AHEAD

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Transportation Electrification Policy in California and Germany

Comparison and Implications for German Electric Vehicle Policy

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Contents

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Executive summary

The future is electric and California and Germany are currently behind the wheel. After spending years as more of a conception than a reality, electric vehicles (EVs) are becoming a global trend bound to grow beyond niche demand. California and Germany stand out as two key markets for both the development and purchase of EVs, particularly because of their visions or strategies for transportation summarized under the concepts "Verkehrswende" (transportation transition) and "transportation electrification" respectively. Therefore, this report compares the California and Germany EV markets and regulatory frameworks, taking stock of the current state and upcoming opportunities and challenges analyzed through the lens of the technology innovation system (TIS) framework. The report employs a comparative methodology based on a review of the literature, media, and online material and 16 semi-structured expert interviews conducted in summer 2016 with policy analysts and stakeholders (industry and public sector) in Germany. It aims to inform policy makers and stakeholders in one jurisdiction about developments in the other jurisdiction, and to identify best practices and mutual lessons for future policies and other jurisdictions. Given that California is at a more advanced stage, this work particularly addresses German policy makers and stakeholders, who may find insights from California PEV policies and market developments valuable.

A first overarching finding is that regardless of the structural differences, Germany and California face common challenges. These include:

1. development of new policies and regulatory frameworks to promote **expansion in niches capable of inducing disruptive innovation** as a next step and the broader market in the long-term, including expanding public charging infrastructure,
2. **vehicle-grid integration** (VGI) including the design of electricity rates for efficient charging as well as scheduling EV charging to complement grid operation, the use of EVs for demand side services (storage), and accompanying operation and expansion of the grid as necessary,
3. and management of the interactive effects occurring along with **other trends such as mode-switching, car-sharing, autonomous vehicles,** and increased penetration of variable renewable energy resources.

A second overarching finding is that several elements stand out from California's richer and more comprehensive policy approach for potential learning and transfer to Germany, including:

1. **centralized coordination** of all public-sector activities through **a concrete action plan** and knowledge sharing through a single government body,
2. greater policy **focus on the need and preferences of consumers** combined with wide availability of related data,
3. explicit consideration of equity and the **inclusion of disadvantaged communities,**
4. and the use of a broad portfolio of **market based instruments** targeting fuels, manufacturers and consumers alike.

None of these elements is a simple recipe for success or can be seen as one-size-fits-all solution. Rather, they provide inspiration and help to refine the major questions that German policymakers and other stakeholders should seriously consider when making choices as to how to shape the future of electric vehicles and more broadly also the transportation sector.

1. Introduction

As automakers and policymakers make almost daily major announcements concerning the EV sector, it is clear that plug-in electric vehicles (PEV), and especially battery electric vehicles (BEV), are becoming a global trend. [1] California and Germany stand out as two key markets for the development and purchase of PEVs. This report compares industry best practices and potential future policies.

California has evolved into a leading market for transportation electrification, driven by its air quality concerns, strong environmental ethic, high dependence on cars and trucks, need to integrate renewables into a grid that was originally designed for dispatchable fossil fuel generation, and culture and economy focused on technical innovation. Approximately 250,000 electric vehicles are on California roads today[2], and the state has plans and programs in place to reach its goal of 1.5 million electric vehicles by 2025. In contrast Germany, with its world-leading automotive industry and robust grid, appears to have a more cautious culture, and faces other pressing environmental concerns not directly related to transportation, such as reducing coal consumption. Perhaps as a result, Germany has taken a "wait and see" approach to transportation electrification, at least until recently, despite also having a strong environmental ethic. Even though the country has a goal of 1 million electric vehicles by 2020, with a mere 57,000 PEVs (of which 39,000 are BEV) on the road today,[3] it is highly unlikely that this goal will be met. Driven by a need to reduce greenhouse gas (GHG) emissions in the transportation sector, where emissions are still above 1990 levels, the federal government has recently begun pursuing more ambitious transportation electrification policies, such as vehicle purchase rebates (*Umweltbonus*). So far, these policies have had only a minor impact on vehicle adoption. Nevertheless, it is widely acknowledged – as interviews carried out for the purpose of this study confirm (see below) – that PEVs are coming, if not yet truly at a tipping point in Germany.

Against this background, we assess recent developments in California and Germany. We target stakeholders in both California and Germany that are exploring what needs to be done to push PEV markets into a more self-sustaining expansion. Our focus is thus on policy lessons and recommendations, in light of both Californian and German experiences to date. Given that California is at a more advanced stage of PEV adoption, we believe that German stakeholders in particular may benefit from this presentation of California PEV policies and market developments. At the same time, it is clear that policies cannot be simply transferred from one region to another – policies and feasible paths forward are highly dependent on the specific economies, political systems, regulatory competencies, electricity systems, geographies, lifestyles, and cultures of each region. Additionally, both regions are only at the beginning of the transformation of their transportation sectors.

We employ a comparative methodology based on (1) a review of the literature, media, and online material and (2) 16 semi-structured expert interviews conducted in summer 2016 with policy analysts and stakeholders (industry and public sector) in Germany, as well as three expert interviews conducted in Japan, to provide a broader perspective. Our analysis utilizes the technology innovation system (TIS) framework borrowed from the sociotechnical change literature[4] introduced in Section 2, which allows us to highlight similarities and differences regarding policy

1 A Plug-in Electric Vehicle (PEV) is a general term for any car that runs at least partially on battery power and is recharged from the electricity grid. There are two different types of PEVs: pure battery electric vehicles (BEV), which run completely on electricity stored in batteries and have an electric motor rather than a gasoline engine, and plug-in hybrid vehicles (PHEV), which combine two propulsion modes in one vehicle – an electric motor that is battery powered and can be plugged in and recharged, and a gasoline engine that can be refueled with gasoline. (Source: https://driveclean.arb.ca.gov/pev/Plug-in_Electric_Vehicles/PEV_Types.php).

2 Source: Plug-In Electric Vehicle Collaborative, http://www.pevcollaborative.org/sites/all/themes/pev/files/161110_PEVC_PEV_250KSales_Milestone_Release%5B4%5D.pdf

3 Source: Kraftfahrt-Bundesamt (KBA), http://www.kba.de/SharedDocs/Pressemitteilungen/DE/2016/pm_08_16_bestand_01_16_pdf.pdf

4 Hekkert, M.P., R.A.A. Suurs, S.O. Negro, S. Kuhlmann, and R.E.H.M. Smits. 2007. "Functions of Innovation Systems: A New Approach for Analysing Technological Change." Technological Forecasting and Social Change 74 (4): 413–32.

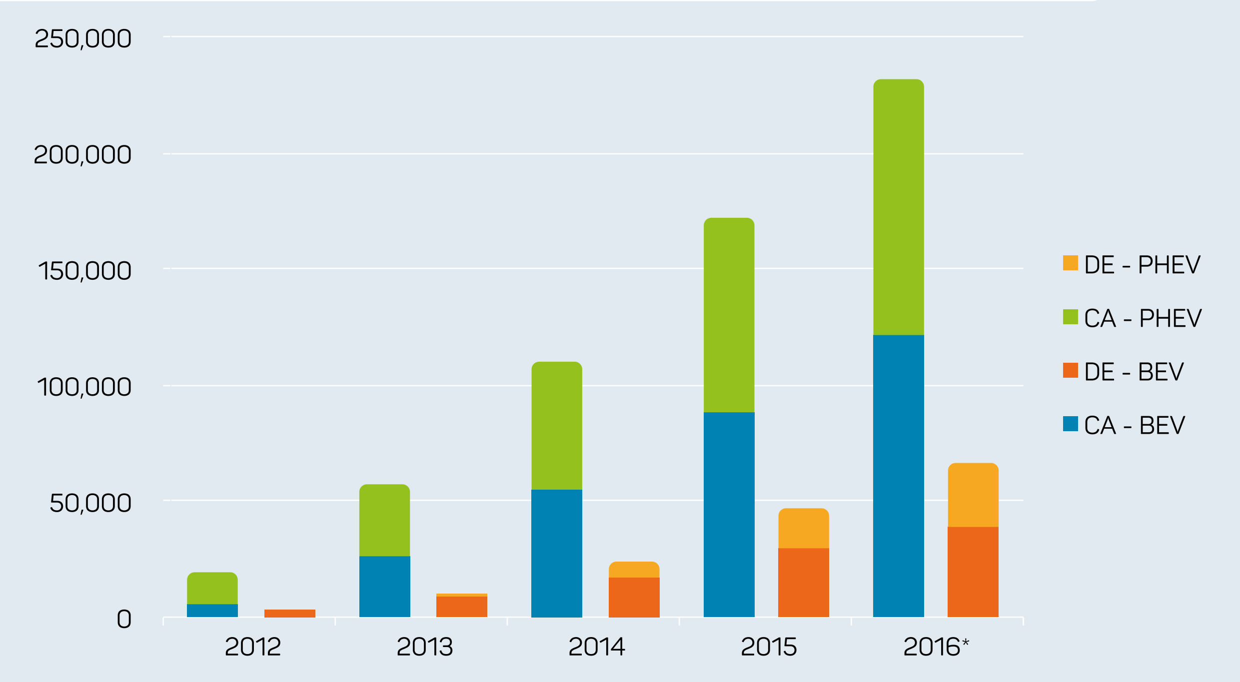
innovations in the two regions, and to identify areas for potential improvement. We apply the TIS framework along three dimensions: policy context (Section 3), stakeholders (Section 4), and regulation & policies (Section 5). In the last section, we will make observations and recommendations for the path forward for German policy making, as well as raise open questions for further consideration. We begin with a short overview of market developments in California and Germany in the following section.

1.1 Electric Vehicle Market Development

Plug-in electric vehicle (PEV) sales in California and Germany have primarily been in the light duty vehicle segment (cars), though model availability and sales are expanding into other vehicle types such as SUVs and buses. In Germany, as of October 2016, around 39,000 battery electric vehicles (BEVs) and around 28,000 plug-in hybrid electric vehicles (PHEVs) had been registered since 2012, a combined 0.1% of all personal automobiles.[5] In the same period, approximately 122,000 BEVs and 110,000 PHEVs have been sold in California, representing 1% of all personal automobiles (excluding pickup trucks).[6] In other words, California has roughly quadruple Germany's cumulative PEV sales, despite the fact that about half as many cars are sold in California each year. On a percentage point basis, considering cumulative PEV sales relative to total personal automobile registrations, California has *seven times* the sales of electric cars. Annual sales data, shown in Figure 1 below, demonstrate that while Germany's PEV sales are increasing relative to California's, a significant gap remains.

Charging infrastructure penetration is also a key indicator of market development. As of August 2016, California had 10,280 public charging stations (charging outlets) located at 3,376 facilities, as well as 2,041 private charging stations located at 609 facilities.[8] Germany, meanwhile, as of June 2016 has 6,517 public charging stations at 2,859 facilities. Out of thse stations, 230 offer DC (direct current) fast

Figure 1 | Cumulated light duty electric vehicle sales (CA) or registrations (DE) since 2012 (*data for 2016 only until October)[7]

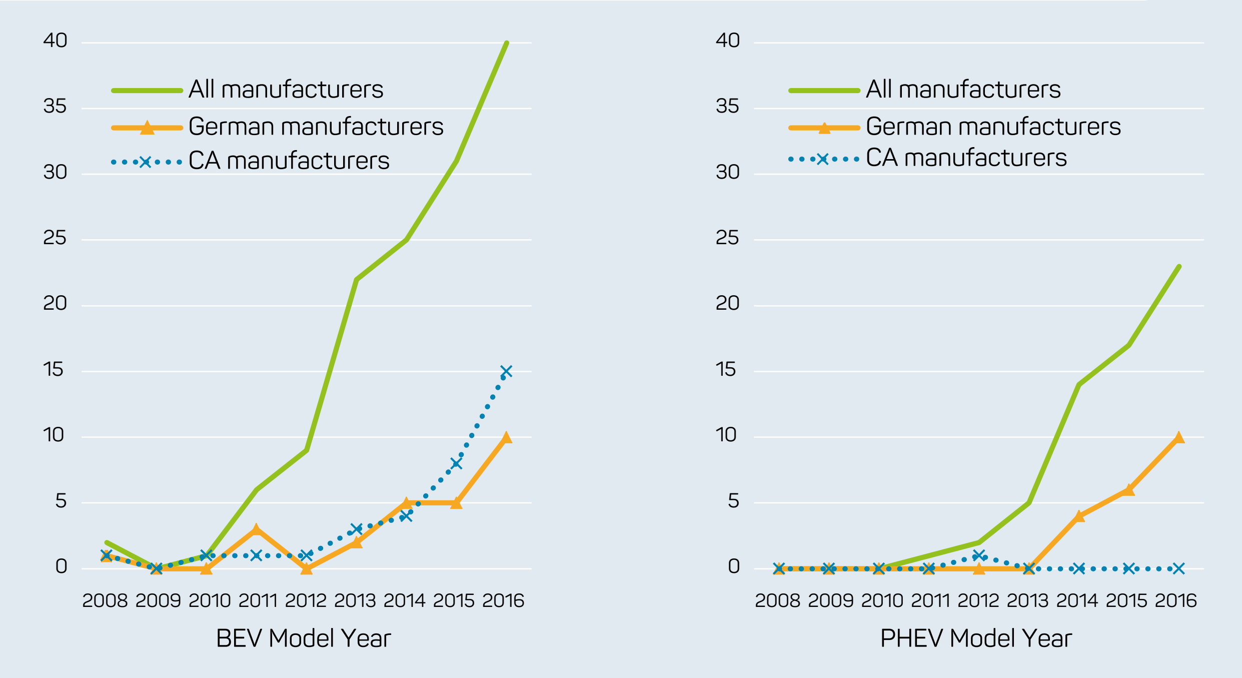


5 Source: KBA, http://www.kba.de/DE/Statistik/Fahrzeuge/fahrzeuge_node.html. PHEV data were not collected until 2013 and therefore the number of PHEVs in Germany excludes vehicles registered in 2012.
6 Source: ZEV Facts, http://www.zevfacts.com/sales-dashboard.html
7 Source: KBA and ZEV Facts (see previous footnotes)
8 Source: US DoE, http://www.afdc.energy.gov/fuels/stations_counts.html

charging; the respective number for California was not provided in the used sources.[9] Technically, fast charging capacity is defined as larger than 22 kW, which can be up to 200 kW or even 350 kW in the CCS (Combined Charging System) standard. Depending on battery size, e.g. 33 kWh for a BMW i3 and 60 kWh for a Tesla Model S, charging times can be reduced considerably.

While lack of charging infrastructure and range anxiety – the fear felt by drivers of electric vehicles that they will run out of fuel and be left stranded – is a critical barrier to adoption, and was frequently brought up in interviews in Germany as the second most critical barrier after cost, it is important to note that lack of infrastructure might be a less significant problem than drivers expected. In fact, nearly 70 % of PEV drivers need out of home charging less than once per month, if they have it available in the home.[10] Other studies have shown that the daily travel needs of over 85 % of US drivers can be met by charging existing BEVs only at night[11], and that 87 % of US vehicle-day needs could be met by an existing, affordable electric vehicle[12]. At the same time, many potential PEV drivers do not have access to overnight charging, e.g. because they live in multifamily dwellings without dedicated parking. Moreover, most PEV drivers do use public charging infrastructure at least on occasion, and the very existence of the infrastructure can help to ease range anxiety, even if it is not frequently used; individuals who are aware of charging stations have also been found to be more willing to consider purchasing a PEV.[13] As further discussed in Section 5.5, the need to build up public infrastructure and determine who should pay for it are important questions to be considered.

Figure 2 | PEV model availability in California from Californian, German, and other manufacturers[14]



9 Source: BDEW, https://www.bdew.de/internet.nsf/id/bdew-erhebung-elektromobilitaet-de
10 Source: INFRASTRUCTURE MARKETS, STAKEHOLDERS, AND NEEDS THROUGH 2025-2030, Michael Nicholas and Gil Tal, April 2016. http://steps.ucdavis.edu/wp-content/uploads/04-26-2016-Nicholas-Charging-Workshop-CEC-2016-Nicholas.pdf, page 5.
11 Saxena, Samveg, Jason MacDonald, and Scott Moura. 2015. "Charging Ahead on the Transition to Electric Vehicles with Standard 120V Wall Outlets." Applied Energy 157 (November): 720–28. doi:10.1016/j.apenergy.2015.05.005.
12 Needell, Zachary A., James McNerney, Michael T. Chang, and Jessika E. Trancik. 2016. "Potential for Widespread Electrification of Personal Vehicle Travel in the United States." Nature Energy 1 (9): 16112. doi:10.1038/nenergy.2016.112.
13 The role of infrastructure in PEV adoption, Gil Tal and Michael Nicholas April 2016. http://steps.ucdavis.edu/wp-content/uploads/04-26-2016-Tal-STEPS-Workshop-4_26_16-V2.pdf, page 5; and Consumer Views on Plug-in Electric Vehicles – National Benchmark Report, Mark Singer, National Renewable Energy Laboratory (NREL), January 2016, page iii. http://www.nrel.gov/docs/fy16osti/65279.pdf.
14 Source: California Air Resources Board (CARB), http://www.driveclean.ca.gov/Search_and_Explore/Technologies_and_Fuel_Types.php. Variations are counted as distinct models.

Model availability is also a key element of market development, as market niches can only adopt vehicles if appropriate models are available. The availability of models from Californian and German manufacturers is an important indicator of stakeholder evolution in the two regions and of the ability for regional manufacturers to benefit from PEV incentives. Trends in model availability for passenger cars are shown in Figure 2.

Beyond passenger PEVs, other types of electric vehicles are emerging. E-bikes have been particularly successful in Germany, where they now comprise 12.5 % of bicycle sales. As of early 2016, Germany had 2.5 million e-bikes, with 535,000 sold in 2015 alone. Also a leader in e-bike manufacturing, Germany exported 140,000 e-bikes in 2015.[15] In the last-mile delivery sector, Germany's DHL has entered the market with its own PEV delivery vans, which it also plans to sell externally.[16] Other emerging vehicle types include buses, trucks, and other medium and heavy-duty vehicles.[17] However, according to our interviews, lack of diverse vehicle types in large-scale production (even amongst passenger vehicles) continues to be a major market barrier in both regions. And in Germany, to the extent that most vehicle types are today available from foreign manufacturers, support for PEVs would hardly be effective from the perspective of national industrial policy. We return to this in Section 6.

15 Source: Zweirad-Industrie-Verband, Zahlen – Daten – Fakten zum Deutschen E-Bike-Markt 2015, March 2016. http://www.ziv-zweirad.de/fileadmin/redakteure/Downloads/Marktdaten/PM_2016_08.03._E-Bike-Markt_2015.pdf

16 Source: http://www.dw.com/en/deutsche-post-dhl-makes-its-own-electric-delivery-vans/a-19332124

17 Source: Examples include BYD and Proterra electric buses, http://www.byd.com/na/ebus/ebus.htmland, http://www.proterra.com, Orange EV terminal trucks, https://orangeev.com/, and more examples at http://www.energy.ca.gov/altfuels/2015-MISC-04/documents/2015-12-02_presentations.php

2. Technology Innovation System Framework

Several frameworks have been developed in the literature to analyze industry- and society-wide transitions towards sustainability in different sectors. As one of the most prominent of such approaches, the Technology Innovation System (TIS) framework[18], drawn from the techno-economic transitions literature, is particularly well suited to compare the emergence and diffusion of new technologies that have the potential to profoundly transform a sector of the economy. Other approaches such as transition management or socio-technical transitions theories are closely linked to TIS, but generally adopt a broader perspective. The TIS framework maps important aspects of the innovation process into seven "functions". As shown in Table 1 below, these functions are used to map activities within the TIS. Rather than constituting a linear sequence of steps, the functions are dynamically interlinked. In the later sections of this paper, we highlight how current, planned, and proposed policies in California and Germany fit into this framework (using identifiers such as "F1", "F2", etc. – or "-F1", "-F2", etc. to refer to barriers or actions hindering innovation).

Several previous studies have used TIS to assess the development of electric vehicle markets. One study applies the framework to seven countries, focusing on functions F4 to F7.[20] In an in-depth case study of the Norwegian market, it finds that policies guiding the formation of markets and the signaling effect of

Table 1 | Technology Innovation System (TIS) Functions

Function	Description
F1 – Entrepreneurial activities	Presence of new entrants or innovative incumbents who diversify their strategies and are ready to engage in risky experimentation with a new technology; contributes to knowledge generation.
F2 – Knowledge development	Learning and knowledge generation; can be reflected in patents, projects or funds spent on research and development.
F3 – Knowledge diffusion through networks	Knowledge generated meets broader networks of policymakers and other industry stakeholders; diffusion of knowledge may promote increased standardization.
F4 – Guidance of the search	Selection of specific technological paths to be pursued and invested in; can be prompted by government action, stakeholder expectations.
F5 – Market formation	Creation of protective conditions or niches for nascent technologies to compete in incumbent markets.
F6 – Resource mobilization	Making funds available for R&D, niche experiments and protective spaces to facilitate the uptake of specific technologies.
F7 – Legitimation[19]	Growing advocacy coalitions for specific technologies; creates legitimacy/acceptance for specific technologies.

18 Hekkert, M.P., R.A.A. Suurs, S.O. Negro, S. Kuhlmann, and R.E.H.M. Smits. 2007. "Functions of Innovation Systems: A New Approach for Analysing Technological Change." Technological Forecasting and Social Change 74 (4): 413–32. doi:10.1016/j.techfore.2006.03.002.

19 "Legitimation" as used here should not be confused with political legitimacy. A more descriptive term might be advocacy or political support.

20 Veragis, Sydney et al. 2014. "Plug-In Electric Vehicles: A Case Study of Seven Markets ". UC Davis Research Report – UCD-ITS-RR-14-17. Available at: https://itspubs.ucdavis.edu/wp-content/themes/ucdavis/pubs/download_pdf.php?id=2369

goals set by the government contributed to the emergence of a leading market for EVs, while others factors such as lower temperatures and related reduced range were negative factors. Another study applies a TIS framework to the deployment of EVs elsewhere in Europe and finds market formation to be a missing piece.[21]

Another study applies a modified TIS framework to the case of hydrogen fuel cell technology in Denmark and the US.[22] The authors identify vastly different strategies in the two cases, more climate policy driven in Denmark and more fragmented and geared towards experimentation in the US, but conclude that neither has been effective to date. They also call for more studies using a TIS-focus in the field of low-carbon transport. Another study uses an expert elicitation technique and finds the availability of charging points, structural factors such as gross domestic product and government incentives to be likely factors for the successful uptake of EVs in Europe.[23]

21 Köhler, Jonathan, Wolfgang Schade, Guillaume Leduc, Tobias Wiesenthal, Burkhard Schade, and Luis Tercero Espinoza. 2013. "Leaving Fossil Fuels behind? An Innovation System Analysis of Low Carbon Cars." Journal of Cleaner Production 48 (June): 176–86. doi:10.1016/j.jclepro.2012.09.042.

22 Andreasen, Kristian Peter, and Benjamin K. Sovacool. 2015. "Hydrogen Technological Innovation Systems in Practice: Comparing Danish and American Approaches to Fuel Cell Development." Journal of Cleaner Production 94 (May): 359–68. doi:10.1016/j.jclepro.2015.01.056.

23 Zubaryeva, Alyona, Christian Thiel, Enrico Barbone, and Arnaud Mercier. 2012. "Assessing Factors for the Identification of Potential Lead Markets for Electrified Vehicles in Europe: Expert Opinion Elicitation." Technological Forecasting and Social Change 79 (9): 1622–37. doi:10.1016/j.techfore.2012.06.004.

3. Demographic, Environmental, and Policy Context

California and Germany are relatively similar in geographic size and vehicle sales volumes, as indicated in Table 2 below. However, Germany has over twice the population density, which has implications for electric vehicle usage patterns and market needs, such as in trucking and last-mile delivery routes.

Additionally, in California 63% of dwellings are single-family homes, where residents may be more easily able to charge a plug-in vehicle. In Germany, only 33 % of dwellings are single-family homes, though 63 % of all households do have access to a parking garage or dedicated parking space.[24] Looking at owners of electric vehicles, 96 % of California EV owners own their own dwelling, and 91 % reside in a single-family home. Moreover, 75% park in a garage, and nearly all of the remainder park in a driveway or carport.[25] While renters and condominium owners can adopt electric vehicles, single-family residents who own their own home face fewer barriers and seem to be serving as a niche demographic for market formation (F5).

Table 2 | Basic Comparison of California and Germany

	Germany	California
Population (millions)[26]	81	39
Size (km2)[27]	357,376	403,466
Population per km^2	227	97
Percent Single-Family Dwellings	33 %[28]	63 %[29]
Personal Automobiles (millions)[30]	45.1	24.5
Light Vehicle Sales, 2015 (millions)	Cars: 2.2; Light Trucks: 0.9[31]	Cars: 1.2; Light Trucks: 0.9[32]
Share of GHG Emissions from Transportation[33]	17 %, of which[34]… Passenger Vehicles: 56 % Freight (road): 26 % Aviation: 14 % Other: 4 %	37 %, of which[35]… Passenger Vehicles: 72 % Freight (road): 20 % Aviation: 2 % Other: 6 %

24 Source: Statistisches Bundesamt, Fachserie 15, Sonderheft 1, EVS 2013. Table Ü2 (dwelling type) and Ü3 (garage or parking space access). https://www.destatis.de/DE/Publikationen/Thematisch/EinkommenKonsumLebensbedingungen/Wohnen/EVS_HausGrundbesitzWohnverhaeltnisHaushalte2152591139004.pdf?__blob=publicationFile
25 Source: California Center for Sustainable Energy California PEV Owner Survey, 2012, pages 4-5. https://cleanvehiclerebate.org/sites/default/files/docs/nav/transportation/cvrp/survey-results/California_PEV_Owner_Survey_Report.pdf
26 Source: http://data.worldbank.org/indicator/SP.POP.TOTL, https://www.census.gov/quickfacts/table/PST045215/06
27 CA Source: https://www.census.gov/quickfacts/table/PST045215/06 155,779.22 square miles. DE source: http://www.statistikportal.de/Statistik-Portal/de_jb01_jahrtab1.asp
28 Source: Statistisches Bundesamt, Fachserie 15, Sonderheft 1, EVS 2013. Table Ü2 (dwelling type) https://www.destatis.de/DE/Publikationen/Thematisch/EinkommenKonsumLebensbedingungen/Wohnen/EVS_HausGrundbesitzWohnverhaeltnisHaushalte2152591139004.pdf?__blob=publicationFile
29 Source: California Residential Appliance Saturation Survey 2009, Table ES-2. http://www.energy.ca.gov/2010publications/CEC-200-2010-004/CEC-200-2010-004-ES.PDF
30 Sources: KBA, http://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/bestand_node.html, and California Department of Motor Vehicles, http://www.dmv.ca.gov/portal/wcm/connect/5aa16cd3-39a5-402f-9453-0d353706cc9a/official.pdf?MOD=AJPERES
31 Source: http://www.kba.de/DE/Statistik/Fahrzeuge/Neuzulassungen/MonatlicheNeuzulassungen/2015/201512GV1monatlich/201512_nzbarometer/201512_n_barometer.html?nn=1207072
32 Source: http://www.cncda.org/CMS/Pubs/Cal%20Covering%204Q%2015.pdf
33 Sources: BMVI Aktionsplan Güterverkehr und Logistik, https://www.bmvi.de/SharedDocs/DE/Publikationen/G/aktionsplan-gueterverkehr-logistik-2015.html?linkToOverview=%23id61432, p. 38; and California Air Resources Board, http://www.arb.ca.gov/cc/inventory/data/data.htm.
34 Energy consumption used as a proxy for GHG emissions. Source: https://www.greenpeace.de/sites/www.greenpeace.de/files/publications/sektorkopplungsstudie.pdf
35 Source: Based on CARB 2014 Greenhouse Gas Emissions Inventory, https://www.arb.ca.gov/app/ghg/2000_2014/ghg_sector_data.php

Both regions' new car purchasers (whether EV or IC engine) belong to relatively concentrated demographic groups, demonstrating the emergence of initial niches in the market development process (F5). In Germany, 60 % of new cars are purchased by commercial/fleet owners[36], not by private individuals. And in California, just 4 % of households are buying 28 % of new cars.[37] At the same time, policies that target more varied demographics are important for societal acceptance of new technologies (F7).

GHG emissions in the transportation sector are one of the major drivers for transportation electrification, but as Table 2 above shows, the context for transportation emissions is somewhat different in the two regions. Several factors contribute to the fact that the transportation sector is responsible for 37 % of overall greenhouse gas emissions, compared to just 17 % in Germany. For example, California has a relatively mild climate, relatively less coal-fired power generation including power imported from out of the state, and relatively little industrial activity, relatively less public transportation and relatively more vehicle miles traveled.[38] Hence, it is necessary that the transportation sector play a more central role in achieving California's greenhouse gas reduction goals.

Yet in absolute terms, GHG emissions from the transportation sector in Germany are high, and achieving the country's recently adopted 2030 sectoral target also will require decarbonizing the transportation sector. The need for action in Germany is particularly pressing because GHG emissions in the transportation sector are still above 1990 levels.

Air quality is a key element of the environmental context for transportation electrification. Mobile sources – both on and off-road – are responsible for approximately 80 % of NO_x emissions and 90 % of diesel particulate matter emissions in California.[39] With some of the worst air quality in the United States, California must take significant action to meet federal ozone and NO_x standards by 2023 and 2031.[40] Currently, only 40 % of California's South Coast residents live in communities that meet federal ozone standards; statewide, over 30 % of Californians live in areas that exceed federal ozone and PM2.5 particulate matter standards.[41] As a result, in California air quality is a driver for transportation electrification that is on par with carbon reductions. The relatively equal importance of these drivers can be seen in the California Air Resource Board's recently published Mobile Source Strategy, which addresses transportation-related emissions of ozone, NO_x, particulate matter, and greenhouse gases in a coordinated manner.[42]

In the interviews, air quality was brought up repeatedly as a potential secondary driver in Germany for transportation electrification after carbon reductions. In particular, some interviewees mentioned local advocacy related to air quality as an important driver in urban niches (F7), as well as the threat of EU legal action and potentially even occasional driving prohibitions as further incentives for EV adoption in areas regularly exceeding the limits (F4/5). For example, the city of Stuttgart exceeded EU limits on 31 days between January and August 2016 (35 such days are permitted annually).[43] However, this seems to be a local issue, as most of Germany is compliant with EU air quality regulations.[44] Moreover, there are alternatives available to reduce local air pollution that mostly stems from diesel fuel, such as banning respective cars from city centers. Accordingly, legitimacy of action to support transportation electrification (F7) based on air quality arguments in Germany is also primarily local, and further depends on whether other options are viewed as more viable or desirable by the public. Nevertheless, both the EU and the German

36 Source: KBA
37 Source: http://steps.ucdavis.edu/wp-content/uploads/04-26-2016-Tal-STEPS-Workshop-4_26_16-V2.pdf
38 Source on California's electricity mix: http://www.energy.ca.gov/almanac/electricity_data/total_system_power.html
39 Source: California Air Resources Board Mobile Source Strategy, p. 5, May 2016. http://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.pdf
40 Source: California PEV Collaborative, (CG1-1). American Lung Association in California, The Road to Cleaner Air, 2011. http://www.pevcollaborative.org/sites/all/themes/pev/files/CG1-1.jpg
41 Source: California Air Resources Board Mobile Source Strategy, p. 20-21, May 2016. http://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.pdf
42 Source: California Air Resources Board Mobile Source Strategy, May 2016. http://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.pdf
43 Source: http://www.stuttgart.de/feinstaubalarm/
44 Source: Air quality in Europe — 2015 report, http://www.eea.europa.eu/publications/air-quality-in-europe-2015/at_download/file

Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) are planning to take action to meet air pollution limits and pave the way to ban diesel vehicles from city centers respectively.[45]

Another relevant policy driver in Germany is a broad **industrial policy** aim of technological leadership, which was first applied to transportation electrification in the 2009 *National Electromobility Development Plan* (NEDP).[46] The NEDP called for a lead market industrial policy approach – the creation of a domestic market that would create an early-mover advantage for the German auto industry globally. Such an industrial policy strategy had been previously pursued in the electricity sector with some success and thus at the time also promised to be a way forward for transportation – but eventually did not induce action.[47] Moreover, interviews suggest that many stakeholders – in particular the auto industry – felt that industrial policy aims would not be well served through aggressive promotion of EVs, resulting in several years of continued focus on incumbent ICE technologies, a lack of programs to implement the NEDP, and little legitimacy for transportation electrification (F4, F7).

But as several interview participants noted, the German auto industry has recently become more engaged in transportation electrification. Indeed, the auto industry's shift to supporting vehicle purchase rebates, after years of resistance, along with a recent announcement from most of the major German companies (together with Ford) of plans to invest in 400 fast-charging stations in 2017, suggests that a significant change in the policy context is underway.[48] Seen through a TIS lens, increasing industry support for policy action is a positive development and an important innovation function, because it has increased the legitimacy of transportation electrification (F7). However, the degree to which industrial policy will be domestically or internationally focused remains to be seen.

45 Sources: http://www.spiegel.de/wissenschaft/mensch/stickoxid-wo-luft-in-deutschland-krank-macht-a-1120859.html, http://www.spiegel.de/auto/aktuell/deutschland-umweltministerium-ermoeglicht-fahrverbote-fuer-dieselfahrzeuge-a-1126230.html

46 Source: http://www.bmvi.de/SharedDocs/DE/Artikel/G/elektromobilitaet-nationaler-entwicklungsplan.html

47 In 2009, both wind and solar were booming and German companies ranked at top positions in the global market. Today, the solar industry is experiencing significant international competition; industrial policies seem to have been more successful in the wind industry: Also see: Pegels, Anna, and Wilfried Lütkenhorst. 2014. "Is Germany's Energy Transition a Case of Successful Green Industrial Policy? Contrasting Wind and Solar PV." Energy Policy 74 (November): 522–34. doi:10.1016/j.enpol.2014.06.031.

48 Source: https://www.press.bmwgroup.com/global/article/detail/T0266311EN/bmw-group-daimler-ag-ford-motor-company-and-volkswagen-group-with-audi-porsche-plan-a-joint-venture

4. Transportation Electrification Stakeholders

Beyond the broader demographic and environmental context, the ecosystem of stakeholders specifically involved in transportation electrification is an essential factor in where and how markets are formed (F5). A given region's stakeholder landscape can influence the direction pursued by entrepreneurs, the viability of business models, and the feasibility of policy proposals. Moreover, stakeholders might also mobilize considerable private finance, which may exceed public finance (F6) and impact what is politically feasible (F4/6).

Broadly speaking, relevant stakeholders for transportation electrification include the government (at all levels), the energy and automotive industries, the media, advocacy groups, investors, vehicle end-users, and the general public, as listed in Table 3.

Of note are several significant differences in the two regions' transportation electrification ecosystems. The landscape in **Germany is largely shaped by its highly successful auto industry**, which has been central to the overall economy for decades. Volkswagen, Daimler, BMW, Bosch, and Continental are major forces in the German transportation sector, and play a crucial role, not just in building cars but also in fundamental research and venture capitalism activities (F1/2/6). Because of its significant role in the economy, actions of the auto industry also have the power to create a sense of legitimacy for new mobility approaches (F7).

At the same time, the German auto industry has a long tradition and considerable comparative advantage worldwide in manufacturing internal combustion engines (ICEs), resulting in significant status quo inertia. For example, multi-billion dollar investments have been made in new ICE-based power train models, and the auto industry expects a return on these ICE investments. Moreover, electric motors are relatively low–tech, from a mechanical perspective, and some of our interviewees suggested that they therefore do not play to the German industry's traditional business model strengths, as they offer much lower value-added. As a result, German automakers have widely been seen as laggards in the PEV market. However, this status quo approach is beginning to undergo a fundamental change. According to Germany's Climate Action Plan 2050, the domestic auto industry has invested 15€ billion in PEV development to date.[49] Notable activities are BMW's development of the i3 model (3€ billion, 2013 estimates[50]) and the development of a global battery supply chain by Daimler (1€ billion).[51] Looking forward, Volkswagen (VW) has announced the "TOGETHER – Strategy 2025", which among other goals lays out a plan for 30 new pure-electric vehicle models and annual sales of 2-3 million PEVs by 2025.[52] Daimler has announced the EQ portfolio, which will encompass all future battery-electric cars as well as the associated products and services from Mercedes-Benz.[53]

Yet, perhaps in response to the limited PEV initiatives from the major automakers prior to 2016, some new players are now entering the German transport electrification scene. For example, as previously mentioned, Deutsche Post (the German postal service and operator of the worldwide shipping company DHL) recently announced its intention to manufacture electric delivery vans through its subsidiary "Streetscooter", citing a lack of vehicle availability from existing manufacturers.

In contrast to Germany's robust traditional auto industry, California's only major auto manufacturer is Tesla, an electric vehicle manufacturer with no history

49 Source: http://www.bmub.bund.de/fileadmin/Daten_BMU/Download_PDF/Klimaschutz/klimaschutzplan_2050_bf.pdf (p.52)
50 Source: http://www.manager-magazin.de/unternehmen/autoindustrie/a-899479.html
51 Source: http://media.daimler.com/marsMediaSite/de/instance/ko/Daimler-baut-globalen-Produktionsverbund-fuer-Lithium-Ionen-.xhtml?oid=14184860
52 Source: https://www.volkswagenag.com/presence/konzern/pdf/Group_Initiatives_Strategy_2025.pdf
53 Source: https://www.daimler.com/innovation/specials/electric-mobility/eq.html

Table 3 | Transportation Electrification Stakeholders Segments & Types

Segment	Stakeholder Type
Government	→ International → Federal → State → Regional → Local

Energy Industry	→ R&D institutes
	→ Environmental advocates
	→ Ratepayers and ratepayer advocates
	→ Utilities, retailers, and grid operators:
	  → Transmission System Operators (TSOs), Distribution System Operators (DSOs)
	  → Utility-owned generation
	  → Energy retailers and community choice aggregators
	→ Generators:
	  → Distributed energy resource providers, aggregators
	  → Utility-scale generators

Auto Industry	→ Vehicle and part manufacturers
	→ Charging infrastructure providers:
	  → Charging station (physical device, maintenance)
	  → Software
	  → Networks
	→ Dealerships
	→ R&D institutes
	→ IT sector:
	  → Autonomous vehicle developers
	  → Car-sharing platform developers
	  → App and connected car software developers
	→ Environmental and health advocates

Investors	→ RD&D funders
	→ Venture capitalists and incubators
	→ Pension and other investment funds
	→ Private investors
	→ Landowners (investors in charging infrastructure and aspects of land use):
	  → Real Estate Investment Trusts (REITs)
	  → Property management companies
	  → Large employers
	  → Developers

Vehicle Owners and Users	→ Fleets and fleet managers
	  → Trucking and last-mile delivery companies
	  → Taxi, car-sharing and rental car companies
	  → Transit and other government vehicles
	  → Major end users such as ports and airports
	→ Private individuals who own/lease/share vehicles

General Public, Media	→ All residents and citizens → Low income individuals, disadvantaged communities → Media

of ICE development, and a much smaller share of the overall economy. Moreover, Tesla's early growth relied on venture capital, enabling it to pursue riskier investments than the German auto industry; this financial and to some degree cultural difference in investment strategies is a factor that was brought up by several interviewees as a comparative advantage for California in achieving rapid change. To the extent that traditional vehicle-related R&D and entrepreneurial activities occur in California, these sessions are often conducted via the satellite offices of German automakers, and are much less central to the state's transportation ecosystem than in Germany.

Instead, **California's transportation electrification landscape is largely shaped by its world-leading IT sector**. The state is home to powerhouses like Alphabet (Google) and Apple, significant newcomers like Uber, Lyft, and Tesla, and numerous startups. Additionally, as previously mentioned, California also has the world's strongest network of venture capitalists and incubators. This ecosystem contributes significantly to all seven innovation system functions: engaging in entrepreneurial activities, developing and sharing technical knowledge, creating cultural expectations of rapid technological advancement, exploring market niches, mobilizing resources for risky new ideas, and advocating for the sector's interests.

Germany's IT sector is much smaller in comparison. Initiatives combining IT and transportation that do exist, such as car2go and DriveNow, are often led by pre-existing giants in the transportation sector, such as automakers BMW and Daimler, rental car companies Europcar and Sixt, and even Deutsche Bahn. In other words, while entrepreneurial activity (F1/2) is occurring, there are relatively few new entrants or VCs to support them; there is therefore not as strong a coalition advocating exclusively for new IT-transport interests (F7), and the willingness to mobilize resources for risky approaches and niche market development is lower (F5/6). Additionally, overall expectations of technology are shaped more by the dominant traditional actors, perhaps resulting in more status quo expectations (F4). As a result, to the extent that IT-transportation initiatives exist in Germany, they are more focused on incorporating IT into traditional vehicles (such as in car-sharing), and on promoting the interests of traditional ICE manufacturers, and less focused on transportation electrification (F7).

There are also **significant differences between the two regions' electricity sectors** and utility roles. In California, the majority of electricity consumption is served by vertically integrated utilities, monopolies that are regulated by the **California Public Utilities Commission** (CPUC). These investor-owned utilities (IOUs) supply 69 % of the electricity used in the state, and another 6% of electricity consumption is served by on-site self-generation in their service territories.[54] Of IOU customers, almost all are served by just three electric utilities.[55] These utilities are responsible for transmission and distribution system infrastructure, distribution system operation, and some utility-owned generation. The remaining share is provided by public utilities, which are also vertically integrated in many instances.

Germany, meanwhile, has a deregulated (also referred to as "liberalized") power system, in which there is less central planning and control, and a distribution of functions across many competitive companies at each stage in the value chain. As a result, entrepreneurial activities related to vehicle-grid integration (VGI) may be undertaken by different sets of stakeholders, and approaches may be somewhat different (F1). Additionally, California has nodal pricing, while Germany has uniform market prices across the country. Nodal pricing in general provides better incentives for efficient charging behavior, but ultimately relevant are the electricity rates customers are offered for charging. Neither jurisdiction has time-varying electricity prices, but the potential advent of this type of rate structure could allow EV owners to schedule charging at times when wholesale electricity prices are at their minimum (typically during the night) and could be a forceful feature in broadening EV adoption. Accordingly, rated design and adoption play a crucial role for VGI, and here again there are important differences between California's regulated and Germany's deregulated system. We address some of the differences related to regulatory frameworks in Section 5.

54 Source: http://www.ecdms.energy.ca.gov/elecbyutil.aspx. Los Angeles and Sacramento, as well as several smaller regions, are served by publicly owned utilities, cooperatives, or public power agencies.

55 Pacific Gas & Electric Company, Southern California Edison, and San Diego Gas & Electric Company. Southern California Gas Company is also a major stakeholder, but is a gas-only utility.

Due to its regulatory framework, California has a clearer path to mobilize resources for market formation (F5/6) via directed utility actions in the areas of rate design and infrastructure, and as described later in this document, has been a leader in doing so. German regulators, on the other hand, are less able to mobilize resources or direct market formation via command-and-control utility regulation. Instead, our interviews revealed that German utility regulatory efforts were more focused on developing and providing time- and location- variant grid usage fees (*dynamische Netzentgelte*), which, unlike electricity rates, are under the control of the regulator. However, these efforts are only in a preliminary phase of discussion (F5). Nevertheless, if German regulators decide to consider charging infrastructure as a part of the distribution grid and not an independent service, it is possible that they could intervene more directly in infrastructure investments.

Furthermore, as the largest players in the electricity sector, all major utilities in both regions are taking varying degrees of initiative under different regulatory frameworks. In Germany, both RWE and Vattenfall operate public charging stations in major cities, while E.ON sells home charging stations. At the local level, the larger of Germany's distribution system operators (DSOs) are involved in experiments and pilot projects. In California, all three large electric utilities have pilots either underway or pending approval, and all electric utilities, both large and small, have been directed by policymakers to submit additional applications for programs and projects supporting widespread transportation electrification.

Yet despite their differences in industry makeup and regulatory frameworks, certain aspects of the two regions' ecosystems are quite similar. Most significantly, **both have strong environmental advocates** (important for F4 and F7) and **strong R&D institutions** (F1/2/3). Both California and Germany also have several major transportation end-users, such as international ports and airports, and large commercial fleets, which may be viewed as niches for market formation (F5).

5. Regulation and Policies

5.1 Regulatory Frameworks

In **California**, transportation electrification initiatives are largely led by the **California Air Resources Board (CARB)**. The **California Energy Commission** (focused on RD&D and forecasting) and **California Public Utilities Commission** (energy utility regulator) also play significant roles. Other relevant agencies include the California State Transportation Agency, California Environmental Protection Agency, Natural Resources Agency, and California Department of Transportation (Caltrans).

CARB is responsible for regulating air quality and air pollution, including NO_x, SO_x, particulate matter, ozone, and carbon emissions. CARB is unique in the sense that it combines authority and technical expertise for both air quality and climate change issues, which allows respective coordination, strategic planning and sharing of expertise. The agency administers the state's Zero Emission Vehicles (ZEV) Mandate, carbon emissions cap and trade system, fleet emissions standards, low carbon fuel standard, and air quality initiatives. It also develops key program and policy roadmaps, in particular the recently released Mobile Source Strategy for the transportation sector, which lays out a comprehensive strategy to reduce emissions from mobile sources to meet critical air quality and climate goals over the next fifteen years. The Mobile Source Strategy also informs other state roadmaps, including CARB's AB 32 Scoping Plan Update for greenhouse gas emissions reductions, the State Strategy for the State Implementation Plan to meet federal air quality standards, and the multi-agency Sustainable Freight Action Plan.[56]

CARB is particularly active in Functions 4/5/6, strongly guiding markets with long-term roadmaps, policies, and regulations (F4), implementing and administering market development programs (F5), and mobilizing resources to support decarbonization and air quality improvement (F1/6). For example, the low carbon fuel standard (LCFS), ZEV Mandate, and cap and trade program generally set long term goals (F4) and require participants to either meet targets or pay for credits/offsets (F5). Moreover, purchase of credits and offsets helps to fund entrepreneurial activities of market actors contributing towards meeting the policy targets (F1/2/5/6).

In addition to the state agencies and goals focused on energy, transportation, and air quality, we note that the **Governor's Office of Business and Economic Development (GO-Biz)** is also an important actor. GO-Biz regularly brings together relevant agencies to share knowledge and coordinate activities (F3). The Governor's Office also issued a revised ZEV Action Plan in October 2016 that outlines state goals and actions for each agency (F3/4/7).[57] This coordination and knowledge sharing is particularly important considering the large number of agencies active in transportation electrification initiatives in California. For example, the aforementioned Sustainable Freight Action Plan was jointly developed by seven state agencies: the California State Transportation Agency, California Environmental Protection Agency, Natural Resources Agency, California Department of Transportation (Caltrans), the CEC, CARB, and GO-Biz.

In **Germany**, transportation electrification initiatives are less centralized, without any primary ministry or roadmap to guide government efforts. Initiatives mainly fall under the responsibility of the **Federal Ministry for Economic Affairs and Energy (BMWi)**, which is responsible for vehicle rebates (F5) and technology-oriented R&D, and the **Federal Ministry of Transport and Digital Infrastructure (BMVI)**, which is primarily focused on vehicle charging infrastructure (F5/6).[58] Additional programs, mostly R&D and pilots, are implemented by the **Federal Ministry for**

56 More information available at: https://www.arb.ca.gov/cc/scopingplan/scopingplan.htm, https://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.htm, http://www.casustainablefreight.org/
57 https://www.gov.ca.gov/docs/2016_ZEV_Action_Plan.pdf
58 An overview of all activities can be found here: http://www.bmvi.de/DE/VerkehrUndMobilitaet/DigitalUndMobil/Elektromobilitaet/AktivitaetenBundesregierung/aktivitaeten-bundesregierung_node.html

the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) and the Federal Ministry of Education and Research (BMBF).

In addition, the federal government established the **German National Platform for Electric Mobility**[59] in 2009. Its members – representatives from industry, science, politics, unions, and trade associations – are tasked with investigating the economic, social and environmental potential of transportation electrification, and with recommending actions for government and industry (F2/3/7). The Platform has issued a number of reports and continues to meet regularly. However, interviewee opinions differed as to the effectiveness of this group in including the perspective of emerging market actors, rather than just incumbents.

In contrast to California, there are no binding roadmaps for transportation electrification in Germany. However, BMVI periodically issues a transportation infrastructure plan (*Bundesverkehswegeplan*), which includes environmental aspects as a secondary consideration. Additionally, BMUB has issued broad climate action plans for 2020 and 2050; the 2050 plan was adopted by the Cabinet in November 2016.[60] Both plans are not tied to binding programs; rather, they take stock of the transportation sector and bring together ideas and proposals for how to advance transportation infrastructure and climate protection in the short and long term. Accordingly, many of the measures called for are vague and will in turn require development via new programs or roadmaps.

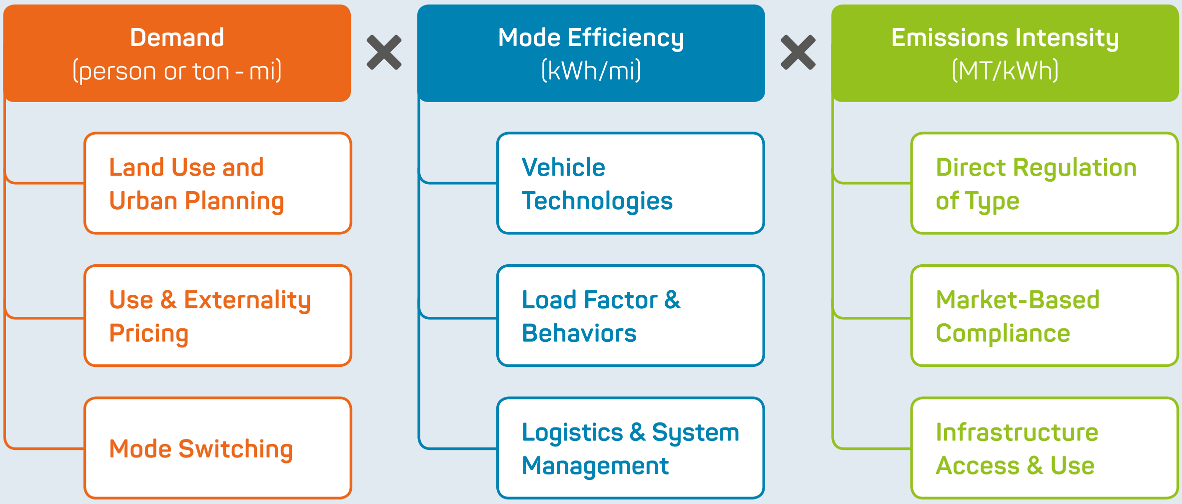
Beyond the federal government, the **European Commission (EC)** and Germany's **state, regional, and local governments** are also engaged in transportation electrification, though their jurisdiction and budgets are somewhat limited. Two locally driven market formation options that came up in interviews were a congestion charge similar to London's, from which ZEVs would be exempt, and local government fleet electrification (F5). Yet, while some interviewees spoke of the potential for local and regional governments to disrupt the status quo, others spoke to their limitations. For example, the state government of Baden-Württemberg proposed the introduction of low-NO_x vehicle eco-labels, with the aim to only permit cars with this eco-label within Stuttgart's city limits (*Blaue Plakette*); however, such labeling schemes fall under the authority of the federal government.[61] Because the federal government (as well as other German states) opposed the measure, the proposed labeling scheme was shelved, and the city continues to be precluded from creating any local low-NO_x vehicle regulations.[62]

In the following subsections, existing broad decarbonization and air quality policies (section 5.2) and more targeted transportation electrification policies and initiatives (section 5.3-5.5) will be reviewed in more detail. To aid in structuring and categorizing the many possible regulatory structures and actions, we introduce the framework shown in Figure 3, developed by regulators at the California Public Utilities Commission (CPUC). The framework groups policies according to the different regulatory levers that exist to reduce total emissions.

For example, regional planning efforts may encourage mode-switching that reduces the number of miles individuals drive in personal vehicles, thereby reducing demand for transportation services (the first column in the chart). Meanwhile, government-funded R&D and PEV market formation programs may support the development and deployment of more fuel-efficient vehicles that can go more miles per unit of in-vehicle energy consumption, impacting the second column in the chart. Emissions intensity (the third column in the chart) refers to programs that lower the carbon intensity of used energy, and provide access to lower carbon vehicle fuels (such as the LCFS and renewable portfolio standards). This last column is particularly relevant because for EVs to have a beneficial effect on emission reductions, the used electricity must be "clean". Accordingly, in a policy framework, transportation electrification needs to be coupled with a suitable mix of companion policies to reduce emissions in the power sector.[63] This

59 http://nationale-plattform-elektromobilitaet.de/en
60 http://www.bmub.bund.de/fileadmin/Daten_BMU/Download_PDF/Klimaschutz/klimaschutzplan_2050_bf.pdf
61 Source: http://www.stuttgarter-zeitung.de/inhalt.blaue-plakette-ein-kampf-auf-verlorenem-posten.00146bc2-e33f-43e6-9c57-5c56b391b60e.html
62 Source: http://www.blaue-plakette.de/
63 For a discussion of the role of different policies see: http://www.rff.org/files/RFF-PB-16-05.pdf

Figure 3 | Regulatory levers for decarbonization of the transportation sector



Source: CPUC, http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=11287

is particularly important when electricity demand grows due to EVs. It is also important to note that changes in one area may impact another; for example, increasing mode efficiency could increase demand through rebound effects, and land use and urban planning choices could impact the feasibility of logistics and system management solutions.

While the framework shown in Figure 3 is useful from a technical perspective to describe the tools available to regulators, it requires some adaptation to fit the purposes of this paper including putting more emphasis on some of the less technical aspects of innovation systems, such as creation of legitimacy. In the following subsections, we therefore apply the following broad categories:

- **Broad goals, targets, caps, prices or taxes focused on decarbonization or air quality**, such as decarbonization standards, emissions trading schemes (ETS), or long term zero-emission vehicle (ZEV) deployment goals.
- **Vehicle-focused policies,** such as vehicle technology research, development, and deployment (RD&D), vehicle purchase rebates, special privileges for EV drivers (e.g., permission to access special lanes, zones, or parking), and policies for emerging use cases such as car-sharing and autonomous driving.
- **Land use, building, and charging infrastructure policies,** such as RD&D and specifications for charging station physical connections, communications, and interoperability; charging infrastructure planning, funding/rebates, and mandates; land use planning; and regulations and funding for large end-users such as ports.
- **Electricity market and infrastructure regulation and planning,** such as transmission and distribution infrastructure investments, electricity rate regulation, and resource aggregation rules.
- **Civic engagement and equity initiatives,** such as test ride events, consumer protection and privacy regulations, rebates for low-income individuals, and funding carve-outs for disadvantaged communities.

Seen through an innovation systems lens, many of the above regulatory actions fall under Function 4, guidance of the search, Function 5, market formation, and/or Function 6, resources mobilization. Functions 4 and 6 are frequently designed to support Functions 1-3 or 5, as in the examples of RD&D programs (F1/2/3), vehicle and infrastructure rebates (F5), and special privileges for EV drivers (F5).

However, while sometimes less apparent, legitimization (F7) is also a key element of many of the above regulatory levers. For example, plans, regulations, codes, and standards not only enable and support market formation (F5), they also, by creating a common set of performance expectations and signaling commitment, create a framework for deployment that lends the e-mobility ecosystem more of a sense of legitimacy. Civic engagement and equity initiatives also fall squarely under Function 7, and are of critical importance.

In the following sub-sections, we review and apply a TIS perspective to recent Californian and German policies in the above categories. For more specific information on regulatory initiatives through mid-2015, we suggest reviewing *A comparative analysis of electric-drive policy in California and Germany*, from the International Council on Clean Transportation (ICCT).[64] For a meta-study listing all measures proposed by recent studies in Germany, see *Meta-analyse über Maßnahmen und Instrumente für die Energiewende im Verkehr*, a publication of the German Renewable Energies Agency (in German).[65] For background on relevant EU directives and associated laws in Germany, see *Accelerating E-Mobility in Germany: A Case for Regulation*, by Markus Adam.[66]

5.2 Broad goals, targets, caps, or taxes focused on decarbonization and air quality

A summary of key policy targets and standards in both regions is shown in Table 4 below. Both regions are well on their way towards meeting their existing renewable electricity and fleet standards. However, Germany has not made progress to date on its transportation fuel goal,[67] is highly unlikely to meet its 2020 EV target, and may need to take stronger actions to meet the forthcoming iteration of EU fleet standards. As indicated in the government's Climate Action Programme 2020, adopted in 2014, additional action will also be required to meet Germany's economy-wide 2020 GHG emission reduction target of 40 % below 1990 levels.[68] Moreover, while Germany is on track to meet the 2020 EU goal for GHG reduction in non-ETS sectors (including fuel), it will need to substantially increase efforts to meet the EU Commission's recently-proposed 38 % reduction goal for 2030 (F4).[69] In California, meeting the US air quality standards and the ZEV Mandate target of 1.5 million EVs by 2025 will require aggressive action.

In our interviews with German experts, GHG emission reduction goals (F4) were raised as the most significant long-term policy driver of transportation electrification. Many interviewees expressed the belief that if these goals are taken seriously, they must prompt greater action in the near future, particularly in light of the momentum gained through the COP21 Paris Agreement.

It is, however, an open and controversial question at what time significant action should be focused on emission reductions in the transportation sector, as compared to other, possibly less challenging sectors like energy. But while past, less stringent climate goals could be met via action in other sectors, increasingly aggressive commitments have shifted attention to the transportation sector and to renewably-powered electric vehicles in particular. Indeed, interviewees agreed that business-as-usual R&D and pilot-scale transportation electrification efforts would be insufficient to meet Germany's long-term climate commitments, whether at the federal, EU, or international levels. Given that in the long term a transformation of the overall vehicle fleet is required, it is particularly important to deploy BEVs at large scale early on in order to avoid further perpetuating ICE lock-in, as each new vehicle will remain in service for many years.

Relatedly, interviewees almost uniformly highlighted the importance of the EU-level GHG standards for new vehicles. As is the case for the United States, these standards apply to each vehicle manufacturer's fleet as a whole (F4). The current EU standards

64 Published in August 2015 and available online at: https://www.now-gmbh.de/content/5-service/4-publikationen/3-modellregionen-elektromobilitaet/160408_germcalif-comparison_mit-titelseite.pdf
65 http://www.forschungsradar.de/metaanalysen/einzelansicht/news/metaanalyse-ueber-massnahmen-und-instrumente-fuer-die-energiewende-im-verkehr.html
66 http://www.springer.com/de/book/9783319448831
67 In fact, transportation sector GHG emissions have increased slightly in recent years. Source: https://www.umweltbundesamt.de/sites/default/files/medien/376/bilder/dateien/jaehrliche_treibhausgasemissionen_in_deutschland_1990-2014_nach_kategorie.xlsx
68 More information available at: http://www.bmub.bund.de/fileadmin/Daten_BMU/Pools/Broschueren/aktionsprogramm_klimaschutz_2020_broschuere_en_bf.pdf. The German target is more ambitious than the EU requirement of 14% reduction relative to 2005 by 2020, but unlike the EU requirement, is not legally binding.
69 Source: http://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/1-2016-482-EN-F1-1-ANNEX-1.PDF

Table 4 | Key Policies, Targets, and Standards in California and Germany (*=not legally binding or enforced)

	Germany[70]	California[71]
EVs on the road	1 million by 2020*	1.5 million by 2025 ("ZEV Mandate")
CO_2 reductions (relative to 1990 unless otherwise stated)	40 % in 2020*, 55 % in 2030* -40 % in transportation sector in 2030[72]* EU target for Germany's non-ETS sectors, including transportation: → 14 % relative to 2005 by 2020 → *Proposed: 38 % relative to 2005 by 2030*	40 % in 2030 *Carbon price currently $12.73/ton (near floor price)*
Fleet standards (grams CO_2/km)	Cars, 2021: 95 Vans, 2020: 147 *Revision underway.*	Cars: 107 in 2021; 89 in 2025 Light Duty Trucks: 167 in 2020; 126 in 2025
Transportation fuel energy/emissions	10 % reduction in total transportation energy by 2020, relative to 2005	Low Carbon Fuel Standard: 10 % reduction (vs 2011) in carbon intensity of transportation fuels by 2020
Air quality (NO_x, ozone, particulate matter)	EU Standards: 120 µg/m³ ozone, 25 µg/m³ PM 2.5, 200 µg/m³ hourly or 40 µg/m³ yearly NO_x, and other standards	US Standards: 75 ppb ozone, 12 µg/m³ PM 2.5 *South Coast: 70 % reduction in NO_x by 2023, 80 % by 2031. Regional ozone and PM 2.5 deadlines range from 2021-2031.*
2030 electricity[73]	50 % ± 2.5 % renewable	50%+ renewable *Excludes rooftop solar and large hydropower*

are not stringent enough to force manufacturers to sell electric vehicles, but the standards are due to be revised, and interviewees frequently expressed the belief that an aggressive new target could be adopted, and would provide a significant market signal pushing manufacturers towards PEVs (F4/5).

One interviewee also mentioned that there has been discussion of a two-part requirement, with both an overall fleet GHG standard and a standard for PEV sales as a percentage of each manufacturer's fleet; such a requirement would send a particularly strong signal both in guiding the market and in establishing niche markets (F4/5). However, another stated that a PEV sales requirement (or a standard low enough to

70 Sources: Energiekonzept 2010 (EVs on the road, fleet standards, and air quality): http://www.bmwi.de/English/Redaktion/Pdf/energy-concept,property=pdf,bereich=bmwi,sprache=en,rwb=true.pdf http://ec.europa.eu/clima/policies/transport/vehicles/index_en.htm http://ec.europa.eu/environment/air/quality/standards.htm . http://www.eea.europa.eu/publications/air-quality-in-europe-2015/at_download/file

71 Sources: http://www.leginfo.ca.gov/pub/15-16/bill/sen/sb_0301-0350/sb_350_cfa_20150911_201606_asm_floor.html http://www.arb.ca.gov/cc/capandtrade/auction/results_summary.pdf. https://www3.epa.gov/otaq/climate/documents/420f12051.pdf (original US units: Cars: 172 g/mi, 2021; 143 g/mi, 2025. Light Trucks: 269 g/mi, 2020; 203 g/mi, 2025). http://www.arb.ca.gov/fuels/lcfs/lcfs.htm more info at http://www.arb.ca.gov/fuels/lcfs/background/basics.htm. http://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.pdf http://steps.ucdavis.edu/wp-content/uploads/04-26-2016-Baroody-EV-Merit-REview-4-26-16final.pdf.

72 According to the Climate Action Plan 2050 emissions in the transportation sector should be reduced to 98 Megatons of CO_2 in 2030. Percentage target calculated based on 1990 emission data provided by UBA: http://www.umweltbundesamt.de/sites/default/files/medien/376/bilder/dateien/jaehrliche_treibhausgasemissionen_in_deutschland_1990-2014_nach_kategorie.xlsx

73 The regions' renewable energy targets are an important component of transportation electrification policy, as the growing challenge to reliably and economically operate a grid with high-penetration intermittent resources (such as solar and wind) is a long-term driver of vehicle-grid integration. We address grid issues in Section 5.5, *Electricity market and infrastructure regulation and planning*.

require PEVs) would be unthinkable in Germany today, as it would result in German automakers subsidizing international competitors that have more PEV vehicles available. But this could of course change in the future given the ambitious plans announced for new models (see above). Yet even with the current, relatively weak fleet standards, according to one expert interviewed, there is already an incentive promoting PEV market formation: because low gasoline prices have prompted increased sales of high-emission SUVs, manufacturers are now under increased pressure to sell more PEVs in order to bring down their average emissions and meet the fleet standard (F5).

A secondary but nevertheless important policy driver in Germany is the federal target of "putting one million electric vehicles on the road by 2020, possibly reaching over five million by 2030" (F4). This target is featured in the 2009 National Electromobility Development Plan and in the 2009 Coalition Agreement, which established Germany's intention to become a lead market in electromobility.[74] It was also formulated in the 2010 Energy Concept, but unlike other climate targets never became a legally binding law (F4/5). Nevertheless, experts frequently brought up this goal as a driver that is setting expectations (F4, F7) and pushing the government to allocate more resources to transportation electrification (F6). Adding to this policy pressure, Germany's upper house (*Bundesrat*) recently adopted the recommendation that all new vehicles should be "zero emission" by 2030, EU-wide. [75] While this is unlikely to be implemented as EU law, it signals unexpected consensus and support for transportation electrification on the member state level (F4).[76]

In California, fleet GHG standards are also important and will become more so as the 2025 requirements approach. But they remain less significant drivers for transportation electrification initiatives in comparison to the German regulatory landscape. Instead, the ZEV Mandate and Low Carbon Fuel Standard (LCFS) are key policy drivers (see Table 4 above). Both are not just broad policy targets (F4) but also binding programs administered by CARB (F5). The ZEV Mandate applies to vehicle manufacturers, while the LCFS applies to fuel suppliers.

Similar to the state's greenhouse gas cap-and-trade system[77], these two programs allocate credits based on the policy targets, and allow the trading of credits amongst regulated parties in order to achieve compliance with the programs' ZEV and carbon intensity targets.[78] While both programs are fuel-neutral (e.g., fuel cells and PEVs are both lower-carbon-intensity ZEVs), simply improving ICE performance is insufficient to meet the targets, and the monetary value of the credits provides a direct incentive to industry to develop and sell more ZEVs, including PEVs (F1/5/6). With LCFS credit prices at approximately $100 per metric ton, and Tesla's cumulative ZEV credit revenues at over $500 million, these programs are major forces.[79]

While the ZEV Mandate and LCFS have been the primary targets/programs pushing for broad industry action to date in California, the state's need to comply with federal air quality requirements is also an important driver, particularly for transportation electrification beyond the passenger vehicle segment. As mentioned in Section 3, the transportation sector is the most significant source of many air pollutants. To meet federal requirements, the state has developed several policy roadmaps focused on the transportation sector, as described in Section 5.3 below (F4).

5.3 Vehicle-focused policies

Beyond its work implementing and enforcing standards, in California **CARB** offers PEV incentives to the public through its Low Carbon Transportation Investments and Air Quality Improvement Program (including the Clean Vehicle Rebate Project and

74 Available at: https://www.bmwi.de/English/Redaktion/Pdf/national-electromobility-development-plan,property=pdf,bereich=bmwi,sprache=en,rwb=true.pdf
75 Source: http://www.bundesrat.de/SharedDocs/drucksachen/2016/0301-0400/387-16(B).pdf?__blob=publicationFile&v=1
76 Unlike in the United States, the German upper house is composed of state governors and ministers, rather than of independently elected senators.
77 California's cap and trade system also includes transportation fuels. However, it is not as significant a driver for transportation electrification due to low carbon and gas prices, which result in a relatively small market signal to drivers.
78 More information available at https://www.arb.ca.gov/msprog/zevprog/zevprog.htm and https://www.arb.ca.gov/fuels/lcfs/lcfs.htm
79 Sources: http://www.bloomberg.com/news/articles/2016-10-27/tesla-s-rare-profit-delivers-pie-musk-ordered-for-his-skeptics, https://www.arb.ca.gov/fuels/lcfs/credit/20161011_sepcreditreport.pdf

Hybrid and ZE Truck and Bus Vouchers), which can be layered on top of federal and local rebates.[80] It also offers non-monetary incentives in the form of "carpool lane" stickers that allow individual PEV drivers to use lanes otherwise designated for vehicles with multiple occupants, and thereby save time in traffic.[81] These programs are an essential component of market formation (F5). The Clean Vehicle Rebate Project incentives average approximately $2,130 per vehicle, while separate **federal government** incentives range from $2,500 for lower-range PHEVs to $7,500 for higher-range PHEVs and BEVs.[82] The sum of all state and federal customer-side incentives for personal vehicles, including carpool lane access, is valued at approximately $6,000 to $11,000 per vehicle.[83] When supply-side incentives are also considered (ZEV Mandate, LCFS, and carbon cap and trade system), ZEV incentives are even greater (F5).

Providing long-term guidance to the market (F4), in May 2016 CARB issued an integrated *Mobile Source Strategy* policy roadmap, which lays out a comprehensive strategy to reduce emissions from mobile sources to meet critical air quality and climate goals over the next fifteen years. In July 2016, multiple state agencies, including CARB, jointly released the *California Sustainable Freight Action Plan*, providing further guidance (F4) to the heavy-duty sector.[84] Both publications detail numerous actions that state agencies can take to support all seven innovation functions as listed above. The agency is also in the process of revising its Advanced Clean Transit rule, which will provide further guidance (F4) and support market formation (F5) in the transit market niche.[85]

The **California Energy Commission** (CEC) is also responsible for key elements of the state's ZEV initiative. These include hundreds of millions of dollars in research, development, and deployment (RD&D) funding and associated knowledge diffusion initiatives such as reports and merit review workshops (F1/2/3/5/6). The two primary CEC programs supporting transportation electrification are the *Alternative and Renewable Fuel and Vehicle Technology Program* and the *Electric Program Investment Charge*.[86] The CEC's RD&D work includes both vehicle-focused and infrastructure investments and pilots, as the two are very closely related. Examples of market formation efforts (F5) include funding for PEV charging infrastructure along major highways and engagement in the Ports Energy Collaborative.[87]

The **California Public Utilities Commission** (CPUC) is also becoming increasingly active in supporting PEV deployment, but plays less of a lead role in developing vehicle-focused policies. CPUC actions are therefore primarily described under *electricity market and infrastructure regulation and planning*, below.

The **Governor** has also been a strong proponent of transportation electrification. In addition to the broad policies and coordination efforts mentioned in the previous section, in October 2016 the administration also announced increases in state electric vehicle and charging infrastructure procurement.[88]

Within the **federal government,** the US Department of Energy supports PEV R&D, outreach, and public-private partnerships under the EV Everywhere initiative (F1/2/3/6/7).[89] In a major press release in July

80 More information available at: http://www.arb.ca.gov/msprog/aqip/aqip.htm
81 More information available at: http://www.arb.ca.gov/msprog/carpool/carpool.htm
82 Source: Center for Sustainable Energy (2016). California Air Resources Board Clean Vehicle Rebate Project, Rebate Statistics. Data last updated July 05, 2016. Retrieved 21 August 2016 from https://cleanvehiclerebate.org/eng/rebate-statistics; and A comparative analysis of electric-drive policy in Germany and California, International Council on Clean Transportation, https://www.now-gmbh.de/content/5-service/4-publikationen/3-modellregionen-elektromobilitaet/160408_germcalif-comparison_mit-titelseite.pdf, page 18.
83 Source: A comparative analysis of electric-drive policy in Germany and California, International Council on Clean Transportation, https://www.now-gmbh.de/content/5-service/4-publikationen/3-modellregionen-elektromobilitaet/160408_germcalif-comparison_mit-titelseite.pdf, page 4.
84 More information available at: http://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.pdf, http://www.casustainablefreight.org/
85 More information available at: http://www.arb.ca.gov/msprog/bus/bus.htm
86 More information available at: Alternative and Renewable Fuel and Vehicle Technology Program: http://www.energy.ca.gov/drive/ , Electric Program Investment Charge: http://www.energy.ca.gov/contracts/epic.html
87 Sources: http://steps.ucdavis.edu/wp-content/uploads/04-26-2016-Baroody-EV-Merit-REview-4-26-16final.pdf , http://www.energy.ca.gov/commission/documents/ports_energy_collaborative.pdf .
88 Sources: https://www.dgs.ca.gov/dgs/Newsroom/tabid/72/ArticleID/135/Brown-Administration-Announces-Updated-Actions-To-Accelerate-Zero-Emission-Vehicle-Adoption-Reduce-Carbon-Emissions.aspx
89 These actions are cross-cutting and fall under several of the policy type categories. More information at: http://energy.gov/eere/eveverywhere/about-ev-everywhere

2016, the Obama Administration, in coordination with numerous federal agencies and private organizations, issued *Guiding Principles to Promote Electric Vehicles and Charging Infrastructure* (F4/7), stated that it will make $4.5 billion available in loan guarantees (F1/5/6), and announced infrastructure planning and other initiatives (F2/3/4).[90] However, with the change in administration in 2017, the future of such policies is unclear.

Also of note, both the US and California governments have also recently reached settlements with Volkswagen in the wake of revelations of diesel vehicle fuel economy manipulation. As part of these settlements, California will receive $1.18 billion in zero-emissions technology investments and $86 million in civil penalties from the automaker (F1/4/5/6).[91] Meanwhile, the **German government** has yet to reach any settlements with Volkswagen, or otherwise fine the company, weakening its overall CO_2 emissions guidance to the market (-F4/7).

Compared to California, Germany has long refrained from implementing vehicle-focused policies beyond R&D and pilots (F5). This changed fundamentally in mid-2016, when the **federal government** introduced an EV market incentive program (*Marktanreizprogramm*),[92] which among other things instated a 4,000 Euro per-BEV customer rebate (*Kaufprämie*) for vehicles with a list price below 60,000 Euros (3,000 Euros for PHEVs), in an effort to spur market development (F5).[93] This rebate is lower than California's customer-facing incentives, which are valued at $6,000-$11,000 per vehicle, and unlike in California, there are no incentives applied to automakers or fuel suppliers beyond the EU fleet emissions regulations.

Nevertheless, according to our interviews and the latest sales statistics, the new incentive seems to already be having an effect, if a small one. The program came into effect in May 2016 and by the end of the year 9,023 applications were received, of which 3,892 were for plug-in hybrids.[94] While the long-term impacts of the incentive remain to be seen, many of the experts we interviewed were of the opinion that the rebate alone is likely insufficient to bring PEV adoption to the mainstream.

What's more, our interviewees almost uniformly listed the comparatively higher cost of PEVs (in particular for sufficient batteries to achieve a reasonable driving range) as the top barrier to widespread adoption. If the German government wishes to accelerate adoption, it seems that more initiatives to reduce incremental PEV costs for end purchasers will almost certainly be required (F1/5/6). Indeed, the market incentive program already includes two additional measures to help make PEVs more financially attractive to end users (F5) – a 10-year exemption from vehicle taxes (*Kraftfahrzeugsteuer*) for new electric cars, and an exemption from income tax on the electricity employees use at their workplace to charge their cars (normally, this employee perk would be taxed as a part of income).

A further vehicle-focused component of the market incentive program is public procurement (F5/6): 100€ million was allocated to increase the share of EVs in the fleet of government vehicles to at least 20 % by 2019.

In addition, a number of R&D programs and pilots are run by BMUB, BMVi and BMWi (F1/2/3/6). They include the "Showcase Regions for Electric Mobility" program (formerly *Modellregionen Elektromobilität*), which ran from 2012 through 2016 and distributed 300€ million towards large-scale demonstrations and public awareness campaigns via 140 projects in 4 regions.[95] Other programs include "Elektromobilität vor Ort" (BMVI) and "Erneuerbar Mobil" (BMUB), which

90 Source: https://www.whitehouse.gov/the-press-office/2016/07/21/fact-sheet-obama-administration-announces-federal-and-private-sector
91 Source: http://autoweek.com/article/vw-diesel-scandal/vw-pay-86-million-california-emissions-cheating
92 Source: https://www.bmbf.de/pub_hts/flyer_elektromobilitaet.pdf
93 Interestingly, car manufacturers and the federal government agreed to split the rebate costs, with each committing to provide up to 600€ (for a program total of 1.2€ billion) through 2019. One possible reason for this, as well as for Germany's initial reticence to provide direct customer rebates, may be the country's experience with its cash-for-clunkers program (*Umweltprämie*), introduced in 2009. According an unpublished study commissioned by the newspaper *Welt am Sonntag*, most buyers would have purchased a new car anyway, suggesting a high level of free-ridership that policymakers wished to avoid in PEV incentives.
94 Source: http://www.bafa.de/SharedDocs/Downloads/DE/Energie/emob_zwischenbilanz.pdf
95 More information available at: http://www.schaufenster-elektromobilitaet.org

also aim to facilitate technology adoption, as well as technology R&D programs under BMWi.[96] While interviewees were in agreement that more market-formation policies beyond R&D and the existing market incentive program are needed (F5), what form any further vehicle-focused initiatives may take in Germany is an open question. For example, the rebate could be increased, tax incentives for corporate purchasers could be changed, or a credit trading mechanism similar to the Low Carbon Fuel Standard or ZEV Mandate could be introduced.

5.4 Land use, building, and charging infrastructure policies

The **California Energy Commission** is the state's lead agency for many activities falling under this category. For example, it has issued regional planning grants (F6/7) and develops the state's Integrated Energy Policy Report, which includes long-term energy transportation forecasting (F4).[97] Additionally, as mentioned in the previous section, the CEC is a major funder of charging infrastructure RD&D and pilots (F1/2/3/6).

CARB also funds some charging infrastructure via pilots in its Low Carbon Transportation Investments and Air Quality Improvement Program (F5/6).[98] Additionally, it has been tasked by the state legislature with integrating ZEV initiatives into local planning initiatives (SB 375), an important element of creating legitimacy and overcoming resistance (F7).

Recently, the **CPUC** has also taken an increasingly active role in promoting charging infrastructure investments; these are discussed in the following section. Additionally, the agency oversees a $100 million program for free public charging infrastructure that was initiated via a settlement with NRG Energy, relating to California's energy crisis in the early 2000s (F1/4/5/6).[99]

California state agencies are also actively engaged in rulemaking and stakeholder working groups to develop standards for the physical connection, submetering, communications protocols, and network interoperability of electric vehicle charging infrastructure (F2/3/4/7).[100] Such activities involve a wide range of state agencies, not just those focused primarily on transportation or energy. For example, the Division of Measurement Standards at the Department of Food and Agriculture is developing requirements for charging performance tolerances, a degree of regulatory attention that parallels requirements for gasoline refueling.

In Germany, the National Platform for Electric Mobility (*Nationale Plattform Elektromobilität, NPE*) has endorsed common standards for charging infrastructure, including the Combined Charging System (CCS), pursuant to the provisions of the EU Directive 2014/94/EU on the deployment of alternative fuels infrastructure. However, it focusses primarily on technical questions, and does not address questions related to purchasing and driving behavior like range anxiety.

Additionally, the German RD&D programs mentioned in the previous section include some funding for charging infrastructure, and the market incentive program also includes 300€ million to fund new super-fast and standard charging infrastructure.

5.5 Electricity market and infrastructure regulation and planning

As previously described, the vast majority of California's electricity consumption is served by just a handful of vertically integrated investor-owned utilities (IOUs), which are regulated by the **CPUC**.[101] Because of this centralized and highly regulated electricity system structure, the CPUC is able to mobilize significant resources for market formation (F5/6) via directed utility actions in the areas of rate

96 Sources: http://www.bmvi.de/SharedDocs/DE/Artikel/G/foerderrichtlinie-elektromobilitaet-foerderaufruf.html, http://www.erneuerbar-mobil.de/en/node/955 http://www.bmwi.de/DE/Themen/Industrie/Elektromobiltaet/forschungsfoerderung-elektromobilitaet.html
97 Source: Integrated Energy Policy Report: http://www.energy.ca.gov/2016_energypolicy/
98 More information available at: https://www.arb.ca.gov/msprog/aqip/fundplan/fundplan.htm
99 Source: https://www.gov.ca.gov/news.php?id=17463
100 For example, the issues being considered by the CPUC can be found at http://www.cpuc.ca.gov/General.aspx?id=5597 .
101 Source: http://www.ecdms.energy.ca.gov/elecbyutil.aspx. 69% of total usage is supplied by the IOUs, and an additional 6% is self-generated within the IOUs' service territories.

design, charging infrastructure deployment and rebates, and energy resource procurement. It is able to do so in a manner that encourages entrepreneurial activity, knowledge development, and knowledge diffusion via public reporting and workshops (F1/2/3). In its long-term resource planning role, the CPUC is also able to set expectations for technology adoption (F4). Additionally, the CPUC regularly engages in working groups to facilitate technical knowledge development and diffusion in areas such as sub-metering and infrastructure standards (F2/3).

Recent CPUC actions include authorizing two large-scale charging infrastructure and rate design pilots in Southern California, totaling $67 million, which will result in the installation of approximately 5,000 charging stations at 500 sites (F1/2/3/5/6). The San Diego pilot also includes an innovative vehicle-grid integration tariff with day-ahead hourly pricing that incorporates local distribution grid conditions and energy prices (F1/2/3). Both pilots focus on key niches such as multi-family dwellings, workplaces, and disadvantaged communities (F5/7), incorporate measures to encourage competition in the market (F1), and require extensive data collection and public reporting to inform future decision-making (F2/3). A similar but larger pilot application from PG&E has recently been approved by CPUC.[102] A description of each pilot is shown in Table 5 below.

Another important pilot program related to demand response is the "ChargeForward" cooperation between PG&E and BMW USA. In a first phase that was completed this year, around 100 PG&E customers from the San Francisco Bay Area signed up to earn an incentive by offering flexibility in charging their EV. Results include: (1) A total of 192 demand response events took place between July 2015 and October 2016, with events scheduled through the end of 2016. (2) In 94 % of the demand response events through October 2016, the full grid load reduction of 100 kW requested by PG&E was reached. (3) By August 2016, more than19,000 kilowatt-hours (kWh) were shifted.[104] Starting November 2016 the program will be continued with a second phase, which targets a larger number of costumers with a broader range of BMWs models.

Table 5 | California Regulated Utility Charging Infrastructure Pilots[103]

	Southern California Edison	San Diego Gas & Electric	Pacific Gas & Electric
Program status	Approved and underway	Approved and underway	Approved and underway
Budget	$22 million	$45 million, plus O&M	$130 million, plus O&M
Duration	1-2 years	4-5 years	3 years
Number of stations/sites	1,500 stations 150 sites	3,500 stations 350 sites	7,500 Level 2 stations (750 sites)
Station ownership	Landowner (rebated)	Utility	Utility (35 %), building owners or third parties (65 %)
Market segments	→ Multi-family dwellings → Workplaces and fleets → Destinations	→ Multi-family dwellings → Workplaces	→ Multi-family → Workplaces → Schools, other
Grid integration	Time of Use (TOU) Rates, demand response capability	Day-ahead hourly pricing: consider circuit conditions and generation forecasts	TOU Rates
Disadvantaged communities	Free participation 10 %+ of sites	Free participation 10 %+ of sites	Free participation 15 %+ of sites

102 Source: http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M169/K668/169668696.PDF
103 Source: Southern California Edison: http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M157/K724/157724767.PDF
San Diego Gas & Electric: http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M158/K071/158071336.PDF
Pacific Gas & Electric: http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M159/K711/159711579.PDF
More information at http://www.cpuc.ca.gov/General.aspx?id=5597
104 Source: https://www.pge.com/en/about/newsroom/newsdetails/index.page?title=20161114_pge_and_bmw_partner_on_next_phase_of_pilot_studying_advanced_electric_vehicle_charging_

The CPUC was also tasked by the **legislature** in the Clean Energy and Pollution Reduction Act of 2015 (SB 350) with soliciting applications from the utilities to support "widespread transportation electrification" (F4).[105] As with CARB's Mobile Source Strategy, this incorporates all forms of mobility, such as vehicles, e-bikes, boats, and trains. Additionally, SB 350 establishes transportation electricity as a form of basic utility service, setting technology expectations (F4/7), and making it easier for regulators and utilities alike to mobilize resources and provide market guidance (F4/6). Further legitimizing transportation electrification (F7), and providing guidance as to how market formation could be pursued (F4/5), the law also declares that investment cost-benefit considerations should incorporate:

- Better renewables integration via improved system utilization
- Energy efficiency improvements in transportation
- Air pollution reductions
- Greenhouse gas emissions reductions
- Alternative fuel usage increases
- Economic benefits in disadvantaged communities

In September, the **CPUC** issued its application guidance (F4); the first applications are due in January 2017.[106]

In its role as transmission system and electricity markets operator, the **California Independent System Operator** (CAISO) is also a key regulatory stakeholder. While the CAISO is a nonprofit public benefit corporation and not a public agency, it's board is appointed by the Governor of California, and it is regulated by the Federal Energy Regulatory Commission. Numerous ongoing CAISO initiatives touch on vehicle-grid integration topics, such as the energy storage and distributed energy resources initiative, which establishes a framework under which PEVs can participate in energy markets (F1/4/5/7).[107]

The **CEC** also plays an essential role in electricity system planning via development of the Integrated Energy Policy Report, mentioned previously, which includes detailed demand forecasts (F2/3/4). **CARB** also develops electric vehicle adoption forecasts that are used in the state's electricity system planning (F2/3/4).

In Germany, there has been relatively less focus on the interactions between transportation electrification and the electricity sector, though the concept (*Sektorkopplung*) is gaining momentum (F7). Because Germany's grid has more excess transmission and distribution capacity than California's, interviewees agreed that there seems to be little need to build new transmission or distribution infrastructure to accommodate transportation electrification in the near or medium term.[108] However, interviewees stated that charging needs might be an important long-term issue for the transmission and distribution grids.

Indeed, several experts brought up aspects of **vehicle-grid integration** (VGI) as issues that are beginning to be discussed and addressed. In the near to medium term, our interviewees stated that distribution grid operators are concerned about *simultaneous charging* (in which many customers plug in their cars at once), and *unexpected charging* (in which customers purchase a car and charge it at home, without the DSO's advance knowledge or ability to plan for it) – particularly given that homes in Germany typically have relatively high capacity grid connections. Some interviewees suggested that one partial solution for unexpected charging would be mandatory registration of all EVs. Another relevant aspect is how electricity rates and tariffs should be designed. Unlike in California, pricing is not regulated in Germany and suppliers are free to choose rates as they deem appropriate. So far, flat rates are the dominant form of pricing for smaller consumer like EV owners. But this is obviously inefficient given the rising share of renewables and the price fluctuations that come with it. In particular, it might imply that efficient charging takes place in times of high renewable generation –

105 SB 350 also sets a 50% renewable energy target and calls for doubling of energy efficiency by 2030. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB350 .

106 Source: http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M167/K099/167099725.PDF .

107 Source: ESDER initiative: https://www.caiso.com/informed/Pages/StakeholderProcesses/EnergyStorage_AggregatedDistributedEnergyResources.aspx

108 The industry generally acknowledges that there is a significant long-term need for more distribution capacity, but this discussion is centered on grid integration of distributed solar, and is unrelated to transportation electrification. Moreover, the Federal Network Agency (BNetzA) considers investment plans submitted by the DSOs for the next 10 years to be sufficient: http://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Allgemeines/Bundesnetzagentur/Publikationen/Berichte/2016/Jahresbericht2015.pdf?__blob=publicationFile&v=2.

and not generally during the night when total demand is generally lowest.

Limiting simultaneous charging, however, requires some form of rate design or other market framework intervention. Yet because Germany's electricity sector is deregulated, the government has limited ability to influence electricity rates in order to support PEV market formation or align charging behavior with grid needs (-F5). To the extent that such conversations are occurring, interviewees indicated that they were generally a part of broader discussions of rates for distributed energy resources (and of enabling technologies such as smart meters), rather than specific to PEVs. The primary focus of such conversations seemed to be on developing time- and location-variant grid usage fees (*Netzentgelte*), as well as on regulations and market signals for resource aggregators, as these are the primary areas where regulators in a deregulated market have authority to provide a market signal or framework (F5/7). Interviewees also mentioned discussion of nodal pricing, but this concept did not seem to have much traction in Germany (-F7).

Because Germany has hundreds of DSOs, and because customers can register with the electricity retailer of their choice, interoperability and coordinated infrastructure planning are more challenging issues in Germany than in California (F5). However, both jurisdictions must think beyond borders and build a harmonized networks across both charging station providers and neighboring regions. "Roaming" was brought up as one area of concern: the ability, not currently guaranteed, to charge a car regardless of the customer's electricity retailer or the charging station operator. At this early stage in market formation, roaming is a decentralized and unregulated activity, and it occurs only via private agreements amongst infrastructure operators. For example, on the initiative of the municipal utilities of Aachen, Osnabrück, and Duisburg, about seventy municipal utilities have joined forces under the umbrella of "ladenetz.de", a network of 700 charging stations nationwide.[109] Of the large utilities, Innogy (formerly RWE) operates around 1,700 charging stations in cooperation with eRoaming partners across Germany.[110] EnBW, another large utility, has so far concentrated just on the city of Stuttgart, with partnerships to allow its customers to roam.

The large number of DSOs in Germany also complicates – and perhaps limits – the government's role in charging infrastructure planning and rollout. For example, some of the experts interviewed raised the question of whether charging infrastructure should be viewed as an element of the distribution system, in which case it would be subject to more regulation, or whether it should be viewed as a private investment, and therefore subject to more competition. Relatedly, there is also the question of whether electricity sales to retailers or end users at a charging station should be occurring inside or outside of the electricity market. US electricity market liberalization experience suggests that this is potentially a big issue because of potential cross-subsidization between regulated aspects of the business and deregulated aspects. A particular concern is that captive customers subsidize new activities by the regulated utilities. But the downside of leaving this unregulated is that there is no control on typical regulatory issues such as energy access.

Interviewees could not agree on the best solutions, but were in agreement that these questions need to be clearly decided, so that regulators and market participants can proceed to resolve the technical, market, and regulatory issues that arise from the decision, and roll out charging infrastructure with more regulatory certainty (F4). This question mirrors California's explorations of both utility and privately owned charging infrastructure, as seen in the various approaches taken under the recently approved IOU pilots.

109 https://www.ladenetz.de/leistungen/ladenetz-de-stadtwerke-verbund
110 https://www.innogy.com/web/cms/de/3213482/home/privatkunden/epower-direct/

5.6 Civic engagement and equity initiatives

In California, equity initiatives are woven into many ZEV-related policies, which help to create legitimacy and overcome resistance (F7). For example, as part of its ZEV Mandate activities, CARB implements low-income/equity programs (pursuant to state legislation, SB 1275). And the charging infrastructure pilots authorized by the CPUC include free charging infrastructure for disadvantaged communities, along with requirements that at least 10% of pilot installations be located in such communities.[111]

State agencies have also developed several websites, such as www.driveclean.ca.gov, to engage the public in transportation electrification initiatives and inform citizens of the costs and benefits of purchasing an electric vehicle. Additionally, the Governor's Office, GO-Biz, CARB, the CEC, and the CPUC are all active participants in the **PEV Collaborative**, a public-private partnership that engages in knowledge diffusion within the industry (F3/7), as well as in public engagement activities such as test drive events. The collaborative also supports a website with information on PEV costs and benefits (F7).[112]

In Germany, the aforementioned "Showcase Regions Electric Mobility" (*Schaufenster Elektromobilität*), which ran from 2011 to 2016, was the primary vehicle for civic participation and raising consumer awareness of PEVs. The program supported projects that rendered transportation electrification more visible, allowed prospective consumers to experience the technologies, and deployed charging infrastructure and vehicles at large pilot scales.[113] It is unclear if this program will be continued in the future.

111 See for example the recently approved PG&E program: http://www.sfchronicle.com/business/article/PG-E-to-launch-biggest-installation-of-electric-10799314.php?t=ff15cdd671&cmpid=twitter-premium

112 http://www.pevcollaborative.org/

113 More information available at: http://schaufenster-elektromobilitaet.org/de/content/ueber_das_programm/foerderung_schaufensterprogramm/foerderung_schaufensterprogramm_1.html

5.7 Overview of policy landscapes

Figure 4 and Figure 5 provide an overview of the major components of the PEV policy landscapes as described in the previous sections. Given the complexity of the landscapes and the particular interest in market formation of this report, the focus is on action targeting PEV deployment and integration, leaving out essentially all programs related to technology R&D like e.g. battery improvements. Moreover, the California overview focuses on the main agencies and does not includes (a) strategies and plans not directly related to PEVs like the *Climate Change Scoping Plan and Sustainable Freight Action Plan* nor (b) incentives or programs on the sub-state or federal level, which are in fact quite significant.[114] The most helpful resources to get a more comprehensive overview of the California landscape are the ZEV Action Plan and the accompanying GO-Biz website.[115]

Figure 4 | Major elements of PEV policy landscape in California (state level) [115]

California state level

Strategies & Plans

ZEV Action Plan (GO-Biz)
Outlines progress to date and identifies new actions state agencies will take in continued pursuit to place 1.5 million ZEVs in California by 2025

Mobile Source Strategy (CARB)
Demonstrates how to meet air quality standards, achieve GHG emission reductions, decrease health risk and reduce petroleum consumption

Policies & Measures

CARB
- **ZEV Mandate**
  Implements a quota for zero-emission vehicles sales by large manufacturers
- **Low Carbon Fuel Standard (LCFS)**
  Sets a carbon-intensity standard for gasoline and diesel fuels
- **Advanced Clean Cars Program**
  Sets a GHG emission standard for new passenger vehicles
- **Cap-and-Trade Program**
  Sets a price on GHG emissions on fuels

CEC
- **Alternative and Renewable Fuel and Vehicle Technology Program**
  Investment program to support related development and deployment projects through grants, loans etc.

CPUC
- **Low-Carbon Electric & Natural Gas Fuel**
  PEV rate design pilots
- **Charging infrastructure**
  Approval of IOU infrastructure proposals in multi-unit dwellings, workplaces, and at public interest destinations
- **Vehicle-Grid Integration (VGI) Research**
  R&D and pilots on integration, e.g. use of PEV as demand response resources

114 For an overview of state and local level ZEV incentives see: http://business.ca.gov/Programs/Zero-Emission-Vehicles-ZEV/ZEV-Incentives

115 http://business.ca.gov/Programs/Zero-Emission-Vehicles-ZEV

116 More information available at: ZEV Action Plan: https://www.gov.ca.gov/docs/2016_ZEV_Action_Plan.pdf, Mobile Source Strategy: https://www.arb.ca.gov/planning/sip/2016sip/2016mobsrc.pdf, CARB programs: https://www.arb.ca.gov/msprog/msprog.htm, CEC programs: http://www.energy.ca.gov/altfuels/, CPUC programs: http://www.cpuc.ca.gov/General.aspx?id=5597

Figure 5 | Major elements of PEV policy landscape in the EU and Germany[116]

European level

Packages & Strategies

EU Climate and Energy Targets
Define targets to reduce GHG emissions by a minimum of 20 % in 2020 and 40 % in 2030 respectively

European Strategy for Low-Emission Mobility
Identifies three priority areas for action including moving towards zero-emission vehicles

Policies & Measures

Vehicle emission performance standards
Emission performance standards for new passenger cars (REG. 443/2009) and new light commercial vehicles (REG. 510/2011)

Germany federal level

Plans

National Electromobility Development Plan (2009)
Defines a target of 1 million electric vehicle by 2020 intending to create a lead market

Climate Action Plan 2050
Defines a target of -40 % in the transportation sector by 2030 and proposes new policies & measures

Policies & Measures

Platform for Electric Mobility (Stakeholder Platform)
Orchestrates the development of electric mobility by investigating its potential and recommending actions for politicians and business

Market Incentive Program (BMWi,BMUB,BMVI,BMBF)
Comprises rebates, public funding for charging infrastructure, procurement for the government fleet, and extended tax exemptions

117 More information available at: EU Climate & Energy Targets: http://ec.europa.eu/clima/policies/strategies/2020_en, http://ec.europa.eu/clima/policies/strategies/2030_en, EU Strategy for Low-Emission Mobility: http://ec.europa.eu/clima/policies/transport_en, EU vehicle emission performance standards: http://ec.europa.eu/clima/policies/transport/vehicles_en, National Electromobility Development Plan: https://www.bmwi.de/English/Redaktion/Pdf/national-electromobility-development-plan,property=pdf,bereich=bmwi,sprache=en,rwb=true.pdf, Climate Action Plan 2050, http://www.bmub.bund.de/fileadmin/Daten_BMU/Download_PDF/Klimaschutz/klimaschutzplan_2050_kurzf_en_bf.pdf, Platform for Electric Mobility: http://nationale-plattform-elektromobilitaet.de/en/, Market Incentive program (German): https://www.bmbf.de/pub_hts/flyer_elektromobilitaet.pdf

6. Observations, Recommendations and Open Questions

In this section, we draw on our previous analysis to synthesize relevant observations, recommendations, and open questions for the way forward for transportation electrification in Germany. Where possible and useful, we employ a comparative perspective, contrasting developments in Germany with California, and pointing out potential learning opportunities.

In our interviews with German stakeholders, two key barriers to widespread PEV adoption were frequently mentioned: the incremental cost of the vehicles (the batteries in particular), and the lack of diverse vehicle models from German automakers that are able to meet equally diverse end user needs. The cost barrier, while important, is more straightforward – continued investment in battery R&D (F2/3/6), along with vehicle rebates (F5/6), can help to reduce incremental costs.

Lack of PEV model availability, however, seems to be a more complex barrier. Upscaling beyond the niche in the mid to long term will require not just 4-door sedans but also SUVs, sports cars, trucks, vans, last-mile delivery vehicles, buses, forklifts, drayage trucks, and so on – yet German automakers have developed almost none of these PEV vehicle types to date. And as many interviewees noted, it will be politically infeasible for aggressive market formation efforts to move forward, if such efforts would primarily benefit foreign competitors with diverse PEV models, and disadvantage German automakers. While the German government has long supported R&D and pilots (F2/3/6), we agree that market formation and product legitimacy (F5/7) require the existence of a sufficient number of model offerings that German automakers can actually benefit from aggressive ZEV incentives or quotas, rather than being harmed by them. At the same time, developing each new PEV model is a substantial, multi-year investment, and one that automakers understandably do not wish to undertake before the time is ripe – from both technological (sufficient range at reasonable cost), and societal (political/regulatory support, customer demand) perspectives.

Nevertheless, stakeholders generally acknowledged that now is the time to focus on market formation efforts. And we agree with many of the interviewees that increasingly stringent EU fleet standards (ideally with a ZEV quota), along with higher customer rebates, would likely be the most effective market drivers (F4/5/6). We also think that a high enough price on carbon (or cap and trade with a floor price) that is specific to the transportation sector, similar to the Low Carbon Fuel Standard, would be an equally important and effective signal for market formation (F4/5) and orientation towards the ultimate policy driver: the need to reduce greenhouse gas emissions (F7).

At the same time, we question whether there is the political will in Germany to make a strong push in these areas unless it is coordinated with other initiatives focused on transportation electrification industrial policy, and specifically on the availability of domestic PEV models (F7). For example, while the German Upper House (*Bundesrat*) recently proposed that EU legislation should consider new passenger vehicles to be "zero emission" by 2030, this non-binding proposal – though an important signal of expectations (F4) – seems highly unlikely to translate into enforceable regulations or market formation efforts at this time (-F5).

Indeed, a historical perspective suggests that the "readiness" of the underlying technologies and of the auto industry is likely an important factor in following through on ambitious policies. As previously mentioned, the 2009 *National Electromobility Development Plan*, which is dependent on domestic automaker readiness to create a lead market, seems to have lost all relevance. German automakers are laggards in developing BEV vehicles (see Figure 2 above), and PEV sales by German automakers in Germany are dramatically lower than in other regions such as California and China. This seems to parallel early transportation electrification efforts in California, in which CARB established a ZEV mandate in 1990, but then went on to weaken its targets as battery costs and vehicle ranges did not improve as quickly as anticipated.[118]

However, California ultimately did choose to lead via its ZEV Mandate once technology improved – complemented by increasing awareness of air quality and climate concerns associated with transportation. In comparison, if German automakers choose to lead in PEVs at this point, it will not be as first movers, and the change will likely be driven at least as much by external markets as by domestic policy – in particular by China's proposed 8 % PEV mandate for 2018, which would almost certainly put German automakers at a competitive disadvantage.[119]

Nevertheless, there are signs (such as industry support for the recently-introduced vehicle rebates, F7) that the auto industry is finally becoming ready to act to avoid being left behind in both domestic and international markets. In particular, important international markets like California and more recently China, in which PEV deployment measures are planned or are already in place, exhibit an increasingly strong market pull. Today, the German automakers all have plans to introduce diverse new PEV models over the next several years. For example, BMW has committed to producing a BEV SUV in 2019, and a BEV Mini in 2020.[120] Partly in response to the diesel scandal, Volkswagen also recently committed to rolling out a wide range of PEVs over the next several years. Finally, Daimler has also created the new brand EQ, around which new e-mobility products will be developed. The planned availability of these new passenger vehicle models provides an opportunity for policymakers to introduce aggressive light duty vehicle PEV market formation efforts with complementary timing.

At the same time, long-run transportation electrification will require that many more vehicle types be developed, beyond standard passenger vehicles. These include medium and heavy-duty vehicles, and off-road vehicles. While Daimler has a medium duty truck available, there is certainly a need for a higher diversity of models and products. For these vehicle types, German policymakers could play an important role in both addressing the model availability barrier and developing complementary market formation initiatives. Looking for useful lessons, California was to some extent able to avoid the chicken-and-egg industrial policy hurdle of coordinating market incentives with model availability due to its lack of traditional automakers, and due to the presence of its IT sector, which sees opportunities in transportation electrification and is more comfortable making risky investments. Indeed, perhaps a more relevant example for Germany is Japan; according to additional interviews we conducted there, close collaboration and coordinated, long-term strategic planning have been among the most significant factors in enabling Japanese policymakers and automakers to push the envelope in developing mass market ZEVs.

To help guide a smooth transition, it is also clear that there needs to be a strong federal policy within Germany that considers all forms of transportation (including alternatives like public transit and car-sharing), not just industry-developed timetables for light duty PEVs (F4). Just as California's agencies coordinate with one another and with industry via the ZEV Action Plan and PEV Collaborative (among other initiatives), Germany would also benefit from a clear roadmap that incorporates diverse stakeholder input beyond the current *Plattform Elektromobilität* activities. Such a roadmap might, for example, consider how quickly vehicle models could be introduced in different market segments, and lay out complementary government policies to incentivize market formation in those segments, especially given that domestic vehicles are expected to become available (F4/5/6). The ultimate aim of such a roadmap would be to induce a rapid yet orderly transformation (F1/5/6/7) in a predictable and clear manner that allows the German economy to adjust and adapt to new expectations.

While industry should be a major partner in informing this market guidance, it should not be the only partner – environmental organizations, end users, ratepayers, electric utilities, distributed energy resource aggregators, and other stakeholders all deserve a seat at the table. From a German perspective, this is one of the great strengths of the California process, which not only ensures political support, but also broad societal involvement, including from disadvan-

118 Source: http://www.ppic.org/content/pubs/cep/EP_907LBEP.pdf
119 Source: http://english.caixin.com/2016-11-14/101007386.html
120 Source: http://www.autoexpress.co.uk/bmw/x3/97612/confirmed-all-electric-bmw-x3-suv-and-mini-ev-models-by-2020

taged populations. In particular, while vehicle model availability is a key bottleneck that needs to be considered from an industrial policy perspective, from a societal perspective, carbon reduction targets should also be considered a primary policy constraint, and transportation electrification targets should be aligned with these broader environmental targets.

Beyond the national and EU-level climate targets, many interviewees also brought up the United Nation's COP21 Paris climate agreement as a key goal that is, or should be, guiding the market and setting expectations (F4). Yet many also lamented that government priorities and actions do not sufficiently follow through on this guidance via resource allocation (F6) and market development policies (F1/5), undercutting the guidance and legitimacy that Germany's climate targets might otherwise have (F4/7). Indeed, this wish – that the government would reprioritize policymaking around its carbon emissions goals and take more serious steps towards supporting carbon reductions across the economy (F1/5/6/7) – was one of the most frequent and passionately formulated pleas we heard in our interviews.

At the same time, many interviewees also stressed that it is important to take a measured approach that will enable existing market actors and members of the workforce to smoothly transition into a low-carbon paradigm and thereby avoid widespread economic hardship. This reemphasizes the usefulness of a comprehensive roadmap for a transportation transition. The Climate Action Plan 2050, adopted in response to the Paris climate agreement, proposes the development of a *Klimaschutzkonzept Straßenverkehr* (Climate Action Concept for Road Transport), which could be an important first step. But a truly effective transportation electrification roadmap will need to be more than simply conceptual, and will need to be broader than just road transport – it will need to be binding and action oriented, cover various modes of transportation and their interactions, and have stakeholder buy in.

Chief among PEV policies that such a carbon-driven yet industry-acknowledging roadmap could consider are those mentioned previously: fleet CO_2 standards and/or sector-based carbon pricing, ZEV sales quotas, and either upstream or customer rebates to reduce first costs (F4/5/6). Carbon emission or ZEV standards (or similar pricing/trading schemes) seem particularly essential to guide the market and create market formation incentives over the long term (F4/5). However, other policies and initiatives are also necessary, and some of these can begin today. One such best practice can be seen in a key difference that we observed between California and Germany: while Californian transportation electrification efforts are customer-focused, in Germany the end users – drivers – did not seem to be a major element of policy considerations. Interviewees often simply noted that German drivers prefer ICEs, and that incremental costs are a hurdle, and then moved on to more industry-oriented concerns. To address this lack of customer orientation, we believe that a roadmap should include more programs for customer research and education.

In California, such customer surveys and ethnographic studies have found that there are many overlapping reasons to purchase or not purchase an electric vehicle – and many different reasons why PEV owners are satisfied or dissatisfied. For example, many California drivers are strongly motivated to purchase PEVs because of preferential rules that allow them to go in high-occupancy vehicle ("carpool") lanes, even when the driver is alone. The time saved is a major motivation in highly congested California, yet it is not something that would be considered in a typical economic analysis. The "wow factor" of PEVs is another such motivator. Meanwhile, studies also show that while many non-owners are concerned about having sufficient range, most PEV owners are quite satisfied with their vehicle range, and do not suffer from range anxiety.

Such analyses, as well as conferences and events to share findings, are a core element of California's transportation electrification policy efforts – particularly via the CEC and the University of California, but also via industry conferences and customer-facing events promoting ZEVs (F2/3/7). Because electric vehicles – unlike other industrial products such as wind farms – are ultimately consumer products, we believe that it is important for German policymakers to better understand what ultimately motivates customer purchase (or non-purchase) decisions, as well as owners' satisfaction (F2), to actively disseminate study findings (F3), and to ensure that these learnings are incorporated into industry guidance (F4) and non-monetary incentives (F5). These findings should also inform customer outreach, educating the public in a targeted and effective manner on the benefits and costs of PEVs (F3/5/7).

Another area that a roadmap could address is guidance on niche market formation (F4/5). Numerous experts mentioned to us that it is important to focus on the simpler, more cost-effective market segments today, and to expand to additional market segments in the future. For example, local governments, taxis, other vehicle fleets such as last-mile delivery vehicles, and single family homes may be good places to start, due to more unified purchase decisions and vehicle usage that is consistent with current charging availability (F5). Other applications, such as heavy-duty vehicles and end users in multifamily dwellings, might take longer to adopt PEVs. In collaboration with stakeholders, such a roadmap could consider these and other market niches, and provide guidance to industry that will facilitate the development of the right vehicle types for the right market segments at the right time (F4/5). This would mirror some of California's efforts, which include separate proceedings for transit and other heavy-duty vehicles (F4/5), as well as program carve-outs for multifamily applications (F4/5), which are a priority in the state for equity reasons.

Beyond the above key observations and recommendations, we wish to conclude with several open questions, as transportation electrification efforts in Germany seem to be shifting from R&D and pilots (F1/2/3) to more market formation and legitimacy needs (F5/7):

- The German auto industry largely acknowledges that e-mobility is the future, but is still **waiting for the right time to act**. So, what is the proper policy to clarify that now is the time?
- How can German transportation electrification policy become more forward-looking and intentional, and **less reactive**? What lessons can be learned from past examples of German industrial policy in other sectors?
- If Germany wishes to pursue **CO_2-driven policy and an associated regulatory structure that is clear, coordinated, and long term,** are certain structural changes necessary in the federal agencies, such as a clarification of responsibilities or reallocation of staff?
- How can the federal government **empower and encourage regional governments** to take action at the community level to support improved **urban land use, health, and quality of life**?
- To what extent should publicly-accessible conventional or fast **charging infrastructure** be promoted, given that range may soon match that of ICEs, and what is an appropriate regulatory treatment of such infrastructure? Related questions suggesting themselves for further scientific analysis are: (1) How will the need for public charging stations develop over time and is there an economic case for government intervention, e.g. due to network externalities, and standardization? Does the development of telephone booths provide a useful analogy? (2) How should the required expansion of power grids on the distribution level be financed? Which incentives should be instituted to encourage efficient use?
- What is the appropriate balance between promoting equal access to transportation electrification (**equity**, particularly for residents of multifamily housing, and lower-income communities), and promoting somewhat **exclusive niche markets** (taxis, corporate cars, last-mile delivery vehicles, etc.)?
- How can Germany treat **vehicle-grid integration (VGI)** in a holistic manner, and in coordination with other distributed energy resources, so that PEVs help reduce need for new power plants and transmission lines, and do not require as many new distribution lines? A related question, especially in the context of rising shares of renewables, is how electricity rates and tariffs should be designed to incentivize efficient charging and how EVs could be used to provide demand services – an issue currently also under experimentation in several California pilots.
- How can Germany address cultural **attachment to ICEs** within the auto industry, as well as end user unfamiliarity and concerns with PEV technology?
- How will transportation electrification interact with **other important trends**, such as car-sharing, autonomous vehicles, multimodal transportation, stationary storage, and energy management systems?

- How should Germany pursue **other ZEV technologies** beyond PEVs, such as fuel cell vehicles, more rail-based public transit, catenary lines for freight and public transit, biofuels (especially for aviation), renewably-generated natural gas vehicles, and e-bikes?
- Which role will policies on the **EU level** play and how should respective policy making evolve in the future? More specifically, should the transportation sector be included in the EU ETS or continue to be regulated through performance standards – or even both? A related question for further scientific examination is to what extent such standards have already triggered innovation, or could be expected do so in the future under higher levels of stringency.
- A final and more forward-looking question relates to the **future of mobility**: What if car sharing replaces car ownership and the car companies sell to the Ubers or Zip cars of the world and not individual consumers? What if autonomous vehicles significantly penetrated the market, and those vehicles were increasingly electric?

Current developments around e-mobility make clear that there is an increasing need for German policymakers and other stakeholders to take on the task of seriously considering and answering these questions. The choices made in the coming few years will shape the future of transportation sector innovation in the country, providing considerable environmental and economic opportunities. We think that the California example, policy recommendations, and open questions brought up in this paper can serve as an aid in making these choices.

Notes

Notes

Notes

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