congestion and offer a fair-priced alternative for commuters not connected to the public transport system. The optimization of charging patterns could minimize the cost of charging and its impact on the energy system.

Figure 17: Synthesis of San Francisco Bay Area's local factors

		Level	Rationales	Example of tailored recommendations
Infrastructure & design	Smarter cities maturity	Low – High	• Amongst top 5 smartest cities in the world • 1st global start-up ecosystem in the world enabling smart urban development projects	• Develop charging hub integrated into the local energy system (grid and off grid) with dynamic pricing, to push for charging off-peak (during the day or overnight)
	City density	Low – High	• Average density; 4th most congested city worldwide	
Energy System	Carbon intensity	Low – High	• Clean energy mix in California with already 29% from renewables	
	Dispatchability	Non dispatchable – Dispatchable	• Driven by increasing decentralized and non-dispatchable solar and wind generation	• Build mobility charging hubs in cooperation with the utilities prioritizing location where there is low demand during the day in the outskirts of the city
	Level of decentralization	Centralized – Decentralized	• Growing curtailment	
Mobility culture and patterns	LDV ownership culture	Owned – Shared	• High ownership culture with 70% of households owning a personal-use vehicle • Mobility-as-a-service and carpooling rising in the city (27% of motorized transport)	• Continue to promote personal-use vehicles electrification while prioritizing public and private fleets through incentives and public procurement while driving AV penetration
	AV penetration potential	Low – High	• AV regulatory framework and ongoing pilots in the city (e.g., General Motors, Lyft, Uber, Waymo)	
	Public transport system coverage	Limited – Excellent	• Good coverage of public transport system through bus and tramway networks (35% of motorized commuting)	

c. Mexico City

Mexico City differs from Paris and San Francisco primarily by the carbon intensity of its energy mix, the limited development of its public transport system and the prevalence of collective transport.

Invest in decentralized and clean renewables to power the charging infrastructure

Today, Mexico City's energy mix relies on carbon-intensive sources. Combined-cycle power plants, powered by natural gas, dominate the system as they replace thermal plants that run on coal and fuel oil. The city has prioritized investment in decentralized and clean, renewable power generation. This strategy aligns with national targets set out in the country's energy reforms to take full advantage of Mexico's potential for renewables and push for its uptake to reach 35% by 2024. Such a shift is critical for the electrification of transport to have a positive effect air quality.

Electrify collective means of mobility and public transport while discouraging use of personal-use vehicles

Personal-use vehicle ownership is low and public transport has not kept pace with the rapid expansion of the city. Thus, collective motorized means of mobility, such as *colectivos* and *peseros* – minibuses and vans that carry groups of passengers – account for nearly half of motorized commuting trips. Local authorities should therefore regulate and encourage their replacement and electrification, as well as the electrification of the roughly 140,000 registered cabs. As congestion is a major issue, local authorities should discourage the use of personal-use vehicles and invest in developing an electrified rapid transit network to connect the districts of the growing city.

Develop publicly accessible smart charging stations located at destination points and depots

The public and private sectors should cooperate to finance and operate a network of publicly accessible, standardized smart charging stations to complement the points already installed by the public electricity network operator. Charging stations should primarily be located at destination points and at depots served by taxis, *colectivos* (collective mini-bus services) and buses. They must also be accessible to personal-use EVs, whose number will increase as emission regulations strengthen. Their digitalization, including a publicly accessible database, would facilitate the development of services such as priority booking for fleet vehicles.

Figure 18: Synthesis of Mexico City's local factors

		Level	Rationales	Example of tailored recommendations
Infrastructure & design	**Smarter cities maturity**	Low – High	• Around 80th smartest city in the world • High density and strong demographic growth; 12th most congested city worldwide • Most polluted city in the Americas	• Invest in decentralized and clean renewables to power the development of the charging infrastructure • Prioritize the electrification of the taxis, mobility-as-a-service and collective mobility means, including public transport while discouraging the use of personal-use vehicles • Develop a network of publicly-accessible smart charging stations primarily located at destination points and depots with fast chargers
	City density	Low – High		
Energy System	**Carbon intensity**	Low – High	• Carbon-intensive energy mix in the country (60% gas, 21% coal and oil, 15% renewables) with ambition to reach 35% of renewables by 2025 • Dispatchable energy mix (only 3% of DER) • Power market where state-owned company CFE has the largest capacity, new bidding mechanisms anchoring competitive renewable energy and gas generation • Transmission and distribution of electricity controlled by the state	
	Dispatchability	Non dispatchable – Dispatchable		
	Level of decentralization	Centralized – Decentralized		
Mobility culture and patterns	**LDV ownership culture**	Owned – Shared	• Personal-use vehicles representing only 28% of commuting motorized trips • ~50% of commuting motorized trips through collective alternative transport means (taxi, colectivo, mobility-as-a-service) • Low AV automation potential with no established regulatory framework • Underdeveloped public transport system (22% of commuting motorized trips, trolley buses already electrified)	
	AV penetration potential	Low – High		
	Public transport system coverage	Limited – Excellent		

d. Value calculation methodology

Figure 19: Synthesis of value drivers

BENEFIT		VALUE DRIVERS	CALCULATION METHODOLOGY
Energy		Smart demand	Based on electricity prices in California and Northeast US energy markets (CAISO and PJM) and the load optimization, applied to mileage
		Capacity	
Environment		CO_2 emissions	• Emission efficiency improvement x mileage x $/$CO_2$ • $/$CO_2$ forecasts based on new electric generation mix • Air pollution benefits also included: welfare and labor savings
		Additional emission savings (curtailment through smart loading)	Based on California and Northeast US energy future energy curtailment (CAISO and PJM) and the load optimization, applied to mileage
Mobility		Operating costs	• (EV vs. ICE cost / mile) x EV mileage • (AV vs. mobility-as-a-service with driver cost / mile) x AV mileage • Based on forecasted cost per mile
Other	Health	Accident and fatality	(current LDV stock – forecasted LDV stock) x # accidents per vehicle x cost per accident
	Congestion	Productivity	• Cost without mobility-as-a-service / AV – cost with mobility-as-a-service / AV • Based on forecasted $/VMT; ratio 1:2 for mobility-as-a-service and AV

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