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Strategies for setting a national electric vehicle charger standard: Relevant factors and the case of Chile

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Executive summary

This working paper summarizes the development of electric vehicle (EV) chargers and charger standards across the four major vehicle markets of China, the European Union, Japan, and the United States. It identifies three strategies available to national authorities for choosing among charger standards (the technical specifications that shape charger use and ultimately determine which EVs can be used in a country). Governments can 1) take a laissez-faire approach, leaving the shaping of the charger landscape to other players; 2) adopt a single standard and require that EV manufacturers conform to it; or 3) adopt interoperability regulations that accommodate diverse charger types and a wide range of EVs.

Using a historical and technical analysis of international charger standards for battery-electric vehicles (BEVs),[1] the paper identifies factors that shape a country's strategy for setting a charger standard. These varying factors include the country's status as an EV importer or exporter, the power of private industry innovation, and market size and regulatory strength. The array of factors and their various expressions in different countries yields the three charger strategies found in different markets.

This paper uses Chile as a case study of how a country might develop a charger standard strategy, and of the lessons policymakers learned (and are still learning) in the process. Early in the transition to zero-emission vehicles, and with progressive plans to decarbonize its economy, Chile presents challenges similar to those faced by many other countries seeking a rapid transition to EVs over the coming decades.

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1 Plug-in hybrid electric vehicles are not included in the scope of this report.

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THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Introduction

As governments work to address climate and air quality challenges, many seek to decarbonize transportation by promoting a rapid transition away from internal combustion engine (ICE) vehicles. Zero-emission sales targets and requirements are increasingly common; deadlines for meeting 100% new zero-emission vehicle sales goals range from 2025 in Norway to 2050 in Costa Rica and 2070 in India.[2] Meanwhile, markets seem ready to supply the chief alternative to ICE technology, electric vehicles (EVs): their share of global vehicle sales nearly doubled in a single year, from 4.2% in 2020 to 8.3% in 2021.[3] The combination of elevated government attention and growing market interest in EVs suggests that a new age of clean and more sustainable electrified transport is unfolding.

The transition to EVs is not automatic or guaranteed, however. A common obstacle to rapid growth of EV markets is the absence of public charging infrastructure, whose development is complicated by the broad array of charger types—eight and counting—across major markets today.[4] Indeed, part of the hard work for countries transitioning to EVs is settling on a charger standard strategy that accelerates growth of the EV fleet consistent with national development priorities.

Charger standard strategies cover a spectrum of choices, from accepting many chargers without regard to their interoperability, to allowing a single standard to which manufacturers must conform, to incorporating interoperability regulations that accommodate many vehicle types. A country's choice is consequential: it implies serious investment by governments and manufacturers, and it can define a country's long-term path for charging infrastructure, making change later difficult and expensive. International standards organizations and vehicle manufacturers each exert influence over national charger strategies, which shape vehicle markets and charging infrastructure within nations.

This paper explores drivers of charger proliferation, the history of charger development, and factors involved in choosing a strategy for setting a charger standard. It also reviews the case of Chile, which is navigating the question of charger choice as it stands, like many emerging market countries, on the cusp of the EV transition.

Concepts and definitions

A country's choice of a charger standard strategy is influenced by a host of international institutions, government agencies, firms, and other actors, and by the outputs they produce (Figure 1).

2 "Internal combustion engine phase-outs," (ICCT: Washington, DC, 2022), https://theicct.org/ice-phase-outs/; Santosh Sharma Poudel, "India Commits to Net-Zero Emissions by 2070," *The Diplomat,* November 11, 2021, https://thediplomat.com/2021/11/india-commits-to-net-zero-emissions-by-2070/.

3 Roland Irle, "Global EV Sales for 2021," *EVvolumes.com*, accessed March 16, 2022, https://www.ev-volumes.com/; IEA, "Global EV Outlook 2021," April 2021, https://www.iea.org/reports/global-ev-outlook-2021.

4 Jing Li, "Compatibility and Investment in the U.S. Electric Vehicle Market," (MIT: Boston, 2017), https://www.mit.edu/~lijing/documents/papers/li_evcompatibility.pdf.

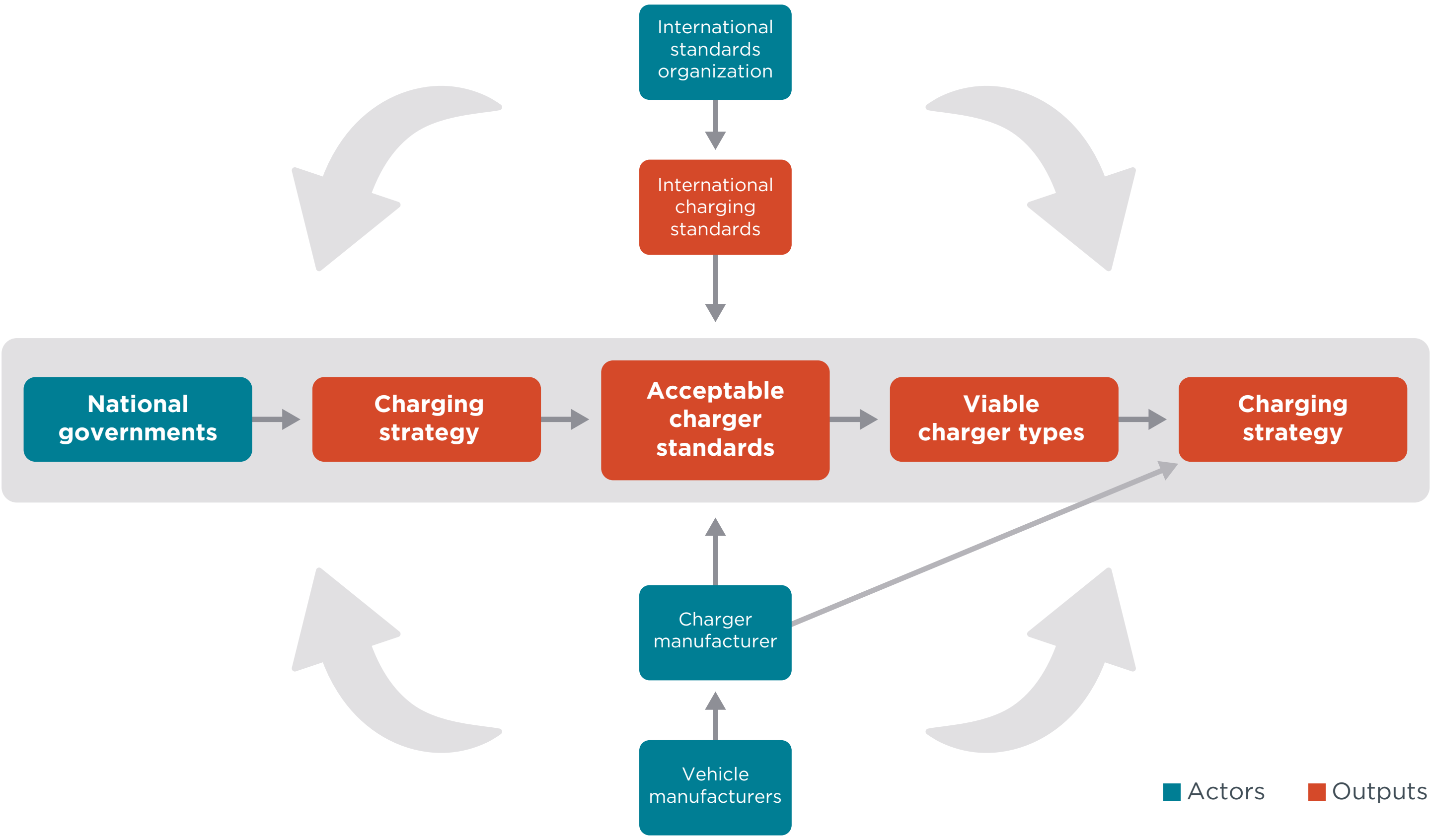


Figure 1. Relationship among key actors and outputs involved in the creation and implementation of charger strategies. Actors are depicted in blue, and outputs in orange. Broad arrows from vehicle manufacturers and from international standards organizations suggest broad influence over the actors and outputs of the middle axis.

For the purposes of this paper, these actors and outputs are defined as follows:

International standards organizations prepare and publish international standards for electric technologies, including charger standards. Three standards-creating bodies that appear in this paper are shown in Table 1.

Table 1. Examples of international standards organizations that set charger standards

Name	Headquarters
The International Electrotechnical Commission (IEC)	European Union
SAE International (SAE)	United States
Standardization Administration of China (SAC) (Chinese governing branch of the IEC)	China

International charging standards are guidelines or processes governing the technical requirements of EV charging, including requirements for chargers. They are often developed by a group of experts from multiple countries and are set by an international standards organization. (Table 3 lists leading charger standards and their regions of common use.)

National governments analyze the international standards set by an international standards organization, then choose their own strategies, based on international standards.

A **charging strategy**, created by governments, is a plan for a country or governing body to provide and/or facilitate the installation of EV chargers, charging stations, and their respective networks. This paper discusses three strategies: 1) use a "hands-off" laissez-faire approach; 2) adopt a single standard and require that EV manufacturers conform to it; 3) adopt interoperability regulations that accommodate diverse charger types.

Acceptable charger standards are the technical charger specifications permitted within a jurisdiction. Acceptable charger standards for a government emerge from its national charging strategy and differ from country to country. Some countries may choose to implement a single standard, while others focus on multiple standards, with or without interoperability regulations.

Viable charger types are chargers that meet a country's acceptable charger standards.

Charging stations, or charging points, contain the equipment that receives electricity from a power source and delivers it to the vehicle via the charger, including the connector, or "plug." Charging stations are part of what is known collectively as electric vehicle supply equipment (EVSE). A station's structure depends on a country's choice of acceptable charger standards and can include one or more types of connectors (Figure 2). Their technical configuration depends on the country's electrical infrastructure.

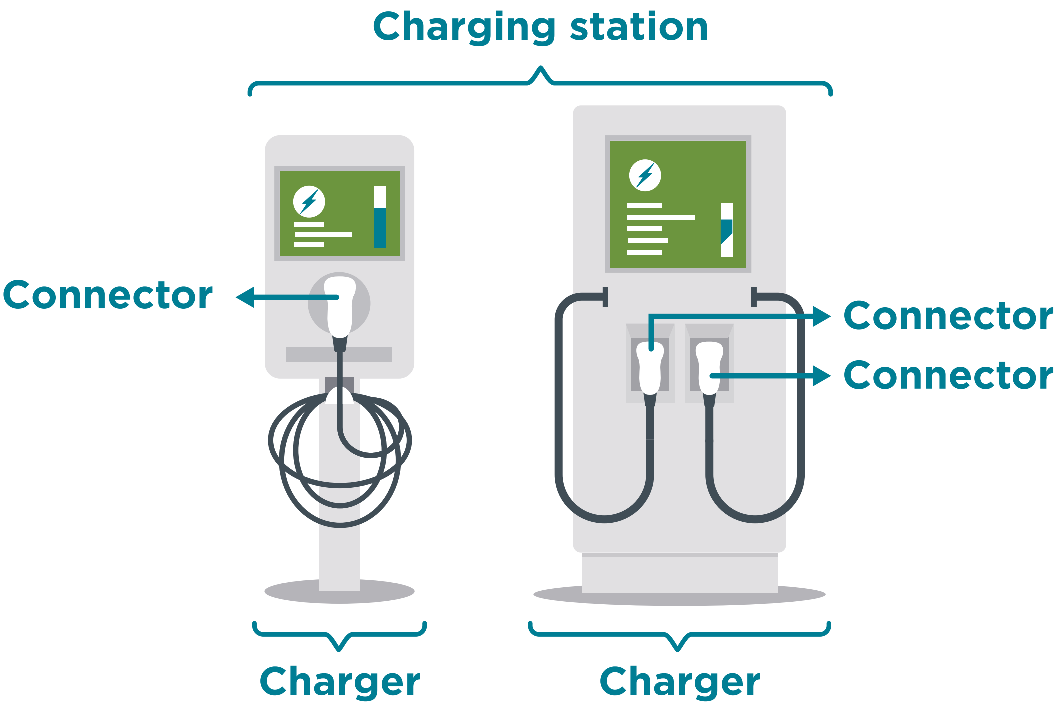


Figure 2. An EV charging station comprised of two chargers and three connectors

Source: Superintendence of Electricity and Fuels of Chile

Vehicle manufacturers, also known as original equipment manufacturers (OEMs), are private companies that produce EVs. Their vehicles must comply with charger standards in the country of sale. In some cases, as with Tesla, OEMs also produce their own vehicles' chargers and/or charging stations.[5] Vehicle assembly can be affected by the international standards adopted by the country in which the vehicle will be sold (whether that is the country of assembly or an export customer), as particular connector types may be required.

Charger manufacturers design and make EV charging equipment. Some chargers, such as CHAdeMO, are named after their manufacturer. Charger assembly is influenced by a country's acceptable charger standards. Charger manufacturers can develop public charging infrastructure that matches a government's strategy for setting a charger standard.

5 At the time of publication, Tesla was the only vehicle manufacturer that produced its own chargers. In this paper, Tesla is not considered a charger manufacturer.

Drivers of charger proliferation

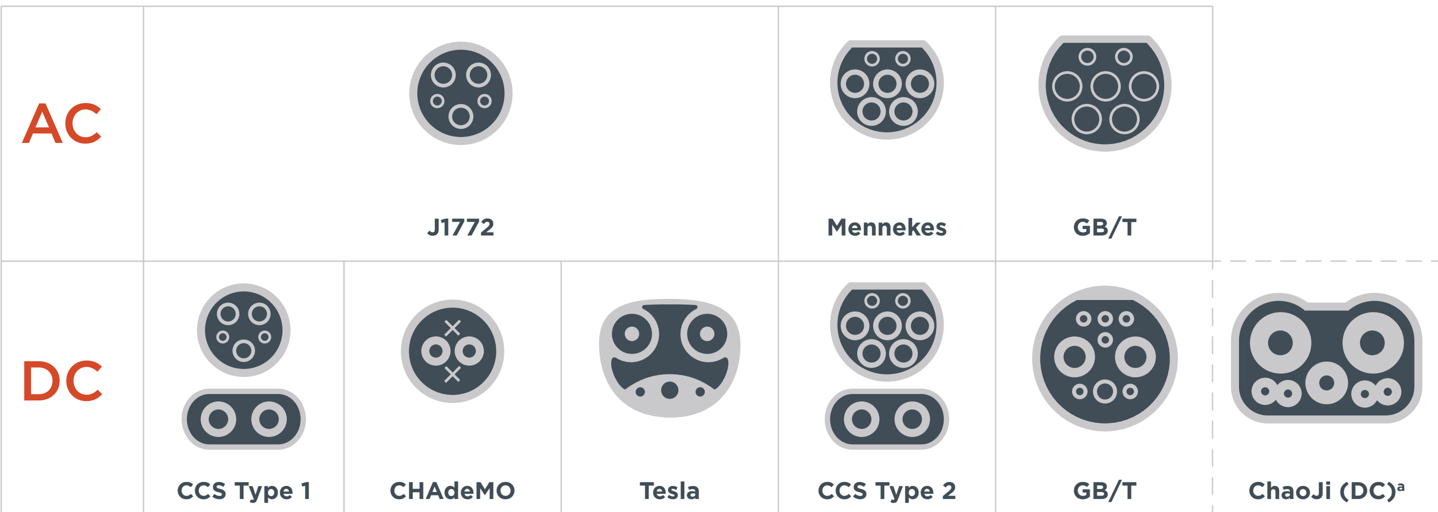
The diversity of charger types in markets today is the result of many factors: the several dozen automakers that produce EVs; the need for slower or faster power technologies (AC and DC) in different circumstances; the variety of EV types (two- and three-wheelers; light- and heavy-duty vehicles); varieties of national or regional electrical infrastructures; and evolving national standards governing charger development.

Many makes, many markets

The global roster of EV manufacturers is growing rapidly. In 2021, nearly 120 vehicle manufacturers in 51 countries sold at least one battery-electric vehicle (BEV) model in at least one country, and about 15 countries had a significant volume of exports.[6] In China alone, 33 different manufacturers produced vehicles; conversely, a single maker, VW Group, manufactured vehicles for 37 countries. In such a global mix of technologies, and in the absence of regulation, some chargers and EVs are bound to be mismatched, seriously challenging the establishment of a comprehensive and effective charging infrastructure. Regulations can compel manufacturers to comply with charger standards in the manufacturing stage, as a vehicle can be equipped with different chargers without too much extra effort in the manufacturing process. For example, the 33 manufacturers working in China—including European companies like VW Group—are all required to use chargers that comply with China's single-standard regulation.

AC and DC power

All long-range BEVs can be charged in two ways: using alternating current (AC) or direct current (DC) charging.[7] As of 2022, three AC charger types and five DC charger types were widely used for light-duty EVs. Figure 3 depicts the plugs of the connectors found on light-duty AC and DC chargers.



a. ChaoJi is a planned charger for future use but is not currently in use.

Figure 3. AC and DC light-duty EV connectors organized by principal market pairings

Source: Adapted from Enel X Way, https://evcharging.enelx.com/

AC and DC chargers perform differently and are best suited for different situations:

6 Marklines, Vehicle sales data (2022), https://www.marklines.com/en/; Electric Cars Exports by Country, World's Top Exports, accessed August 9, 2022, https://www.worldstopexports.com/electric-cars-exports-by-country/.

7 Alternative Fuels Data Center, "How Do All-Electric Cars Work?" U.S. Department of Energy, accessed March 17, 2022, https://afdc.energy.gov/vehicles/how-do-all-electric-cars-work.

- DC chargers charge a battery faster than AC chargers due to their differences in energy conversion (AC current requires an on-board converter; DC does not).
- AC charging is slow, but in homes with private garages or designated parking spaces that can accommodate overnight charging, AC charging is convenient and available through existing electrical connections. AC charging can also reduce intense demand on the electric grid when charging is done during off-peak overnight hours. In other situations, AC charging is used at shopping centers and other commercial areas, where customers can charge their vehicles while parked.
- DC charging, also known as "DC fast charging," is often used at highway charging points, where truckers and travelers need to charge quickly, and in areas where the grid can handle fast charging in large quantities. Powerful DC fast chargers are essential for users who cannot afford downtime. They can reduce charging periods to under a half hour.

Because AC is needed in some contexts and DC in others, new long-range BEVs are configured to receive both types of chargers—either directly or through use of an adapter. (AC/DC dual functionality was not always common in EVs and still does not apply to PHEVs.) Five compatible AC and DC charger pairings are described in Table 2. Other AC/DC pairings are generally not compatible.

Table 2. AC and DC compatibility of EV connectors by region in selected markets

AC connector	Compatible DC connector	Main region(s) of use
GB/T AC	GB/T DC	China
J1772	CHAdeMO	North America, Japan, South Korea
J1772	CCS Type 1	North America
J1772	Tesla[a]	North America
Mennekes	CCS Type 2	Europe

[a] Teslas in the United States can use a J1772 adapter to charge at AC public chargers.

The connector and vehicle's port may appear not to match because the port often has holes to receive both AC and DC chargers. Sometimes a vehicle's AC and DC ports are side by side, as in the case of CHAdeMO-compatible vehicles (Figure 4); in other cases, the holes overlap (Figure 5). Dual AC/DC functionality is one reason so many connectors are in use today, and it explains why types of AC and DC connectors are about equal in number.

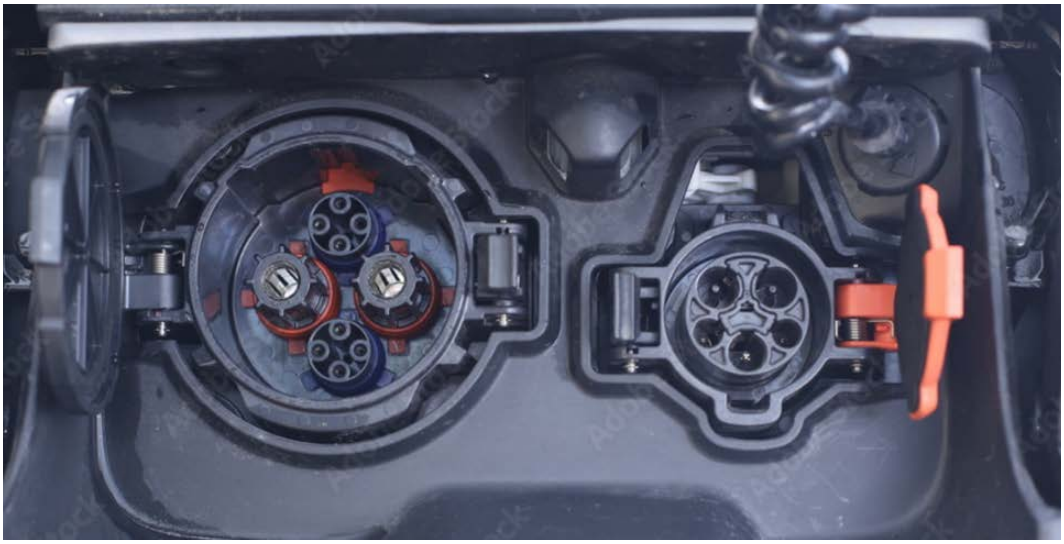


Figure 4. A CHAdeMO connector port (left) and a J1772 connector port (right) on an EV

Figure 5. A connector positioned before a CCS Type 1 connector port (the round set of holes on top and the oblong set on the bottom) which overlaps with a J1772 connector port (the round set of holes only)

Vehicle variety

The wide range of vehicle types on roads today also contributes to the diversity of charger types. The global EV fleet now includes two- and three-wheelers such as mopeds and motorcycles; light-duty vehicles such as passenger cars; light- and medium-duty trucks and vans; and heavy-duty vehicles including trucks and buses. Not all vehicle types require the same level of power; some require different battery capacities and often different charging equipment.[8]

8 Shyamasis Das, Chandana Sasidharan, and Anirudh Ray, "Charging India's Two- and Three-Wheeler Transport," (AEEE: New Delhi, 2020), https://aeee.in/wp-content/uploads/2020/09/full-report-charging-indias-two-and-three-wheeler-transport.pdf.

Electrical infrastructure

In some cases, a charger type needs to be adjusted in the manufacturing stage to accommodate a country's particular electrical infrastructure. For example, CCS is listed twice in Table 2, as Type 1 and Type 2. This is because the regions in which the chargers are used—Europe and North America—have different electrical infrastructures, each with its own set of outlets and voltages, and cannot accommodate the same connector. Just as travelers carry electrical adapters to accommodate their devices in different countries, EV chargers must be similarly adapted. Even for a charger like CCS, which is used across markets, manufacturers tailor chargers to meet the needs of each end-user region.

The evolution of charger standards

Finally, an assortment of standards governing charger types shapes the charger landscape in many countries. When a country imports or produces a vehicle, it does so under certain international standards. These standards are usually adopted and enforced by individual governments.

Table 3 lists a set of international charger standards, along with their associated vehicle types and regions of primary use. These standards are created by industry regulators responding to new technologies (in the cases of Europe and North America), or by regulators pursuing a government's goals for charging (China). Technical specifications of each charger can be found in the Annex.

Table 3. International charger standards governing EV charger use in selected markets

Standard	Vehicle type	Main region(s) of use
SAE J1772	Light-duty	North America, Japan, South Korea
IEC 62196	Light-duty, heavy-duty	Europe
GB/T 20234	Light-duty, heavy-duty	China
SAE J3068	Heavy-duty	North America, South Korea

While the use of charger standards generally limits the number of chargers in the market, the growing number of standards over the years has tended to increase the number of simultaneously accepted chargers.

The combination of the factors above—multiple independent EV manufacturers, AC and DC charging options, diverse vehicle types, electrical system variations, and different charger standards—has created a tangle of charger needs that are a challenge for governments to manage.

Chargers and standards: A brief history

This historical and technical review explains how chargers in four of the largest vehicle manufacturing markets—China, the European Union, Japan, and the United States—evolved to their current state. That history is a story of conflicting tendencies toward multiplication and consolidation of charger types across countries and periods as various influences were brought to bear on the EV landscape.

Figure 6 provides a timeline of the introduction and use of chargers for light- and heavy-duty vehicles from 1995 to 2025. Gray bars indicate chargers no longer in widespread use, blue bars depict AC chargers, and green bars show DC chargers. Figure 7 depicts the timeline by major vehicle market.

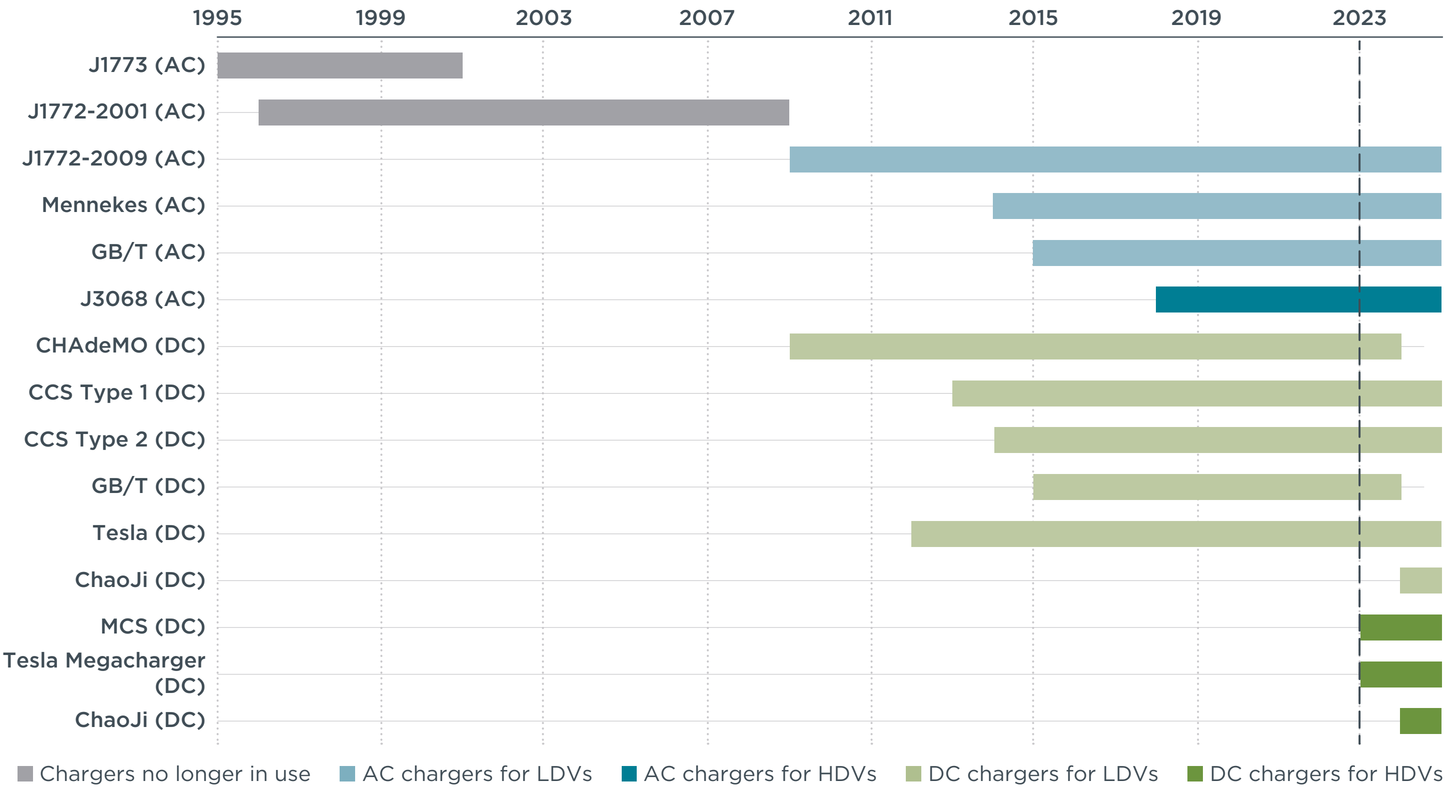


Figure 6. A global timeline of EV chargers (1995–2025)

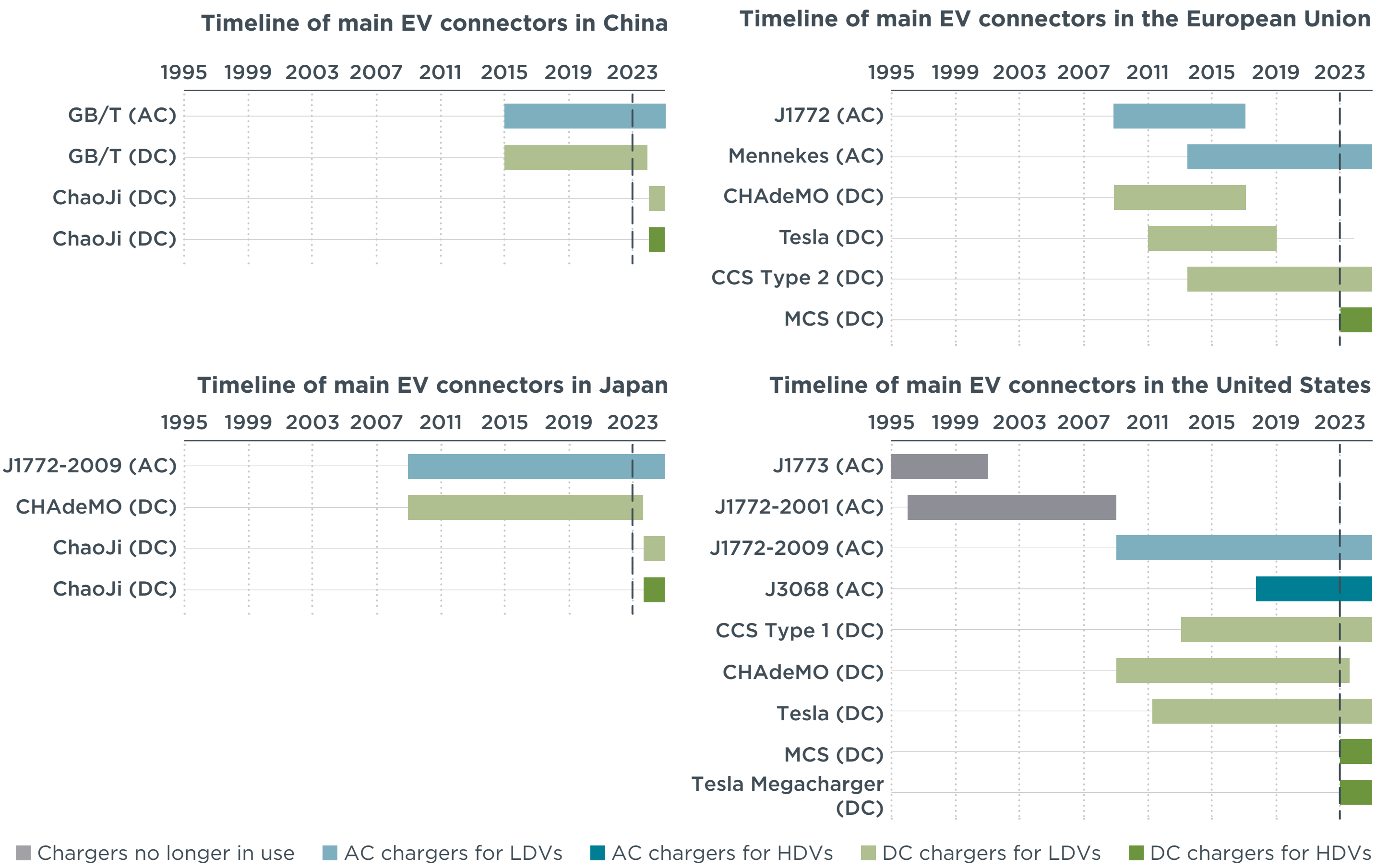


Figure 7. Main EV chargers in use, by year, in China, the European Union, Japan, and the United States

Early movement toward charger diversity

Multiplication of charger types was evident relatively early in the modern charger movement. In the early 1990s, the United States (principally the California Air Resources Board) led charger development with two AC models, the Magne Charge (under the SAE 1773 standard) and the AVCON charger (under a preliminary version of SAE J1772). In 2001, AVCON became the default charger in the United States, effectively phasing out SAE J1773 and paving the way for the newer technology of the current J1772 standard published in 2009. In 2010, Japan introduced a DC charger, CHAdeMO, which has proven to be a durable option, having powered new EVs for decades.[9] Working independently, the United States and Japan stimulated innovations that would inform later charger developments. As other governments like the European Union and China followed suit, the result was a proliferation of charger diversity that, to some degree, continues today.

In 2012, EV manufacturer Tesla offered an innovative advance in charger development with the introduction of the Supercharger, a DC fast charger that can also be used for AC charging with a J1772 adapter. The effect on charger diversity was mixed: the use of one charger (plus an adapter) for both AC and DC charging helped to reduce the number of chargers; on the other hand, the Supercharger was designed for exclusive use with Tesla cars,[10] creating a separate EV charging infrastructure and further fragmenting charger networks.

9 The CHAdeMO 2.0 protocol was created in 2018 and references the CHAdeMO charger widely used in today's market.

10 "Charging your Tesla," Tesla, accessed March 14, 2022, https://www.tesla.com/support/charging.

Fast chargers shift the field

In the 2010s, as charger power grew in importance with the rapid adoption of DC fast chargers, the powerful Combined Charging System (CCS) Type 2 charger was introduced in Europe in 2014, increasing the number of Europe's DC chargers to three: CHAdeMO, Tesla, and CCS. In 2014, the CCS charger's 350kW of power was greater than that of previously introduced technologies, such as CHAdeMO, whose market power (the full capability in public charging infrastructure) was originally rated at 150kW.[11] A stronger CHAdeMO 2.0 (400kW) was introduced in 2018, but by then, CCS had consolidated its market power—even Tesla ultimately decided to use CCS Type 2 technology in Europe. Tesla's adoption of CCS, combined with the support of other manufacturers and new government regulation, moved Europe closer to a single-standard strategy.

In the United States, lack of a consistent vehicle electrification strategy kept the country from developing comprehensive charging infrastructure. During this time, the United States adopted a version of the CCS system, CCS Type 1, that was compatible with U.S. electrical infrastructure. But in contrast to European Union regulators, U.S. regulators did not require that EVSEs be outfitted with a specific type of charger, nor did they require Tesla to integrate Superchargers into the public grid. As the U.S. EV market grew, mostly organically, and as charging infrastructure needs increased sharply, the United States continued to authorize use of three different DC chargers (CHAdeMO, CCS Type 1, and Tesla DC) from 2014 through 2022.[12]

Western government choices diverge

The decline in popularity of CHAdeMO helped to streamline the charger market in Europe, but in the United States it continued to hang on. Separate from the U.S. government's decision regarding CHAdeMO, and because of CHAdeMO's initially lower market power (150kW as opposed to Tesla's 250kW and CCS's 350), most manufacturers switched from the old CHAdeMO to the new CCS between 2014 and 2019. Even with the new and stronger CHAdeMO 2.0, by 2020, only one new model, a Mitsubishi PHEV, was sold with CHAdeMO in the United States. Mitsubishi, too, has now begun to replace CHAdeMO with other options.[13] Despite clear evidence that CHAdeMO chargers were becoming obsolete, 21% of DC chargers in the United States are currently CHAdeMO, many of them installed within the last few years.[14] Retroactive planning and lack of broader regulation in the United States have resulted in this mismatch of chargers. Electrify America, a private EVSE provider, moved to rectify this error with its announcement in early 2022 that it would deploy only CCS chargers moving forward.[15] The CHAdeMO phaseout will reduce charger fragmentation in the United States, trimming charger types from three to two DC chargers (CCS Type 1 and Tesla).

By 2021, driven by European regulation and market expansion, Tesla's Supercharger network began to integrate with the public charging infrastructure in parts of the European Union. Consequently, the CCS-adapted Tesla charging network in Europe will soon be usable by non-Tesla EVs.[16] There is no sign of a similar integration in the United States. In November 2022, Tesla proposed the North American Charging Standard

11 CHAdeMO, "Organisation," accessed November 1, 2022, https://www.chademo.com/about-us/organisation.

12 Sophia Schmidt, "Excitement, but also 'range anxiety,' over electric vehicles at Philly Auto Show," March 11, 2022, WHYY, https://whyy.org/articles/philly-auto-show-electric-vehicles-gas-prices-range-anxiety/; Jo Borrás, "Electric Car FAQs: Do EVs All Use The Same Plug?," November 27, 2021, https://cleantechnica.com/2021/11/27/electric-car-faqs-do-evs-all-use-the-same-plug/.

13 Bryce Gaton, "End of the Plug Wars: Electrify America to stop installing CHAdeMO chargers," *The Driven*, August 13, 2021, https://thedriven.io/2021/08/13/end-of-the-plug-wars-electrify-america-to-stop-installing-chademo-chargers/.

14 PlugShare, EV Charge Point data, April 2022, https://www.plugshare.com.

15 This is true in all states except California.

16 Lora Kolodny, "Elon Musk says Tesla Supercharger network will be open to other cars this year," *CNBC*, July 20, 2021, https://www.cnbc.com/2021/07/20/elon-musk-says-tesla-will-open-its-chargers-to-other-electric-vehicles.html.

(NACS), a rebranding and expansion of the Tesla Supercharger.[17] With the biggest market share of EVs in the United States, Tesla has had little reason to integrate its charging infrastructure with other charging networks.[18] Compared to Tesla, other EV brands have been slow to take off in the United States, but this has begun to change as other brands offer EVs at a lower cost. Once the non-Tesla EV market expands, a shift in U.S. regulation matching Europe's consolidation strategy could take place; however, Tesla's charger technology remains superior to that of CCS Type 1 (unlike CCS Type 2 in Europe), which reduces the possibility of U.S. consolidation in the near term.

China takes a different path

Separately, China has also made great progress over the same period, introducing its own EV charger standards in 2015 using a single-standard strategy. It is the only country that has consistently taken the single-standard route, avoiding the introduction of large numbers of multiple EV charger types into its market. In China, the GB/T 20234.2-2015 standard regulates two chargers: one AC and one DC, which are commonly known as GB/T AC and GB/T DC chargers, respectively.[19] A significant advantage of the GB/T charger is its low price. However, the physical limitations of GB/T in terms of power output are significant; GB/T has 125kW of DC market power, compared to CCS Type 1's 350kW.

Chinese EV sales have skyrocketed from 1.2 million EVs in 2019 to 3.3 million in 2021, all equipped with GB/T.[20] Much of this growth has been internal, but less expensive Chinese technology could be attractive to lower-income countries that are wrestling with charger decisions, and this could be an economic advantage for China.

The case of heavy-duty EVs

Heavy-duty EVs have different charger standards from those of light-duty vehicles because heavy-duty vehicles have higher charging power requirements.[21] A higher-powered AC charger to service heavy-duty vehicles was, at one point, considered for SAE J1772 standards but was eventually abandoned.[22] Instead, efforts to create high-power chargers for medium- and heavy-duty vehicles were organized under SAE J3068, the first heavy-duty international standard. SAE J3068 was created to replace the CCS Type 1 charger in North America for heavy-duty vehicles. J3068 is also compatible with the CCS standard used in Europe and harmonizes standards between the two regions (but with adaptations to accommodate the different electrical infrastructures).

The MegaWatt Charging System (MCS) and the Tesla Megacharger, both designed for heavy-duty vehicles, are in pilot stages as of 2022.[23] While some form of the MCS is likely to be used in Europe and the United States, it is expected that the Tesla Megacharger—likely a conglomerate of four 250+ kW DC charging stations—will be used only in the U.S. market and that heavy-duty Tesla vehicles in Europe will be modified to the MCS standard, similar to how CCS was treated in the light-duty market. This would further the trend

17 "Opening the North American Charging Standard," Tesla, November 11, 2022, https://www.tesla.com/blog/opening-north-american-charging-standard.

18 IEA, Electric cars fend off supply challenges to more than double global sales, IEA, Paris, 2022, https://www.iea.org/commentaries/electric-cars-fend-off-supply-challenges-to-more-than-double-global-sales.

19 Chinese EV chargers have female inlets on the vehicle, as opposed to the male inlets common in the plugs and sockets in the rest of the world.

20 Eamon Barrett, "China electric vehicle sales surged 154% last year, with Warren Buffett-backed BYD topping Tesla," *Fortune Magazine,* January 7, 2022, https://fortune.com/2022/01/07/china-electric-car-ev-sales-2021-growth-tesla-byd-li-auto-xpeng-nio/.

21 Adam Panayi, "Energy Density and the Challenges of Electrification for Heavy-duty Vehicles," *Benchmark Mineral Intelligence*, February 14, 2019, https://www.benchmarkminerals.com/energy-density-and-the-challenges-of-electrification-for-heavy-duty-vehicles/.

22 SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler, Appendix M, SAE J1772_201710, October 13, 2017, https://www.sae.org/standards/content/j1772_201710/.

23 "Megawatt Charging System," CharIN, accessed December 19, 2022, https://www.charin.global/technology/mcs/; "Tesla Semi Will Charge At 1+ MW Using New V4 Charging Cable," InsideEVs, December 5, 2022, https://insideevs.com/news/624881/tesla-semi-1mw-v4-charging-cable/.

toward fragmentation in the United States and consolidation in the EU, driven by differing regulations and electrical infrastructures. As with light-duty vehicle charging, signs of division between regional manufacturers are emerging in ways that, at least initially, could lead to fragmentation of the heavy-duty vehicle charger market across the globe.

Future developments

The charging landscape continues to evolve, and will likely be shaped by a new charger, ChaoJi. Part of the Japanese CHAdeMO line, ChaoJi (market power 500kW) is slated for launch in 2024. Backed by China and Japan—a significant collaboration aligning two historically distinct markets—ChaoJi will replace GB/T DC chargers in China (with a version called ChaoJi-1) and CHAdeMO chargers in Japan (ChaoJi-2, also known as CHAdeMO 3.0).[24] ChaoJi-1 will follow the GB/T protocol and is slated for deployment primarily in mainland China, while ChaoJi-2 could be expanded to multiple markets across the globe. With this emergence, other countries will have the option to follow Japan's lead (now in alignment with China), or to use standards more closely aligned with those in Europe and North America. As a new entrant to the charger world, ChaoJi's emergence further fragments the charger market in the short term, but if it performs well and is widely adopted, it could lead to a long-term consolidation of chargers.

ChaoJi could also further streamline the heavy-duty charger scene. Once launched, ChaoJi is expected to be the first charger to accommodate both light- and heavy-duty vehicles. Even though different chargers will likely be used for light- and heavy-duty vehicle types (a version called Ultra-ChaoJi is designed for heavy-duty vehicles, for example), the two vehicle types will be serviceable at the same charging station, creating further flexibility and streamlining infrastructure needs. Ultra-ChaoJi will initially be used primarily for heavy-duty vehicles in the Chinese and Japanese markets. Still, it is likely to expand to other markets due to its power. Backward compatibility (the capacity for a new charger to also serve older chargers) could allow the charger to potentially meet all current global standards (including those in the United States and European Union).[25]

In sum, the history of charger development is a story of two opposing forces. On one hand, the many variables affecting charger choice, from competitive market pressures to diverse electrical infrastructures, have tended to multiply the number of charger types and the standards that govern them. On the other hand, efforts to adopt more powerful technologies have created cooperation across national borders, introducing regional innovations (such as the Tesla-European Union agreement on fast chargers, and the China-Japan collaboration on the ChaoJi charger). This cooperation has slowed fragmentation and likely congealed charger options into a smaller set than was the case a few years ago. More information on the technical specifications of each charger can be found in the Annex.

Choosing a charger standard strategy

Three broad charger standard strategies are available to governments: 1) take a "hands-off" stance with little regulation, allowing many different chargers to be used without ensuring interoperability; 2) adopt a single national standard that all vehicles and chargers must meet; and 3) adopt interoperability regulation that accommodates a diverse set of EVs.

24 High Power (ChaoJi), CHAdeMO, accessed September 7, 2022, https://www.chademo.com/technology/high-power.

25 Liu Yong Dong and Makoto Dave Yoshida, "ChaoJi Standard," *chademo.com*, accessed March 16, 2022, https://www.chademo.com/wp2016/wp-content/uploads/ChaoJi202006/ChaoJi_Presenataion_EN.pdf.

Allow the market to lead, with little regulation

At one extreme, governments might take a laissez-faire or hands-off approach, allowing vehicle manufacturers and other actors to determine which chargers are deployed, with little regulation and no guarantee of interoperability. This option could minimize the burden on government to plan and build infrastructure. But without the coordinating hand of government, equipment at some charging stations would likely be incompatible with some EVs, leaving those EVs unserved and leading to a charging gap.

A passive government stance could produce other unacceptable social outcomes—for example, customer dissatisfaction with charging convenience and availability—that could also slow EV uptake. Additionally, a laissez-faire charger policy allows large automakers to use their market power to monopolize the provision of charging infrastructure and determine its pricing. EV companies could introduce their own charging networks, as Tesla did until 2012, with chargers incompatible with cars of competing brands, leaving EVs with incompatible chargers unserved in some areas, and arguably slowing EV deployment. Due to the serious limitations of the hands-off approach—it slows the advance of electrification and leaves infrastructure development to private parties, resulting in unequal access to charging—the laissez-faire option used in some countries today will not be discussed as a recommendation in the latter part of this paper.

Single charger standard

At the other extreme, governments could adopt a single standard for chargers (with one AC and one DC option, so two total chargers). This strategy varies in stringency and can involve modifying vehicles to fit a government's single standard—either through customization when the vehicle is manufactured, or, in the importing country, by providing adapters for use on imported vehicles. For example, the European Union allows multiple charger types to be used via IEC 62196, but requires all charging stations to be equipped with *at least* CCS Type 2 or Mennekes. A more stringent example is found in China, where all chargers must be GB/T. The single-standard strategy could simplify the planning and building of charging infrastructure but could also exclude many vehicles.

A single charger standard simplifies a country's infrastructure requirements and creates an efficient charging network, in the sense that the number of vehicles served per charger is relatively high. With a more streamlined charger market, countries avoid redundant infrastructure, reducing overall costs in the transition to EVs.

A disadvantage of the single-standard strategy, early in its implementation, is the need for external adapters to ensure that all EVs on the road will be chargeable at any public charging station; this issue recedes in importance as new cars increasingly feature the single charger type. A more fundamental challenge to adopting a single-charger standard is that it typically requires substantial market power—countries with large vehicle markets are best positioned to assert regulatory power over manufacturers. Countries with smaller markets lack the leverage over manufacturers to set the terms of charger choice.

For countries seeking a single charger standard, ChaoJi and CCS Type 2 are likely to be the two leading options in the short term. Because combining Mennekes AC chargers with ChaoJi DC chargers is currently not possible, it is likely that the future global market will continue to splinter as ChaoJi rolls out. The dominant technologies and trends in the leading EV regions suggest that EV infrastructure pairings like these could emerge in the short term:

- China: ChaoJi DC + GB/T AC
- Europe: CCS Type 2 + Mennekes
- Japan: ChaoJi (modified) DC + J1772
- North America: CCS Type 1 + J1772

In the long term, these four options narrow into two principal AC-DC charger combinations exist for creating single charger standards.

Combination A: ChaoJi DC + GB/T AC. Many markets in Asia that choose single standards are likely to adopt this combination (or at least ChaoJi, as in the Japanese case), for a host of reasons. For DC charging, ChaoJi offers the ability to charge light- and heavy-duty vehicles, an estimated market power of 500kW, and support of the Chinese and Japanese governments. Another current CHAdeMO market, South Korea, also has the proper infrastructure to join the initiative. ChaoJi DC is also versatile: in addition to GB/T compatibility, ChaoJi will have backward compatibility with CHAdeMO.[26] Potential backward compatibility with CCS has also been discussed, but the details are yet to be agreed upon. Combination A can also be used on vehicles with low power charging needs, such as the large fleets of two- and three-wheelers in India and Vietnam, some of which require power as low as 7kW.

Combination B: CCS DC + Mennekes AC. While CCS has less power (350kW) than the ChaoJi DC maximum of 500kW, CCS's power can meet most[27] real-world charging demand, which is for relatively low power levels, depending on use (domestic versus commercial; urban versus highway). With this option, a separate MCS charger would be required for some medium-duty and all heavy-duty vehicles, which is not the case for ChaoJi. While Europe and the United States are likely to adopt some version of Combination B, CCS's lower voltage limit of 200V is incompatible with large swaths of the vehicle market in some regions, such as parts of Asia.[28] Other solutions for these cases will be required.

While a single global standard is unlikely to emerge—even in the long term—as the forces of fragmentation assert themselves across the globe, countries entering the EV transition will likely choose from one of these available single-standard options. Alternatively, they might adopt interoperability regulation, discussed below.

Interoperability regulation

A middle option—less extreme than either the laissez-faire or the single-standard strategy—is to adopt a charging infrastructure policy that accommodates many chargers at once. This option is more complex and expensive but could facilitate a rapid expansion of the fleet of EVs. Interoperability regulations do not necessarily require that all chargers accommodate all vehicles. Infrastructure providers can opt to provide for a subset of vehicles, which could create charging gaps for some vehicle types.

Interoperability regulations also require modifying new charging infrastructure to accommodate the multiple vehicle types included in a country's regulations. Examples of this approach are common:

26 Tomoya Imazu, "CHAdeMO TC snapshots ChaoJi Strategy," accessed March 28, 2022, http://www.chademo.com/wp2016/wp-content/uploads/techws/European_TWG_Meeting_2019_10_17/1.%20CHAdeMO%20EUR%20TWG%20TC_Imazu.pdf.

27 ICCT, "Five things you know about electric vehicles that aren't exactly true," July 19, 2021, https://theicct.org/stack/explaining-evs/.

28 NITI Aayog, Ministry of Power (MoP), Department of Science and Technology (DST), Bureau of Energy Efficiency (BEE), and World Resources Institute (WRI) India, "Handbook of Electric Vehicle Charging Infrastructure Implementation," August 12, 2021, https://www.niti.gov.in/sites/default/files/2021-08/HandbookforEVChargingInfrastructureImplementation081221.pdf.

- In the United States, charging stations such as EVgo can (Figure 8, left) accommodate up to three DC charger types (CHAdeMO, CCS Type 1, and Tesla) and one AC charger type (J1772).[29] The J1772 AC plug can be adapted to all EVs in the United States.
- In Costa Rica, charging stations are adapted to accommodate many different types of cars (Figure 8, right).
- The manufacturer Grasen, operating under European and Chinese standards, offers a 90kW charging station that accommodates both CCS Type 2 and GB/T chargers.[30]
- Some chargers accommodate only AC charging, but adapters like the "J1772 to Tesla" can facilitate charger use for multiple types of cars.

Figure 8. EVgo charger in the United States with CHAdeMO and CCS Type 2 interoperability (left); GB/T and CHAdeMO fast charger from The Costa Rican Institute of Electricity in Costa Rica (right).[31]

One disadvantage of an interoperability strategy is cost. When multiple charger types are widely accepted and accommodated, more investment in public charging infrastructure is required to satisfy the needs of all drivers, which is a less efficient use of public investment funds. On the other hand, interoperability increases accessibility and equity—EVs of many kinds, including lower-cost models that may be favored by people of low incomes, are more likely to find charging service when interoperability is the standard. By contrast, if a charging station is private and exclusionary, the EV market could see slower and less equitable advancement.

Factors affecting the choice of charger strategies

As charger technology has evolved, choosing a charger standard strategy has been complex and indirect for the four major markets discussed in this paper. Small importer countries will likely face at least as great a challenge setting their own paths. Their choice of strategy and subsequent standard(s) will be shaped by a range of factors,

29 "Welcome to EV101: Electric Vehicle Charging Basics," EVgo Fast Charging, accessed March 14, 2022, https://www.evgo.com/ev-drivers/charging-basics/#4-types-of-connectors.

30 "90kW CCS2 GB/T PLUGS DC EV Charging Station," Grasen, accessed March 14, 2022, https://www.grasen.com/dc-fast-chargers/90kW-CCS2-GBT-PLUGS-DC-EV-Charging-Station.html.

31 It is uncommon—but not impossible—to charge two vehicles at the same time from the same EVSE. Dual home chargers are more likely to possess this capability.

including a country's status as a vehicle importer or exporter, the influence of private industry, and the size of its national vehicle market and regulatory strength.

Vehicle-importing countries choose strategies that align with their imports. Most countries discussing charger strategies today are importers; their choice of charger strategy is likely influenced by the types of cars imported and by the regulations of exporting countries. Just as dozens of vehicle-importing countries worldwide adopted "world-class" Euro and U.S. EPA emission standards,[32] the United States and Europe began working on aligned EV charging station standards in 2022.[33] EV importing countries today may find that adoption of the EV standards of their suppliers, like the United States and European Union, is the easiest way to set a course on charging. If a large majority of a country's vehicle stock is expected to be imported from Europe, for example, the CCS Type 2 standard would be a logical choice. If most cars come from China, adopting GB/T standards—or at least including GB/T in the array of accepted chargers—may make the most sense.

Private industry can influence a country's strategy. In the absence of an assertive single charger standard or interoperability strategy, private industry players are strongly positioned to influence the charging landscape in vehicle manufacturing countries. Tesla, for example, created its own U.S. charging infrastructure as a competitor to other public charger options. While much of the 21st century EV progress in the United States can be credited to Tesla,[34] the company's exclusionary charger station policy was allowed to grow with little government intervention and with insufficient attention given to accommodating a broader set of EVs and charger types. The unregulated playing field has resulted in charging infrastructure gaps, with non-Tesla EV brands having inadequate access to public charging infrastructure.[35] Starting in 2022, the United States government has recognized this problem and has sought to rectify it by creating a plan, in partnership with Tesla, to allow non-Tesla drivers to access Tesla charger stations.[36]

Each vehicle maker or group, competing for market share, seeks to differentiate its product. Among dozens of EV manufacturers, Tesla is the only one to have a patent for its charging infrastructure as of 2022, but this could quickly change with future innovation and market developments. In June 2022, General Motors (GM) announced a partnership with a charging infrastructure company and a traditional rest stop (fuel station), to roll out CCS Type 1 chargers available to the public, under a joint GM-Evgo brand called Ultium Charge.[37] While GM has chosen to use chargers already part of the North American network, in the absence of a clear government-led strategy for setting an EV charger standard, there is little stopping new companies from creating and patenting their own exclusionary charger network. While private sector innovation is often helpful to grid decarbonization, industry power can also be used irresponsibly, possibly limiting access to charging and undermining a country's climate and air quality goals. Governments should, therefore, thoroughly consider the costs and benefits of company-owned exclusionary charging stations.

32 Josh Miller, Li Du, Drew Kodjak, "Impacts of World-class vehicle efficiency and emissions regulations in select G20 economies," (ICCT: Washington, DC, 2017), https://theicct.org/sites/default/files/publications/ICCT_G20-briefing-paper_Jan2017_vF.pdf.

33 Valero, Deutsch, Nussbaum, "EU, US to Develop Standards for Electric Car Charging Stations," Bloomberg Law, May 16, 2022, https://news.bloomberglaw.com/environment-and-energy/eu-us-to-develop-standards-for-electric-car-charging-stations.

34 Fred Lambert, "Tesla (TSLA) still dominates US electric car market with 68% market share," Electrek, August 15, 2022, https://electrek.co/2022/08/15/tesla-tsla-dominates-us-electric-car-market-share/.

35 Bauer et al., Charging up America: Assessing the growing need for U.S. charging infrastructure, (ICCT: Washington, DC, 2021), https://theicct.org/wp-content/uploads/2021/12/charging-up-america-jul2021.pdf.

36 Andrew Hawkins, "Tesla will open up Superchargers to non-Tesla electric vehicles in the US later this year," The Verge, July 7, 2022, https://www.theverge.com/2022/7/7/23198696/tesla-supercharger-non-tesla-ev-us-white-house.

37 Scooter Doli, "GM announces new nationwide DC fast charging network with Pilot Co. and EVgo," *Electrek*, June 24, 2022, https://electrek.co/2022/07/14/gm-dc-fast-charging-network/.

Market size and strong regulation often influence manufacturers. China's adoption of a single standard prompted compliance from manufacturers, who sought to ensure continued access to the large market. In the European Union, another large and powerful market, regulations were adopted to diminish the influence of Tesla, and the well-established company eventually acceded to the EU's CCS standard.[38] A smaller country, lacking such market power, likely could not take the same course of action. From a regulatory perspective, the infrastructure choices of first-mover or early-adopter countries, such as the major markets discussed in this paper, create infrastructure options that countries pursuing the transition to EVs can adopt.[39] Vehicle regulation has historically begun in large markets, like the European Union and United States, where governments have more resources and where the risk of being a first mover is lower. Small and vehicle-importing countries can take advantage of the path laid out by first movers, a development dynamic that is also likely to play out with respect to EVs.

The case of Chile

Having wrestled with choosing a charger standard strategy in recent years, Chile's experience may be instructive to other emerging economies on the threshold of the EV transition. As a small country of 19.4 million people, its vehicle market is modest and it imports 100% of its new vehicles—37,000 in 2021,[40] two-thirds of which were from Asia. Chile has not historically been a first mover in technology, but it has shown leadership in climate policy, including by passing a litany of climate legislation in recent years.[41] Given the factors cited above that affect the choice of charger standards, these characteristics suggest that Chile is not in a strong position to choose a single charger standard, but would instead fare better with an interoperability strategy. In December 2021, a Chilean interoperability strategy was opened for public consult; as of December 2022, a final resolution was yet to be made.

Overview of the Chilean EV charger market

The EV market in Chile is still in its infancy but is growing steadily. As of September 2022, Chile was home to 2,134 light-duty BEVs and 949 plug-in hybrid electric vehicles (PHEV).[42] New EV sales in 2021, at 556 vehicles, represented just 0.17% of all light-duty vehicle sales, but are seeing rapid growth in 2022. The electromobility trend is not new for Chile—since 2018 Chile has hosted one of the largest electric bus fleets in Latin America, with around 1,770 buses expected on the streets by 2023. With internal combustion engine phase-out targets for all new vehicles by 2045 (and for new light-duty vehicles by 2035), these numbers are expected to grow exponentially in the coming years. The leading light-duty EV brands in Chile include Maxus (China; 22% of total market share), Hyundai (South Korea; 21%), and Nissan (Japan; 14%). Figure 9 illustrates Chilean EV countries of origin, also led by China (29%), South Korea (22%), and Japan (15%).

38 Fred Lambert, "Tesla confirms Model 3 is getting a CCS plug in Europe, adapter coming for Model S and Model X," Electrek, November 14, 2018, https://electrek.co/2018/11/14/tesla-model-3-ccs-2-plug-europe-adapter-model-s-model-x/.

39 "Superintendencia de Electricidad regula la interoperabilidad de las estaciones de carga de vehículos eléctricos en Chile," Portal Movilidad, June 17, 2020, https://portalmovilidad.com/el-gobierno-de-chile-trabaja-en-una-normativa-para-trabajar-la-interoperabilidad-en-las-estaciones-de-carga-de-vehiculos-electricos/.

40 José Ignacio Gutiérrez, "Más de 37 mil unidades: el mercado automotor chileno abre 2022 con el mejor enero de la historia," La Tercera, February 2, 2022, https://www.latercera.com/mtonline/noticia/mas-de-37-mil-unidades-el-mercado-automotor-chileno-abre-2022-con-el-mejor-enero-de-la-historia/RZ432YS33ZBCBNN76L53GVOQAA/.

41 Delgado and Pettigrew, 'New legislation in Chile shows climate leadership," (ICCT: Washington, DC, 2022), https://theicct.org/chile-latam-lvs-leg-en-apr22/.

42 "Electromovilidad en Chile," Chilean Energy Sustainability Agency, accessed March 11, 2022, https://datastudio.google.com/u/0/reporting/4a522b4d-2073-49ea-8720-9fdae7904eb6/page/p_jhyxfyrmsc.

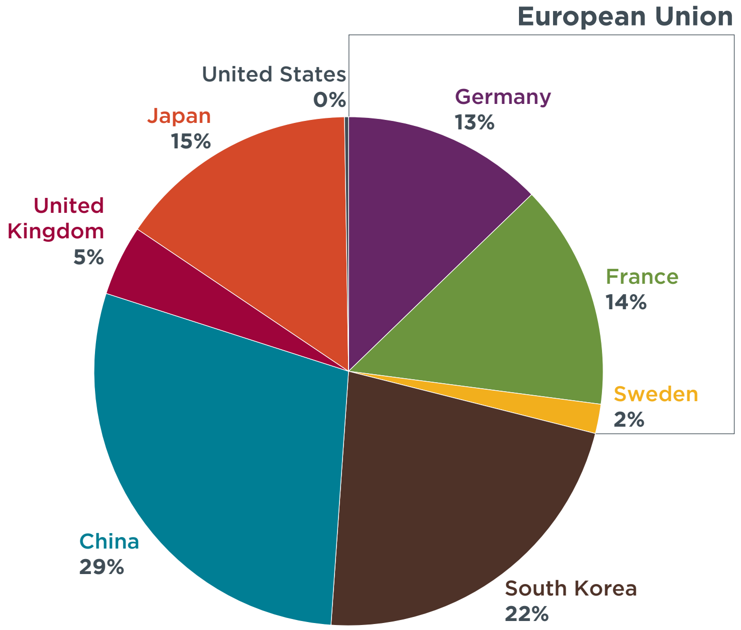


Figure 9. Distribution of Chilean EVs by market of origin in 2021

Source: The Chilean Energy Sustainability Agency and the National Automotive Association of Chile

The Ministry of Energy of Chile currently accepts EV chargers from all major markets, including J1772 and Mennekes AC chargers; CHAdeMO, CCS Type 2, and GB/T DC chargers.[43] As of October 2022, Chile was home to 286 public charging stations with a total of 697 chargers, 411 connectors, and 13.76 MW of power. Most—492 of these chargers—are AC chargers (36 J1772; 456 Mennekes), and 205 are DC (97 CHAdeMO; 104 CCS Type 2; 4 GB/T DC).[44] There has been little public interest in expanding GB/T infrastructure to date, and most cars coming from China have been outfitted with CCS chargers,[45] since acceptance of GB/T was delayed. Chile does not include the GB/T AC charger as a viable option in its 2020 user manual.[46] Without this, GB/T-equipped vehicles lack a public AC charging option, making them less attractive. Figure 10 shows the breakdown of public chargers in Chile by type.

43 "Manual del usuario, Plataforma TE6, usuario declarador, Comunicación de energización de infraestructura para la recarga de vehículos eléctricos," Superintendence of Electricity and Fuels of Chile, accessed April 14, 2022, https://www.sec.cl/sitio-web/wp-content/uploads/2020/08/Manual-de-Usuario-TE6-v2-2020.pdf.

44 "Charging Infrastructure Indicators Portal," Superintendence of Electricity and Fuels, accessed March 11, 2022, https://app.powerbi.com/view?r=eyJrIjoiZGY4NmY3ZmItOGFiNS00ZG M4LTgzN2MtYzlhZWQ1NmFj YWJkIiwidCI6ImE0ZjdlMmM 5LTBmMzYtNDZjOC05YWVjLWY1MDcxMmVmNmZhZSIsImMiOjR9.

45 All CCS chargers in Chile are Type 2 (Europe) due to electrical infrastructure configuration.

46 "Manual del usuario, Plataforma TE6," Superintendence of Electricity and Fuels of Chile.

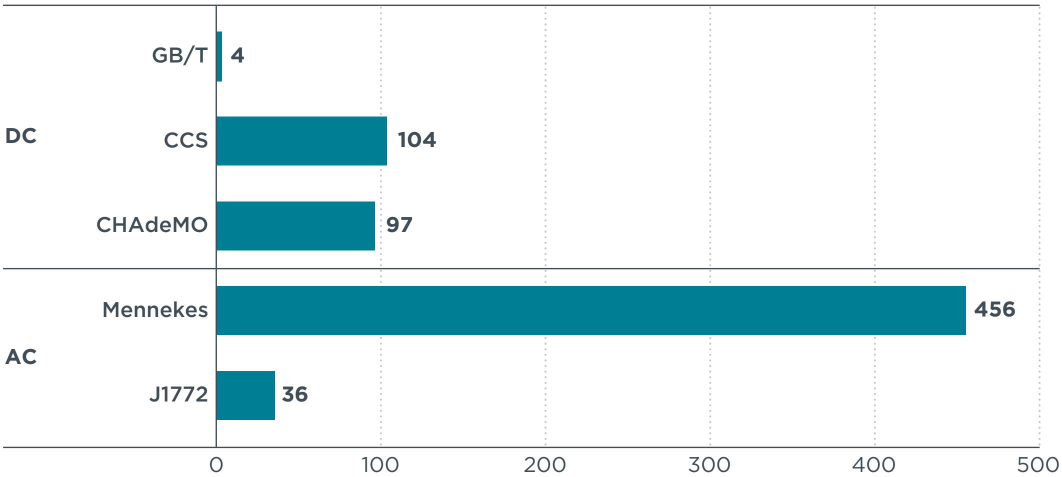


Figure 10. Public light-duty EV chargers in Chile by type (October 2022)

Source: Data from the Superintendence of Electricity and Fuels of Chile

The 21 EV brands available in Chile use a variety of AC and DC chargers. The number of BEVs and their charger types recorded at the end of 2021 is presented in Figure 11. The vehicles are divided into two types: vehicles with CHAdeMO chargers are compatible with J1772, and vehicles with CCS DC chargers are compatible with Mennekes AC. The EVs with GB/T chargers are an outlier and are not included in this graph.

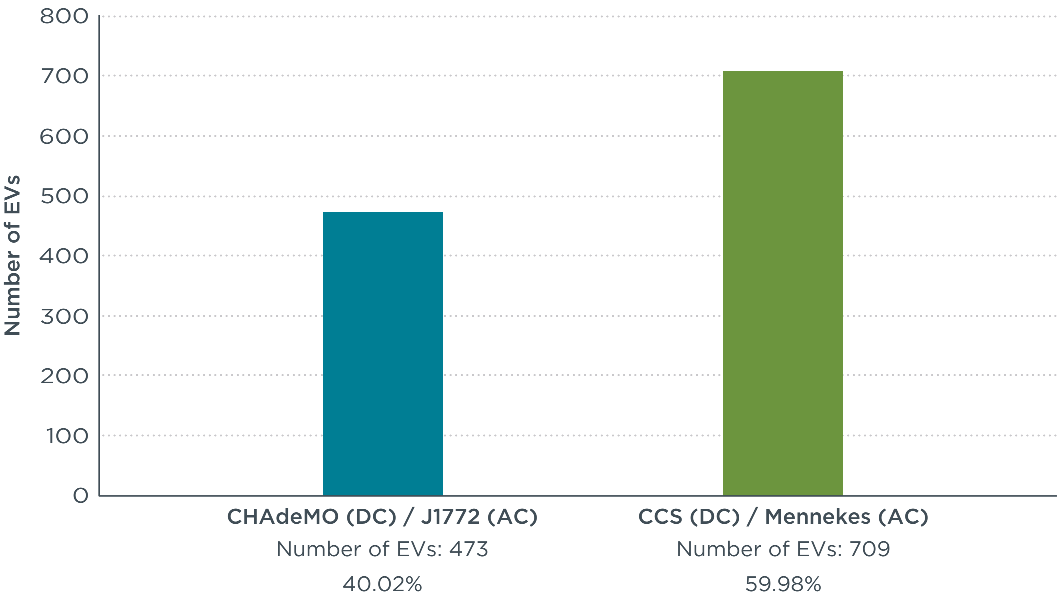


Figure 11. Distribution of chargers for light-duty EVs in Chile (2021)

Source: Data from The Chilean Energy Sustainability Agency

Policies and lessons learned from Chile

Chile has used a broad suite of laws and regulations to shape governance of EV charging infrastructure in the country. As a vehicle importer with a relatively small vehicle market, the government chose to pursue an interoperability strategy, borrowing infrastructural lessons and policies from larger markets and first movers.[47] Some of the country's most important actions and lessons learned in relation to this decision—actions and lessons that countries in similar situations can follow—include:

47 "Pliego técnico normativo RIC Nº15," Superintendence of Electricity and Fuels of Chile, accessed April 14, 2022, https://www.sec.cl/sitio-web/wp-content/uploads/2020/10/RIC-N15-Infra-para-la-recarga-de-vehiculos-electricos-Final.pdf

1. Including EVs in new fuel economy and climate policies
2. Using a proven regulatory model to choose a charger standard
3. Allowing flexibility in policy and adjusting as needed

Including EVs in new fuel economy and climate policies

The first opportunity to regulate charging infrastructure arose in 2017, through Article 2 of Supreme Decree 145, which defined the five types of chargers that could be used in Chile (J1772, Mennekes, CHAdeMO, CCS Type 2, and GB/T DC). A complementary 2021 law on energy efficiency allowed for regulation of interoperability regulation in anticipation of widespread EV use.[48] The law facilitates access to the public charging network, with the goal of establishing and overseeing charging station interoperability, charging service requirements, communication protocols, and user simplification processes.[49] Safety requirements published in April 2021 must also be met by both public and private charging stations across the country.[50] In accordance with the energy efficiency law, a special Supreme Decree was proposed in late 2021, specifying interoperability regulation and an estimated implementation date by the end of 2022.[51] Finally, a separate 2022 declaration allowed the Superintendence of Electricity and Fuels to commission all charger installations, ensuring that all new chargers follow the legal requirements.[52] Due to interoperability regulation requiring more complex consumer tools, as discussed above, this law is key to Chilean EV charging infrastructure success. More information on interoperability regulation can be found on the country's "Electromobility Platform."[53]

Regulation of Chilean charger stations, which is different from regulation of charger standards, requires that public access charging systems have, at a minimum, 22kW of power per connector, and configurations of either Mennekes (through a single AC charger), or CCS Type 2 and CHAdeMO (double DC chargers).[54] Figures 12 and 13 show the current supply and demand of different EVs and their respective chargers.

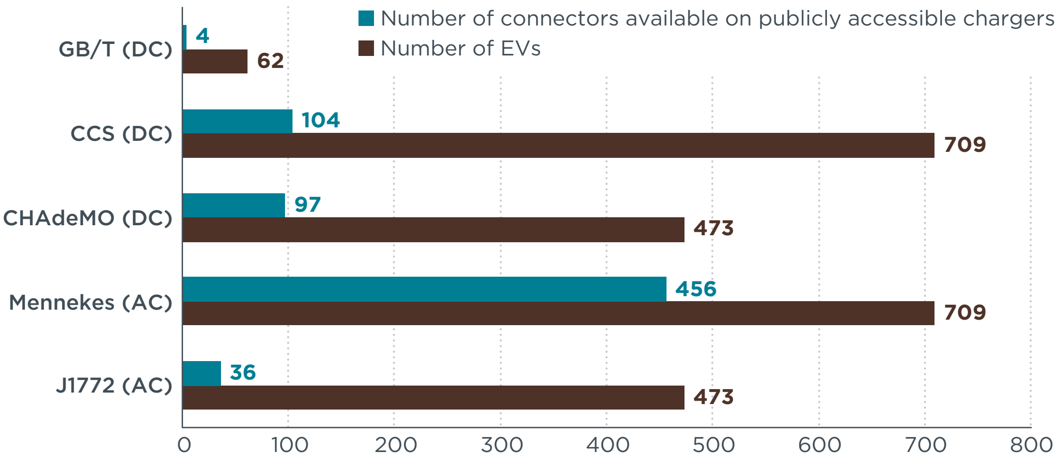


Figure 12. EV charger types (October 2022) and EVs served in Chile (December 2021)

48 Ley 21305 sobre la Eficiencia Energética, Biblioteca del Congreso Nacional de Chile (February 2, 2021), https://www.bcn.cl/leychile/navegar?idNorma=1155887.

49 Decreto Supremo (borrador), Aprueba reglamento que establece la interoperabilidad de los sistemas de carga de vehículos eléctricos, accessed March 14, 2022, https://energia.gob.cl/sites/default/files/borrador_reglamento_interoperabilidad_consulta_-_final.pdf.

50 "Pliego técnico normativo RIC Nº15," Superintendence of Electricity and Fuels of Chile.

51 Decreto Supremo (borrador), Aprueba reglamento, March 14, 2022.

52 "Manual del usuario, Plataforma TE6," Superintendence of Electricity and Fuels of Chile.

53 "Sistemas de Carga: Interoperabilidad," Plataforma de Electromovilidad, Ministerio de Energía, accessed December 19, 2022, https://energia.gob.cl/electromovilidad/sistemas-de-carga/interoperabilidad/las-4-interacciones-de-una-red-interoperable.

54 "Pliego técnico normativo RIC Nº15," Superintendence of Electricity and Fuels of Chile.

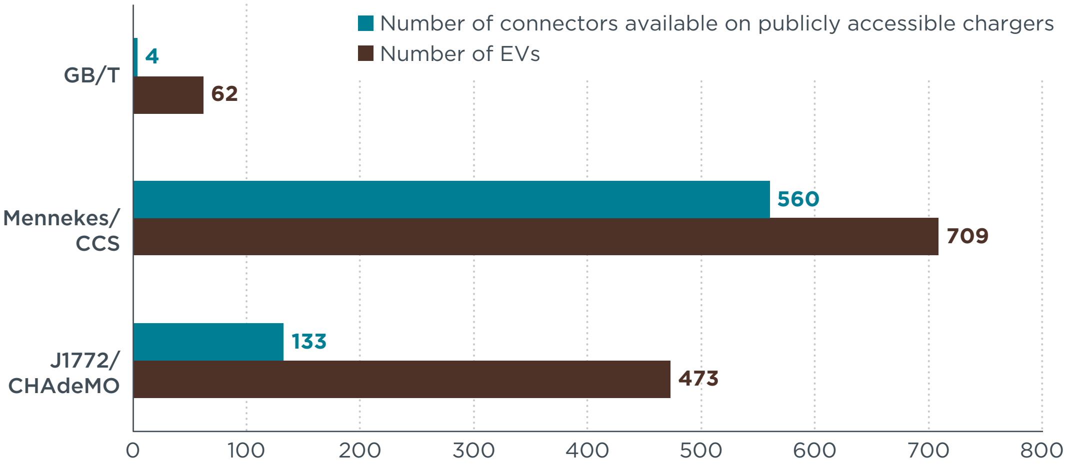


Figure 13. Paired AC and DC chargers and EVs served in Chile (October 2022)

Using a proven regulatory model to choose a charger standard

A key takeaway from Chile's approach to standard setting is to avoid reinventing the wheel, and to instead rely on existing standards from countries with established EV markets to create as comprehensive an EV policy as possible. The 2017 decree required EV chargers used in Chile to be regulated by, at a minimum, one of the four standards from the four major markets listed in Table 2.[55] Chile used its small importer status to its advantage: it did not need to be a first mover and could use standards known to work well with the vehicles it was likely to import.

As it mimics what has worked in other countries, Chile may also need to avoid what has not worked. An example concerns whether it should drop the CHAdeMO charger from its list of approved chargers, given the charger's falling popularity. Of the 21 brands selling EV models in Chile in 2021, only Nissan, Tesla, Hyundai, Mitsubishi, and Citroën use CHAdeMO, and sales of these dropped by 50.3% between 2017 and 2022.[56] Meanwhile, CHAdeMO's relevance is dwindling in most of the rest of the world. These developments suggest that Chile could drop CHAdeMO from its current list. Notably, Chile has added multiple CHAdeMO public chargers between March and October 2022, increasing the risk of repeating the error of the United States, where, as noted earlier, CHAdeMO chargers continued to be installed long after they proved unpopular, an inefficient approach to charger provision.

Allowing flexibility in policy and adjusting as needed

As a relatively inexpensive option for consumers, Chinese-branded EVs have quickly become popular in Chile; as of 2022 they accounted for 29% of the EV market. They also created a challenge for regulation because Chilean standards had previously not allowed use of the Chinese GB/T charger; Chinese vehicles had historically been outfitted with CCS connectors. However, in 2021 the Chilean government modified its regulation to allow circulation of EVs with the GB/T connector, in anticipation of higher demand for Chinese EVs. Adding GB/T chargers to the available mix demonstrated a policy flexibility missing from the European Union and U.S. policy models, a flexibility that worked to the benefit of Chile.

However, while GB/T chargers were permitted under the 2021 revision of the 2017 EV decree, the chargers have been slow to roll out. As of August 2022, only 0.6% of all public light-duty vehicle chargers were GB/T (see Figures 12 and 13). Without concrete

55 Decreto 145, Establece requisitos técnicos, constructivos y de seguridad para vehículos eléctricos que indica, Ministry of Transport and Telecommunications in Chile, December 29, 2017, https://www.bcn.cl/leychile/navegar?idNorma=1125120.

56 "Electromovilidad en Chile," Chilean Energy Sustainability Agency.

government-led action to match the supply of chargers with an increase in demand for new GB/T-outfitted EVs, the Chilean market could suffer from a mismatched supply. Additionally, with the impending shift to ChaoJi chargers in 2024, the Chilean government could learn from the GB/T lesson regarding early planning and alter its strategy to include ChaoJi in its new infrastructure plans.

Conclusion

A key component of the effort to decarbonize transportation, EVs require well-thought-out infrastructure. Creating accessible charger networks that ease consumer adoption of these vehicles is necessary. Three charger standard strategies are available for countries transitioning to EVs, and of those, two are recommended:

Single charger standard. A broad array of charger types means greater complexity and expense in developing widespread charging infrastructure, possibly slowing network development. Governments can control this by adopting a single charger standard and requiring all imported and/or manufactured vehicles to be compatible with specific EV chargers, as per the country's laws. Governments could alternatively require that all chargers provide at least one connector type but still allow for additional ones. A single charger standard can help standardize EV infrastructure across markets, facilitating easier adoption for new users. Still, setting policy firmly in the direction of a single standard could be unwise if it locks a country out of a large portion of the EV market, slowing the zero-emission transition.

Interoperability. Alternatively, governments can pursue interoperability and enact interoperability regulation that allows for multiple standards and requires public charging points to provide multiple charger types. This option involves greater complexity but allows more vehicles to be imported to the country more quickly, which is key to meeting zero-emission sales targets. It is recommended that governments with interoperability strategies supply consumer platforms that accurately provide information for each charging station and their respective chargers. Chile's navigation towards interoperability regulations provides lessons for other small, net-importing countries.

Zero-emission vehicle targets are set to drive up the EV market share very quickly in the coming years, giving countries a short time to set a plan for charging infrastructure. Countries early in the zero-emission vehicle transition can set policies now that would avoid the market disruptions resulting from delayed action. No single recommendation for a charger standard strategy suits all countries; it is essential to base decisions on expected needs, a country's importer versus exporter status, the power of its private industry, and its market size and regulatory strength. Each country's situation is different, which requires a tailored strategy and policies that maximize EV adoption as quickly and efficiently as possible.

Annex

Table 1. Technical capabilities of current light-duty EV chargers (AC)

Charger type	Start of service	Major regions of use	Standard(s) complied with	Volts (V)	Amps (A)	Market power range[b] (kW)
J1772[a]	2009	Japan, North America	SAE J1772	240 (Level 2)	80 (Level 2)	7.7 (Level 2)
Combined Charging System (CCS) Type 2 (Mennekes)	2013	European Union	IEC 62196	400	63	25.2–43
GB/T (AC)	2015	China	GB/T 20234.2-2015	440	63	22–27.72

a. J1772 versions prior to 2009 are not included in this table.

b. Market power refers to the chargers' maximum capability in public charging infrastructure (i.e., the typical power used and/or the maximum power regulated by standards). Range refers to the different power obtained in specific settings and regions of use.

Table 2. Technical capabilities of current and future light-duty EV chargers (DC)

Charger type	Start of service	Major regions of use	Applicable standard(s)	Volts (V)	Amps (A)	Maximum power[b] (kW)	Market power[c] (kW)
Current chargers							
Combined Charging System (CCS) Type 1	2014	North America	SAE J3068	1000	400	400	150
Combined Charging System (CCS) Type 2[a]	2013	European Union	IEC 62196	1000	400	400	350
CHAdeMO	2010	Japan, North America	SAE J1772, IEC 62196	1000	400	400	150
Tesla Supercharger	2012	North America	SAE J1772, IEC 62196	480 (Level 3)	300 (Level 3)	250 (Level 3)	120 (Level 3)
GB/T (DC)	2013	China	GB/T 20234.2-2015	1000	250	250	125
Future chargers							
ChaoJi	2024	China, Japan	GB/T 20234 and IEC 62196 (planned)	1500	600	900	500

a. Compatible with Teslas sold in the European Union

b. Maximum power refers to the charger's technical maximum capability.

c. Market power refers to the chargers' maximum capability in public charging infrastructure (i.e., the typical power used and/or the maximum power regulated by standards).

Table 3. Technical capabilities of current and future heavy-duty EV chargers (AC and DC)

Charger type	Start of service	Major regions of use	Applicable standard(s)	Volts (V)	Amps (A)	Market power range (kW)[a]
Current chargers						
J3068 (AC)	2018	North America	SAE J3068	1,037.5	160	36–166
Future chargers						
MegaWatt Charging System (MCS) (DC)	2024	European Union	IEC 15118-20	1,250	3,000	3,750
Tesla Megacharger (DC)	2024	North America	NACS (proposed)	1,000		1,000+
Ultra-ChaoJi (DC)	2024	China, Japan	(planned)			

a. Market power refers to the chargers' maximum capability in public charging infrastructure (i.e., the typical power used and/or the maximum power regulated by standards). Range refers to the different power obtained in specific settings and regions of use.