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TRENDS OF NEW PASSENGER CARS IN CHINA

AIR POLLUTANT AND CO_2 EMISSIONS AND TECHNOLOGIES, 2012–2021

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icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

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ABOUT THE ICCT

The International Council on Clean Transportation (ICCT) is an independent nonprofit organization founded to provide first-rate, unbiased technical research and scientific analysis to environmental regulators. Its mission is to improve the environmental performance and energy efficiency of road, marine, and air transportation to benefit public health and mitigate climate change.

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ABBREVIATIONS

AT	Automatic transmission
BEV	Battery-electric vehicle
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CVT	Continuously variable transmission
DCT	Dual-clutch transmission
DOC	Diesel oxidation catalyst
DPF	Diesel particulate filter
EGR	Exhaust gas recirculation
EPA	Environmental Protection Agency (U.S.)
FCEV	Fuel cell electric vehicle
GDI	Gasoline direct injection
GPF	Gasoline particulate filter
HEV	Hybrid electric vehicle
ICE	Internal combustion engine
LPG	Liquefied petroleum gas
MT	Manual transmission
NEDC	New European Driving Cycle
NEV	New energy vehicle
NO_x	Nitrogen oxides
OEM	Original equipment manufacturer
PC	Passenger car
PHEV	Plug-in hybrid electric vehicle
PM	Particulate matter
RDE	Real driving emissions
SCR	Selective catalytic reduction
THC	Total hydrocarbon content
TWC	Three-way catalyst
WLTC	Worldwide harmonized Light vehicles Test Cycle
WLTP	Worldwide harmonized Light vehicles Test Procedure

1. INTRODUCTION

In September 2020, President Xi Jinping pledged that China would peak carbon dioxide (CO_2) emissions by 2030 and achieve carbon neutrality by 2060. China has also demonstrated unprecedented determination to provide its citizens with top-quality, healthy air by 2035. Achieving these dual environmental goals will require deep, coordinated reductions in air pollutant and greenhouse gas (GHG) emissions from the road transportation sector, which contributes substantially to both types of emissions.

Today, China is executing one of the world's most stringent vehicle emission regulations, the China 6/VI standards for new light- and heavy-duty vehicles. With a separate program, China began to regulate passenger car fuel consumption in 2005 and subsequently revised the regulation several times to increase the stringency, for a total of five stages. Additionally, for medium- and heavy-duty vehicles, a fuel consumption standard was initially put in place in 2012 and then tightened in 2019. These fuel consumption regulations indirectly reduce CO_2 emissions. Although limits on vehicle air pollutant emissions and CO_2 emissions have historically been established, implemented, monitored, and enforced by different regulatory bodies, to achieve China's dual targets of decarbonization and clean air, they will need to be monitored and regulated in a coordinated fashion going forward.

This report aims to support future policies that synergistically reduce both types of emissions from passenger cars by providing fundamental data. To understand the current baseline and historical trends, we analyze vehicle air pollutant emissions, CO_2 emissions, and key technologies driving reductions in emissions from 2012 to 2021 and assess how previous policies impacted emissions trends. We started with multiple independent sources of data about vehicle characteristics, fuel consumption, air pollutant emissions, and annual vehicle registration volumes at the vehicle variant level. In collaboration with the Vehicle Emissions Control Center (VECC), we then conducted additional data collection, compilation, cleaning, and validation to ensure data quality. Note that the results and findings from this report do not represent any official positions from regulatory bodies in China.

The rest of this report is organized as follows. Chapter 2 investigates various market trends for newly registered passenger cars, mainly in terms of sales changes over the years. Chapter 3 examines the CO_2 emissions trends of the new passenger car fleet and performance at the segment and manufacturer levels. Chapter 4 gives a brief analysis of the change in passenger cars' characteristics throughout the years. In Chapter 5, the trends of various fuel-saving and CO_2 emissions reduction technologies are displayed, and finally, Chapter 6 expands on the emissions trends of key air pollutants and the development of relevant emission control technologies in the market.

2. MARKET TRENDS

Annual sales of new passenger cars (PCs) in China have risen and fallen throughout the past decade. There was major growth from 2012 to 2016, with mostly increases of more than 10% each year. In 2016, the number of newly registered PCs reached a peak of over 23 million, and that was nearly 65% more than in 2012. The market shrank in the years following 2016 and, after hitting a low in 2020 at 19 million, registrations again rose in 2021, by 6.6%. With registrations of new conventional ICE vehicles shrinking each year after the 2016 peak, the rise in 2021 was attributable to the explosive growth of new energy vehicles (NEVs), which nearly tripled from 2020 to 2021. NEVs encompass three types of power trains: battery electric, plug-in hybrid electric, and hydrogen fuel cell electric. The volume of NEV registrations in China has increased by over eightfold since 2016 and at the end of 2021, NEVs represented nearly 15% of national PC sales **(Figure 2-1)**.

Consumer preference has recently trended toward larger, heavier, and more functionally powerful vehicle segments. The volume of new SUVs increased by fivefold in the past decade, to 9.4 million new vehicles registered in 2021. The share of SUVs among all classes of PCs expanded from 12% in 2012 to over 45% in 2021. In contrast, the market share of mini and small passenger cars, categorized as A00, A0, and A-class cars in this study, contracted from 56% to 32% during the same time span.[1] Still, sales of A0 and A00 vehicles have grown quite recently, owing to the NEV surge. The market share of medium and large vehicles, classes B and C, grew slightly over the past decade, except for a temporary dip in the middle years. Though vehicles in class C do not make up a large part of the national fleet—they were around 6% in 2021—nearly four times more were registered in 2021 than 10 years ago **(Figure 2-2** and **Figure 2-3)**.

Over 80% of PCs sold were from about 20 vehicle manufacturers. These are known as original equipment manufacturers, or OEMs. Of the top 20 OEMs, the largest producers, including FAW Volkswagen (8.9% share of the 2021 new vehicle market), SAIC Volkswagen (7.2%), and SAIC GM (6.3%), have remained relatively stable. Meanwhile, some originally smaller OEMs such as BMW Brilliance, Geely, and GAC Toyota have ballooned to over two times larger in terms of market share and thus have become more important. Noticeably, BYD expanded dramatically in 2021 as a result of its strategic choice to focus exclusively on NEV production. Conversely, by 2021, Dongfeng Yueda Kia and Dongfeng Peugeot Citroen had both shrunk to less than half of what they were in 2012 **(Figure 2-4** and **Figure 2-5)**. The most popular three models in 2021 were the Nissan Sylphy, the Volkswagen Lavida, and the Wuling Hongguang Mini; the Wuling Hongguang Mini is the only exclusively battery electric model in the top 10 **(Figure 2-6)**.

1 See Annex 7.2 for details of the vehicle segment classification methodology used in this analysis.

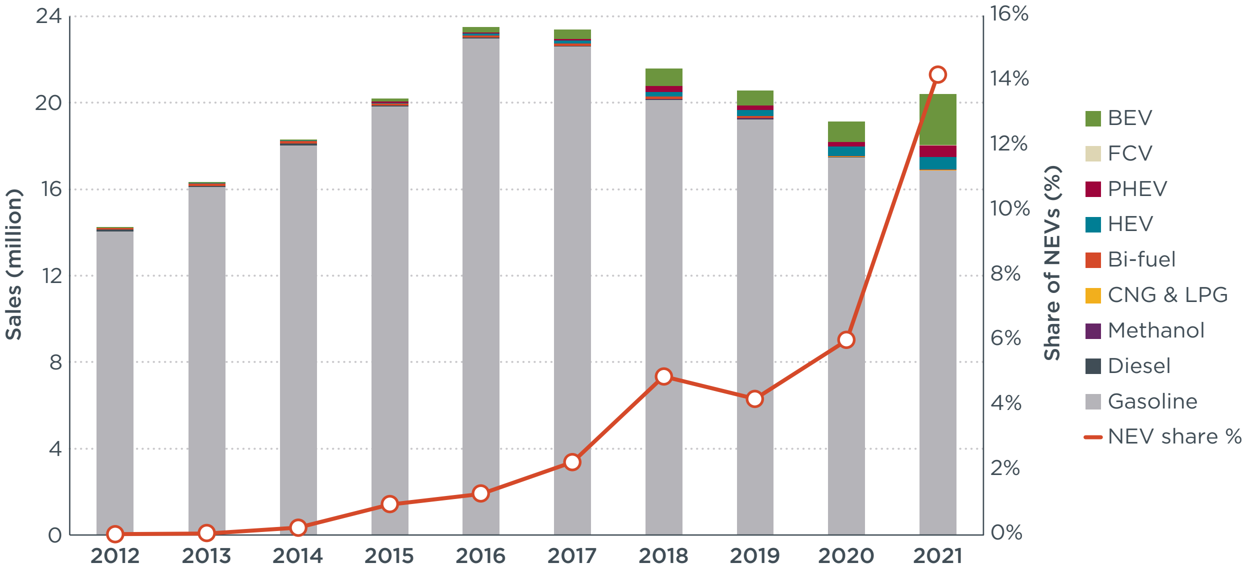


Figure 2-1. Passenger car sales by fuel type and the share of NEVs in the market

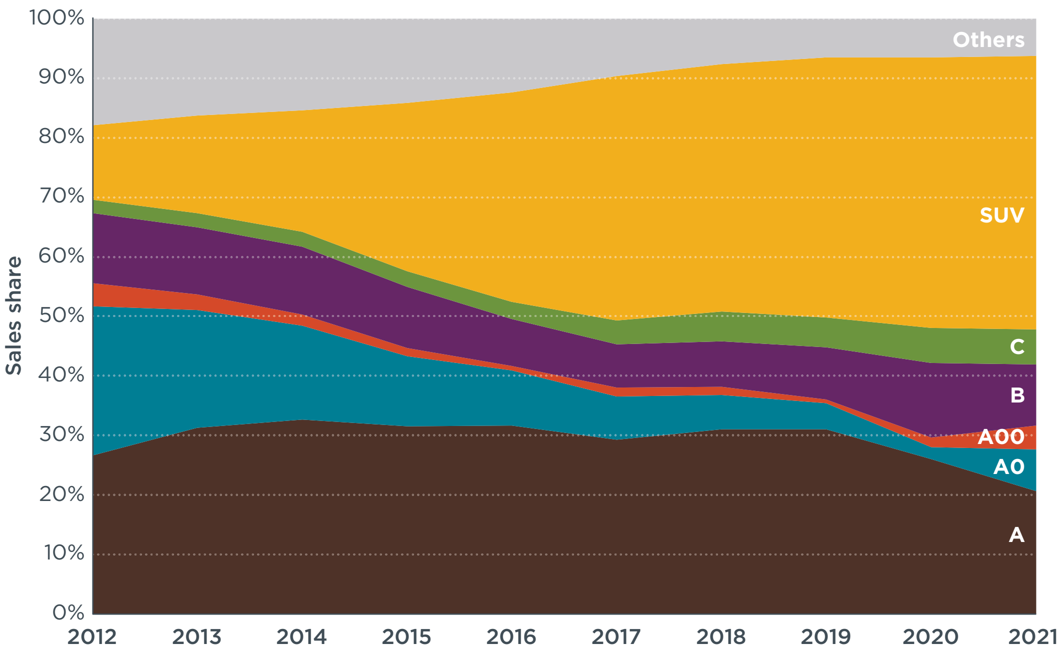


Figure 2-2. Passenger car sales share by segment

*In this report, the "Others" segment/class includes MPVs, crossover vehicles, minibuses, and sports cars. See Appendix 7.2 for details of the methodology behind vehicle segmentation.

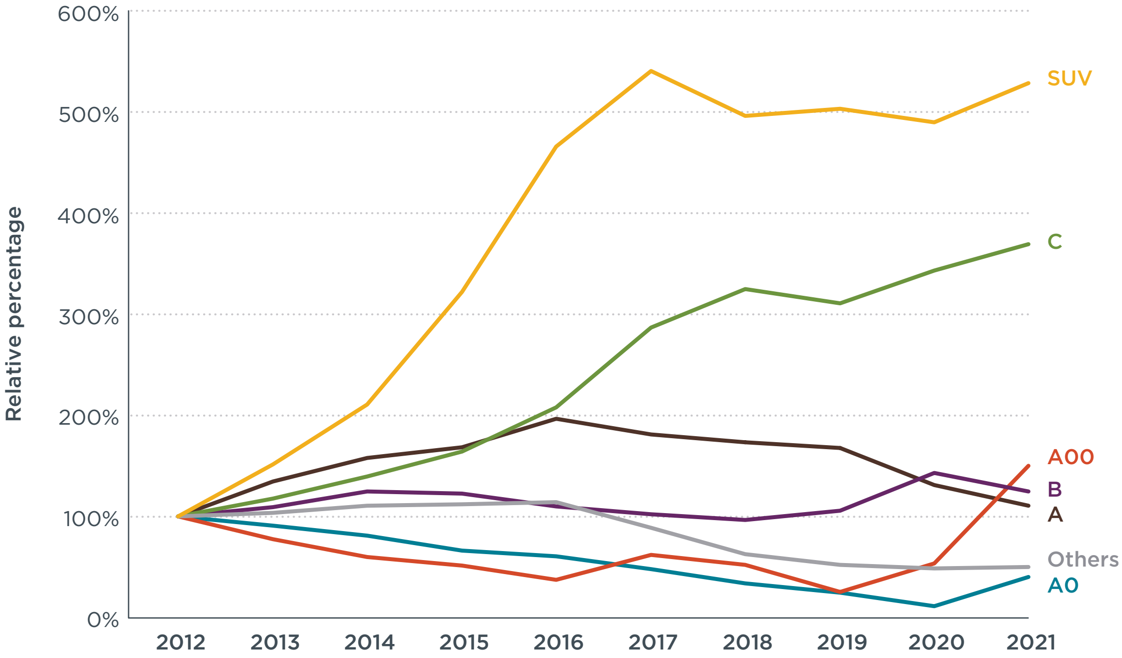


Figure 2-3. Sales by segment normalized to 2012 levels (2012=100%)

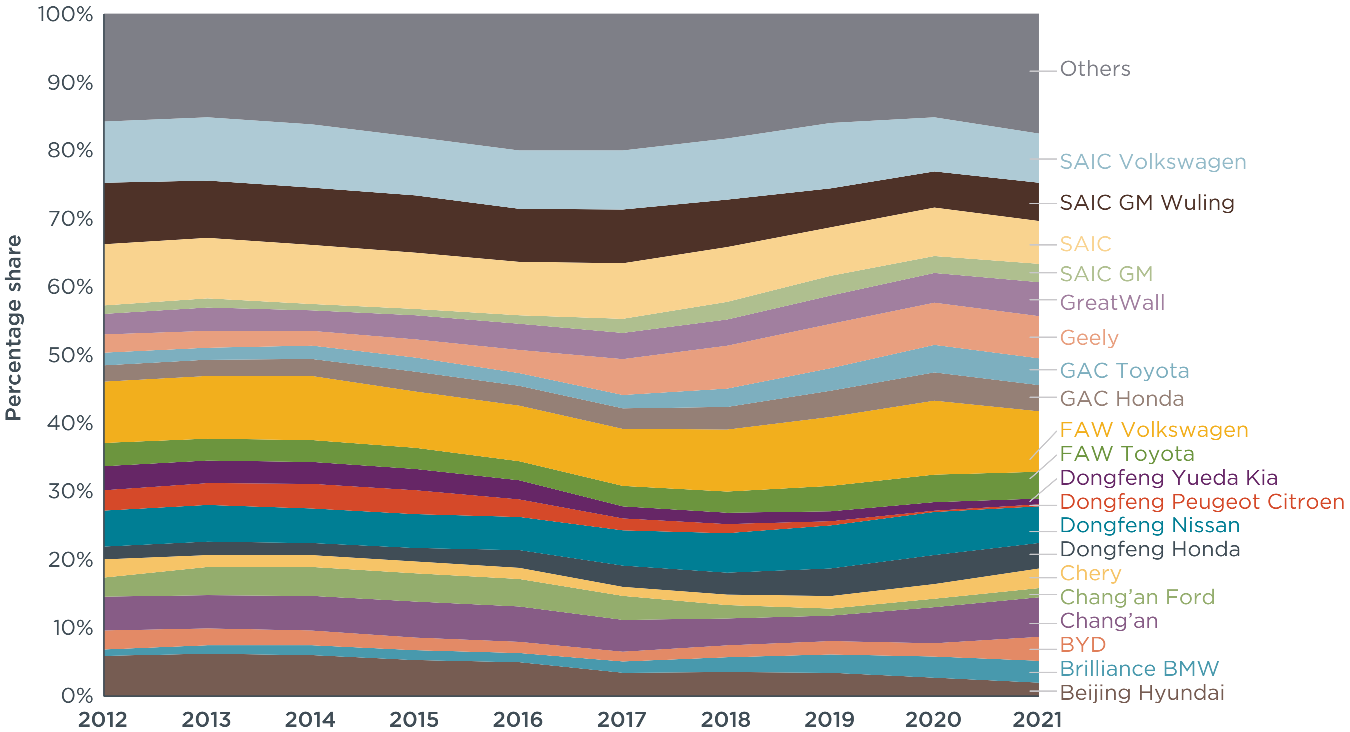


Figure 2-4. Market share of the top 20 OEMs by cumulative sales

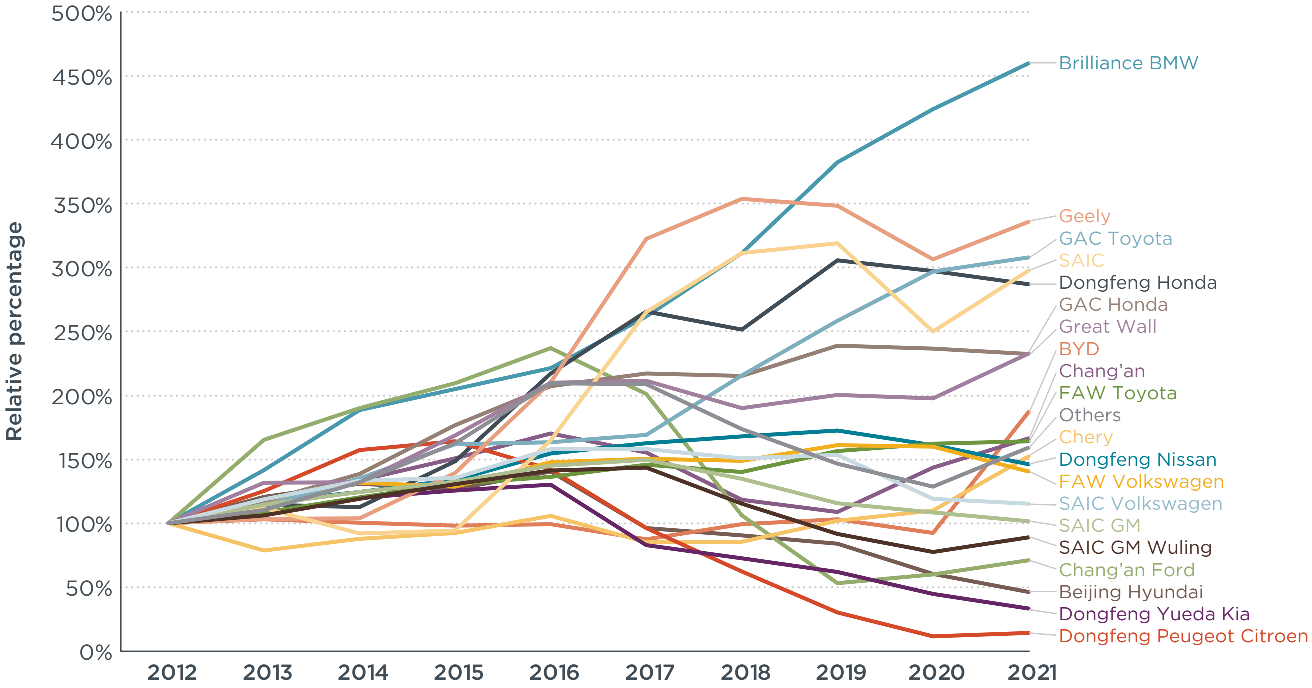


Figure 2-5. Sales by OEM normalized to 2012 levels (2012=100%)

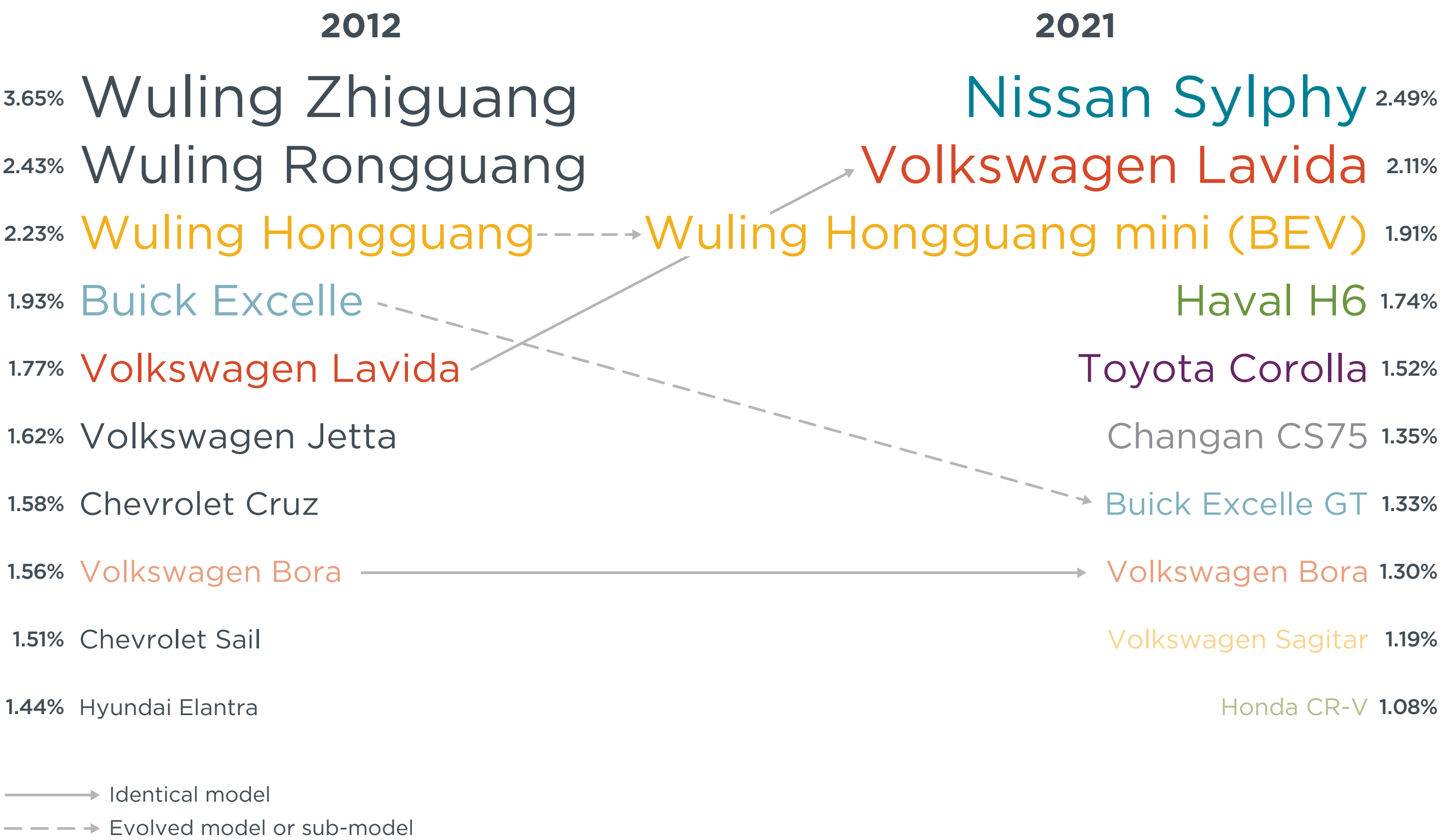


Figure 2-6. Top-selling passenger car models in 2012 and 2021

The most popular models have changed dramatically in the past 10 years. Only four basic models are on both the 2012 and 2021 lists of top-selling PCs. The Wuling Hongguang evolved into more than one model, and among them is a battery-electric vehicle (BEV) model distinct from its original ICE family, the Wuling Hongguang Mini **(Figure 2-6)**.

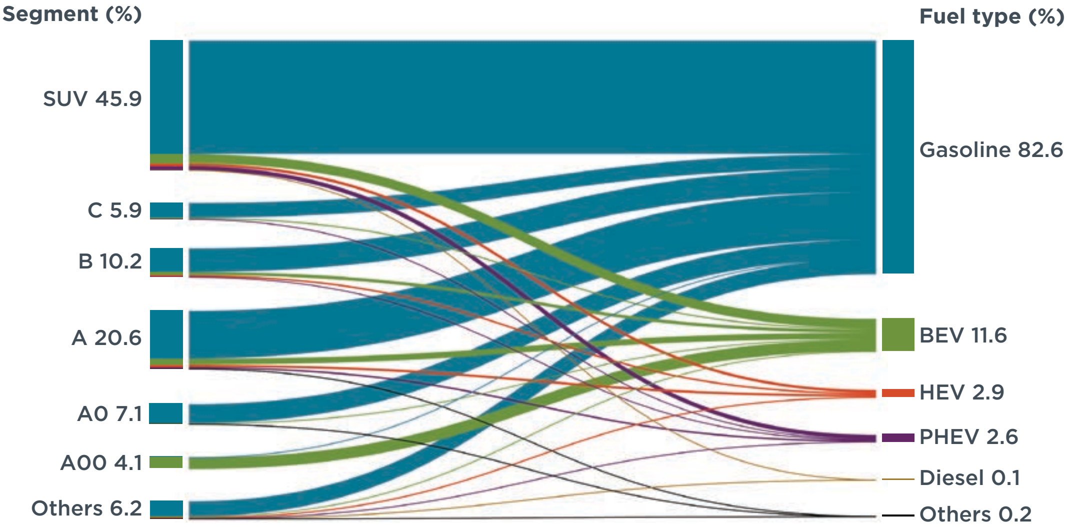


Figure 2-7. Segment and fuel type breakdown in 2021

The dominant fuel type among new PCs registered in 2021 was gasoline (82.6%); that was followed by battery electric (11.6%), conventional hybrid electric (2.9%), plug-in hybrid electric (2.6%), and diesel (0.1%). Vehicles with other fuel types, including methanol, natural gas, liquefied petroleum gas (LPG), and bi-fuel together represented just 0.2% of the registrations in 2021. All car segments except minicars (A00) were powered primarily by gasoline, and the minicar submarket was essentially fully electrified in 2021. Battery-electric technology penetration in the class A and SUV segments was also relatively high, at 10.4% and 7.3%, respectively. This is a major difference in the power train technology mixes across car segments and reflects the historical development of China's NEV industry. Unlike conventional fuel vehicles that cover the full spectrum of diverse consumer demands, NEVs were originally grounded in either the lower-end minicars or premium markets like SUVs and then they gradually penetrated the rest of the car segments **(Figure 2-7)**.[2]

2 For more information, see this ICCT report on the historical development of NEVs in China: https://theicct.org/publication/driving-a-green-future-a-retrospective-review-of-chinas-electric-vehicle-development-and-outlook-for-the-future/

3. TRENDS OF CO_2 EMISSION RATES

This chapter examines the CO_2 emission rates at the fleet **(Figures 3-1** to **3-3)**, vehicle segment **(Figure 3-4** and **Figure 3-5)**, and OEM levels **(Figures 3-6** to **3-13)**.

The certified CO_2 emission rate of the entire new PC fleet, normalized to the New European Driving Cycle (NEDC), decreased by 18% from 2012 to 2021, to 129 g/km, and there was an average annual reduction of 2.2%. The most rapid single-year reduction, 9%, was from 2020 to 2021 as a result of the dramatic increase in the share of NEVs. Such observable emissions reduction was achieved even though the market has trended toward heavier vehicles, greater power, and slightly bigger engine size, all of which are traditionally correlated with more emissions **(Figure 3-1)**. However, there has been a less-encouraging trend in recent years in the CO_2 emissions of the ICE vehicle fleet, shown as the yellow line in Figure 3-1. From 2012 to 2019, the ICE fleet achieved a 13% decrease in CO_2 emissions, but thereafter the trendline was largely flat. In addition, the real-world ICE CO_2 emissions reduction trend has been less positive in recent years, and this is shown as the red line in the same figure. The gap between type-approval and real-world CO_2 emissions for ICEs also became larger: It was 32% in 2019, 35% in 2020, and reached 37% in 2021.[3]

Gasoline cars declined moderately in terms of their sales-weighted fleet average CO_2 emission rate, from 172 g/km to 151 g/km. That is a 12.2% decrease in total and an average reduction of 1.4% annually. Most of the reduction was achieved before 2019, and after that this trend somewhat halted. Other fuel types did not show consistent reduction in their CO_2 emission rates. Diesel cars and hybrid electric vehicles (HEV) both experienced noteworthy growth in CO_2 emissions since 2016, around 1.3% annually on average, and that led to an approximately 8% increase in total for the two types combined from 2016 to 2021 **(Figure 3-2)**.

We also put China's CO_2 emissions trends in the global context. **Figure 3-3** shows that all three major markets—the United States, the European Union, and China—have reduced their fleet-average CO_2 emission rates in the past decade. From different starting points in 2012, the three markets also lowered emissions at different speeds. From 2012 to 2020, the United States achieved a 15.8% reduction in total and 2.2% annually on average. (The U.S. Environmental Protection Agency has not released data for 2021 yet.) China reduced its emissions by 11% in total and 1.5% annually on average. For the European Union, the numbers are 18% and 2.5%, respectively. In the most recent years, U.S. PCs, without counting light trucks, have roughly the same average CO_2 emission rate as China's PCs **(Figure 3-3)**.

Analysis by segment shows a generally decreasing CO_2 emissions trend. When the whole fleet in China is considered, the most popular segment, SUVs, reduced its CO_2 emissions by 25% in the last 10 years, from 194 g/km to 144 g/km, with an average annual reduction of 3.1%. The A, B, and C classes have seen generally similar levels of reduction. The A0 class's emissions reduction is less remarkable, 7% in total from 134 g/km to 124 g/km. The plunge in class A00's emissions by 87% in 2018, from 122 g/km to 16 g/km, was primarily driven by rapid NEV penetration **(Figure 3-4)**. When looking solely at ICE vehicles, most segments made less progress in reducing emissions in the most recent years, similar to the whole ICE fleet. Class B made the best progress with

3 Ruoxi Wu, et al., *Evaluation of Real-World Fuel Consumption of Light-duty Vehicles in China: A 2021 Update*, (ICCT: Washington, DC, 2021), https://theicct.org/wp-content/uploads/2021/12/fuel-consumption-lvs-china-update-sept21.pdf. Note that this study on the gap between China's type-approval and real-world CO_2 emissions (fuel consumption, as in the original paper) factored in the fleet of PHEVs (plug-in hybrid electric vehicles). Given PHEVs constitute only a tiny portion of the entire fleet (2.6% in 2021 new sales and even smaller in earlier years), we assume they do not affect the big picture of the CO_2 emissions gap, and this gap can be applied to ICE fleet emissions alone. However, this generalization would become problematic in the future if the PHEV share continues to expand, because it has been observed that for PHEVs, the gap between certified CO_2 emissions and real-world CO_2 emissions is even bigger than it is for conventional ICE vehicles. See https://theicct.org/publication/real-world-phev-use-jun22/.

a 26% emissions reduction since 2012, from 191 g/km to 142 g/km. Following that are SUVs (22.2% reduction), A (21.8%), and A0 (16%). In 2021, a rebound in A0 class ICE vehicles' emissions made them exceed the emissions of the A class **(Figure 3-5)**.

Progress made varies substantially by OEM. BYD had the most remarkable reduction in corporate average CO_2 emissions, down by 60% over the past decade, or by nearly 9% annually. On the other end of the spectrum, SAIC GM, Chery, Chang'an, and Chang'an Ford, all among the top 20 best-selling OEMs, have produced fleets with increased CO_2 emissions over the 10 years we considered, by 25%, 14%, 4%, and 3%, respectively. The most sizable producers, including FAW Volkswagen, SAIC Volkswagen, and Dongfeng Nissan, generally made average progress in CO_2 emission rate reduction **(Figure 3-6)**. When NEVs are excluded, the most remarkable progress was achieved by GAC Toyota with a 34% reduction from 202 g/km to 133 g/km. Then come FAW Toyota (32% reduction), Dongfeng Peugeot Citroen (22.5%), and SAIC (22.3%). The ICE vehicles from FAW Toyota had, on average, the lowest CO_2 emissions among the top 20 manufacturers, 126.4 g/km in 2021 **(Figure 3-7)**.

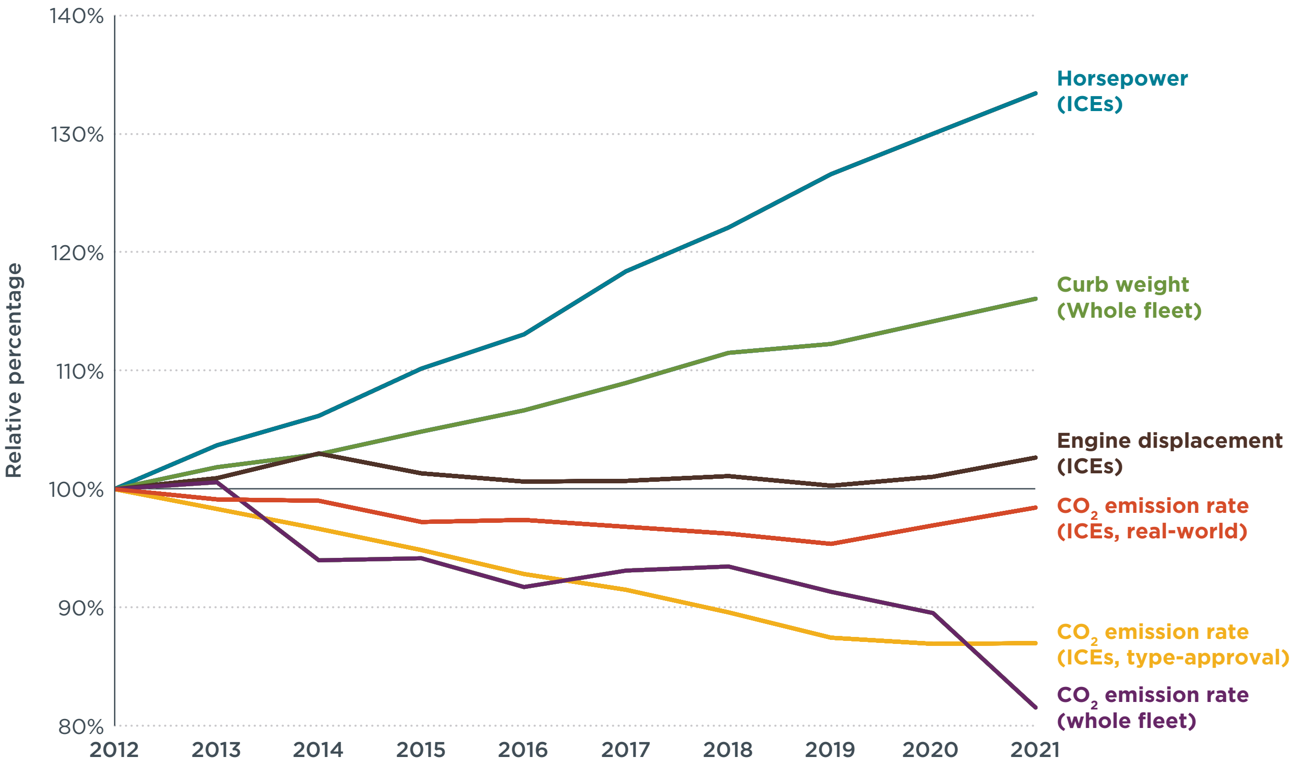


Figure 3-1. Vehicle performance and CO_2 emission rates normalized to 2012 levels (2012 = 100%)

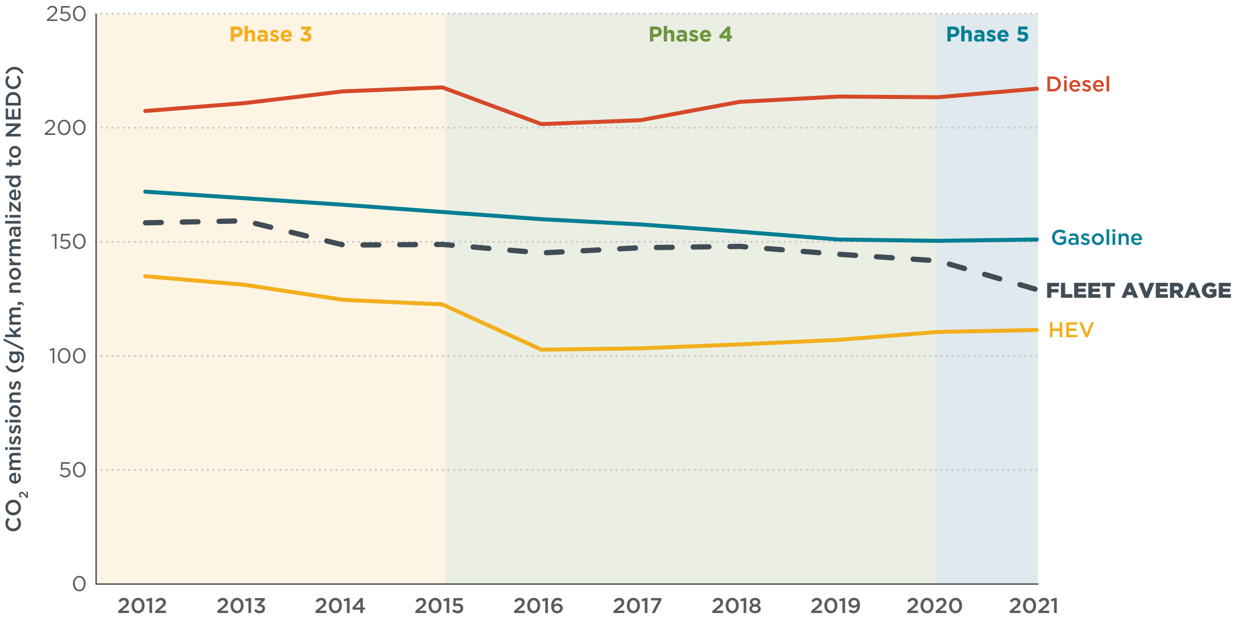


Figure 3-2. CO_2 emission rates by fuel type and fuel consumption regulation phase

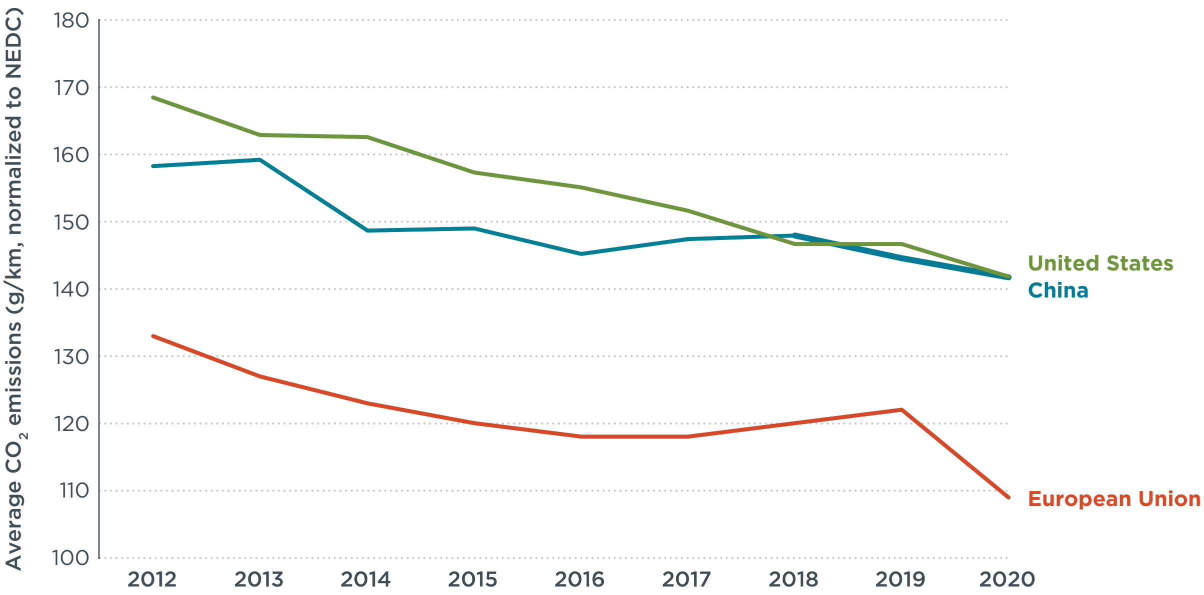


Figure 3-3. Fleet average CO_2 emission rates in the United States, the European Union, and China

* The U.S. CO_2 emission rate result is the compliance/certified data normalized to NEDC (New European Driving Cycle) from the U.S. EPA test cycle. CO_2 emission rate data for the European Union and China are essentially NEDC-based, and the minority of entries that were based on the Worldwide harmonized Light vehicles Test Procedure/Cycle were converted to NEDC values to ensure consistent results.

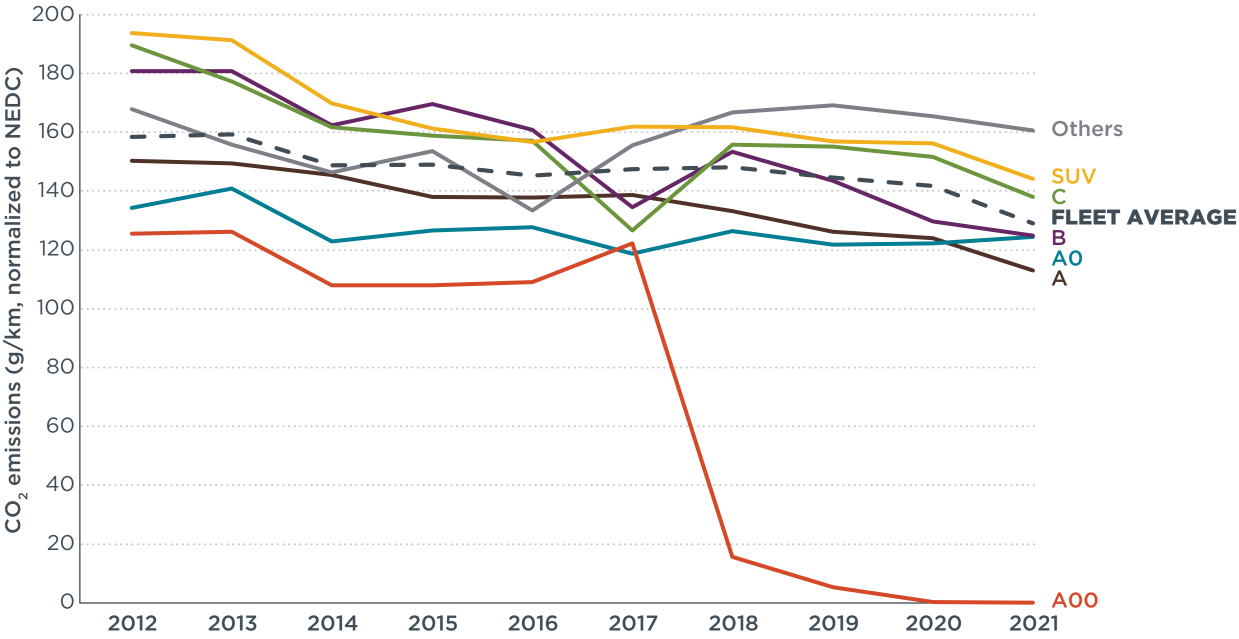


Figure 3-4. Fleet average CO_2 emission rate by segment (ICE and NEV combined)

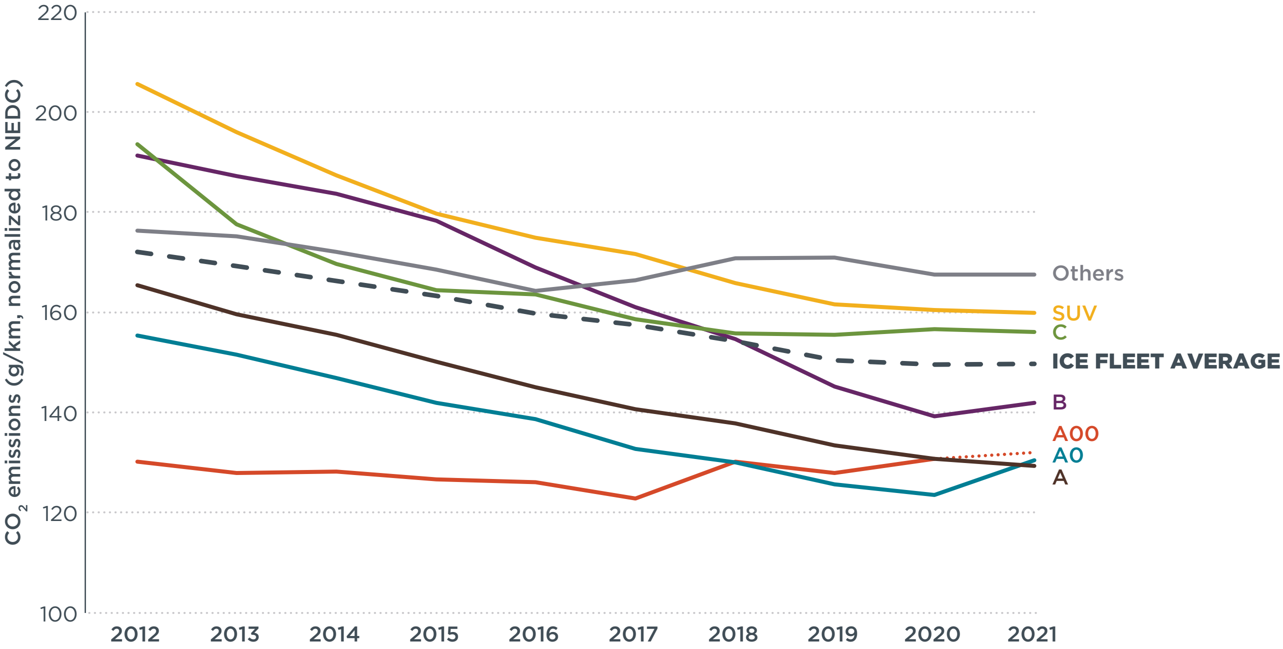


Figure 3-5. Fleet average CO_2 emission rate by segment (ICE only)

* As the A00 class essentially achieved full electrification in 2021, the 2021 data point for that class, which only represents very few cars, does not provide meaningful insight. The 2020–2021 part of the line is dotted to reflect this.

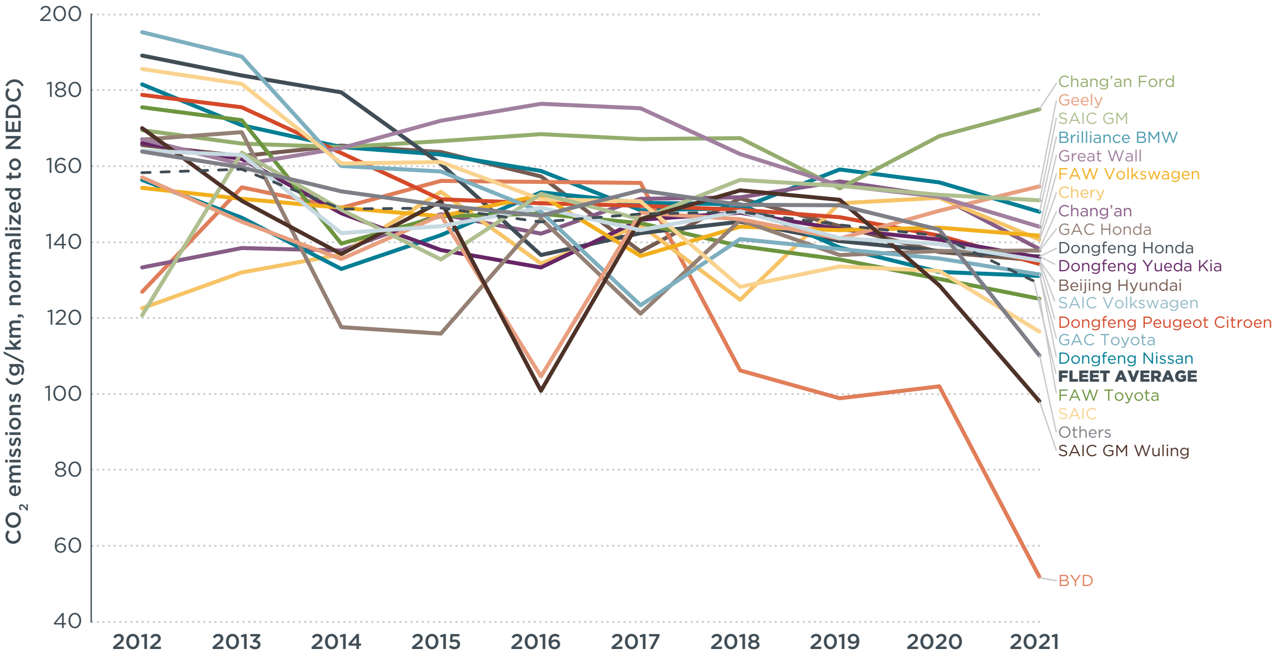


Figure 3-6. Fleet average CO_2 emission rates by OEM (ICE and NEV combined)

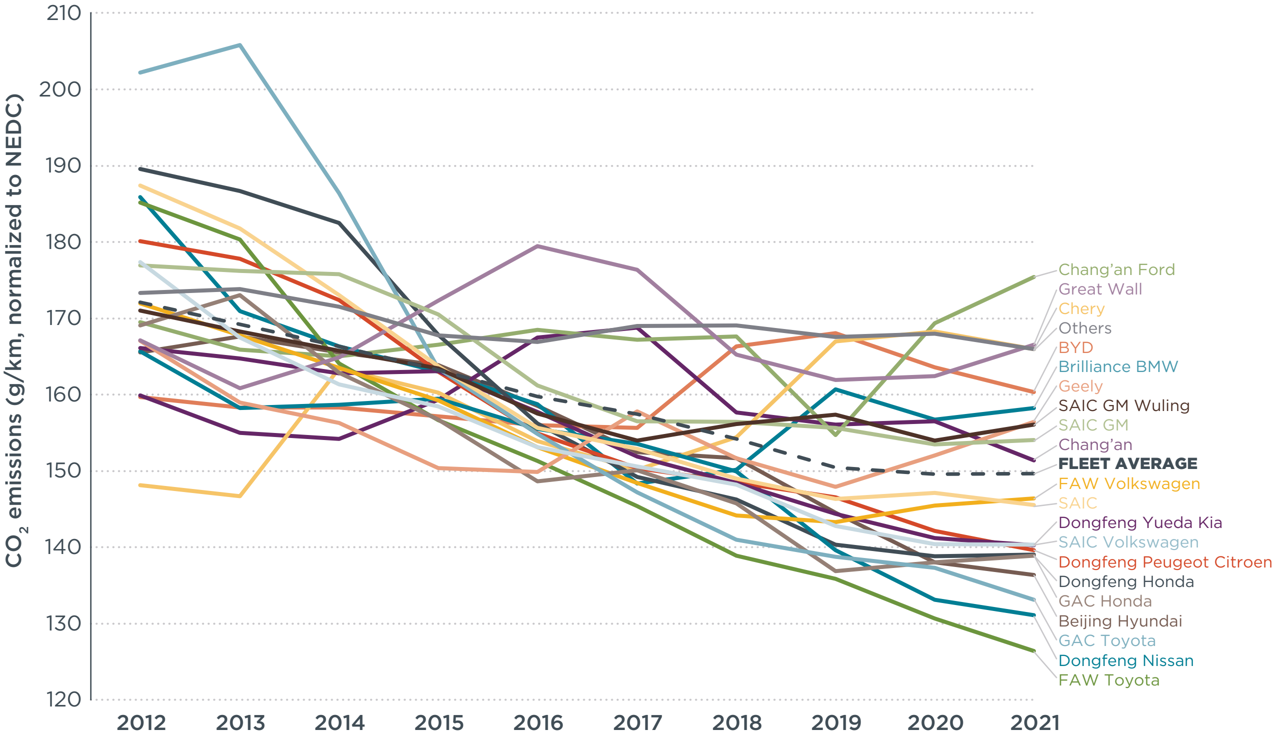


Figure 3-7. Fleet average CO_2 emission rate by OEM (ICE only)

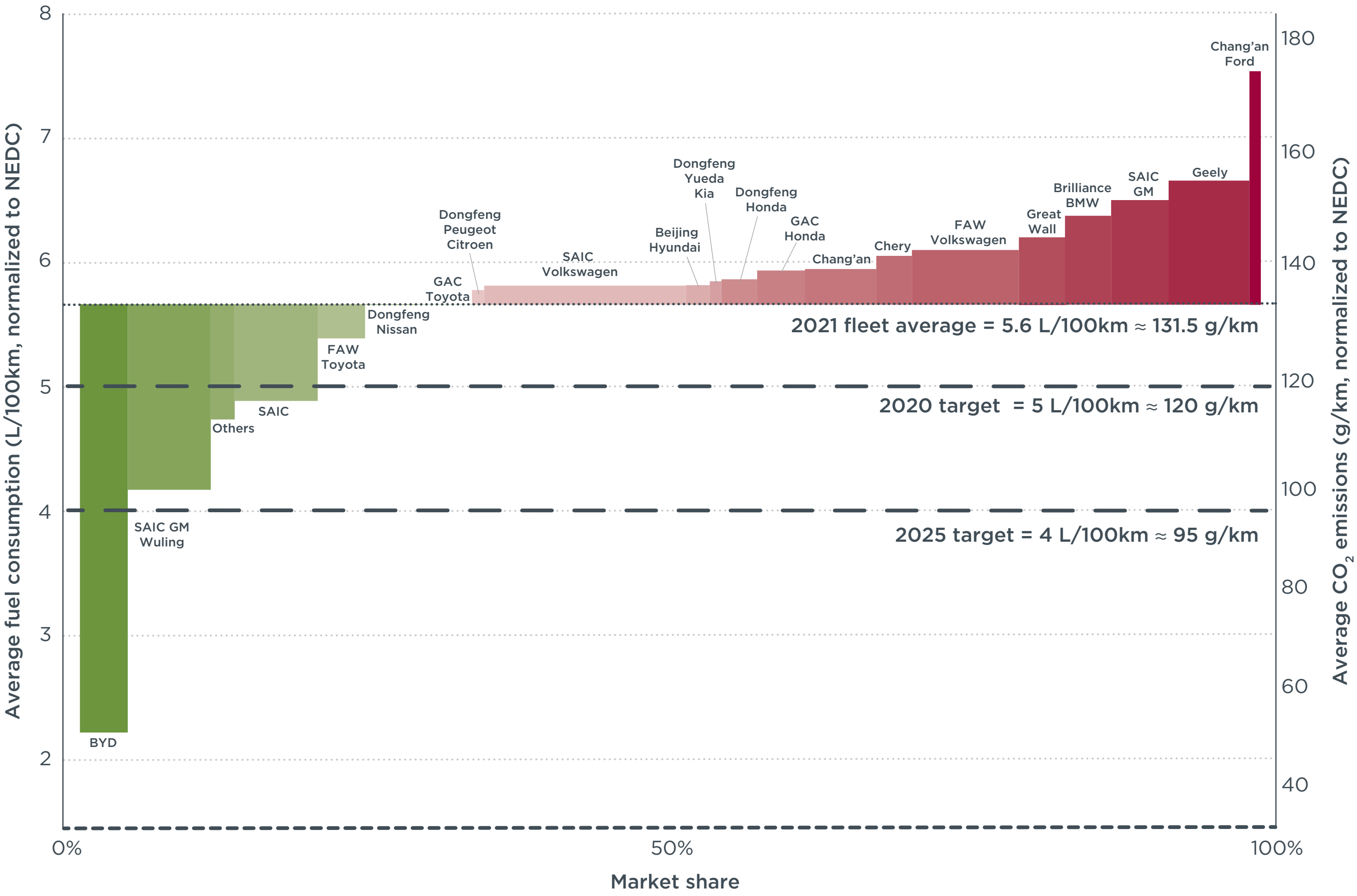


Figure 3-8. CO_2 emission rates (ICE and NEV combined) and market shares by manufacturer in 2021

China's current targets expect the fleet-average fuel consumption to reach 5 L/100 km in 2020 and 4 L/100 km by 2025, roughly equivalent to CO_2 emissions of 120 g/km and 95 g/km, respectively.[4] In 2021, actual fleet-average emissions were 131.5 g/km. Additionally, emissions levels vary widely among OEMs. Of the top-selling OEMs in 2021, BYD (51.8 g/km), SAIC GM Wuling (98 g/km), SAIC (116.4 g/km), and FAW Toyota (125.1 g/km) had the lowest corporate-average CO_2 emissions levels. The highest emissions were from Chang'an Ford (175 g/km), Geely (154.7 g/km), SAIC GM (151 g/km), and Brilliance BMW (148.1 g/km) **(Figure 3-8)**.

4 According to GB 27999-2014 and GB 27999-2019.

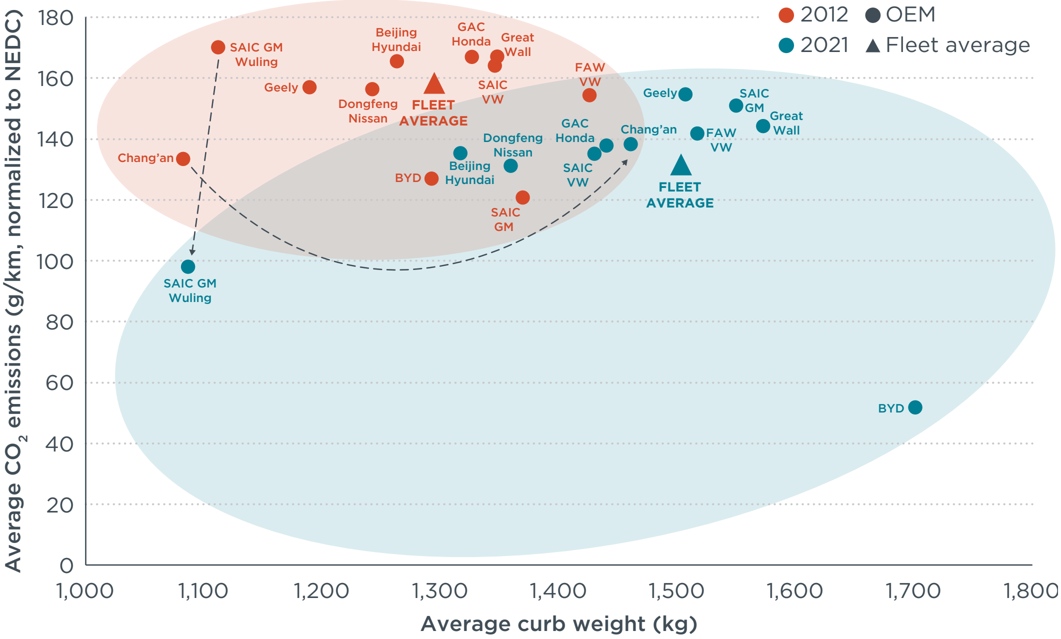


Figure 3-9. Sales-weighted CO_2 emissions and curb weight by manufacturer (dots) and the entire fleet (triangles), 2012 and 2021

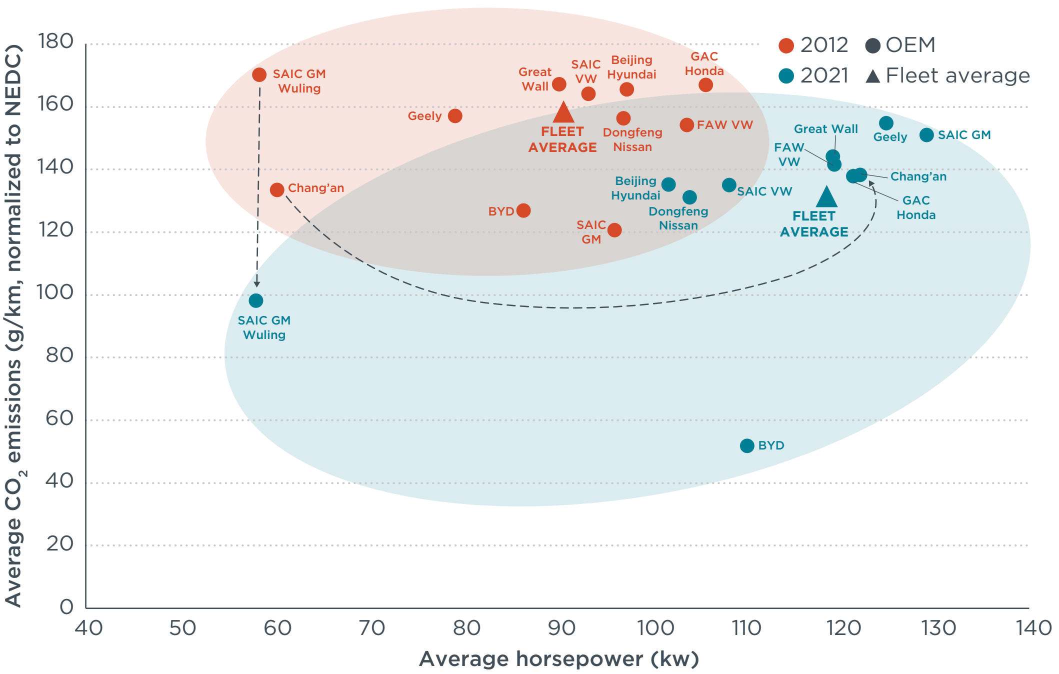
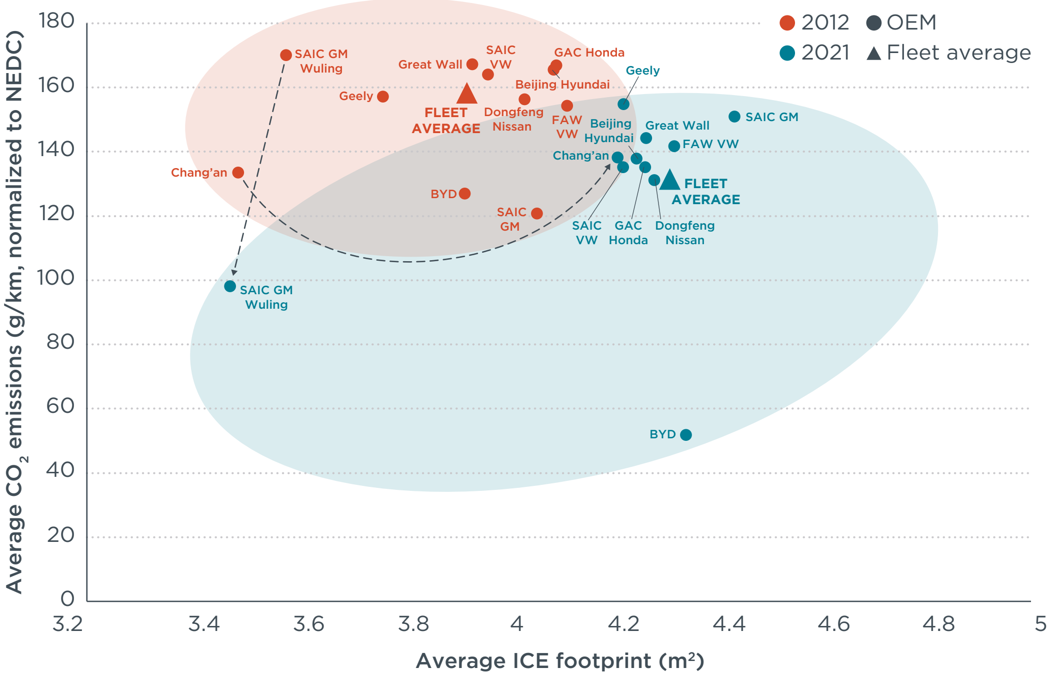


Figure 3-10. Sales-weighted CO_2 emissions and horsepower by manufacturer (dots) and the entire fleet (triangles), 2012 and 2021



*Due to data availability limitations, only ICE footprint data are shown.

Figure 3-11. Sales-weighted CO_2 emissions and ICE footprint by manufacturer (dots) and the entire fleet (triangles), 2012 and 2021

We examined how vehicle utility characteristics and the CO_2 emission rates of major OEMs changed over time. **Figures 3-9** to **3-11** show that the fleet average CO_2 emission rate declined dramatically along with increased vehicle curb weight, horsepower, and vehicle size in terms of footprint. Different manufacturers have followed different pathways. SAIC GM Wuling reduced its average CO_2 emission rate from 170 g/km to 100 g/km without increasing the vehicle's weight, rated power, or size. Meanwhile, Chang'an was able to substantially increase its fleet average curb weight from 1,080 kg to 1,460 kg, its average vehicle power from 60 kw to 122 kw, and its ICE average footprint from 3.5 m² to 4.2 m², all while maintaining the same level of emissions.

Since first introduced in 2005, China's passenger car fuel consumption regulation has been tightened over time. **Figure 3-12** illustrates the five phases of China's standards indexed to vehicle curb weight. The initial two phases of the regulation set the maximum fuel consumption limit on a per-vehicle basis. Starting with the third phase, it switched to a corporate-average approach. The regulation also set different standards for regular-structure vehicles and special-structure vehicles; the latter are usually subject to more lenient requirements. The current regulation, which took effect in 2021, is WLTC-based instead of NEDC-based.

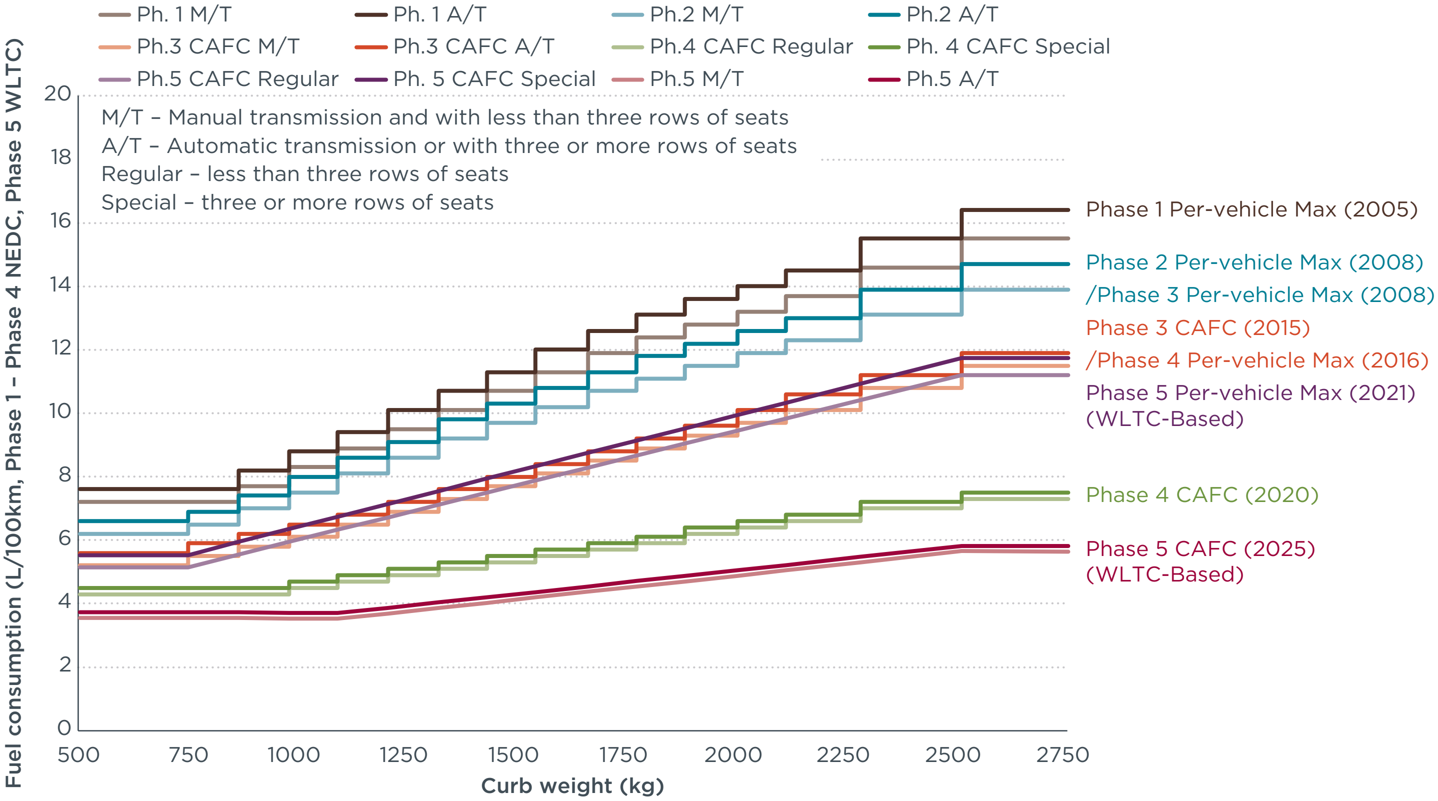


Figure 3-12. History of China's fuel consumption standards for new passenger cars

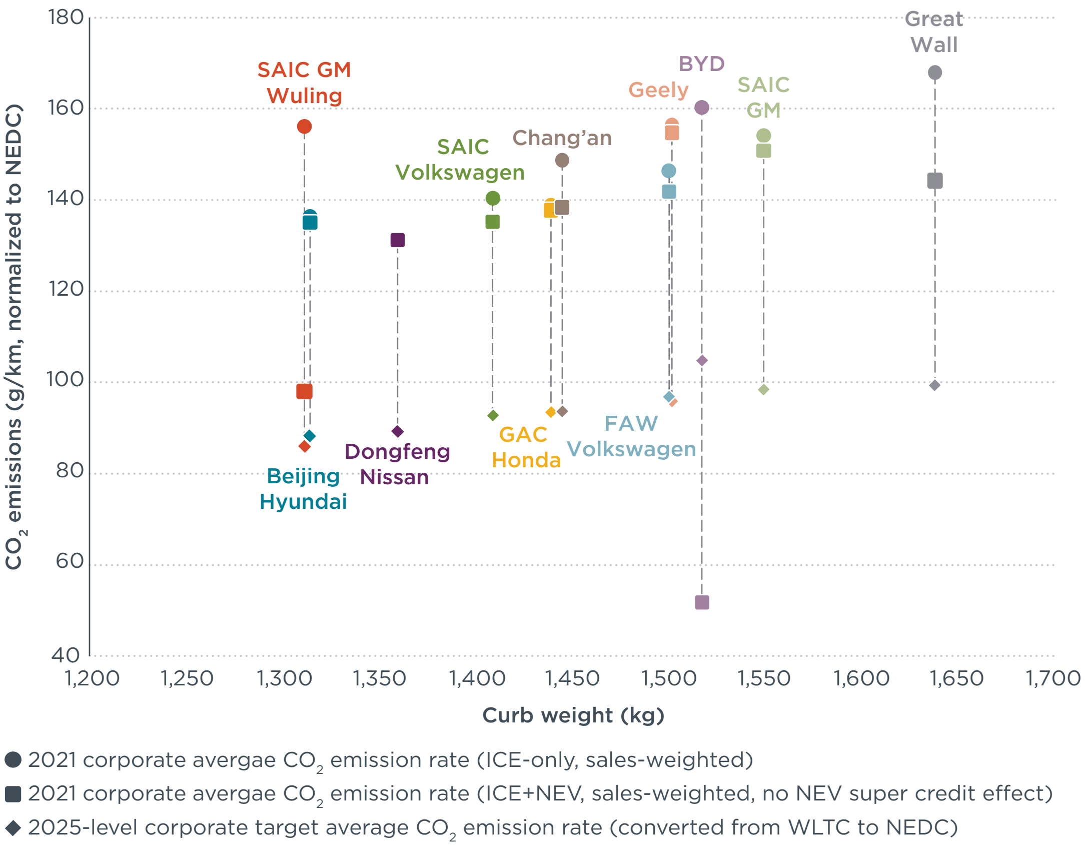


Figure 3-13. Corporate average CO_2 emission rates of major OEMs in 2021, and gaps from their corporate-specific targets for 2025

Figure 3-13 shows the gaps between major OEMs' current fleet-average emissions levels with NEVs included (squares) and without NEVs (dots); their 2025 regulatory targets are diamonds that assume the same product mix in 2025 as in 2021. While most of the OEMs will need to make additional efforts to meet their targets, BYD and SAIC GM Wuling have already surpassed or are approaching theirs. Both OEMs have produced large shares of NEVs.

At present, the calculation of corporate average CO_2 emissions for compliance gives super credits for NEV sales by multiplying a coefficient greater than one with each NEV model's sale; this amplifies each NEV's emissions offset effect. Additionally, corporates are currently allowed to generate CO_2 emissions that are moderately higher than their compliance targets, no greater than a specific percentage in a given year. This buffer mechanism will gradually shrink away by 2025, the same year that super credits are set to be abolished, and all manufacturers will be obligated at that time to strictly meet their targets for CO_2 emissions.

4. TRENDS OF VEHICLE CHARACTERISTICS

This section investigates some major attributes of passenger cars that reflect the vehicle's performance, including horsepower, vehicle mass, engine displacement, and footprint. **Figure 4-1** compares the fleet-wide trend of the attributes between China, the United States, and the European Union. Then we refocus on China and analyze the historical trends of the change in these attributes across segments **(Figures 4-2** to **4-5)** and OEMs **(Figures 4-6** to **4-9)**.

In the United States there was decreased average engine displacement, as opposed to the mostly flat trends observed in the European Union and China. U.S. PCs are generally larger, heavier, and more powerful than those in China and the European Union. In China there was faster growth in horsepower, vehicle mass, and footprint. From 2012 to 2020, the time period for which data is available for all regions, China's fleet average curb weight increased from 1,295 kg to 1,478 kg, which is a 14.1% increase and 1.7% annually on average. Meanwhile, the European Union's vehicle mass (in running order) increased from 1,402 kg to 1,457 kg. That is a 3.9% increase and 0.5% annually on average. The U.S. growth was slower, and it had a larger base value **(Figure 4-1)**.

The fleet-wide horsepower of ICE passenger cars in China slightly increased in most segments. In particular, the SUV segment saw steady and noticeable growth in average horsepower by 12% from 117 kw in 2012 to 131 kw in 2021; that is a 1.3% annual increase on average. The most significant increase in horsepower was in the "Others" section, which includes MPVs, crossovers, minibuses, and sports cars. From 2012 to 2021, the horsepower of this segment increased from 65 kw to 109 kw, which is a 68% increase in total and a 5.9% annual increase on average. When the entire fleet is considered, the general trend is largely identical, except that the average horsepower of the A00 class trends downward, given the less-powerful BEVs have become dominant **(Figure 4-2)**.

Changes in curb weight have been less incremental compared with those of horsepower for the major segments, and the most significant weight increase was also in the "Other" segment. Together, the Other vehicles increased their weight by 3.3% each year on average and by 34% in total, from around 1,200 kg to nearly 1,600 kg; this surpassed the average weight of A0, A, B, and even SUVs in 2021. Here, too, when the scope of examination expands to all ICEs and NEVs, the dynamics do not significantly change **(Figure 4-3)**.

The difference in the average ICE engine displacement of different segments has decreased over time. Larger segments such as C and SUV have remarkably decreased their displacements by 17%–18% since 2012 (1.8% to 1.9% annually), while some smaller segments' displacement either reduced at a much slower rate or remained largely unchanged. The A00 and Others segments were the only two that saw an increase in engine displacement; it rose 20%–30% over the 10 years, or 2%–3% annually **(Figure 4-4)**.

Among ICEs, the footprint of major segments has slightly expanded over the years. Here, too, there has been a significant 22% increase in the footprint of the Others segment, from 3.6 m^2 to 4.4 m^2 or 2.2% annually. This signifies steadily rising market preference for vehicles with larger interior spaces and the additional functionality they offer **(Figure 4-5)**.

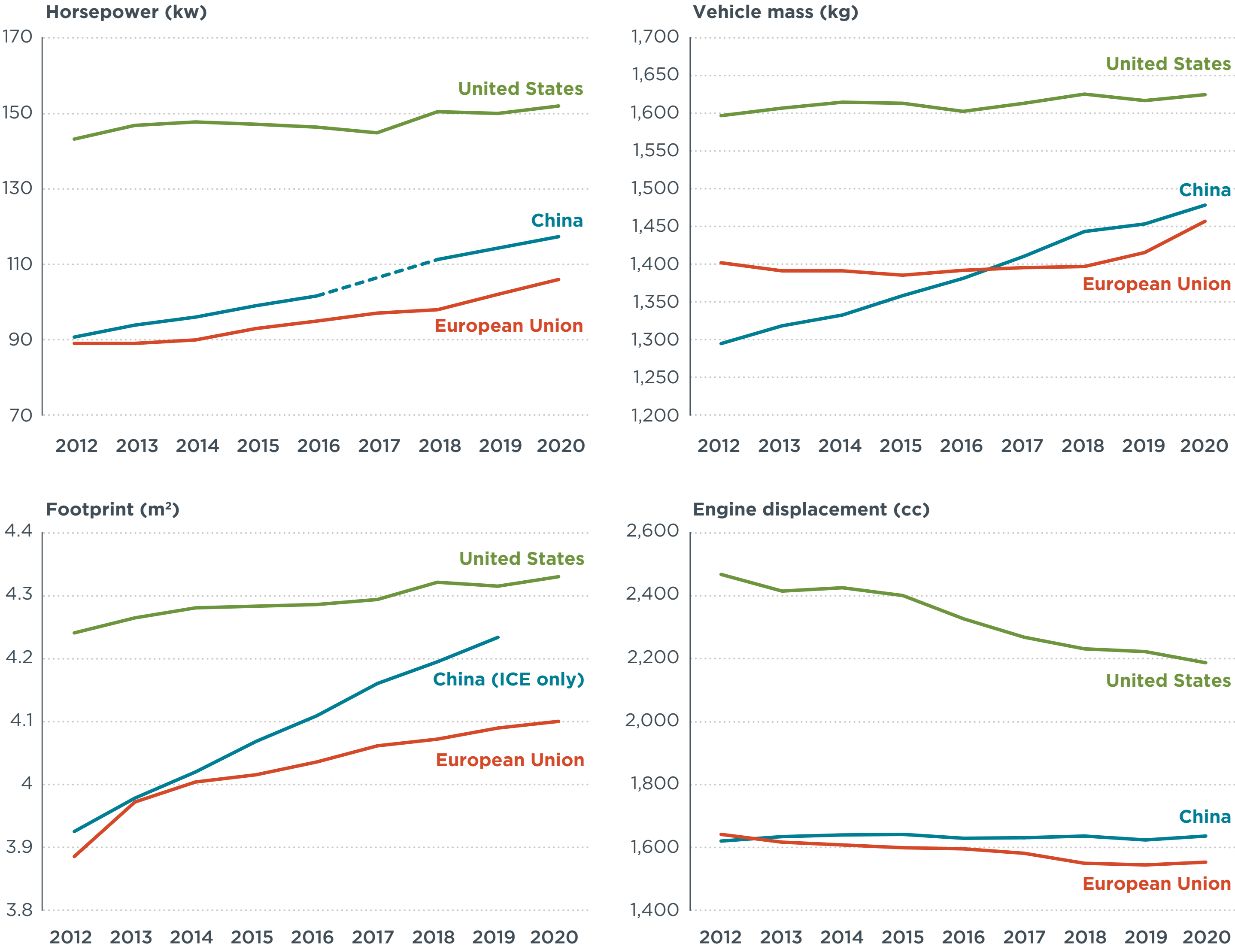


Figure 4-1. Sales-weighted fleet-average horsepower, vehicle mass, footprint, and ICE engine displacement in the United States, China, and the European Union

* Due to limited data availability, China's horsepower data point for 2017 is missing and the points for 2016 and 2018 are connected with a dotted line to simulate the possible trend. Additionally, only ICE footprint data from 2012 to 2019 are provided for China. Vehicle mass shown refers to mass in running order in the European Union and curb weight in China and the United States.

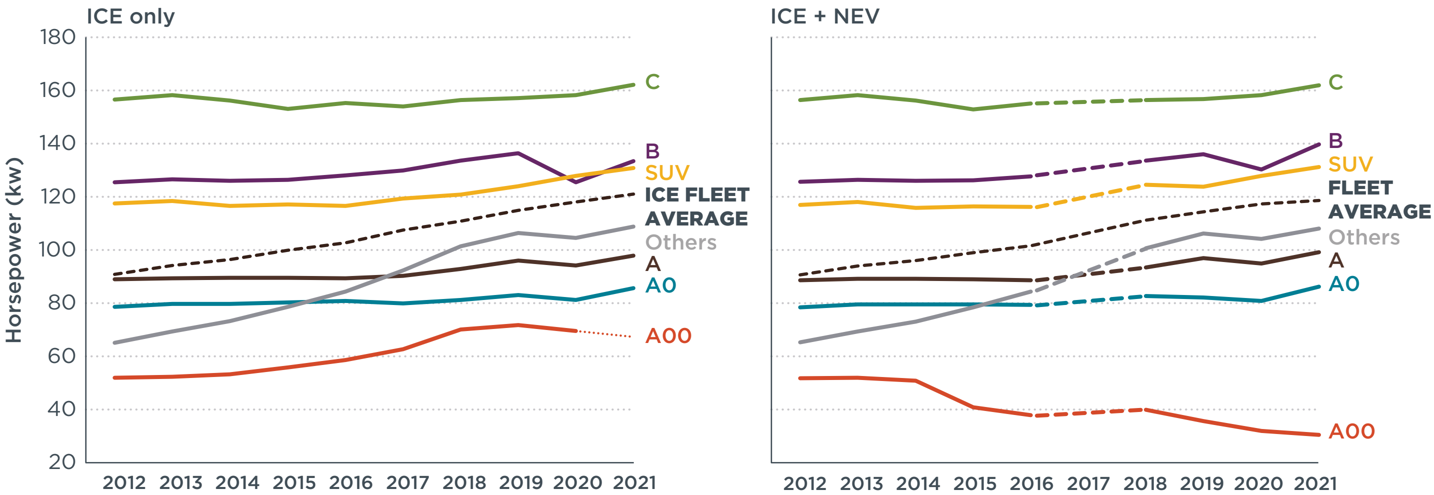


Figure 4-2. Sales-weighted average horsepower by segment

* As the A00 class had essentially achieved full electrification in 2021, the ICE 2021 data point for that class, which represents very few cars, does not provide meaningful insight. This is denoted with a dotted line between 2020 and 2021. Due to NEV data availability, horsepower data points for the ICE + NEV fleet in 2017 are missing; the points of 2016 and 2018 are connected with dotted lines to simulate the possible trend.

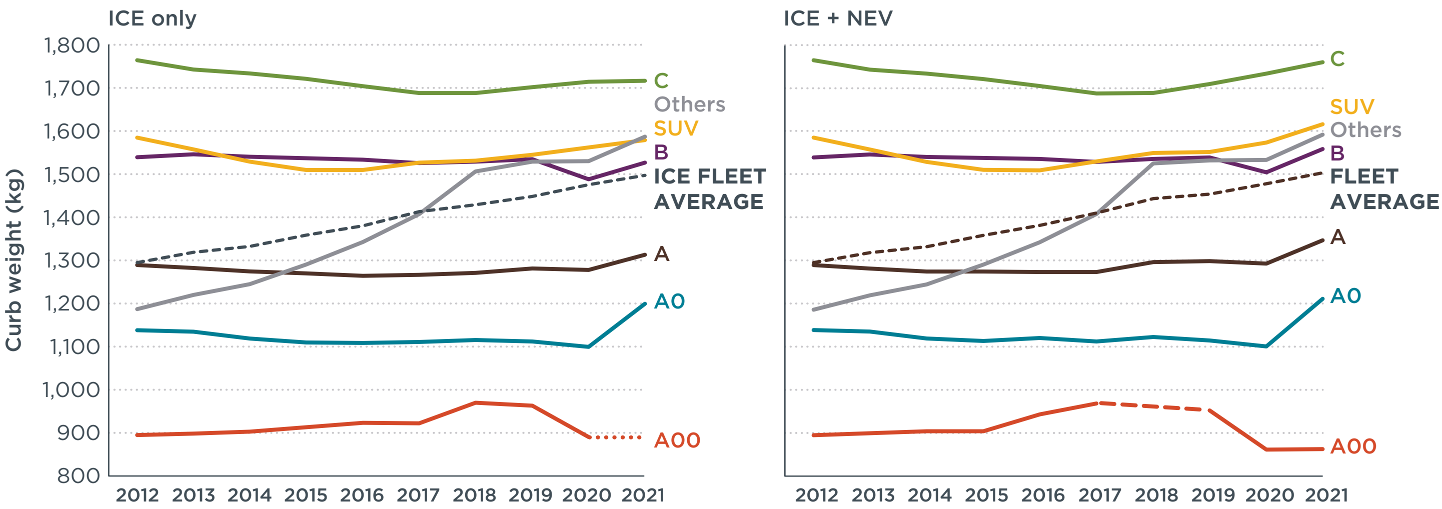


Figure 4-3. Sales-weighted average curb weight by segment

* As the A00 class had essentially achieved full electrification in 2021, the ICE 2021 data point of the A00 class, which represents very few cars, does not provide meaningful insight. This is denoted with a dotted line between 2020 and 2021. The 2018 data point for the A00 class in the ICE + NEV chart is missing because data credibility is in question. The 2017 and 2019 data points are connected with a dotted line to simulate the possible trend.

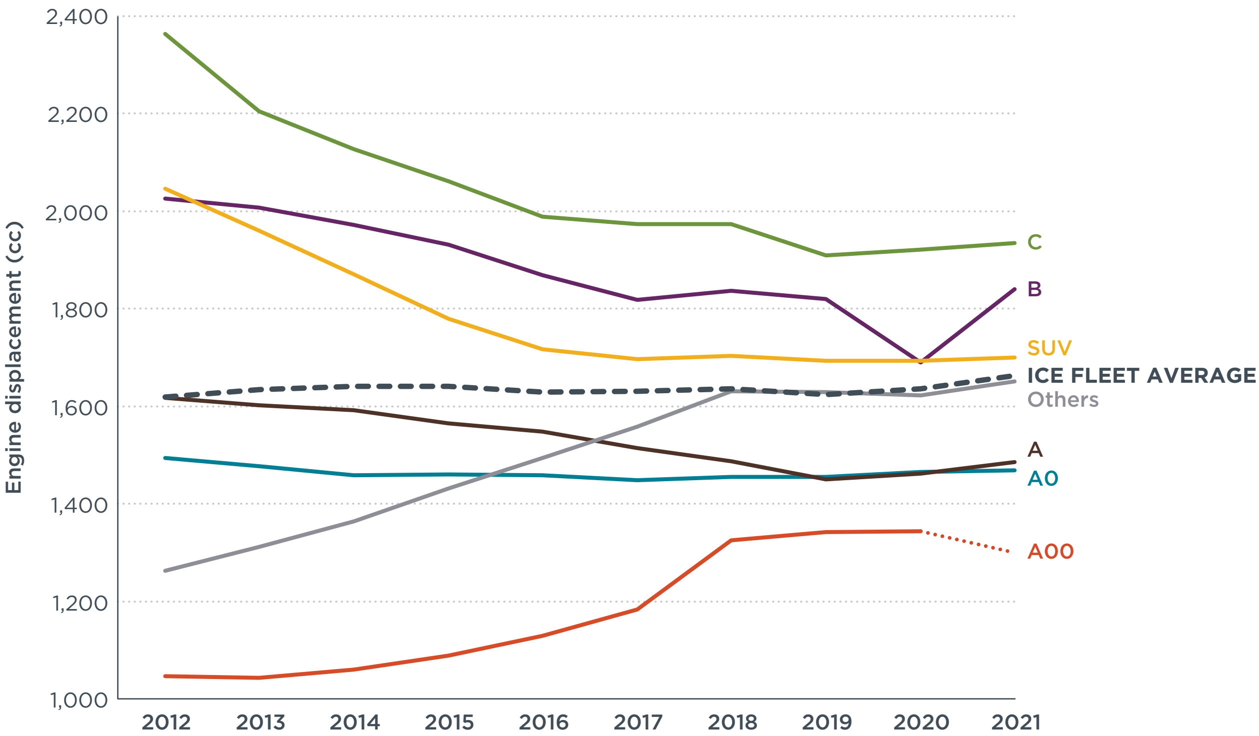


Figure 4-4. Sales-weighted average engine displacement of ICE vehicles by segment

* As the A00 class had essentially achieved full electrification in 2021, the 2021 data point of the A00 class, which represents very few cars, does not provide meaningful insight. This is denoted with a dotted line between 2020 and 2021.

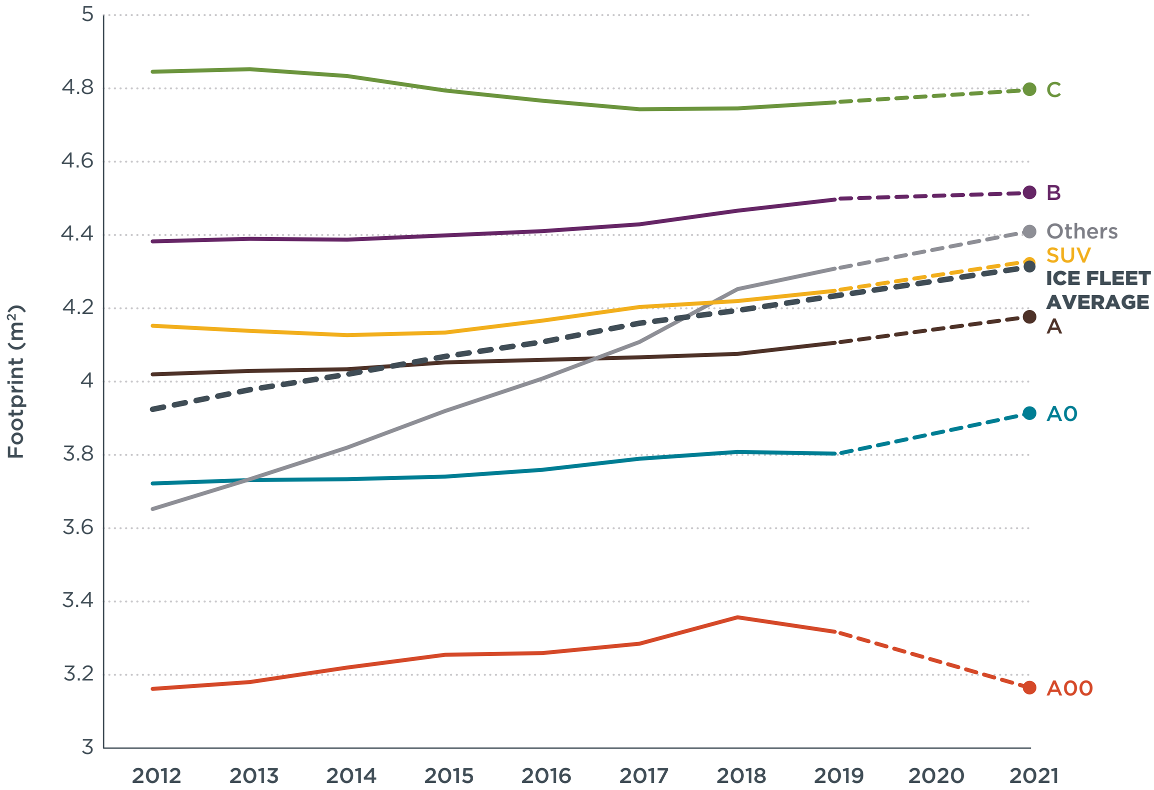


Figure 4-5. Sales-weighted average footprint of ICE vehicles by segment

* Data for 2020 are missing due to limited data availability. The 2019 and 2021 data points are connected with dotted lines to simulate a possible trend.

The growing trend of horsepower, curb weight, and vehicle size (footprint) is more evident when examining by OEM than it is when looking at the segment analysis. This is presumably because major manufacturers respond better to market demand and concentrate on the most typical customer groups. In recent years, some OEMs with a higher share of NEVs, like SAIC GM Wuling, have tended to have lower fleet-average horsepower and curb weight. This is because a large part of their NEV production is mini-sized vehicles, and they drive down the overall fleet horsepower and curb weight. This is not the case for BYD, though, as BYD heavily targets luxury NEV models. OEM-level analysis of engine displacement also shows convergence over the years, implying similar choices and product positioning of ICE models **(Figures 4-6** to **4-9)**.

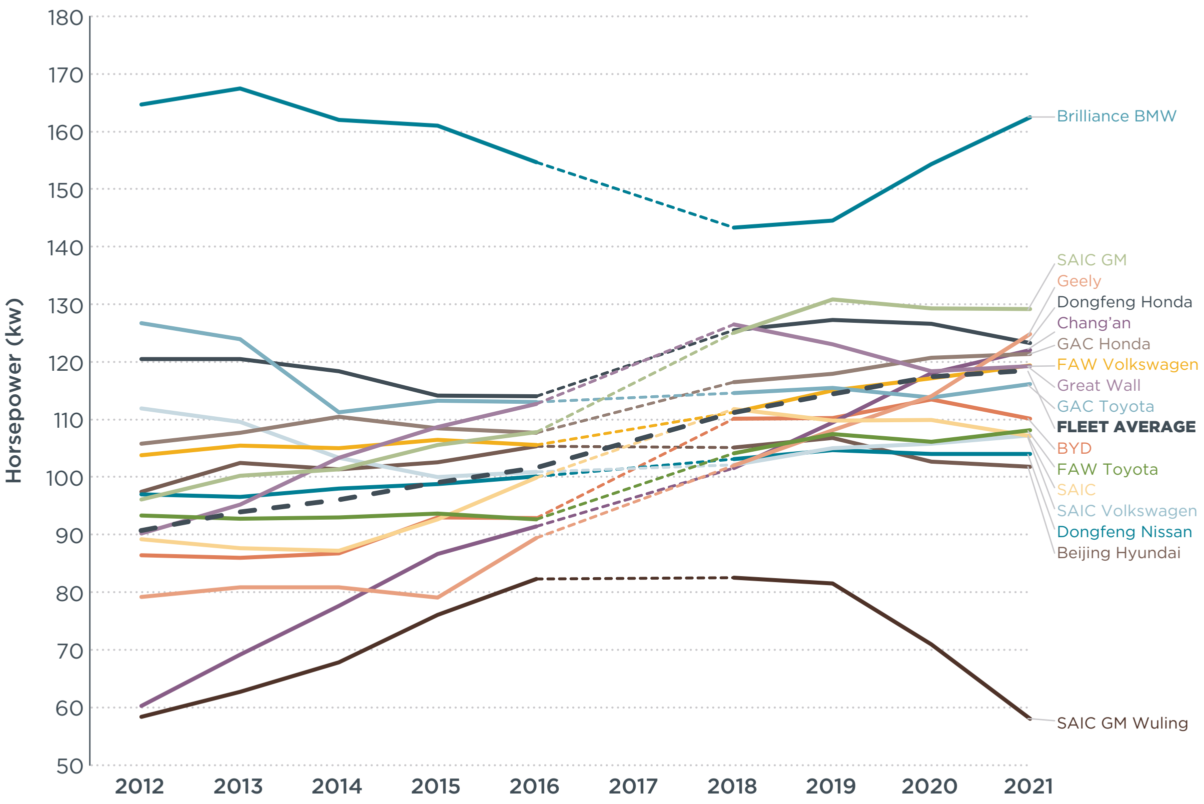


Figure 4-6. Sales-weighted average horsepower of the entire fleet (ICE+NEV) by OEM

* Because the 2017 NEV horsepower data are incomplete, the points for 2016 and 2018 are connected with dotted lines to simulate the possible trend.

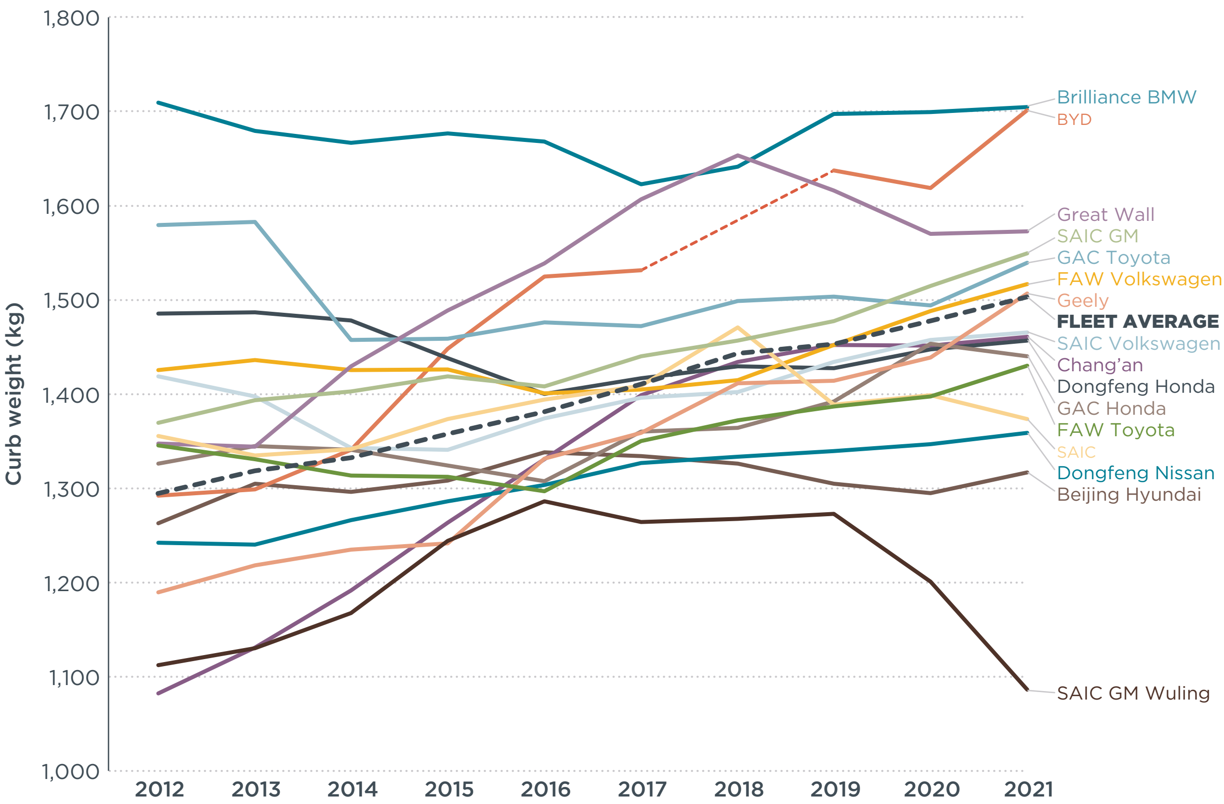


Figure 4-7. Sales-weighted average curb weight of the entire fleet (ICE+NEV) by OEM

* The 2018 data point for BYD is missing because the data credibility is in question. The 2017 and 2019 data points are connected with a dotted line to simulate the possible trend.

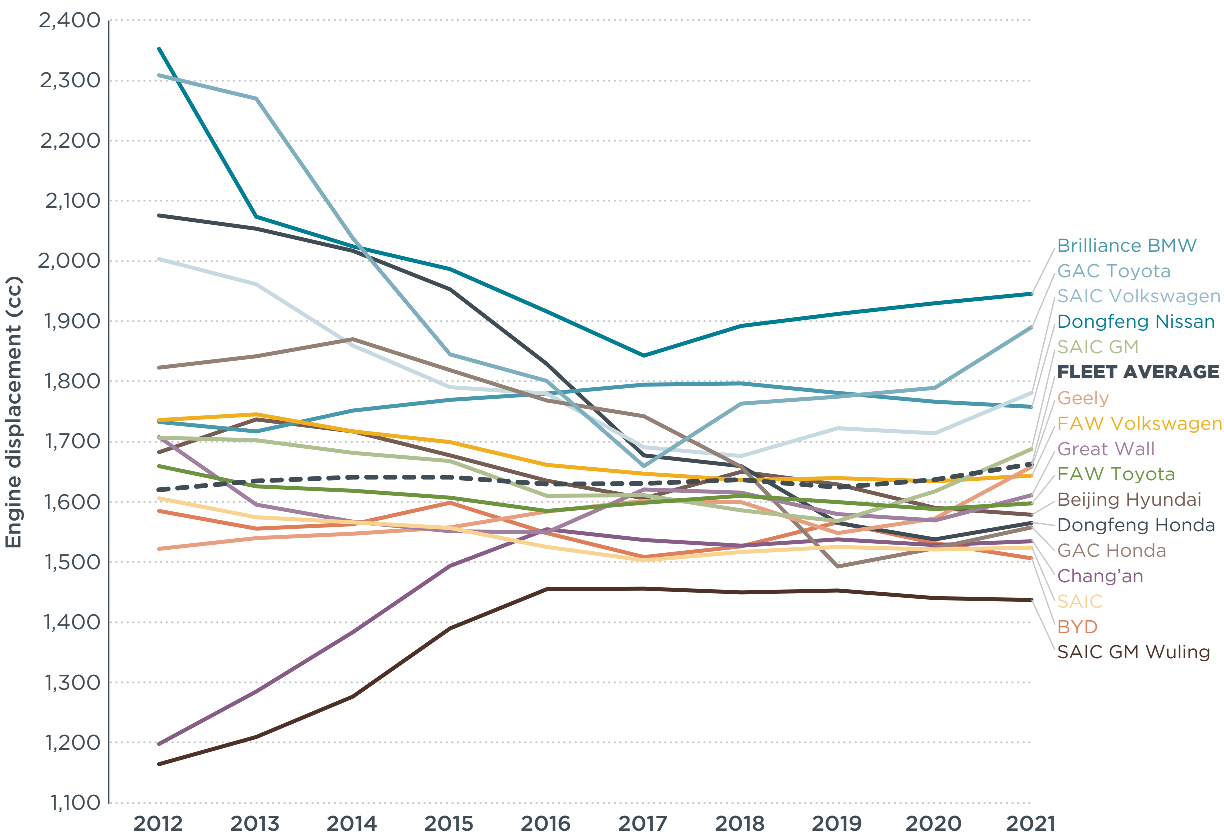


Figure 4-8. Sales-weighted average engine displacement of ICE vehicles by OEM

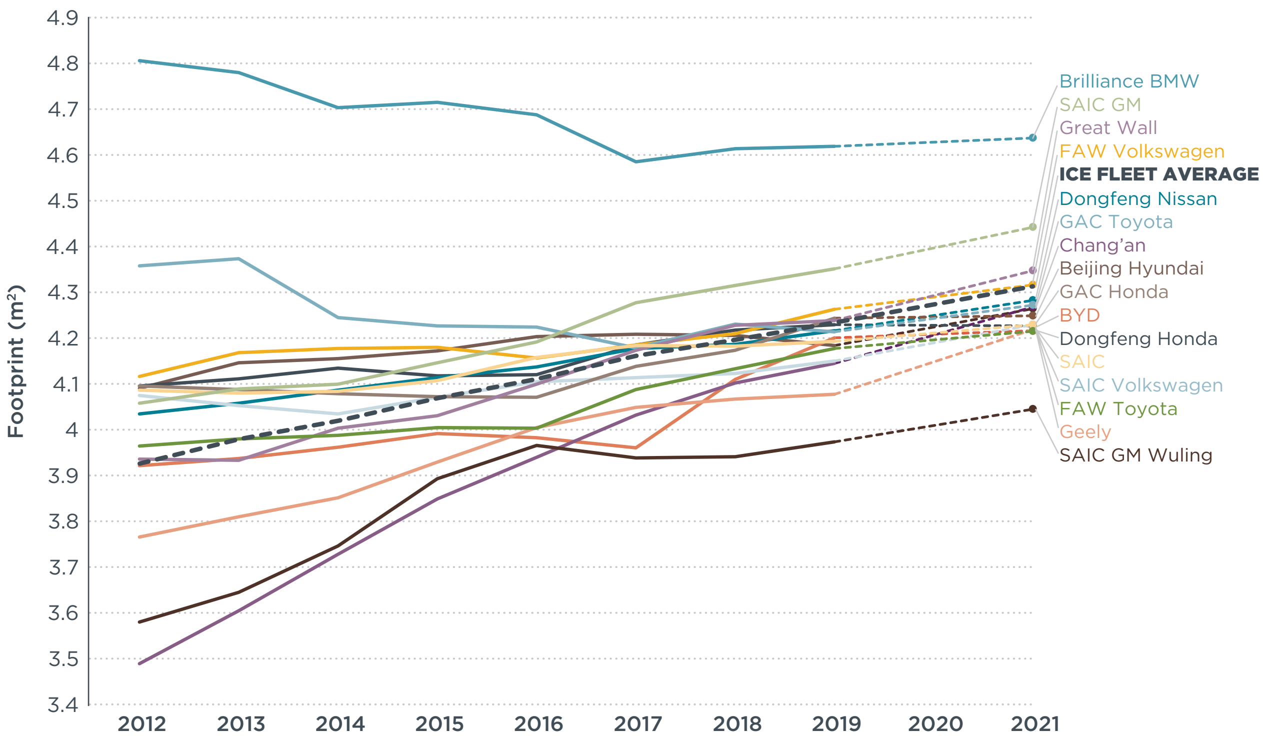


Figure 4-9. Sales-weighted average footprint of ICE vehicles by OEM

* The 2020 footprint data are not available. The 2019 and 2021 data points are connected with dotted lines to simulate the possible trend.

5. TRENDS OF CO_2 EMISSION CONTROL TECHNOLOGIES

This section dives into the market trends of technologies related to fuel consumption and CO_2 emissions reduction. **Figures 5-1** to **5-3** look at the historical adoption of various new energy power train technologies (battery electric, plug-in hybrid, and fuel cell electric vehicles), and various engine and transmission technologies for ICE cars. **Figures 5-4** to **5-7** present a cross-sectional view by further examining the annual market penetration of these technologies and also exploring engine configuration, the number of gears of the transmission system, and drivetrain at the segment and OEM levels. **Tables 5-1** through **5-3** detail major OEMs' adoption rates of NEV technologies and two key advanced vehicle technologies among the ICE cars: gasoline direct injection (GDI) and turbocharging/supercharging.

Overall, adoption of technologies conducive to less CO_2 emissions increased, though to varying extents. Turbochargers and superchargers have become more popular. The portion of ICE PCs equipped with a turbocharger or a supercharger grew from 11% in 2012 to 62% in 2021. GDI has also become the dominant fuel supply technology of gasoline cars, with its presence increasing from 8% in 2012 to 60% in 2021. As for the transmission type, automatic transmission (AT) became a mainstream technology and continuously variable transmission (CVT) increased its share in the ICE fleet from 5% to 27% over the 10 years **(Figure 5-2)**. Finally, electrification is a crucial technology path toward low-carbon vehicles. The market share of NEVs rose to about 15% in 2021. Specifically, BEVs and PHEVs were 11.5% and 2.5% of the newly registered cars in 2021. By 2021, FCEVs were still so rare that they are not visible in our chart **(Figure 5-1)**.

The segment-level analyses in **Figures 5-4** and **5-5** demonstrate that the market share of various advanced technologies increased dramatically across the board from 2012 (2009 for drivetrain technologies) to 2021. For electric power train technologies, only the smallest vehicle segment, the A00 class, was fully electrified by 2021 **(Figure 5-4)**. For ICE sedans, advanced engine and transmission technologies are increasingly popular as vehicle size goes up. Recall that SUV cars in China can vary significantly in size, as they include models ranging from compact SUV to full-size SUV. Thus, the adoption rate of advanced engine and transmission technologies in the SUV segment is not necessarily comparable to a large segment like C. Given the full electrification of A00 in 2021, this segment is excluded from the 2021 ICE-only analysis **(Figure 5-5)**.

The OEM-level analyses in **Figures 5-6** to **5-10** shed light on manufacturers' diversified preferences for these technologies. Over time, most manufacturers have leaned toward more advanced, environmentally friendly technologies. Some manufacturers' technological compositions were nothing alike in 2012 and in 2021. For example, GAC Honda switched its focus from 5-gear transmission to CVT for its ICE product line, and this strategy clearly distinguishes it from other manufacturers. In 2012, no major OEM was producing NEVs, and by 2021, NEVs were the absolute lifeblood of BYD.

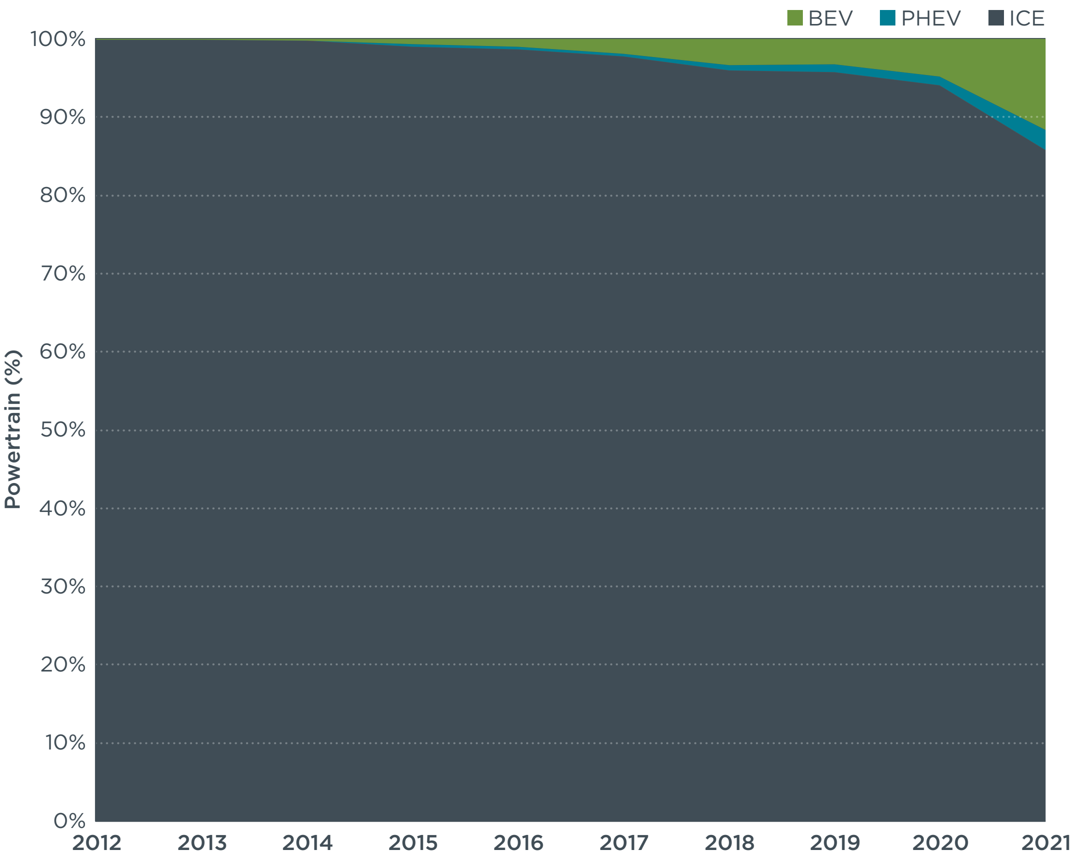


Figure 5-1. Market share of power train technologies

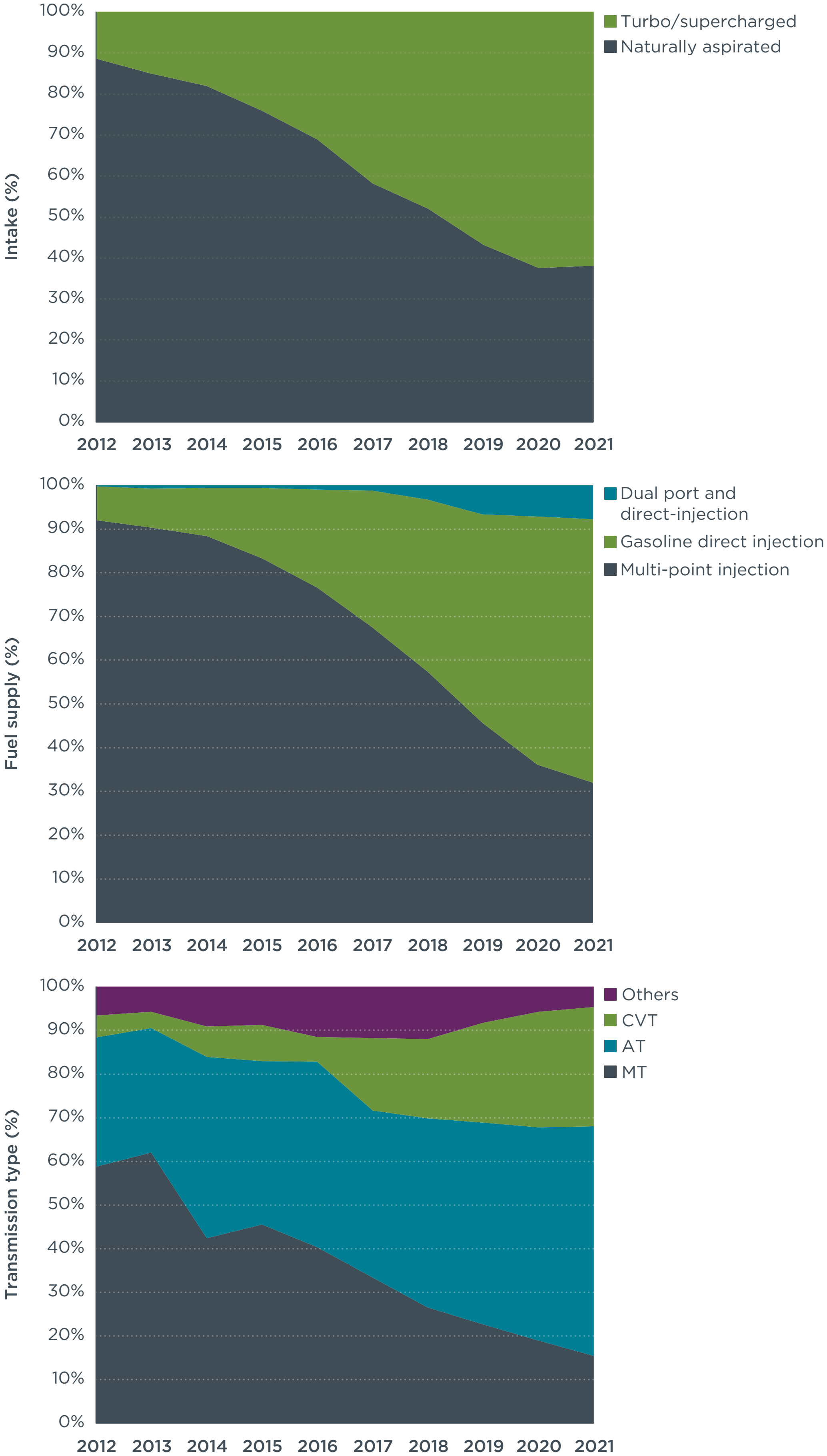


Figure 5-2. Market penetration of air intake, fuel supply, and transmission technologies among ICE cars

* For the fuel supply technologies, our scope is limited to gasoline cars only. Single-point injection, while still in use, is too rare to be shown on the chart.

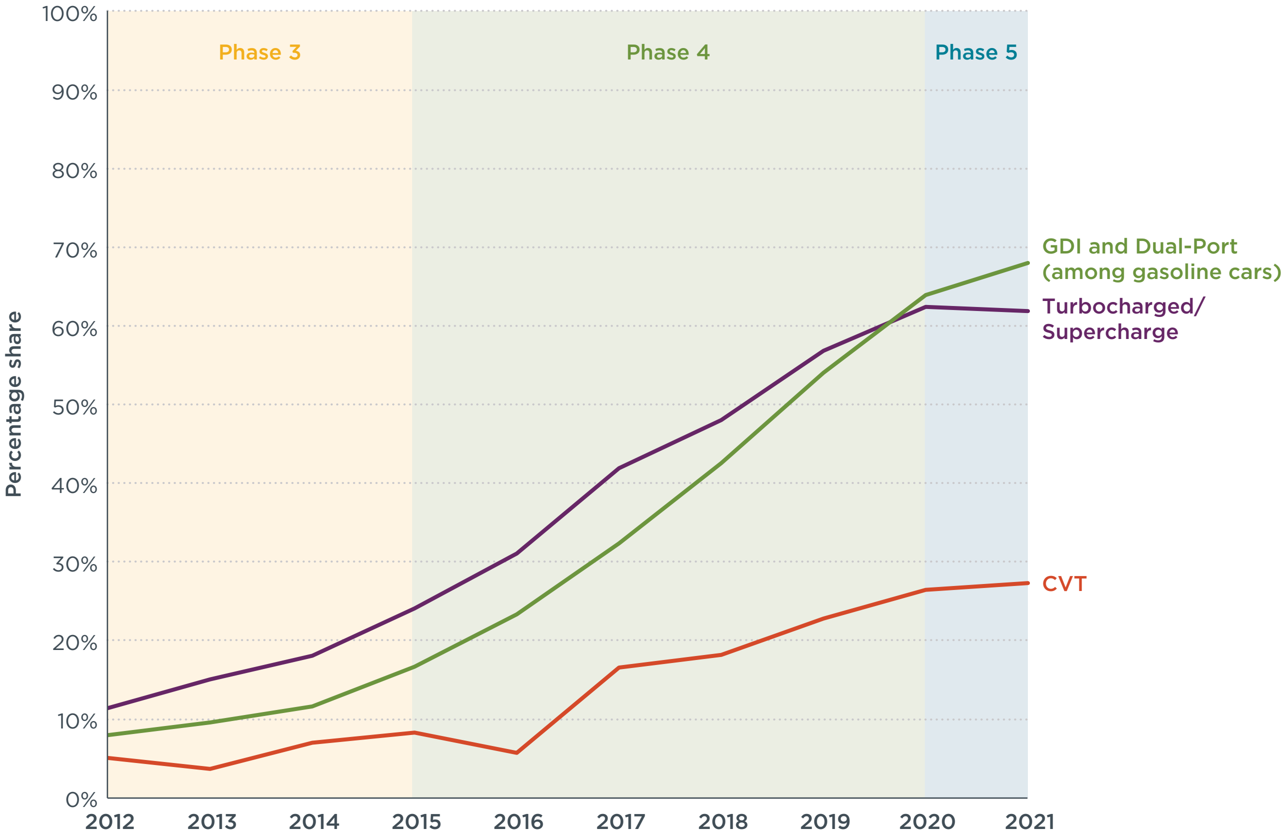


Figure 5-3. Summary of the market shares of advanced engine and transmission technologies for ICE cars during different phases of fuel consumption regulations

* Usually, high gear ratio AT (AT6, 7, 8+), CVT, and dual-clutch transmission (DCT) are all considered advanced transmission technologies. However, due to data availability, only the CVT share is shown.

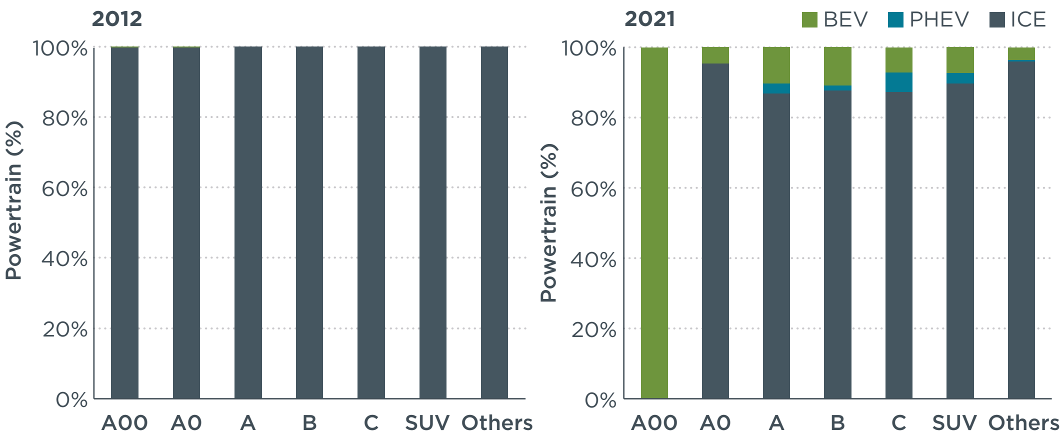


Figure 5-4. Market share of powertrain technologies by segment, 2012 and 2021

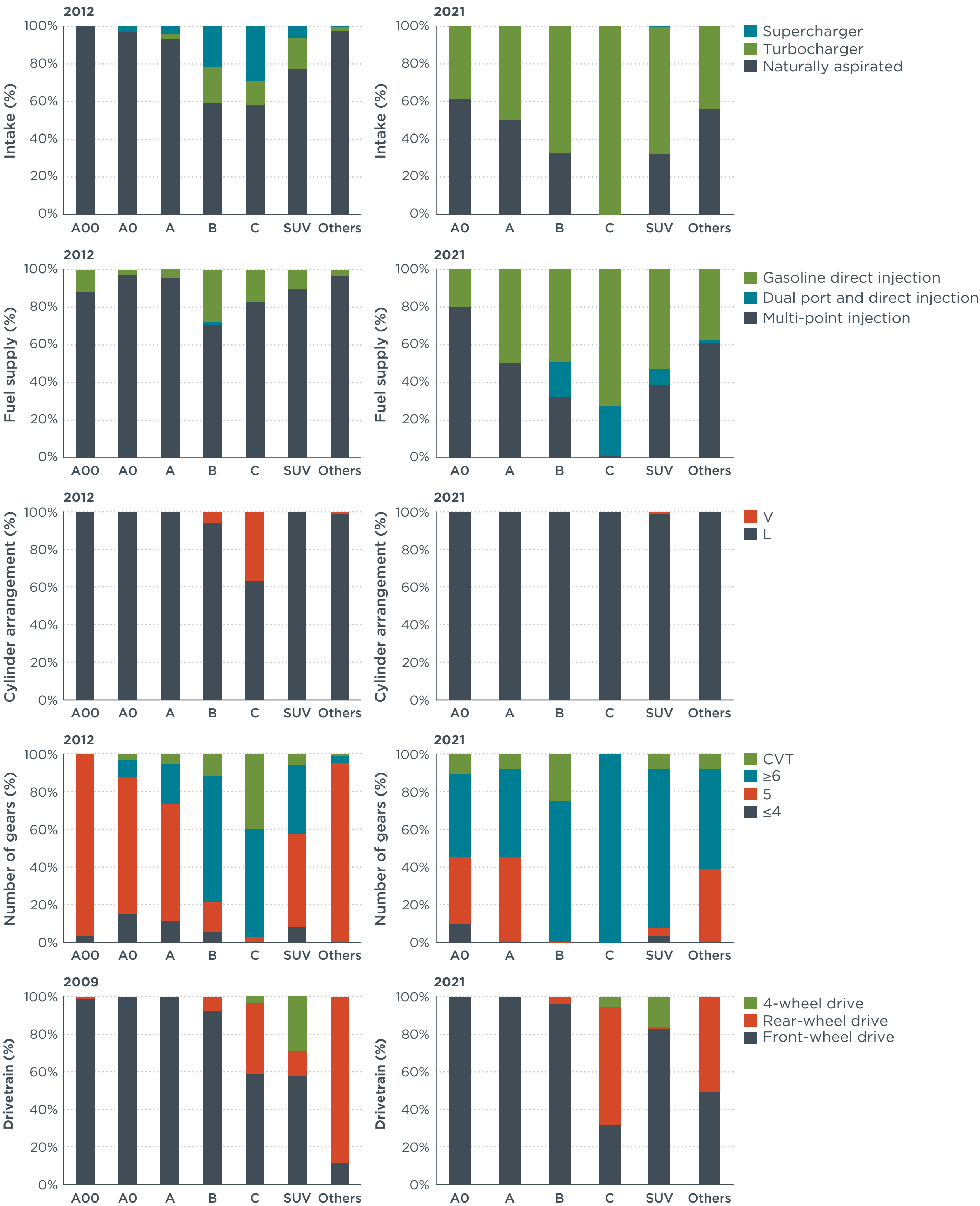


Figure 5-5. Market share of various car technologies by segment among ICE cars, 2012 (2009 for drivetrain technologies) and 2021

* For the fuel supply technologies, the scope of discussion is limited to gasoline cars only.

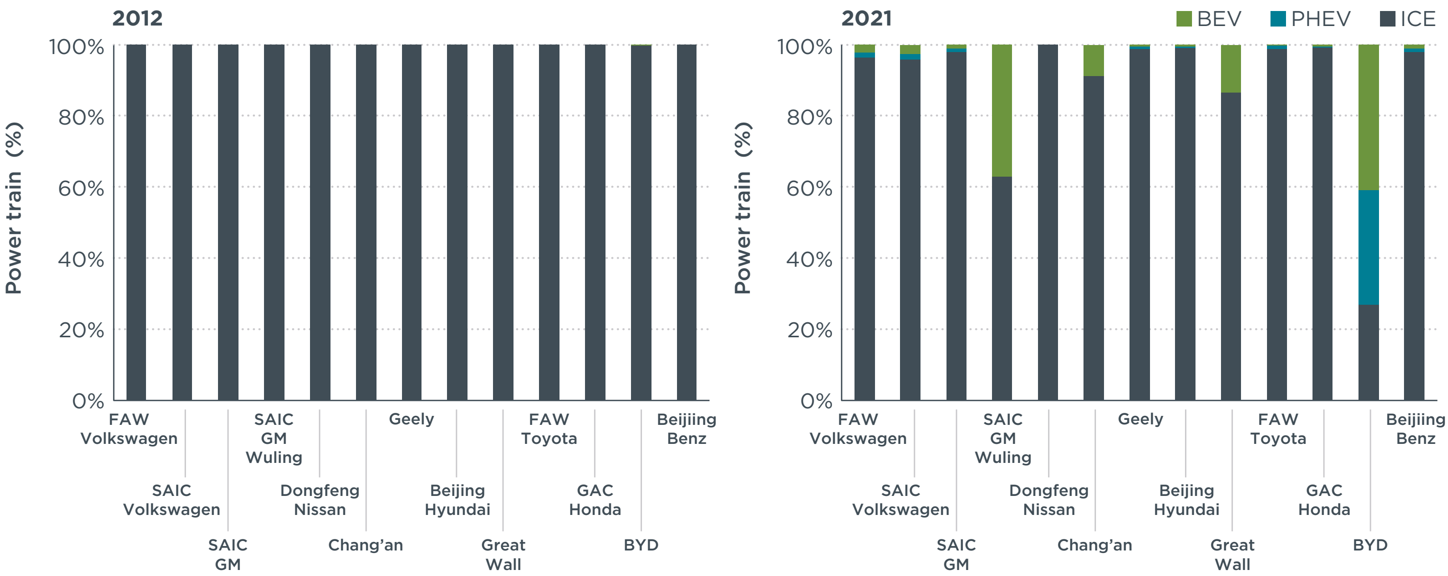
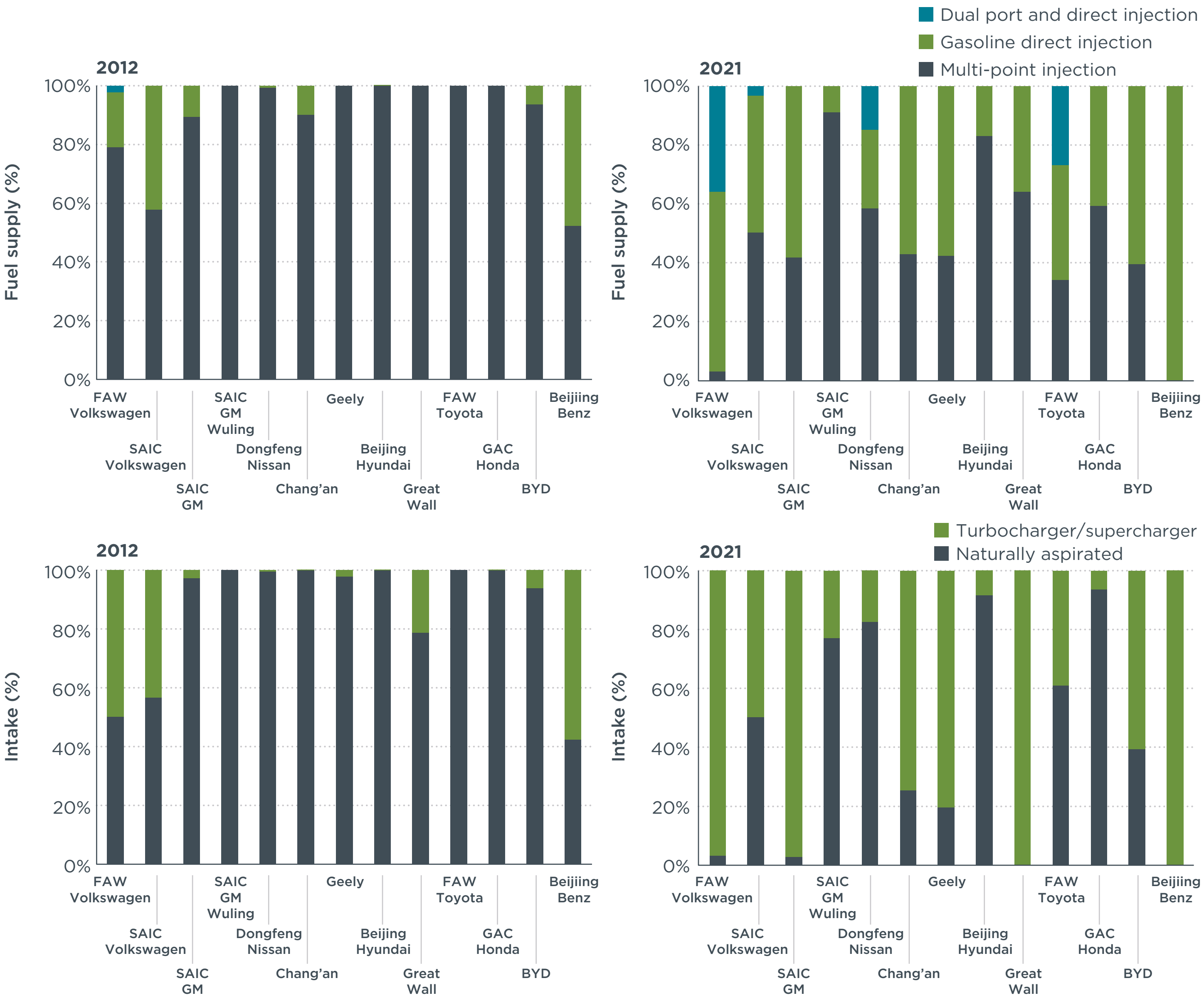


Figure 5-6. Market share of power train technologies by OEM, 2012 and 2021



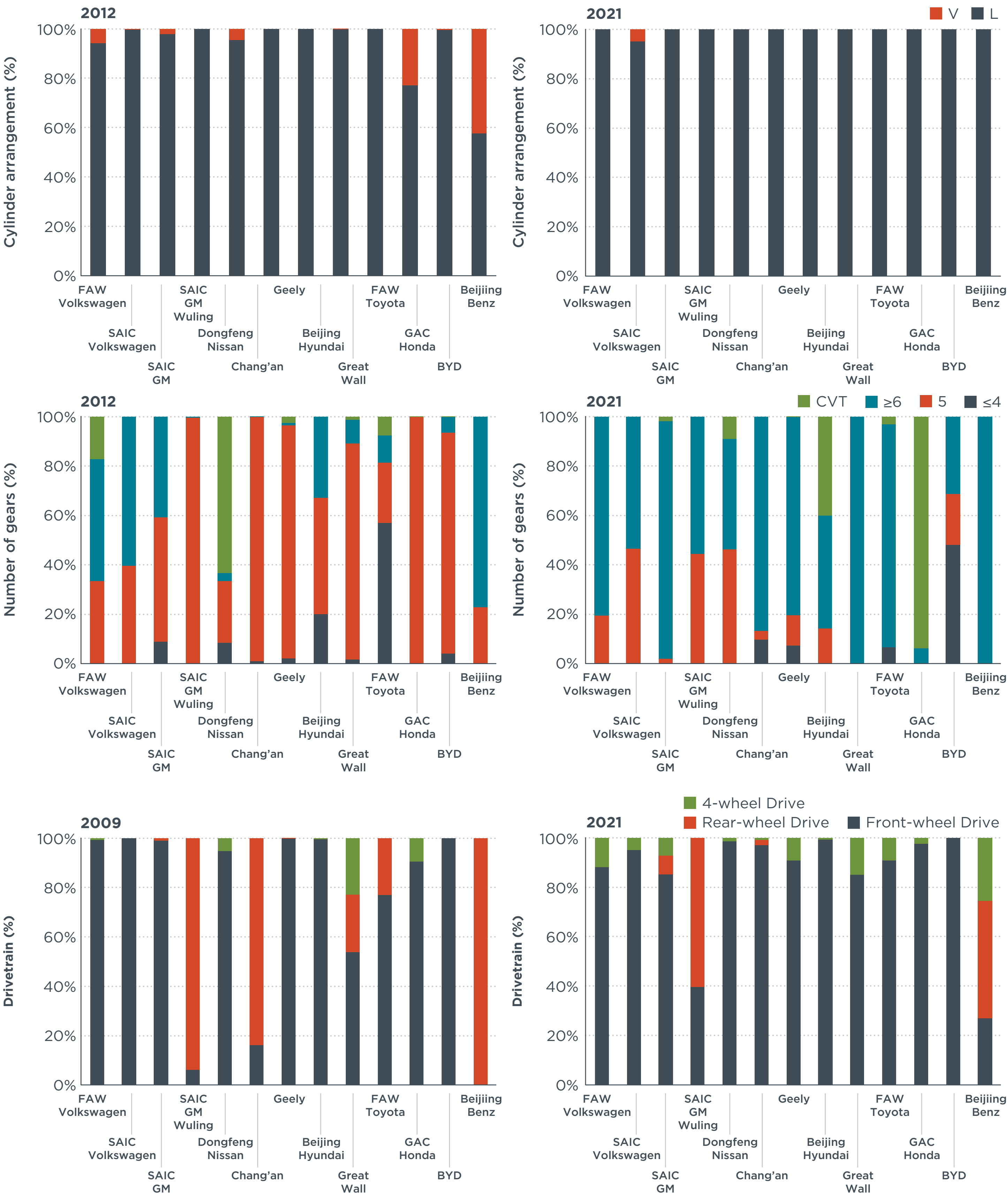


Figure 5-7. Market share of various car technologies by OEM among ICE cars, 2012 (2009 for drivetrain technologies) and 2021

* For fuel supply technologies, our scope is limited to gasoline cars only.

† The OEMs shown in Figure 5-6 and Figure 5-7 are listed in the descending order in terms of their cumulative market share over the 10 years. Beijing Benz and BYD were intentionally selected to reflect their unique choices of technologies.

Tables 5-1 to **5-4** show major OEMs' historical changes in terms of adoption of two fuel-saving technologies for ICEs, GDI and turbocharging; new energy power trains; and conventional hybrid (HEV) technology. Leading Sino-German joint ventures like Beijing Benz, FAW Volkswagen, and SAIC Volkswagen had a clear advantage in both fuel-saving technologies and their adoption rates were significantly higher than other major OEMs in 2012. Beijing Benz achieved 100% penetration in 2016, while some other manufacturers only began to adopt these technologies recently. As for NEV adoption, BYD and SAIC GM Wuling are the undisputed pioneers, although some independent automakers like Chang'an and Great Wall are trying to expedite deployment. When it comes to conventional hybrids, the adoption rates of Sino-Japanese joint ventures like FAW Toyota and GAC Honda stand out.

Table 5-1. GDI and dual-port direct injection adoption rate by OEM (gasoline cars only)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
FAW Volkswagen	21%	20%	21%	25%	38%	50%	62%	77%	81%	97%
SAIC Volkswagen	42%	41%	38%	40%	35%	47%	52%	57%	57%	50%
SAIC GM	10%	12%	13%	25%	40%	57%	63%	62%	66%	58%
SAIC GM Wuling	0%	0%	0%	0%	0%	0%	0%	0%	0%	9%
Dongfeng Nissan	1%	0%	6%	13%	25%	24%	27%	36%	37%	42%
Chang'an	10%	6%	3%	2%	3%	19%	25%	52%	81%	57%
Geely	0%	0%	0%	4%	13%	18%	25%	39%	52%	58%
Beijing Hyundai	0%	3%	2%	9%	30%	40%	41%	39%	28%	17%
Great Wall	0%	0%	0%	4%	6%	16%	50%	54%	52%	36%
FAW Toyota	0%	0%	0%	2%	6%	6%	47%	59%	84%	66%
GAC Honda	0%	4%	26%	39%	55%	59%	71%	89%	86%	41%
BYD	6%	9%	13%	30%	39%	36%	62%	74%	79%	61%
Beijing Benz	48%	54%	77%	95%	100%	100%	100%	100%	100%	100%

Table 5-2. Turbocharger/supercharger adoption rate by OEM (ICE only)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
FAW Volkswagen	50%	49%	52%	55%	52%	55%	59%	72%	81%	97%
SAIC Volkswagen	43%	41%	38%	40%	35%	47%	52%	57%	57%	50%
SAIC GM	3%	9%	15%	28%	37%	51%	70%	85%	82%	97%
SAIC GM Wuling	0%	0%	0%	0%	6%	8%	11%	16%	17%	23%
Dongfeng Nissan	1%	0%	0%	0%	1%	0%	0%	1%	2%	17%
Chang'an	0%	1%	3%	8%	12%	35%	44%	52%	74%	75%
Geely	2%	8%	7%	9%	24%	36%	46%	60%	75%	80%
Beijing Hyundai	0%	1%	1%	8%	21%	26%	23%	30%	28%	8%
Great Wall	21%	45%	68%	81%	89%	97%	100%	100%	100%	100%
FAW Toyota	0%	0%	0%	1%	10%	36%	40%	38%	39%	39%
GAC Honda	0%	0%	0%	0%	1%	14%	30%	58%	60%	6%
BYD	6%	9%	13%	30%	39%	36%	62%	74%	79%	61%
Beijing Benz	58%	54%	75%	95%	100%	100%	100%	100%	100%	100%

Table 5-3. NEV adoption rate by OEM

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
FAW Volkswagen	0%	0%	0%	0%	0%	0%	0%	0%	1%	4%
SAIC Volkswagen	0%	0%	0%	0%	0%	0%	0%	2%	2%	4%
SAIC GM	0%	0%	0%	0%	0%	0%	0%	1%	1%	2%
SAIC GM Wuling	0%	0%	0%	0%	0%	1%	2%	4%	17%	37%
Dongfeng Nissan	0%	0%	0%	0%	0%	0%	0%	1%	1%	0%
Chang'an	0%	0%	0%	0%	0%	3%	4%	0%	3%	9%
Geely	0%	1%	3%	9%	5%	5%	4%	5%	3%	1%
Beijing Hyundai	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%
Great Wall	0%	0%	0%	0%	0%	0%	1%	4%	7%	13%
FAW Toyota	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%
GAC Honda	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
BYD	0%	0%	4%	13%	21%	25%	40%	45%	40%	73%
Beijing Benz	0%	0%	0%	0%	0%	0%	0%	0%	1%	2%

Table 5-4. Conventional hybrid (HEV) adoption rate by OEM (among ICE)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
FAW Volkswagen	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SAIC Volkswagen	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
SAIC GM	0%	0%	0%	0%	0%	0%	1%	1%	0%	0%
SAIC GM Wuling	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Dongfeng Nissan	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Chang'an	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Geely	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%
Beijing Hyundai	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Great Wall	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
FAW Toyota	0%	0%	0%	0%	6%	9%	11%	12%	15%	22%
GAC Honda	0%	0%	0%	0%	0%	2%	3%	8%	14%	15%
BYD	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Beijing Benz	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

6. TRENDS OF ICE POLLUTANT EMISSIONS AND CONTROL TECHNOLOGIES

This chapter explores the fleet-average emissions trends of regulated air pollutants carbon monoxide (CO), nitrogen oxides (NO_x), total hydrocarbon content (THC), and particulate matter (PM) **(Figure 6-1)**; the on-road NO_x emissions of China 6-compliant gasoline and diesel cars **(Figure 6-2)**; and the market penetration trends of advanced air pollutant emission control technologies **(Figure 6-3** and **Figure 6-4)** for ICE cars.

As **Figure 6-1** suggests, the **laboratory** emission intensities, as opposed to the relatively higher on-road emissions, of all four pollutants declined by about 30% (NO_x) to over 70% (PM) in the past decade. The deepest reduction in PM, CO, and THC occurred in 2019 when China announced the 6th stage of emission standards, the China 6 emission standard, and manufacturers began to certify their new models to it. One exception is the NO_x emissions trend, which tilts slightly upward after 2018. After further digging into the fine-level fleet data, the slight increase in certified, fleet-average NO_x level can be attributed to the increase in heavier light-duty vehicle classes that have more lenient emissions requirements.

The average on-road NO_x emission level of China 6 gasoline cars is currently in compliance with both the China 6a regulatory requirement, the first stage of the China 6 standard, effective from July 1, 2020 onward, and the China 6b requirement, which is to be enforced starting in mid 2023 after counting in the conformity factor of real driving emissions (RDE) testing. In addition, the average on-road NO_x emissions level of China 6 diesel cars is higher than that of gasoline cars, even though diesel cars are universally heavier and thus are subject to more lenient emission limits. Their on-road emissions level has also complied with even the China 6b RDE requirement **(Figure 6-2)**.

Figures 6-3 and **6-4** display the market trends of key emission control technologies for gasoline and diesel PCs, respectively. While three-way catalyst (TWC) is a full-fledged technology and has long been used in the gasoline car fleet, the gasoline particulate filter (GPF) is an emergent technology that has increased its presence in a remarkable way, from zero in 2017 to 60% in 2021; this was driven by the China 6 emissions requirements **(Figure 6-3)**. For diesel cars, exhaust gas recirculation (EGR) is mostly universally present. Diesel particulate filters (DPFs) and selective catalytic reduction (SCR) started to gain massive popularity in 2014 and 2018, respectively, and quickly became 100% adopted fleet-wide in 3–4 years. On the contrary, a formerly fully present technology, the diesel oxidation catalyst (DOC), has been seen less since 2018. As of 2021, less than 50% of diesel PCs used a DOC **(Figure 6-4)**.

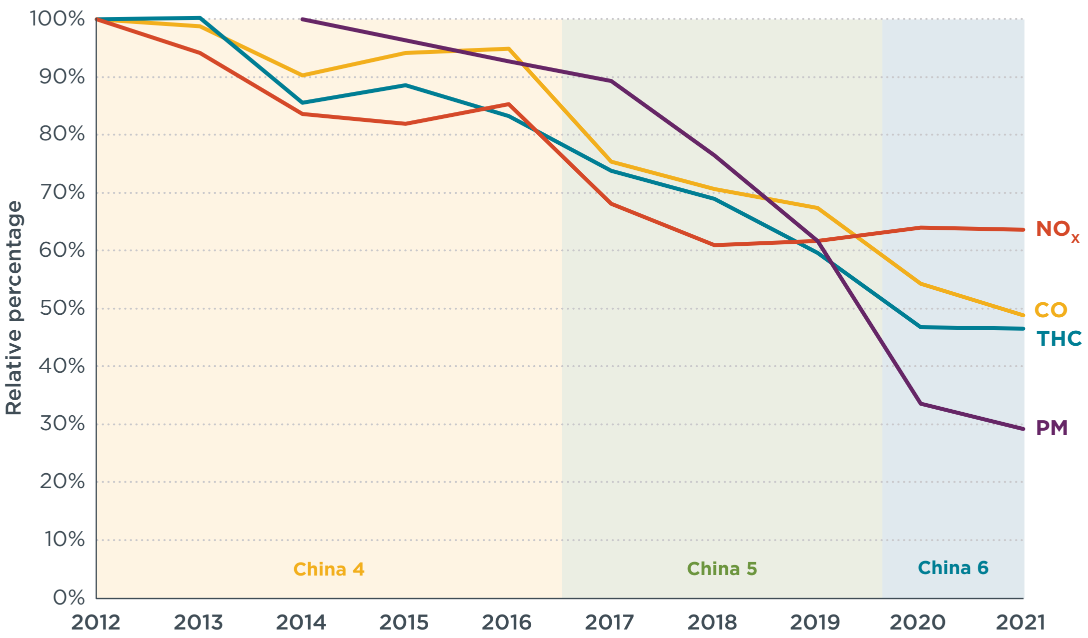


Figure 6-1. Sales-weighted fleet average emission rates of key air pollutants (gasoline cars only, normalized to 2012 level for CO, THC, and NO_x and to the 2014 level for PM, as 2014 is when the first regulatory limit for PM was implemented)

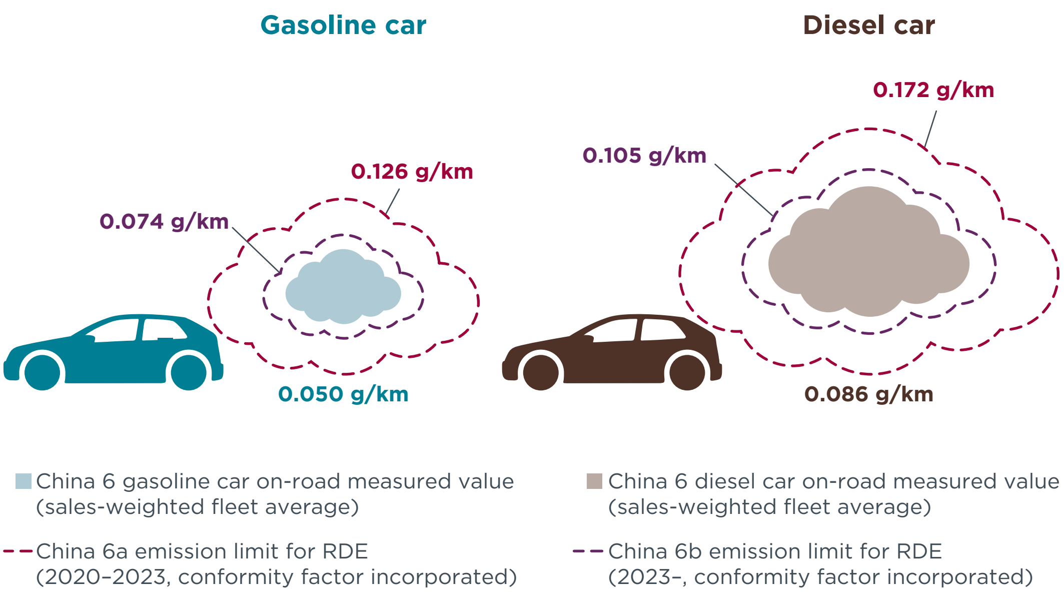


Figure 6-2. China 6 NO_x emission limits and average (sales-weighted) real-world NO_x emissions based on RDE

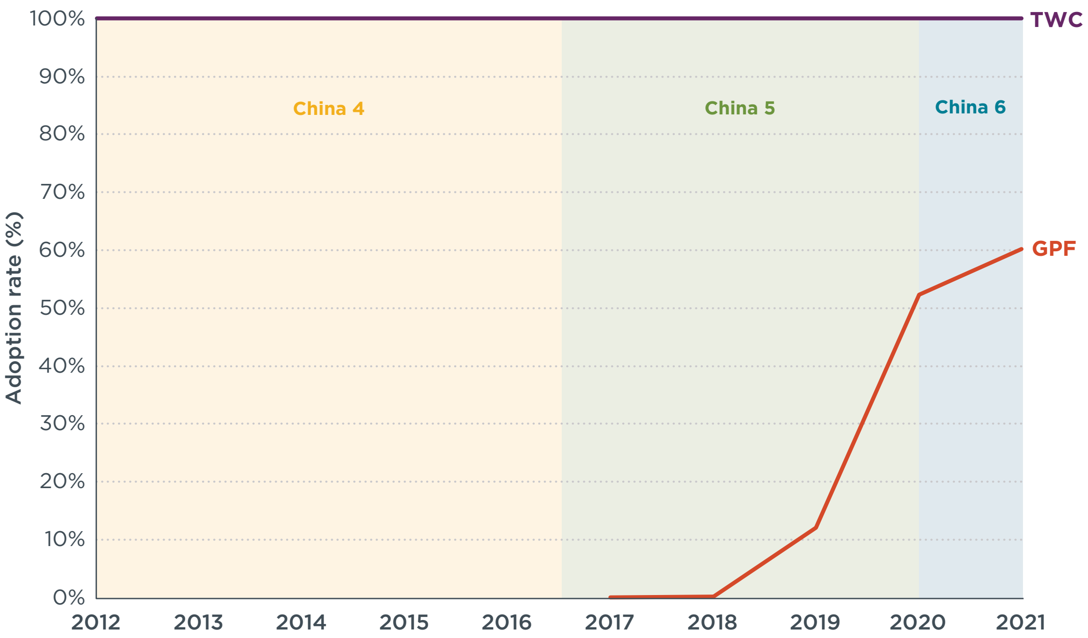


Figure 6-3. Adoption rates of emission control technologies in gasoline cars

* GPF adoption data are available starting from 2017.

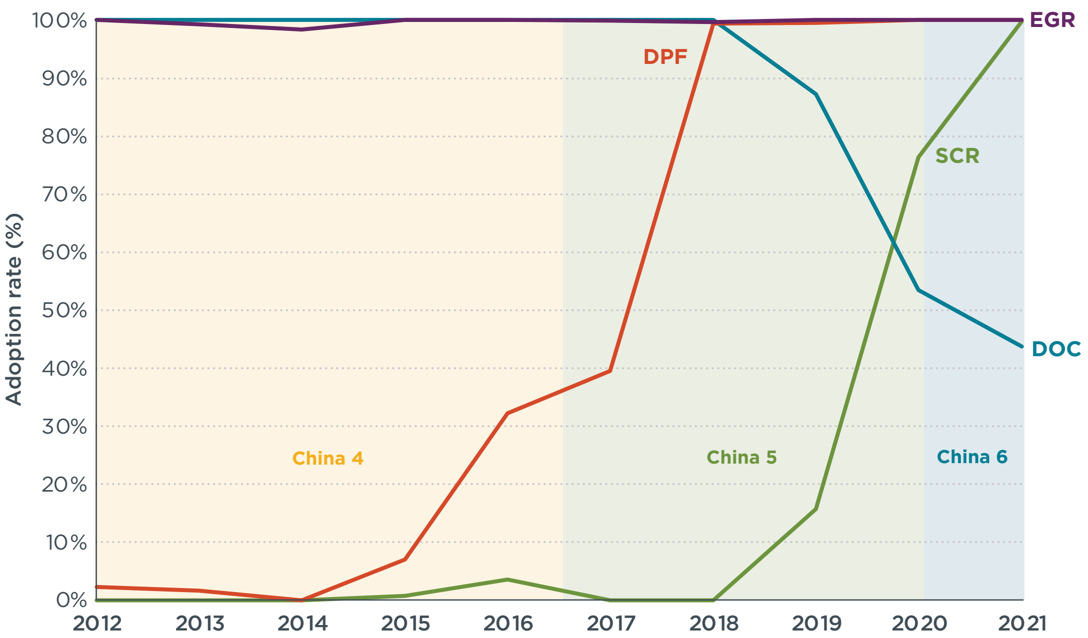


Figure 6-4. Adoption rates of emission control technologies in diesel cars

7. ANNEX

7.1. DATA SOURCES AND AVAILABILITY

This report used several independent data sets and analyses from the China Automotive Technology and Research Center (CATARC Co. Ltd), ZEDATA, China EV100, and Vehicle Emission Control Center (VECC) of the Chinese Research Academy of Environmental Sciences (CRAES). All data were further treated by the ICCT for consistency and quality control. The following tables detail the percentage of valid data by vehicle information/parameter and year.

Table 7-1. Data effective fill rate (fleet-level)

	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012
Sales	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Fuel type	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Segment	99.43%	98.86%	98.20%	96.57%	100.00%	99.94%	99.96%	99.98%	99.97%	100.00%
OEM	100.00%	99.89%	99.37%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Model	100.00%	99.67%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Variant*	100.00%	86.76%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Curb weight	100.00%	99.94%	100.00%	100.00%	99.96%	99.99%	99.95%	99.88%	99.37%	99.35%
Horsepower*	99.94%	99.91%	99.19%	99.89%	92.99%	98.05%	97.25%	96.39%	94.27%	92.26%
Engine displacement*	100.00%	99.94%	100.00%	100.00%	99.99%	99.23%	99.41%	99.65%	99.77%	99.90%
Wheel base	100.00%	100.00%	99.98%	100.00%	97.00%	99.06%	99.29%	99.47%	99.09%	99.24%
Wheel track*	74.35%	0.00%	86.93%	90.79%	97.00%	99.04%	99.27%	99.45%	99.06%	99.17%
Footprint*	74.35%	0.00%	86.93%	90.79%	97.00%	99.04%	99.27%	99.45%	99.06%	99.17%
Transmission type*	73.52%	96.58%	100.00%	90.79%	97.00%	99.07%	99.33%	99.54%	99.48%	99.54%
Number of gears*	73.35%	82.46%	86.93%	90.79%	96.42%	98.40%	98.59%	98.74%	98.29%	98.10%
Fuel supply*	72.93%	81.56%	86.93%	90.79%	97.00%	98.51%	98.41%	98.20%	96.82%	95.69%
Intake*	72.93%	81.43%	86.93%	90.79%	97.00%	98.56%	98.51%	98.35%	97.22%	96.27%
Cylinder arrangement*	73.54%	81.56%	86.93%	90.79%	97.00%	98.56%	98.51%	98.35%	97.22%	96.28%
Number of seats*	99.01%	97.10%	90.76%	90.79%	97.00%	99.07%	99.35%	99.60%	99.73%	99.89%
Drivetrain*†	97.52%	16.47%	100.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Fuel consumption*	97.16%	99.12%	96.80%	96.47%	95.74%	97.07%	96.73%	95.89%	92.84%	89.20%
CO_2 emissions*	97.16%	99.10%	96.80%	96.47%	95.74%	97.07%	96.73%	95.89%	92.84%	89.20%
Emission standard*	74.35%	98.22%	99.25%	87.43%	97.00%	98.88%	99.09%	99.21%	98.69%	98.60%

* The parameters with asterisks next to their names have effective fill rates lower than 95% at the fleet level (ICE+NEV) for one or more years. Their fill rates are further examined at the ICE-only level in Table 7-2. At the fleet-level, some low fill rates are due to the parameter itself, which might be applicable to ICE cars only; in other instances of low fill rates, we removed the analysis of that parameter for certain years, or analyzed the parameter only at the ICE level. The fill rates of pollution-related parameters used in Chapter 6 are separately shown in Table 7-3.

† For drivetrain, the data effective fill rate for 2009 is 100%, thus the related analysis used 2009 as the start year for a start-and-stop year analysis, instead of using 2012 (as in Figure 5-5 and Figure 5-7). The sales and OEM data for 2009 used to complete the same analysis also have effective fill rates of 100%.

Table 7-2. Data effective fill rate (ICE only)

	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012
Variant	100.00%	90.18%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Horsepower	100.00%	99.96%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Engine displacement	100.00%	99.93%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Wheel track	100.00%	0.00%	100.00%	100.00%	100.00%	99.97%	99.93%	100.00%	100.00%	100.00%
Footprint	100.00%	0.00%	100.00%	100.00%	100.00%	99.97%	99.93%	100.00%	100.00%	100.00%
Transmission type	98.88%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Number of gears	98.62%	81.51%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	98.21%
Fuel supply	98.09%	97.65%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Intake	98.09%	97.49%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Cylinder arrangement	98.09%	97.65%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Number of seats	99.52%	98.00%	90.07%	89.85%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Drivetrain	100.00%	0.00%	100.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Fuel consumption	96.28%	98.99%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
CO_2 emissions	96.28%	98.99%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Emission standard	100.00%	97.87%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Table 7-3. Pollution-related data effective fill rate (within applicable type of cars)

	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012
NO_x emissions	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
CO emissions	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
PM emissions	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	0.00%	0.00%
THC emissions	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
GPF (gasoline car)	100.00%	100.00%	100.00%	100.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%
TWC (gasoline car)	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
DPF (diesel car)	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
SCR (diesel car)	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
DOC (diesel car)	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
EGR (diesel car)	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

7.2. VEHICLE SEGMENT CLASSIFICATION

This report divides passenger cars into the following classes/segments: A00 (minicar), A0 (small), A (compact), B (medium), C (large and luxury), SUV, and Others. The SUV class includes sport utility cars that come in various sizes, from compact to luxury, and they were all originally labeled and marketed as SUVs. The "Others" class/segment includes MPVs, crossover vehicles, minibuses, and sports cars.

The segmentation in this report generally follows the raw segment label of each car model in the original dataset, which adheres to a combination of traditional, wheelbase-based industrial segmentation principles and consumer-oriented segmentation methods based on marketing. In the few cases of invalid or blank entries in the dataset, extra data cleaning and processing were conducted to determine the segment. Those models whose segment information was missing in the data and also not disclosed through any official or marketing channels were excluded from the segment-level analysis.

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