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EVALUATING ELECTRIC VEHICLE COSTS AND BENEFITS IN CHINA IN THE 2020–2035 TIME FRAME

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EXECUTIVE SUMMARY

As electric vehicles are produced in greater numbers around the world, per-unit costs decline and the prospects for a large-scale transition to electric vehicles improve. Governments in China, Europe, and North America all work to accelerate electric vehicle deployment to help meet air quality, climate change, oil security, and industrial development goals. China, the largest vehicle market in the world and also the largest electric vehicle market, continues to adapt its longer-term goals on vehicle electrification and adopt policies to accelerate electric vehicle uptake.

As electric vehicle technology improves dramatically, questions arise about how China's policies might evolve. Top policy questions are, How quickly will electric vehicle costs decline and reach price parity with conventional vehicles, and how great are the associated benefits? This paper analyzes declining battery costs and how these reduce electric vehicle prices across the major classes of China's passenger vehicle market through 2035. We analyze bottom-up vehicle component costs (including battery, powertrain, assembly) to evaluate electric vehicle costs, examine their associated consumer benefits by comparing the costs to those of gasoline vehicles, and assess the implications for China's New Energy Vehicle (NEV) regulations.

Figure ES-1 summarizes the findings for conventional gasoline and electric vehicle prices through 2035 in China's two highest-volume passenger vehicle classes, compact cars and sport utility vehicles. Conventional vehicles in these two classes are compared with battery electric vehicles (BEVs) with electric ranges of 250–500 kilometers (km) and plug-in hybrid electric vehicles (PHEVs) with ranges of 40–100 km. The upfront costs of electric vehicles are \$5,000 to \$17,000 higher than their gasoline counterparts in 2020. With declining electric vehicle battery and assembly costs, short-range BEVs are projected to reach price parity by 2026, and long-range BEVs reach this point around 2030.

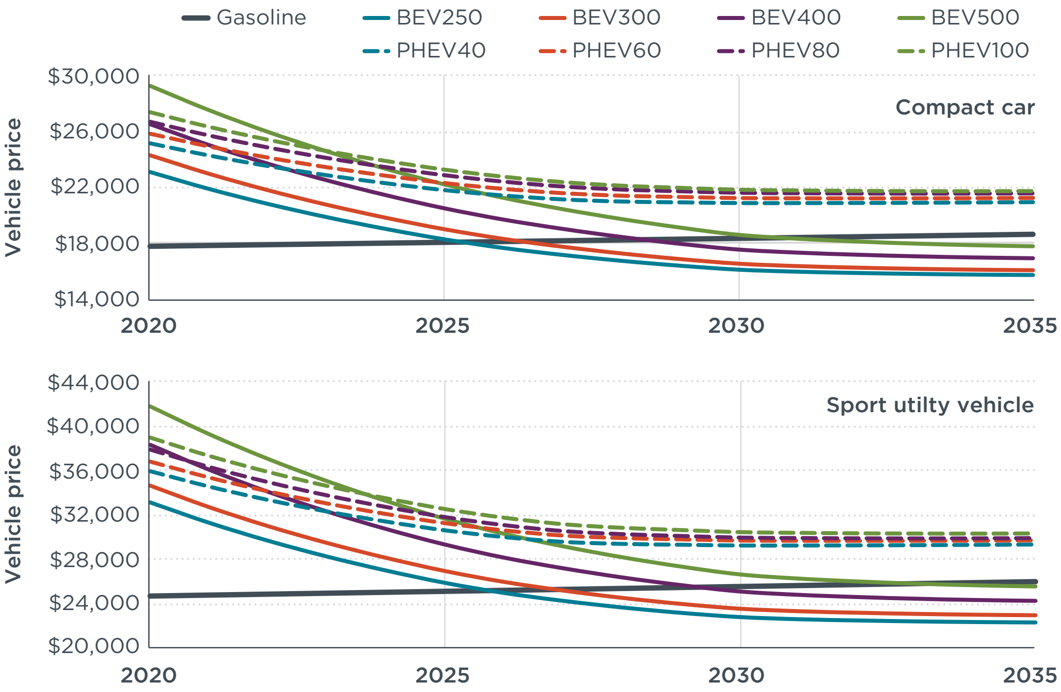

Figure ES-1. Conventional and electric vehicle prices of compact cars and sport utility vehicles in China for 2020–2035.

Our analysis leads us to three high-level conclusions.

Electric vehicle initial price parity is likely to be achieved within 5–10 years in China. With continuing technology and production scale advancements, battery pack costs are expected to drop from $130 per kilowatt-hour (kWh), or ¥0.90 per watt-hour (Wh), in 2020 to approximately $59/kWh (¥0.4/Wh) in 2030. Electric vehicle price parity with conventional cars and sport utility vehicles is likely to occur between 2026 and 2029 for mainstream battery electric vehicles with 300–400-km range. Shorter-range (250 km) electric vehicles reach parity faster, by 2025, but require more charging infrastructure, and for longer-range (500 km) vehicles, parity occurs in 2030 or later. If there is less progress toward technical goals in China (e.g., 12 kWh/100km vehicle efficiency and ¥0.4/Wh battery costs), price parity could be delayed by 1–3 years.

Well before initial vehicle price parity, electric vehicles deliver substantial cost savings to drivers in China. Cost-competitiveness for electric vehicle buyers in China is reached several years faster than initial vehicle price parity, based primarily on electric vehicles' fuel savings. Analysis of first-owners' 5-year vehicle ownership costs shows an attractive new vehicle purchase proposition for electric vehicles in 2022–2026. First owners of electric vehicles purchased in 2025 accrue fuel savings of $2,400 to $3,300 per vehicle for mainstream cars and sport utility vehicles, and electric vehicles' fuel and maintenance savings far outweigh home charger and other costs.

A widespread market transition to electric vehicles will have much broader benefits, and require greatly increased industry investments. When considering the full vehicle lifetime effects and a transition to 90% new electric vehicle sales by 2035, we find larger cost savings that can be experienced widely across drivers in China. Compared to China's current electrification targets, accelerating the electric transition over new 2024–2035 vehicles could result in approximately $445 billion (¥3 trillion) greater benefits to China's drivers. An accelerated transition involves increasing electric vehicle sales from less than 1 million in 2019 to more than 20 million per year by 2035, and the associated annual battery production would need to increase by at least a factor of 30.

These conclusions have several implications for policy. Despite clarity on declining electric vehicle costs and their benefits, the transition to all electric vehicles will not happen without sustained policy. Clear targets from the central government can spur many aligned government and industry actions. Longer-term regulations (e.g., NEV regulation and performance standards) are especially necessary to ensure industry investments, high-volume electric production, and broad electric model availability. Supporting actions like extending incentives, expanding charging infrastructure, and improving consumer awareness will help to overcome the various consumer barriers through the transition.

China, as the world's largest vehicle market and largest electric vehicle market, plays a special role globally. This work suggests China has an opportunity to continue to expand its electric vehicle production, and thus accelerate the time to reach electric vehicle cost parity. Additionally, as 100% zero-emission vehicle goals for 2030–2040 are set in Europe and North America, setting a similar target in China would ensure the country is on an accelerated path and can capture the associated benefits. Such a commitment would also signal to its domestic industry and global manufacturers that China will remain a world leader in electric vehicles and batteries.

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INTRODUCTION

The global electric vehicle market, although still in its early stages, has grown rapidly in recent years. The three regions of China, Europe, and North America accounted for 94% of the more than 10 million passenger vehicles sold globally through 2020, as shown in Figure 1 (based on EV-volumes, 2021). The figure clearly illustrates the large role China plays in global sales; China has accounted for 45% of cumulative electric sales through 2020, followed by 30% in Europe, and 19% in North America. The growth in electric vehicle sales, in China and elsewhere, has been the result of targeted policies to address barriers and grow the market to meet air quality, climate change, oil security, and industrial development goals. Increasingly, the scale in these markets is developing a global automotive supply chain for electric vehicles.

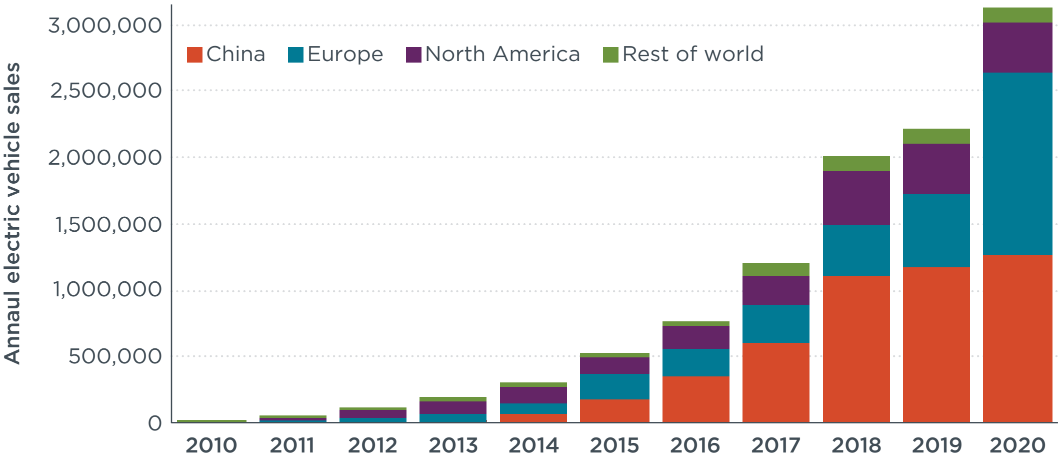

Figure 1. Global passenger electric vehicle sales, 2011 through 2020.

Regulations around the world that require increased electric vehicle production and sales are the foundational driver of electric vehicle model availability and increased sales volume. In China, home to many of the strongest regional electric vehicle markets globally, this was driven by new energy vehicle (NEV) regulations and complementary local policies (Cui, 2018; Hall, Cui, & Lutsey, 2020; Liu et al., 2020). NEV policies in China promote battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell electric vehicles.

There are also strong regulatory levers promoting electric vehicles elsewhere. One example is Europe's passenger vehicle carbon dioxide (CO_2) regulation, which includes zero- and low-emission vehicle benchmarks through 2030 (Mock, 2019). In addition, most electric vehicle sales in North America to date were in regions that adopted the zero-emission vehicle (ZEV) regulation, which requires electric vehicle sales to reach approximately 10% of new vehicle sales by 2025. Many regional governments in Europe and North America are also implementing policies for 100% sales of electric new vehicles within the 2030–2040 time frame (British Columbia Office of the Premier, 2018; Office of Governor Newsom, 2020; French Republic, 2019; Québec, 2020; United Kingdom, 2020).

Such targets and regulations signal to other governments and various industry stakeholders to, in turn, address other electric vehicle barriers. For example, reliable deployment of a large volume of electric vehicles requires investments upstream, in electric vehicle assembly plants and in automakers' battery supply chains. Greater electric vehicle sales volume also means greater electric vehicle model availability across vehicle classes and brands for consumers, and requires greater marketing effort by the automobile industry. Clarity on the expected scope of electric vehicle deployment would help quantify the exact need for public and private funding, for example for charging infrastructure (Slowik et al., 2019). City and regional governments can support a variety of incentives to promote the purchase and use of electric vehicles.

Automakers' electric vehicle plans are increasingly exceeding government goals. Collectively, automakers intend to sell over 20 million vehicles globally per year by 2025, up from the 2 million vehicle sales in 2019 (Slowik, Lutsey, & Hsu, 2020). Earlier electric vehicles were characterized by high development costs and were produced at low volume. The increase in volume into the tens of millions of units annually would mean the emergence of a competitive battery supply and production at scale. Five battery suppliers have already delivered batteries for at least 200,000 electric vehicles annually (Sharpe et al., 2020) and technology improvements continue, including chemistries that reduce the use of high-cost materials, increased material utilization to deliver higher production yield, increased energy density, and greatly increased scale (CATARC, 2019; Chung, Elgqvist, & Sannhanagopalan, 2016).

China's electric vehicle goals especially drive global electric vehicle volume. This is due to its market size, the interest it attracts from the global auto industry, and its dedicated policy efforts. China's first phase (2019–2020) of NEV regulations increased the electric share of new passenger vehicle sales from 4.5% in 2018 to 5.3% in 2019, and 6% in 2020 (Cui, Hall, & Lutsey, 2020; EV-volumes, 2021). China released its second phase of NEV regulations in June 2020, and this could increase the electric vehicle penetration to 10%–12% of new sales, or greater, by 2023 (Ministry of Industry and Information Technology [MIIT], 2020). China's official 2025 target, from the November 2020 State Council's New Energy Vehicle Industrial Development Plan 2021–2035, is to reach a 20% electric share of new vehicle sales in 2025 (China State Council, 2020). In addition, the recently released *Energy-saving and New Energy Vehicle Technology Roadmap 2.0*, prepared by Society of Automotive Engineering (SAE) China under the direction of MIIT, proposed unofficial new vehicle electric share targets of around 40% by 2030 and over 50% by 2035 (SAE China, 2020).

The pace of electrification in China and globally hinges on how quickly electric vehicle costs reduce. To address this question, this paper combines the best available battery and vehicle component cost data in a bottom-up analysis to project electric vehicle costs in China from 2020 through 2035. This study includes full BEVs and PHEVs, and assesses costs for various vehicle classes (e.g., car and sport utility vehicles) in the China passenger vehicle market. We examine vehicle manufacturing cost, vehicle price, and first-owner vehicle user costs, and then compare these to conventional vehicles to estimate when various electric vehicle types will reach parity with conventional vehicles. This paper also assesses how declining electric vehicle costs impact potential regulation costs and the full lifetime benefits of increased electric vehicle deployment in China through 2035.

ELECTRIC VEHICLE COST ANALYSIS

This section analyzes how battery cost reductions impact electric vehicle manufacturing costs and consumer prices, as compared with conventional gasoline vehicles, in the 2020–2035 time frame. Based on a detailed engineering analysis of electric vehicle component costs, overall BEV and PHEV costs in representative car, sport utility, and multi-purpose vehicle classes in China over time are analyzed. The vehicle cost analysis is generally based on the approach of our previous analyses (Lutsey & Nicholas, 2019a, 2019b), but includes updates for new research, data input, vehicle specifications, and vehicle classes for the China passenger vehicle market.

BATTERY PACK COSTS STUDIES

We incorporate the most recent estimates for battery pack production costs and future projections. For global costs, we apply research on the most recent, detailed, bottom-up technical studies of battery cost elements and overall battery pack costs. Several China-focused studies are used to incorporate differences in average China-based battery types and battery production, including lithium iron phosphate chemistries. Projections with explicit technical specifications for battery pack production (e.g., material, cell, pack costs; cost versus production volume; bottom-up cost engineering approach, etc.) and detailed automaker statements are included.

Several sources helped to characterize 2019 battery costs and technical specifications. Although different studies assessed the associated costs differently, this analysis refers to the battery pack cost incurred by a vehicle manufacturer, and therefore we include battery production cost and any associated indirect costs to the supplier. Based on global industry surveys, sales-weighted average battery pack-level costs were approximately $156 per kilowatt-hour (kWh) in 2019 and $137 per kWh in 2020 (Bloomberg New Energy Finance, 2020, 2021). U.S.- and Europe-based automaker battery packs in 2019–2020 averaged $175 per kWh with a pack-level energy density of 325–350 watt-hour per liter (Wh/L) and a specific energy density of 150–170 Wh per kilogram (Wh/kg) when produced for 100,000 electric vehicles per year (Anderman, 2019). These are consistent with announcements by automakers that are moving toward higher production volume. General Motors, Tesla, and Volkswagen indicated 2019–2021 cell-level battery costs of approximately $95–$110 per kWh (Davies, 2017; Ewing, 2019; P3, 2020; Witter, 2018).

Automotive lithium-ion batteries keep evolving with battery innovations in the cathode, anode, and cell design. In terms of the total battery capacity in new passenger electric vehicles sold globally in 2019, nickel-manganese-cobalt (NMC) accounted for over 60%, and nickel-cobalt-aluminum (NCA) technology, largely in Tesla vehicles, was about 30% (EV-volumes, 2021). Lithium-iron-phosphate (LFP) and lithium-manganese-oxide (LMO) were the next most prevalent, and LFP technology has largely been developed and deployed in China. There has been a general shift to more nickel and less manganese and cobalt (e.g., NMC111 to NMC611), and higher specific energy and energy density. NCA and NMC batteries are more typically used in longer-range vehicles, compared to more LFP in shorter-range vehicles with more frequent charging.

The above-mentioned state-of-the-art battery developments continue to advance in line with projections from the research literature. Incremental and next-generation NMC technologies can deliver greater specific cell energy (Wh/kg cathode or cell material), cell density (Wh/L), and cost ($/kWh). Schmuch et al. (2018) showed how, for example, higher-nickel cathodes with silicon-containing anodes can deliver 30%–75% Wh/kg improvement over the most prevalent 2019 NMC611. Berckmans et al. (2017) similarly showed how next-generation technologies decrease cost within NMC cathodes and a shift from graphite to graphite-silicon anode technology. Additionally, Li, Erickson, and Manthiram (2020) found continued lithium-ion advances from NMC, NCA, and increasingly higher-nickel cathode chemistries. Berckmans et al. (2017) and the P3 (2020) analysis of Tesla's October 2020 battery analysis both projected that high-volume production battery pack costs could reach approximately $50 per kWh in the 2025–2030 time frame.

China-specific electric vehicle battery pack cost data show similar developments, typically with lower costs than Europe- or U.S.-based sources. Data from many China-based sources (CAEV, 2020; CATARC, 2019; GGII, 2019; Ma, 2020; Miao, 2020; MIIT, 2017a, 2017b; National Advisory Committee for Manufacturing Power Strategy, 2018; Ren, Lian, & Guo, 2019; SAE China 2016, 2020; Shi, 2020; Su & Zou, 2020) are compared and included in this analysis of China-specific battery pack costs. Comparing all the various sources reveals a variety of important battery pack cost dynamics. For example, LFP technology is typically 10%–20% lower in cost per kWh than NMC and NCA. China battery pack costs, for a given battery chemistry and production volume, are typically 20% lower than U.S. and Europe estimates.

Future cost reduction projections from the various sources, and as applied here, rely on continued lithium-ion battery technology and manufacturing-level improvements. The changes include battery chemistry innovation (e.g., greater relative cathode nickel use, lower cathode cobalt use, shift to silicon-graphite anode mix, greater specific density) and a general increase from about 50,000 to 100,000 electric vehicle battery packs supplied annually in 2020 to about 500,000 and greater from 2025 on. The battery developments simultaneously target improved cost, density, safety, and durability. The projections applied in this analysis are based on continued innovations referenced above in similar NMC, NCA, and LFP technology, and do not require more fundamental breakthroughs (e.g., solid state, metal air). Although the trend toward more NMC and NCA (and chemistries that combine cobalt and aluminum in the cathode) is clear, more industry players in China keep improving LFP technology, accepting its somewhat lower density for its substantially lower cost.

Figure 2 summarizes the applicable data sources described above, including recent 2015–2020 data points from expert and automaker sources and 2020–2030 expert research projections. The data and sources are shown in the Appendix Table A1. Among the projections, the bold blue line in Figure 2 is the ICCT's previous 2019 U.S. battery pack estimate from Lutsey and Nicholas (2019a) with a 7% annual reduction ($152 to $74 per kWh over 2020–2030). The bold red line for 2020–2035 is China's BEV battery pack cost estimate for a nominal 50-kWh pack, declining from $123 to $58 per kWh; this is equivalent to a decline from ¥0.85 per Wh in 2020 to ¥0.40 per Wh in 2030, and to ¥0.35 per Wh in 2035, with an annual 7.3% reduction. The dashed black line, similar to our analysis for 2030–2035, is the battery pack estimate from SAE China's October 2020 *Energy-saving and New Energy Vehicle Technology Roadmap 2.0* (SAE China, 2020). The lowest cost dashed green line represents expert analysis of Tesla's latest announcements (P3, 2020) and provides a reasonable lower bound of cost for companies with lower-cost, high-volume battery manufacturing.

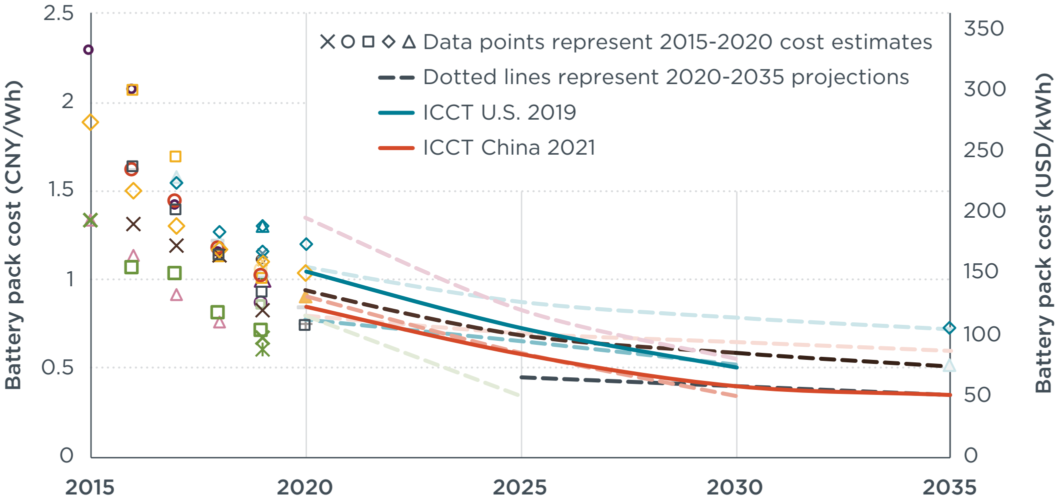

Figure 2. Battery pack cost for recent estimates (2015–2020) and forecasts (2020–2035) in Chinese yuan (left axis) and U.S. dollars (right axis).

We apply the China 2020–2030 trend in our analysis of electric vehicle cost, price, and consumer impacts below. China battery costs are approximately 20% lower than those applied in the 2019 U.S.-focused ICCT study. This is because China's manufacturing remains at higher production volume and lower material cost (e.g., with LFP and NCM811). Through 2019, about half of the world's electric vehicle and associated battery supply production was in China (Slowik et al., 2020). Eight of the world's top 15 automakers in electric vehicle production are based in China; examples are BAIC, BYD, SAIC, Geely, and Chery, each with over 65,000 vehicles produced in 2019 (EV-volumes, 2021). Most of the fastest-growing battery suppliers are in China, including China-based CATL, with its cells in 320,000 electric vehicles sold in 2019, and BYD, with its cells in at least 236,000 electric vehicles sold in 2019, as two of the top three global battery suppliers.

Several additional assumptions characterize costs for different vehicles' battery packs over time. Based on the research cited above, battery pack-level per-kWh costs tend to remain approximately 30%–40% higher than cell-level costs. Future modeling estimates have battery cell costs representing 73% of battery pack cost, with that fraction being higher for larger kWh packs, as assessed by Lutsey and Nicholas (2019a). While the results in Figure 2 are shown for a nominal 50-kWh pack, smaller packs have higher per-kWh cost and larger packs are lower. For example, our estimated average 2020 BEV 42-kWh battery pack costs $130 per kWh and ¥0.9 per Wh, which is somewhat higher than shown. For a future cost example, the 2025 battery pack cost for a 35-kWh pack in a 250-mile BEV car is $86 per kWh, compared to a 90-kWh pack in a 500-km BEV sport utility vehicle costing $83 per kWh. PHEV per-kWh costs are assumed to remain 40% higher than the shortest-range BEVs throughout the time frame of the analysis.

ELECTRIC VEHICLE MANUFACTURING COSTS

Electric vehicle manufacturing costs are estimated on a bottom-up vehicle component cost basis. These costs are determined for representative vehicle classes in the China new passenger vehicle market. The cost analysis applies the same approach as in Lutsey and Nicholas (2019a, 2019b), but with key China-specific data updates. The steps include initially quantifying the reference conventional vehicles and their technical specifications, and then estimating the detailed components for equivalent electric vehicles and their associated costs.

Table 1 summarizes the sales share and average technical specifications for 2019 China conventional vehicle sales across major passenger vehicle classes as applied in this analysis, based on data from China Automotive Technology and Research Center (CATARC, 2020). The reference vehicles shown exclude electric vehicles. As indicated, the market-leading vehicle classes are sport utility vehicles (44% of 2019 sales), compact car (32%), mid-size car (11%), and multi-purpose vehicles (6.7%), and small car (3.3%). The electric vehicle analysis below evaluates costs for those five highest-sales vehicle classes, while micro cars, large cars, and minivans, which together represent 3.7% of the 2019 market, were not analyzed. Average vehicle characteristics, including market share, rated engine power, curb mass, footprint, fuel consumption, and price, are used to define reference conventional vehicles. The fuel consumption values shown are official values from the New European Driving Cycle (NEDC). Adjustments for real-world fuel consumption are discussed further in the consumer valuation below. The prices shown include automaker profit, dealer mark-up, and value-added tax.

Table 1. Average characteristics for 2019 reference conventional vehicles.

Class[a]	2019 sales	2019 sales share	Power (kW)	Curb mass (kg)	Footprint (m²)	Efficiency[b] (L/100km)	Price (CNY)	Price[c] (USD)
Micro car	6,003	0.03%	70	954	3.33	5.31	¥45,700	$6,625
Small car	645,446	3.3%	81	1,087	3.77	5.36	¥79,000	$11,452
Compact car	6,208,489	32%	94	1,279	4.10	5.68	¥122,300	$17,728
Mid-size car	2,109,087	11%	134	1,547	4.51	6.21	¥230,900	$33,471
Large car	591,696	3.0%	171	1783	4.89	7.09	¥421,600	$61,115
Sport utility vehicle	8,635,998	44%	122	1,550	4.25	6.91	¥170,436	$24,706
Multi-purpose vehicle	1,314,314	6.7%	105	1,538	4.30	7.30	¥123,855	$17,954
Minivan	130,229	0.7%	68	1,118	3.72	6.44	¥40,300	$5,842
All classes	19,641,262	100.0%	108	1,398	4.09	6.21	¥149,556	$21,679

[a] Classes represent segments A00 for micro car, A0 for small car, A for compact car, B for mid-size car, C (and C-plus) for large car

[b] Fuel consumption L/100km in liters of gasoline per 100 kilometers on New European Driving Cycle

[c] CNY = Chinese Yuan (6.8985 CNY = 1.0 U.S. dollars); vehicle price includes value-added tax of 13%

Table 2 summarizes the electric vehicle specifications for 2020 and 2030 for four different electric ranges of BEVs and PHEVs, as matched with the same capabilities with the reference conventional vehicles. The technical specifications are based on official electric vehicle range and efficiency values from NEDC, and the battery pack size assumes that BEVs can use 90%, while PHEVs can use 80%, of the kWh. The lower assumed useable fraction for PHEV batteries is due to the higher-power-to-energy packs having restrictions for thermal management, durability, and safety reasons. Adjustments for real-world efficiency are discussed further in the consumer valuation below. Electric efficiency is assumed to improve at 1% annually due to electric component (battery, motor, power electronic) and vehicle-level (mass reduction, aerodynamic, and tire rolling resistance) improvements.

Table 2. Technical characteristics of electric vehicles for 2020 and 2030.

	Vehicle class[a]	Year	Fuel consumption (L/100km)[b]	Electric range (km)[c]				Efficiency (kWh/km)[c]				Battery pack[d] (kWh)			
				Short	Short mid	Long mid	Long	Short	Short mid	Long mid	Long	Short	Short mid	Long mid	Long
Battery electric vehicle (BEV)	**Small car**	2020	—	250	300	400	500	0.119	0.121	0.127	0.127	33	40	56	71
		2030	—	250	300	400	500	0.108	0.109	0.115	0.115	30	36	51	64
	Compact car	2020	—	250	300	400	500	0.130	0.130	0.131	0.134	36	43	58	74
		2030	—	250	300	400	500	0.117	0.118	0.118	0.121	33	39	53	67
	Mid-size car	2020	—	250	300	400	500	0.142	0.143	0.143	0.146	39	48	63	81
		2030	—	250	300	400	500	0.128	0.129	0.129	0.132	36	43	57	73
	Sport utility vehicle	2020	—	250	300	400	500	0.146	0.150	0.157	0.165	41	50	70	92
		2030	—	250	300	400	500	0.132	0.136	0.142	0.149	37	45	63	83
	Multi-purpose vehicle	2020	—	250	300	400	500	0.145	0.149	0.156	0.163	40	50	69	91
		2030	—	250	300	400	500	0.131	0.135	0.141	0.148	36	45	63	82
Plug-in hybrid electric vehicle (PHEV)	**Small car**	2020	4.28	40	60	80	100	0.131	0.132	0.133	0.134	6.5	9.9	13.3	16.8
		2030	4.17	40	60	80	100	0.118	0.119	0.120	0.121	5.9	8.9	12.0	15.2
	Compact car	2020	4.53	40	60	80	100	0.140	0.140	0.140	0.140	7.0	10.5	14.0	17.5
		2030	4.42	40	60	80	100	0.126	0.127	0.127	0.127	6.3	9.5	12.7	15.8
	Mid-size car	2020	4.96	40	60	80	100	0.153	0.153	0.153	0.153	7.6	11.5	15.3	19.1
		2030	4.83	40	60	80	100	0.138	0.138	0.138	0.138	6.9	10.4	13.8	17.3
	Sport utility vehicle	2020	5.52	40	60	80	100	0.170	0.171	0.173	0.174	8.5	12.8	17.3	21.8
		2030	5.38	40	60	80	100	0.153	0.155	0.156	0.157	7.7	11.6	15.6	19.7
	Multi-purpose vehicle	2020	5.82	40	60	80	100	0.168	0.170	0.171	0.173	8.4	12.7	17.1	21.6
		2030	5.68	40	60	80	100	0.152	0.154	0.155	0.156	7.6	11.5	15.5	19.5

[a] Classes represent segments A0 for small car, A for compact car, B for mid-size car

[b] PHEV fuel consumption is 20% lower than conventional vehicles, applies to assumed fraction of kilometers gasoline fueled; PHEV electric kilometer fraction determined by utility factor (Ministry of Ecology and Environment, 2016)

[c] Range, electric efficiency, and PHEV fuel consumption are based on New European Driving Cycle (NEDC)

[d] Battery pack is based on range, electric efficiency, and useable fraction of battery pack (90% BEV, 80% PHEV)

Conventional vehicle efficiency improvements and the associated cost increases are modeled based on Yang and Cui (2020) as follows. From the 2019 reference vehicles in Table 1, the assumed powertrain and vehicle improvements in each of the five vehicle classes reduce fuel consumption 3% annually, with a 0.3% annual cost increase, through 2035. This is based on these vehicles contributing toward achievement of the fleetwide 3.2 L/100km in 2030 efficiency target and approximately matches the Yang and Cui (2020) scenarios for 20% to 30% electric vehicles in 2030.

In this analysis, our conventional gasoline vehicle fleet improves from 6.2 L/100km in 2019 to 4.4 L/100km in 2030 on the NEDC test cycle, while seeing a ¥3,732 ($541) price increase. For an example among the vehicle classes analyzed, the average conventional sport utility vehicle is estimated to reach 4.9 L/100km in 2030 from 6.9 L/100km in 2019, with an incremental cost of ¥4,038 ($585) over 2019. Energy consumption is presented in test-cycle NEDC values, and consumer real-world per-kilometer fuel and electricity consumption values for conventional, PHEV, and BEV are assumed to be 34% higher than the test cycle efficiency values (Yang & Yang, 2018).

Several related factors are applied in the consumer annual driving and energy use estimates. An electric vehicle's annual electric driving is defined by a utility factor (UF). The UF for PHEVs is the fraction of annual kilometers powered by electricity, based on a mathematical function to reflect average driving patterns (Ministry of Ecology and Environment, 2016). After applying our real-world adjustment for 34% higher per-kilometer energy consumption than NEDC test cycle values, we apply real-world consumer UF values of 0.34 for PHEV40 (i.e., 34% of annual kilometers are electric for a PHEV with 40-kilometer NEDC range and a 30-kilometer real-world electric range), 0.49 for PHEV60, 0.61 for PHEV80, and 0.70 for PHEV100. The remaining annual kilometers of PHEVs powered by gasoline are assumed to be with 20% lower L/100km fuel consumption than conventional vehicles of the same model year.

Other vehicle costs, beyond the battery pack, are calculated based on a vehicle teardown study completed by UBS (2017). The UBS study estimated 2017 and 2025 costs for the all-electric Chevrolet Bolt and conventional Volkswagen Golf, which would typically be classified as compact cars (A-class) in China (and C-segment in Europe). Several adjustments are applied to adapt those costs to the China vehicle characteristics shown in Table 1 and Table 2. Based on comparable conventional vehicle costs, China-manufactured powertrain costs are estimated to be 20% lower than those from the previous U.S.-based analysis. The 2017 dollars for the UBS costs are adjusted to 2019 dollars by a 1.04 inflator. Powertrain costs are scaled to rated power, and vehicle assembly costs are scaled to vehicle size as in Lutsey and Nicholas (2019a).

Figure 3 shows vehicle manufacturing costs for the electric and conventional compact car class of four different BEV ranges (250, 300, 400, and 500 km) and PHEV ranges (40, 60, 80, and 100 km). These costs exclude automaker profit, dealer mark-up, and taxes. Costs are shown for the reference year 2019 and future estimates for 2025 and 2030. In 2019, compared to conventional gasoline vehicles at $13,400, BEVs are more expensive by $5,100 to $10,100, primarily due to higher battery and indirect costs. By 2025, conventional vehicle costs rise slightly to $13,600. BEVs in 2025 are between $13,800 and $16,700, and PHEVs are $16,500 to $17,600, depending on electric range. By 2030, the cost to manufacture conventional vehicles rises to approximately $13,800 and electric vehicles, across BEV and PHEV electric ranges, are estimated to be $12,100 to $16,500.

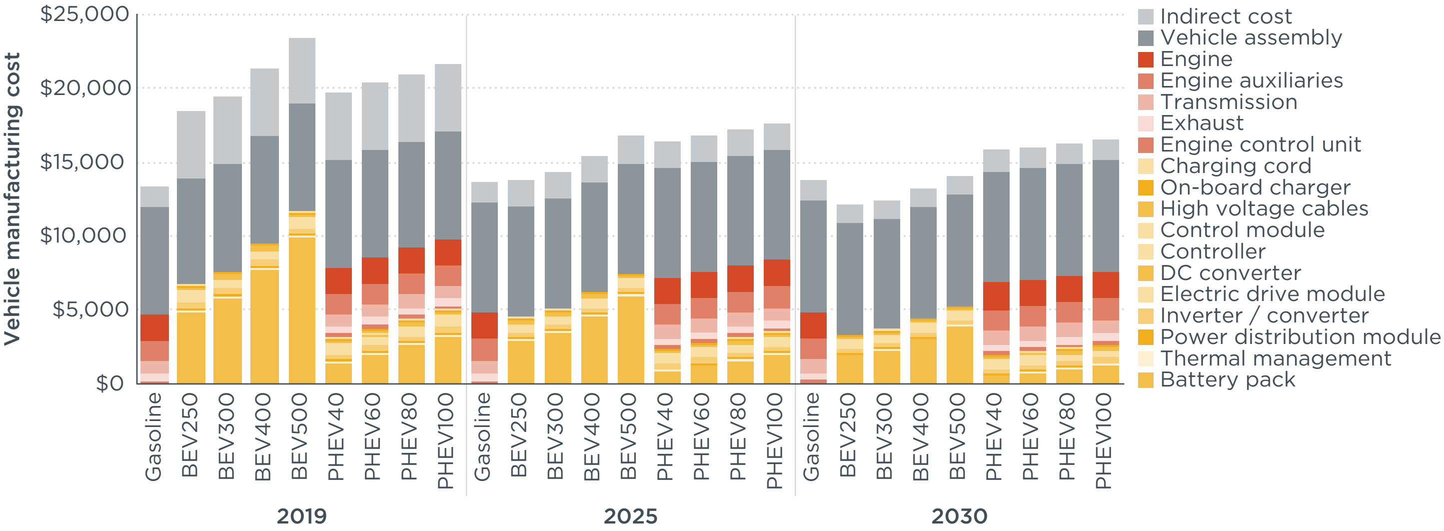

Figure 3. Vehicle manufacturing costs for compact cars in 2019, 2025, and 2030

As shown in Figure 3, the largest electric vehicle cost decreases from 2019 to 2025–2030 are in batteries and indirect costs. Automakers reduce indirect costs, including those related to research and development, depreciation, and amortized costs, from electric vehicle investments by spreading the cost over more vehicles and improving their manufacturing process. For a BEV, per-vehicle indirect costs drop from $4,500 in 2019 to $1,200 in 2030, and this is lower than $1,400 for conventional vehicles. Battery costs for a BEV300 are reduced from $5,800 in 2019 to $2,300 in 2030; BEV500 battery costs decrease from $9,900 in 2019 to $3,900 in 2030, a 61% drop. Non-battery electric powertrain costs see a 21% cost reduction from approximately $1,800 in 2019 to $1,400 in 2030. Cost reductions by 2030 for PHEVs, which have smaller batteries and retain conventional powertrains, are less dramatic than BEVs.

ELECTRIC VEHICLE PRICES

The vehicle manufacturing cost analysis is used to estimate future vehicle prices by technology and electric range. Vehicle price is distinguished from the vehicle manufacturing costs shown in Figure 3 due to two additional factors: automaker profit and dealer markup. In matching the bottom-up vehicle manufacturing costs (e.g., Figure 3) with the vehicle prices for each class (Table 1), an average of 10% automaker profit on manufacturing cost and a 10% dealer markup on manufacturing cost plus automaker profit are applied.

Cost-to-price markup factors vary across vehicle classes. For example, there are lower mark-ups for compact cars (6% profit, 6% dealer) and higher for sport utility vehicles (11% profit, 12% dealer). Treating both conventional and electric vehicles with such adjustments ensures consistent margins are built into each vehicle, and these factors do not impact the electric vehicle price parity timing. A 13% value-added tax is also included after automaker profit and dealer markup to arrive at the initial vehicle retail price. In addition, an excise tax that is imposed on manufacturers, weighted according to engine size (3% small car; 5% compact, sport utility, and multi-purpose vehicle; and 9% large car) is included. These taxes are included on all vehicles in order to focus the analysis on the change in technology costs between 2025 and 2035, without electric vehicles having any tax or incentive advantage. In the case of electric vehicles having lower future costs than conventional vehicles, this analysis assumes that this is provided as a lower price to consumers. Alternatively, automakers could choose to take this electric vehicle cost advantage as additional profit.

Figure 4 shows the vehicle prices by technology for five vehicle classes. From top to bottom are the results for the small car, compact car, mid-size car, sport utility vehicle, and multi-purpose vehicle. The black lines correspond to the conventional gasoline vehicle prices, which rise slightly to comply with increasing vehicle regulations. BEVs experience substantial cost reductions from 2020 to 2035, as described above. The blue, red, purple, and green lines correspond shortest to longest range BEVs (e.g., BEV250 for 250 km to BEV500 for 500 km). The shorter-range 250- and 300-km BEVs typically see price parity around 2025–2027, as compared to longer-range 400-km and 500-km BEVs with larger batteries more typically reaching parity around 2027–2031. The 40- to 100-km range PHEVs, marked with dotted lines, tend to have lower prices than BEV500s through 2023–2025, but have the highest prices in the long run.

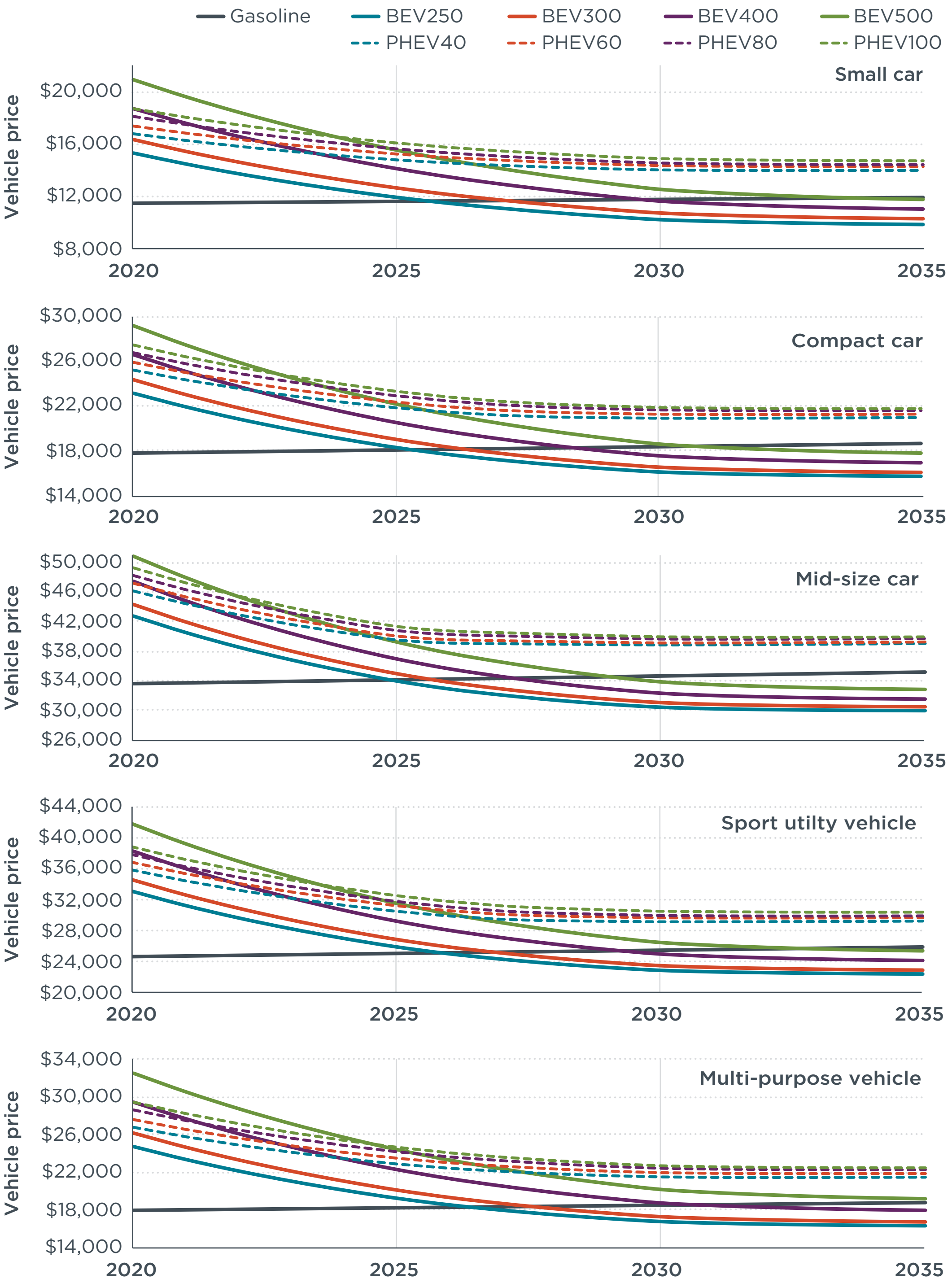

Figure 4. Initial price of conventional and electric vehicles in five vehicle classes for 2020–2035.

As illustrated in Figure 4, the BEVs' reduced prices bring price parity with conventional gasoline vehicles in the 2025–2035 time frame, but the timing varies by electric range and vehicle class. The BEV250 vehicles achieve price parity soonest, crossing the conventional gasoline vehicle price threshold by around 2025 for compact and mid-size cars, and by 2026 for small cars, sport utility vehicles, and multi-purpose vehicles. The longer-range BEVs achieve price parity later. The BEV400 compact and mid-size cars reach price parity in 2027–2028, followed by BEV400 sport utility vehicles, small cars, and multi-purpose vehicles in 2029–2030. For BEV500s, mid-size cars reach parity by 2029, but other BEV500 vehicles reach parity by 2031 or later. Relatively less-expensive vehicle classes (e.g., small cars, less expensive than compact and mid-size cars; and multi-purpose vehicles, which are substantially less expensive than sport utility vehicles) are slightly slower to reach parity, as their batteries and powertrains are a smaller percentage of the overall vehicle cost.

These results reveal several aspects about parity, range, and vehicle class. Within each class, longer-range BEVs' larger battery packs add substantial costs over the shorter-range BEVs. For example, a compact car buyer in 2026 can, for the first time, purchase a 250-km BEV that is less expensive than a conventional gasoline car. However, if that prospective buyer was concerned about charging infrastructure, they could pay $3,600 more for a 500-km BEV or $3,800 more 40-km PHEV. Similarly, a sport utility vehicle buyer in 2026 can purchase a 250-km BEV at less cost than a comparable gasoline version, or pay $5,300 more for a 500-km BEV or $4,900 more for a 60-km PHEV. In both cases, vehicle buyers can essentially choose price parity with a shorter-range BEV, or pay approximately 20% more for a long-range BEV or a PHEV. Thus for consumers the choice is between the lower-cost, shorter-range BEVs versus long-range BEVs or PHEVs with greater charging convenience but also higher cost.

Plug-in hybrid electric vehicles with 40 km (PHEV40) to 100 km (PHEV100) of electric range are also shown in Figure 4. The PHEV price differential versus conventional gasoline vehicles is reduced by 2030, but there are no price parity points with conventional vehicles. The PHEV prices range from $1,600 to $5,400 higher than conventional gasoline vehicles by 2030. The PHEV40 compact car price differential with conventional vehicles declines from $7,300 in 2020 to $3,800 in 2025. For an example of a larger vehicle class and larger pack, the PHEV40 sport utility vehicle cost differential drops from $11,100 in 2020 to $5,400 in 2025. PHEVs do not reach price parity like the BEVs because the battery pack—where there are large price reductions—is a much lower contributor to the PHEV price and because the PHEV retains the combustion powertrain.

These findings were tested for their sensitivity to two key vehicle technology factors: Annual electric vehicle energy consumption improvement and annual battery cost reductions. As compared to the central case with a 1% annual improvement, a lower value of 0%, reflecting efficiency improvements that are offset by increasing vehicle weight and size within the vehicle class, and a higher value of 2%, reflecting greater pressure to improve efficiency, are assessed. Compared to our central case annual battery cost reduction of 7%, a lower annual reduction of 5%, reflecting slowing innovation and production scale up, and a higher annual price reduction of 9%, reflecting greater battery breakthroughs, are assessed.

Table 3 summarizes how the year of electric vehicle price parity with conventional vehicles varies with lesser or greater improvements in electric vehicle efficiency and varying battery cost reduction. The central case reflects the findings as shown in Figure 4 above, and the lower and higher cases reflecting the effect of electric efficiency and battery cost reduction are shown for 300-km and 400-km battery electric compact cars and sport utility vehicles. As shown, if there is no electric vehicle efficiency improvement within each vehicle class, electric vehicle price parity is delayed 0.4 years (BEV300) to 0.9–1.1 years (BEV400). Meanwhile, doubling the annual efficiency improvement from 1% to 2% accelerates the year of price parity by 0.4 to 0.8 years. Additionally, slower annual battery cost decline—5%, instead of 7% in the central case—delays price parity by 1.3 years (BEV300) to 2.5–3.4 years (BEV400). Faster annual battery cost decline of 9%, meanwhile, accelerates price parity by 0.7 to 1.2 years.

Table 3. Battery electric vehicle price parity year for varied vehicle efficiency and battery cost.

	Battery electric vehicle (300 km)					Battery electric vehicle (400 km)				
	Central case	**Lower efficiency**	**Higher efficiency**	**Higher battery cost**	**Lower battery cost**	**Central case**	**Lower efficiency**	**Higher efficiency**	**Higher battery cost**	**Lower battery cost**
Compact car	2026.3	2026.8	2025.9	2027.7	2025.7	2028.4	2029.3	2027.7	2030.9	2027.3
Sport utility vehicle	2026.9	2027.4	2026.4	2028.2	2026.2	2029.2	2030.3	2028.5	2032.6	2028.0
Change in year of electric vehicle price parity from central case due to change in variable										
Compact car	-	+0.5	-0.4	+1.3	-0.7	-	+0.9	-0.7	+2.5	-1.1
Sport utility vehicle	-	+0.5	-0.4	+1.3	-0.7	-	+1.1	-0.8	+3.4	-1.2

The results in Table 3 reinforce how price parity in major vehicle classes is expected to be reached in the 2025—2030 time frame, and it provides additional insight into two key parameters that are closely tracked in China. The electric vehicle efficiency goal from the *New Energy Vehicle Industrial Development Plan 2021–2035* is 12 kWh/100km (China State Council, 2020). Based on the new electric vehicle market moving to larger vehicle classes, as analyzed in the fleet analysis below, achieving a minimum annual kWh/100km improvement of 1%–2% within each vehicle class will be needed to meet that 12 kWh/100km goal for passenger vehicles. This paper's central analysis has battery costs reaching ¥0.4/Wh in 2030, approximately matching the targets of the *New Energy Vehicle Technology Roadmap 2.0* (SAE China, 2020). Higher battery cost (¥0.52/Wh in 2030), as shown in Table 3, results in price parity being delayed by 1–3 years. This underscores the importance of continued improvements in electric vehicle efficiency and battery pack costs in accelerating the transition to price parity.

VEHICLE OWNERSHIP COST ASSESSMENT

Building from the vehicle technology differences presented above, technologies are compared by their first-owner cost-competitiveness and projected consumer lifetime net benefits. The first-owner cost-competitiveness, including the relative fuel and maintenance costs of owning and operating electric vehicles, is important from a car buyer's perspective. The lifetime consumer benefits over the full expected vehicle life include the time in the used car market and provide an important input from a public policy perspective. Electric vehicle subsidies and tax benefits (e.g., central, regional, and local government incentives and tax breaks) are excluded from the analysis to provide a technology-neutral comparison of their costs and benefits. After describing the applicable assumptions for average new vehicle drivers in China, we analyze these two consumer perspectives.

VEHICLE AND FUEL COST ASSUMPTIONS

Vehicle and fuel cost assumptions follow the approach of Lutsey and Nicholas (2019a, 2019b) with updates based on China-specific data. In addition to the value added and excise taxes included above, a 10% vehicle purchase tax is included for all vehicles. Although electric vehicles in 2020 are eligible for an exemption of this purchase tax, the tax is included for a consistent comparison in the absence of technology-specific incentives. Other existing central, regional, and local electric vehicle incentives and tax breaks are similarly excluded to independently assess the technology cost differences. The retail gasoline price is held constant at ¥6.8/L ($0.99/L) due to uncertainty and the potential for future shifts in either direction. Electric vehicle charging is assumed to be done half at home at ¥0.52/kWh ($0.075/kWh) and half via public charging at ¥1.5/kWh ($0.217/kWh). The higher cost for public charging reflects charging service fees and the typically higher costs for direct current fast charging. To assess future-year fuel expenditures for consumers, we assume a discount rate of 5% in net present value accounting. Five years of ownership for the first owner of the vehicle, and a median 15-year vehicle life for vehicle lifetime accounting, are assumed.

As for maintenance costs, conventional gasoline vehicle costs are assumed to scale with vehicle price, for example from $0.03 per kilometer for small cars to $0.06 per kilometer for larger cars and sport utility vehicles. Associated BEV costs are assumed to be 50% lower based on two sources (UBS, 2017; New York City, 2019). PHEV per-kilometer maintenance costs are assumed to be the midpoint between the conventional and BEV costs for each vehicle class, as operating on the battery means they experience part of the reduction of engine use and brake wear as compared to conventional vehicles.

For vehicle driving activity, average annual vehicle travel is estimated to be 14,000 km (Ou et al., 2019). To apply this to vehicle operation, vehicles start at 18,344 km in the first year and decline at approximately 4% annually, such that the median 15-year vehicle life reaches 210,000 km. The same UF function as applied to PHEVs above is used in the BEV consumer valuation. This results in UFs of 0.94 for BEV250 up to 1.00 for BEV500. Where the remaining PHEV non-electric driving is powered by the PHEV combustion powertrain, the non-electric BEV driving is by a "replacement" vehicle (e.g., separate household vehicle or ride-hailing vehicle). BEV replacement kilometers are based on the conventional gasoline vehicle operating cost from this analysis (e.g., $0.22/km for the small car and $0.55/km for the mid-sized car in 2020).

Electric vehicles have additional ownership costs due to their charging needs. Home charger costs of $600 in 2020 (reducing to $400 in 2030) for BEVs and $200 in 2020 (reducing to $160 in 2030) for PHEVs are included to enable more convenient residential charging. These estimated costs are based on findings that indicate lower home charging needs for PHEVs than BEVs (Nicholas, 2019). These BEV home charging costs account for the capital equipment and installation costs, including expected cost reductions over time due to higher production. The value of drivers' time saved due to electric vehicles' use of convenient at-home charging is excluded. Although the cost of all charging in cost-per-kWh are included, any costs for public charging infrastructure that are not passed on to drivers in that rate are excluded.

FIRST-OWNER ELECTRIC VEHICLE COST OF OWNERSHIP

Figure 5 shows the vehicle ownership costs for the first owner of the new conventional, BEV, and PHEV for two classes—compact cars (top) and sport utility vehicles (bottom). As shown above in Table 1, these two classes represent over three-quarters of China's 2019 conventional passenger vehicle sales with 6.2 million (32%) and 8.6 million (44%), respectively. The costs include vehicle manufacturing, profit margin, dealer markup, charging equipment, fueling, maintenance, and purchase tax. In addition, the applicable vehicle replacement for BEVs from 250- to 500-km electric range. The figure shows the 5-year ownership costs for a 2019 reference vehicle and comparable new vehicles in 2025 and 2030. The electric vehicle manufacturing costs, as already indicated above (Figure 3, Figure 4), have the largest cost change over time, primarily due to lower-cost batteries.

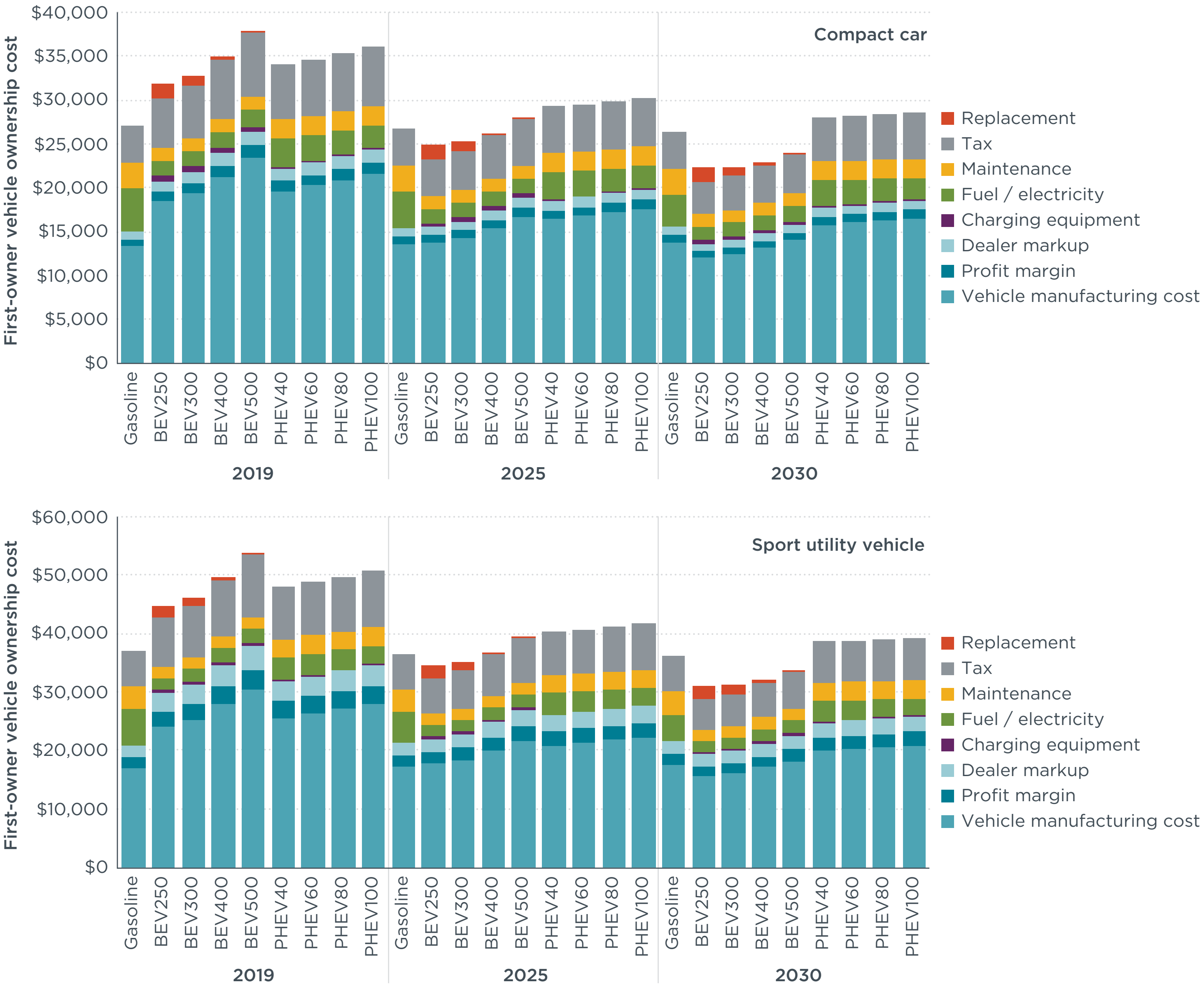

Figure 5. First-owner vehicle ownership costs for compact car (top) and sport utility vehicle (bottom) for 2019, 2025, and 2030.

As shown in Figure 5, the relative electric versus conventional gasoline vehicle ownership costs are similar for the car and sport utility cases, though the sport utility vehicle costs are higher. In both cases, the timing of cost parity for electric vehicle owners is similar. From 2025 on, BEVs have lower ownership costs than for their conventional vehicle counterparts in 13 of the 16 of the BEV cases (BEV compact cars up to 400-km and BEV sport utility vehicles up to 300-km in 2025; and BEVs of all ranges in 2030). For example, the 400-km BEV compact car ownership costs are $480 less, and the 300-km BEV sport utility vehicle costs are $1,400 less, than the comparable gasoline versions in 2025. PHEVs do not reach parity in either the compact car or sport utility vehicle. PHEVs reach within $1,600 to $3,000 of ownership cost parity by 2030 for the compact cars and sport utility vehicles.

Figure 6 shows the total 5-year vehicle ownership cost *differences* between electric and conventional vehicles, again for the compact car (top) and sport utility vehicle (bottom) classes. The figure shows the difference between each of the four BEVs and four PHEVs as compared to conventional vehicles in 2019, 2025, and 2030. The overall net effect of all the cost factors is shown with the white diamonds. A positive number represents a benefit to an electric vehicle owner, and a negative means an additional cost to consumers. Vehicle technology price differences are the dominant factor in 2019, when electric vehicles are more expensive than conventional vehicles.

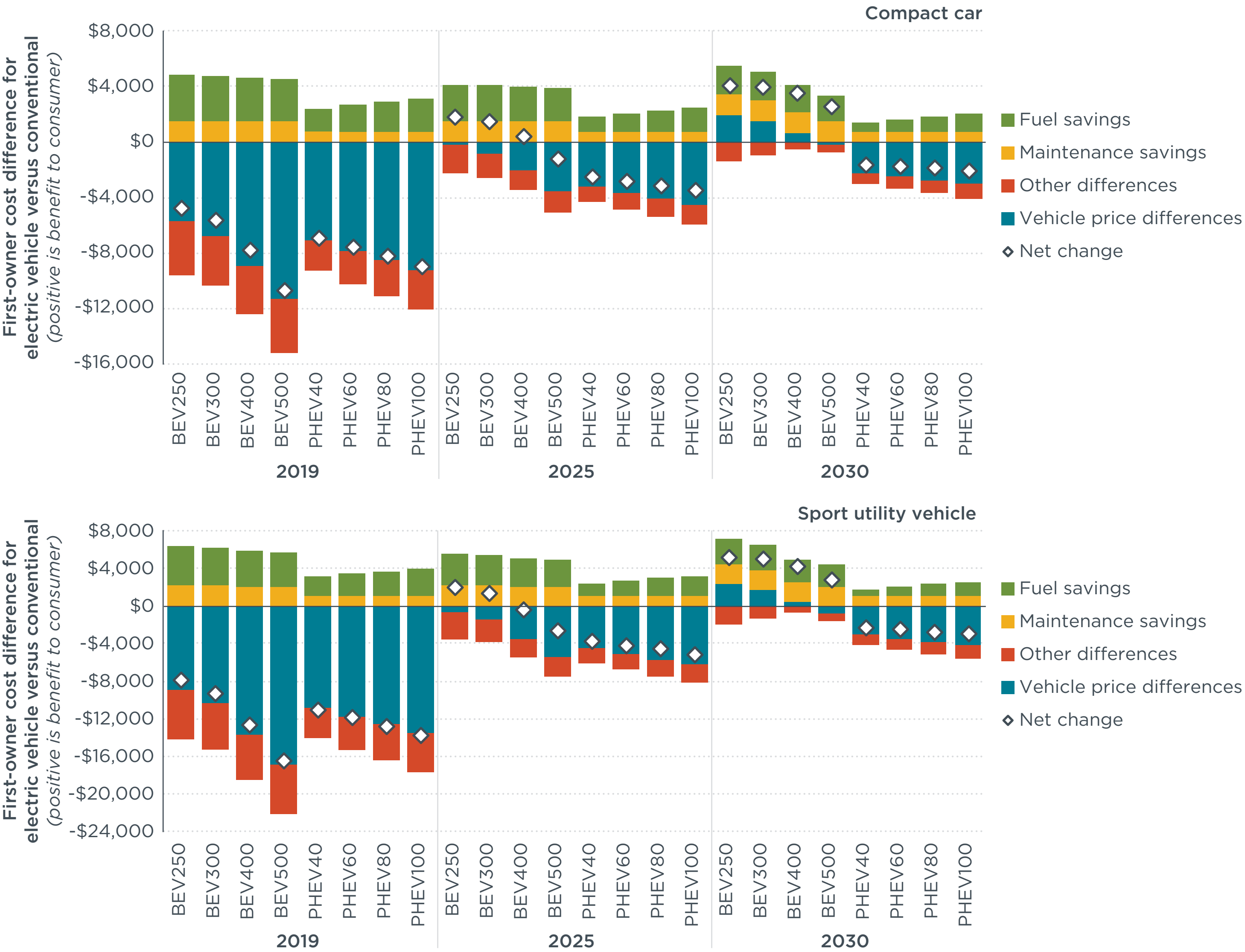

Figure 6. First-owner difference in ownership cost for vehicle technologies for compact car (top) and sport utility vehicle (bottom) for 2019, 2025, and 2030.

From 2025 on, as shown in Figure 6, the fuel and maintenance savings have larger relative effects as electric vehicle prices decline. In 2025, the average new compact car buyer would pay $4,200 for gasoline; the average BEV owner, meanwhile, would pay about $1,600 to $1,800 in electricity, for a total of $2,400 to $2,600 in first-owner fuel savings. BEVs also accrue maintenance cost savings of approximately $1,600 in 2025 for the vehicle's first owner. BEVs have additional costs for the home charger, replacement vehicle, and taxes, and these are shown as "other differences" in Figure 6. After including fuel, maintenance, and other costs, PHEV car owners approach within $1,600 (PHEV40) to $2,100 (PHEV100) of overall conventional gasoline car first-owner costs by 2030.

Regarding sport utility vehicle costs in the lower part of Figure 6, the results are similar to compact cars, but with greater magnitudes. In 2025, the average new sport utility vehicle buyer would pay $5,100 for gasoline, compared to a BEV owner paying about $1,900 to $2,200 in electricity, for a total of $2,900 to $3,300 in first-owner fuel savings. Sport utility BEVs also accrue maintenance cost savings of approximately $2,200 in 2025 for the vehicle's first owner. After including fuel, maintenance, and other costs, PHEV sport utility owners approach within $2,300 (PHEV40) to $3,000 (PHEV100) of overall conventional gasoline car costs by 2030.

Although Figure 5 and Figure 6 show only the compact car and sport utility vehicle first-owner results, the same consumer-level effects and relative magnitudes are seen for the other vehicle classes. The primary difference is that the electric vehicles in the lower-cost vehicle classes (small car, multi-purpose) are relatively less attractive than the compact and sport utility vehicle classes. Based on this analysis, the time that BEVs reach parity on a first-owner basis is 3–6 years earlier than the initial-vehicle price parity that is shown in Figure 4. For example, short-range BEVs (BEV250 and BEV300) reach first-owner parity by 2022–2024, compared to initial vehicle price parity by 2025–2027. Longer range BEVs (BEV400, BEV500) reach first-owner parity by 2024–2026, compared to initial price parity which is typically 2027 or later as shown above.

LIFETIME ELECTRIC VEHICLE COST OF OWNERSHIP

To analyze full lifetime ownership costs, we consider the total net present value of the above electric vehicle costs in each vehicle class driven over the entire vehicle lifetime. The initial vehicle cost differences (i.e., purchase price, home charging, vehicle purchase tax) are unchanged from the first-owner cost analysis shown in the section above. Including lifetime ownership cost accounting reflects the greater effect from annual cost differences (i.e., for fuel, maintenance, replacement costs) between electric and conventional vehicles for 15 years of vehicle use. Although this essentially triples the operating lifetime from the 5-year first owner, the monetary effect is to multiply first-owner costs and benefits by a factor of about 2.0 due to decreasing annual driving as vehicles age and net present value accounting that discounts future-year effects.

Figure 7 shows the lifetime vehicle ownership cost differences between the electric and conventional vehicles for the compact car (top) and sport utility vehicle (bottom) classes for 2019, 2025, and 2030. The overall electric-versus-gasoline lifetime cost difference is shown by the white diamonds and is positive when the electric vehicle provides a net consumer benefit. As an example from 2019, the BEV250 car (the leftmost vertical bar), shows about $3,200 in maintenance benefit (green bar), $6,700 in fuel savings (green), an initial incremental vehicle price of $5,700 (blue), and $3,900 (red) in additional other differences. The net change is that the BEV250 offers an approximate $200 benefit over the conventional car.

Figure 7. Lifetime difference in ownership cost for vehicle technologies for compact car (top) and sport utility vehicle (bottom) in 2019, 2025, and 2030.

Although few electric vehicles deliver net lifetime cost benefits in the reference 2019 vehicles, all BEVs deliver net lifetime benefits to consumers by 2025–2030. The BEV250 (but not the BEV300, BEV400, or BEV500) compact car delivers small lifetime benefits as compared to the gasoline car in 2019; however, the BEV compact cars each deliver from $2,800 to $6,000 in lifetime benefits in 2025, increasing to $6,100 to $7,800 in 2030. The PHEV cars in 2025–2030 range from a $16 benefit to a $900 disbenefit. The bottom part of Figure 7 shows similar lifetime vehicle cost effects for the sport utility vehicle. For 2025–2030 sport utility vehicles, all BEVs deliver net lifetime benefits to consumers: The sport utility BEV benefits range from $2,500 to $7,600 in 2025, and range from $7,200 and $10,000 in 2030. The sport utility PHEVs result in disbenefits from $300 to $1,800.

Considering past speculation that a significant fraction of BEVs might eventually need battery replacements, the potential impact is explored here for illustration purposes. From limited evidence to date, the electric vehicles with the longest electric range have not had significant such problems; Tesla models in the United States with 240,000 to 320,000 kilometers have experienced only approximately 10%–15% range degradation and few battery replacements (e.g., see Lambert, 2018; Lambert, 2020). This is important because these are the long-range BEVs with relatively high lifetime driving and high use of rapid charging. This suggests relatively little concern about battery failure or degradation.

When incorporating a conservatively high assumption of 10% battery pack replacement rate for BEVs, the Figure 7 findings do not fundamentally change. Including battery replacements for 2025 BEVs after the vehicle ages 7 years (i.e., in 2032) would result in an average lifetime battery replacement cost of $180 (i.e., approximately $1,800 for 10% of vehicles) for the BEV250 compact car and up to $430 for the BEV500 sport utility vehicle ($4,300 for 10% of vehicles). Comparing these costs to the data above, the net lifetime benefits in each BEV case are much greater, approximately 6-8 times greater for BEV250s and 34-38 times greater for BEV500s, than the average potential battery pack replacement cost. Still, considering the limited data on the long-term battery effect as well as lifetime gasoline engine and transmission degradation and replacements, this analysis is speculative. As a result, such powertrain cost estimates are excluded from the primary analysis in the results and figures above and below.

POTENTIAL NEV FLEET SCENARIOS

As a final analytical step, we assess the implications of the above technology cost findings for potential NEV regulation scenarios. As part of China's policy framework to support electric vehicles, NEV regulations require vehicle manufacturers to deploy increasing fractions of electric vehicles in future years. The first such regulation for new passenger vehicles established NEV credit requirements of 10% for 2019 and 12% for 2020, and provided credits for electric vehicles sold, typically around 2–4 credits per vehicle, depending on vehicles' technical capabilities (Cui, 2018). China's second phase of NEV regulations was finalized in June 2020, and this increased the NEV credit requirements to 14%, 16%, and 18% for 2021, 2022, and 2023, respectively, and adjusted the per-vehicle credits for NEVs (MIIT, 2020). We take the above benefit and cost data for the various vehicle technologies and assess projected fleets of new passenger vehicles for China in the 2024–2035 time frame, to reflect the period following China's second phase NEV regulations.

ELECTRIC VEHICLE SCENARIOS

We formulate three electric vehicle scenarios—a reference with no new policy, the current NEV targets, and an accelerated one—to incorporate the potential range for increased electric vehicle penetration in China. The scenarios are defined by the electric vehicle share of new passenger vehicle sales, which in turn effects the total number of electric vehicles by type and the overall costs and benefits.

To define the future scenarios, a series of assumptions are made for the overall passenger vehicle sales and the breakdown of vehicle classes in China. Overall passenger vehicle sales are assumed to increase by 10% annually in 2021 and 2022, essentially recovering from the 2018–2020 recession and pandemic-related economic slowdown. After 2022, passenger vehicle growth is set to 0.5% per year. This assumption brings China's passenger vehicle sales from 20.9 million in 2019 to 26.6 million by 2035. Given the uncertainty regarding how the market might change, the breakdown of the market by passenger vehicle class (e.g., 43% sport utility vehicles, 32% compact cars, 11% mid-size cars) is held constant through the future years. The three electric vehicle uptake scenarios are defined as follows.

Reference scenario. The scenario with no new policy reflects a minimum electric vehicle uptake reference case. In this case, no new China policy is developed after the NEV regulations. For the NEV regulations through 2023, the electric vehicle share of new passenger vehicles is assumed to increase to 12% of new vehicles from 2023 and remain constant thereafter. We do not view this as a likely scenario, but it is included to facilitate a simple comparison with the higher electric uptake scenarios.

Current target scenario. The current target scenario achieves a 20% electric share of new passenger vehicle sales in 2025, 40% in 2030, and 50% in 2035, based on prominent targets discussed in China through 2020. The 2025 target was stated in November 2020 in the China State Council's *New Energy Vehicle Industrial Development Plan 2021–2035* (China State Council, 2020). The targets are approximately in line with research targets of 20% in 2025, 40% in 2030, and 50% by 2035, as released by SAE China in its *Energy-saving and New Energy Vehicle Technology Roadmap 2.0* (SAE China, 2020).

Accelerated scenario. The accelerated scenario reflects a rapid increase in electric vehicle uptake reaching 60% in 2030 and 90% in 2035, which puts China on a path to reach 100% in 2040. This accelerated scenario is closer to internationally leading electric markets within Europe and North America that have set 100% zero-emission targets typically around 2030–2040 (Cui, Hall, & Lutsey, 2020; Wappelhorst & Cui, 2020). The intent of this scenario is to show the result of fully taking advantage of the net benefits of electric vehicles at higher electric vehicle shares than China's electric vehicle targets through 2020.

Figure 8 depicts the three electric vehicle uptake scenarios, with electric vehicle shares on the left and annual sales on the right. As shown, the electric vehicles shares all increase to 12% in 2023, from 5% in 2019, as a trajectory to reflect potential compliance with the second phase of China's NEV regulation. The accelerated and current target scenarios show higher new electric vehicle shares and sales from 2024 on, reaching 5 million electric vehicle sales in 2025, up from about 1 million in 2020. The accelerated scenario reaches 60% in 2030 and 90% in 2035. The current target scenario reaches 40% in 2030 and 50% in 2035. Although the trajectories are shown through 2040 for context, the analysis below only analyzes the effect of new vehicles through 2035.

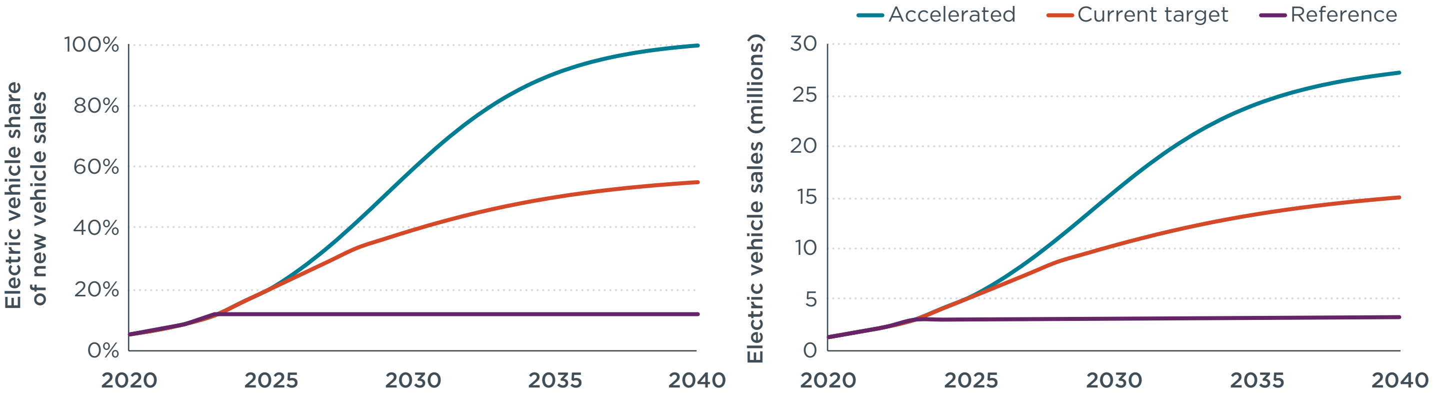

Figure 8. Electric vehicle shares (left) and sales (right) for three scenarios, 2020-2040.

For the trend in technology shares of electric vehicles, increasing BEVs and longer electric ranges are assumed. The BEV share of electric vehicles increases from 70% in 2019 to 100% by 2035. This is supported by the direction of most automakers in China and globally (Slowik, Lutsey, & Hsu, 2020) and by the above findings showing BEVs to be superior to PHEVs from a cost perspective. The breakdown of BEVs and PHEVs includes a mix of all the ranges analyzed above, with increasing sales-weighted average electric range in both technology types: BEVs increase from an average of 330 km on the NEDC cycle in 2019 to 440 km in 2035; PHEVs increase from an average of 42 km in 2019 to 80 km by 2035. The cost and uptake of fuel cell vehicles is relatively uncertain and not included.

Figure 9 shows the initial vehicle price increase and the overall net lifetime cost effect, including fuel, maintenance, and other costs, for the sales-weighted average BEV (red), PHEV (yellow), and combined electric vehicles (black) through 2035. The figure incorporates the assumptions for increasing electric vehicle uptake and the shift to longer-range BEVs and PHEV and other attributes as assessed above. As shown, the average BEV has an incremental price increase of $8,200 over conventional gasoline vehicles in 2020, and then declines to a $1,400 price benefit in 2035. That average BEV net effect increases from -$600 to $8,000 over 2020 to 2030. Over this period, the average BEV battery capacity across all vehicles increases from about 42 kWh in 2020, to 56 kWh in 2030, to 59 kWh in 2035, while the sales-weighted battery pack price decreases, respectively, from $130/kWh (¥0.9/Wh), to $59/kWh (¥0.40/Wh), to $51/kWh (¥0.35/Wh).

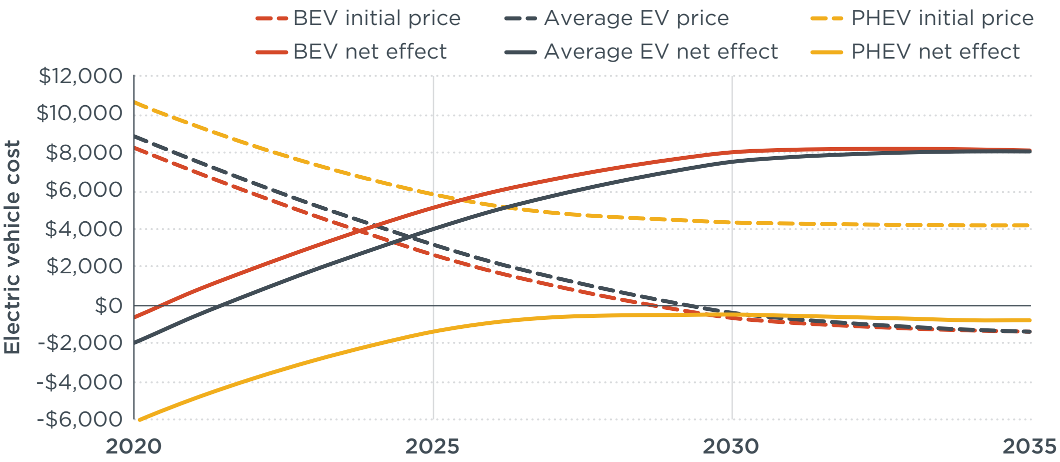

Figure 9. Overall sales-weighted fleet electric vehicle initial price and net effects for BEVs, PHEVs, and combined EVs for 2020–2035.

In addition to BEVs, Figure 9 also shows the initial vehicle price increase and overall net cost effects for PHEVs and electric vehicles overall (i.e., sales-weighted combined BEVs and PHEVs). The trend in average PHEV initial incremental price over gasoline vehicles decreases from $10,000 in 2020 to $4,000 in 2030, even as its average battery size increases from 7 kWh to 12 kWh over that span. Due to the assumption that the BEV share of electric vehicles increases to 100% by 2035, the combined electric vehicle effect is quite close to the BEV results, with lower cost than conventional vehicles from 2029 on, and overall net benefits of $8,000 from 2033 on.

The higher-volume electric vehicle scenarios require increasing scale of annual battery production. This is the case especially in the accelerated scenario. The accelerated scenario results in battery production volume for passenger electric vehicles increasing from approximately 35–40 gigawatt-hours (GWh) in 2020, to over 820 GWh in 2030, and then to over 1,430 GWh by 2035. This rapid increase in annual battery production, by a factor of 20 in 10 years and nearly a factor of 35–40 times over 15 years, would require clear policy signals and coordinated commitments across automakers and battery suppliers to make the necessary supply chain investments.

Improvements to new electric vehicle efficiency have a substantial effect on the required annual battery production. Based on the above analysis (see Table 3), the fleet-level effect of the central case (1% annual reduction in new passenger vehicle kWh/km within each vehicle class), higher efficiency (2% per year reduction), and lower efficiency (0% per year reduction) are assessed. The central case has China's overall new battery electric vehicles at approximately 12.5 kWh/100km in 2030. The 2% per year efficiency case results in a new vehicle fleet-average kWh/100km electricity use of 11.8 in 2025, 11.2 in 2030, and 10.3 in 2035. The 0% per year case results in kWh/100km gradually increasing to 14 kWh/100km by 2035, due to increased BEV uptake in larger vehicle classes. The effect of these two additional efficiency cases is to decrease by 15% (1,220 GWh versus 1,430 GWh) or increase by 17% (1,680 GWh versus 1,430 GWh) the overall annual battery production needed for new passenger vehicles in 2035.

Table 4 summarizes the differences in total electric vehicles, costs, and benefits for the three scenarios. The cost effects in billions of 2019 dollars are summarized in the table in three time periods to reflect the NEV regulation for 2021–2023, the medium-term period of 2024–2030, and the long-term of 2031–2035. These reflect the different periods where electric vehicle costs are most rapidly reducing through 2023, and then the period where more of the electric vehicles of various ranges reach cost parity with conventional vehicles through 2030 (as shown above in Figure 4); then the longer-term through 2035 is when the net benefits are greatest. Breaking down the results into these three periods can also help the consideration of different policy in each period.

Table 4. Comparison of electric vehicle scenario effects.

		Scenarios for electric vehicle sales			Difference between reference and current targets	Difference between reference and accelerated
	Period	Reference	Current targets	Accelerated		
Electric vehicles (million)	2021–2023	6.8	6.8	6.8	0.0	0.0
	2024–2030	20.8	51.4	64.0	30.7	43.3
	2031–2035	15.3	61.4	105.8	46.1	90.5
Incremental vehicle cost over gasoline ($ billion)	2021–2023	($42)	($42)	($42)	$0	$0
	2024–2030	($40)	($61)	($64)	($21)	($24)
	2031–2035	$1	$70	$123	$69	$121
Fuel savings ($ billion)	2021–2023	$39	$39	$39	$0	$0
	2024–2030	$95	$246	$304	$151	$209
	2031–2035	$51	$234	$402	$182	$351
Maintenance savings ($ billion)	2021–2023	$21	$21	$21	$0	$0
	2024–2030	$66	$178	$223	$112	$157
	2031–2035	$48	$223	$386	$175	$338
Other net costs ($ billion)	2021–2023	($12)	($12)	($12)	$0	$0
	2024–2030	($22)	($56)	($68)	($34)	($46)
	2031–2035	($9)	($37)	($64)	($28)	($55)
Total net benefits ($ billion)	2021–2023	$6	$6	$6	$0	$0
	2024–2030	$98	$307	$395	$209	$297
	2031–2035	$92	$490	$847	$398	$755

Notes: Values are rounded. Costs to consumer are shown as (**red**), benefits to consumers are shown in black.

The first three rows of Table 4 show the major differences in total number of electric vehicles from the three scenarios. The reference scenario results in 42.8 million electric vehicles, compared to 119.6 million in the current targets scenario, and 176.6 million in the accelerated scenario over 2021–2035. As shown in the rightmost columns, the current targets and accelerated scenarios result in 76.7 million and 133.8 million more electric vehicles sold in China through 2035 than in the reference scenario.

There are substantial costs, in comparison to conventional gasoline vehicles, to deploying these additional electric vehicles. The higher incremental vehicle price of electric vehicles results in $42 billion in added expenditures over gasoline vehicles over 2021–2023. Over the 2024–2030 period, the costs of the current targets scenario ($61 billion) and accelerated scenario ($64 billion) are very similar because of how close the electric vehicles are to cost parity. For new 2024–2030 vehicles, when compared against the reference scenario (i.e., 12% electric share in 2035), the current target scenario (i.e., 50% electric in 2035) adds $21 billion in initial vehicle costs, and the accelerated scenario (i.e., 90% electric in 2035) adds $24 billion.

As indicated in the bottom rows of Table 4, the total benefits of vehicle price changes, fuel savings, maintenance savings, and other cost changes greatly outweigh electric vehicles' higher initial costs. Even in the early years of 2021–2023, when electric vehicles are relatively expensive, electric vehicles' net ownership benefits of $48 billion (i.e., $39 in fuel benefits, $21 billion in maintenance benefits, and $12 billion in other costs) outweigh the additional vehicle costs of $42 billion for a net benefit of $6 billion. In the later years especially, as electric vehicles become less expensive, the net benefits become far greater. For 2024–2030 new vehicles, the transition to electric vehicles has net benefits that are 5.0 times (i.e., $307 billion versus $61 billion in current targets case) to 6.2 times (i.e., $395 billion versus $64 billion in accelerated case) the initial electric vehicle costs over gasoline vehicles.

The rightmost columns of Table 4 show how the current targets and accelerated scenarios deliver much greater electric vehicles and benefits than the reference case. In the current target scenario, the additional 76.7 million new electric vehicles sold between 2021 and 2035 bring additional net lifetime vehicle benefits of $607 billion (¥4.18 trillion), as compared to the reference case. The accelerated scenario results in 133.8 million more new electric vehicles sold between 2021 and 2035 and additional net lifetime vehicle benefits of more than $1.05 trillion (¥7.26 trillion) over the reference.

The accelerated scenario results in $445 billion (¥3.07 trillion) more net benefits to drivers in China than the current targets scenario. Comparing the two higher-electrification scenarios shows that increasing China's electric vehicle uptake beyond the current targets would deliver both a faster transition to electric vehicles and greater benefits to drivers.

CONCLUSIONS

This paper addresses critical electric vehicle cost questions underlying the pace of electrification in China. Our analysis of electric vehicle assembly costs across different electric ranges and across different vehicle classes reveals a complex consumer proposition with different desired attributes for different drivers. Electric vehicle subsidies and tax advantages were deliberately excluded to provide a technology-neutral comparison of the costs and benefits. By assessing the associated electric vehicle ownership costs (including vehicle price, fuel, maintenance, charging equipment, and other costs) we see the broader benefit for the first owners, and over the vehicle lifetime.

Based on the research findings, we draw the following three conclusions.

Electric vehicle initial price parity is likely to be achieved within 5–10 years in China. With continuing technology and production scale advancements, battery pack costs are expected to drop from $130/kWh (¥0.90/Wh) in 2020 and approximately $59/kWh (¥0.4/Wh) in 2030. Electric vehicle price parity with conventional gasoline cars and sport utility vehicles is likely to occur between 2026 and 2029 for mainstream battery electric vehicles with 300–400-km range. Shorter-range (250 km) electric vehicles reach parity faster by 2025, but would require more charging infrastructure, and for longer-range (500 km) vehicles, parity occurs in 2030 or later. Relatively lower-cost vehicle classes like small cars and multi-purpose vehicles tend to reach cost parity 2–3 years later than higher volume mid-size cars and sport utility vehicles. If there is less progress toward technical goals in China (e.g., 12 kWh/100km vehicle efficiency and ¥0.4/Wh battery costs) price parity could be delayed by 1–3 years.

Well before initial vehicle price parity, electric vehicles deliver substantial cost savings to drivers in China. Cost-competitiveness for electric vehicle buyers in China is reached several years faster than initial vehicle price parity, based primarily on electric vehicles' fuel savings. Analysis of first-owners' 5-year vehicle ownership costs shows an attractive new vehicle purchase proposition for electric vehicles in 2022–2026. First owners of electric vehicles purchased in 2025 accrue fuel savings of $2,400 to $3,300 per vehicle for mainstream cars and sport utility vehicles, and electric vehicles' fuel and maintenance savings far outweigh home charger and other costs. When including the full lifetime effects, the consumer benefits are much greater: Compact electric cars deliver benefits of $2,800 to $6,000 per vehicle in 2025, and this increases to $6,100 to $7,800 in 2030; electric sport utility vehicle consumer benefits are $2,500 to $7,600 per vehicle in 2025, and increase to $7,200 and $10,000 in 2030.

A widespread market transition to electric vehicles will have much broader benefits, and require greatly increased industry investments. When considering the full vehicle lifetime effects and a transition to 90% new electric vehicle sales by 2035, we find larger cost savings that can be experienced widely across drivers in China. Compared to China's current electrification targets, accelerating the electric transition over new 2024–2035 vehicles could result in approximately $445 billion (¥3 trillion) greater benefits to China's drivers. An accelerated transition involves increasing electric vehicle sales from less than 1 million in 2019 to more than 20 million per year by 2035, and the associated annual battery production would need to increase by at least a factor of 30.

These conclusions have several implications for policy. Despite clarity on declining electric vehicle costs and their benefits, the transition to all electric vehicles will not happen without sustained policy. The transition requires sustained policy support through when electric vehicle cost parity is reached for mainstream vehicle classes, and to overcome the prevailing consumer barriers that go beyond vehicle cost. At the highest level, clear zero-emission vehicle targets from the central government can spur many aligned government and industry actions. Longer-term regulations (e.g., NEV regulation and performance standards) are especially necessary to ensure industry investments are made, high-volume electric production is reached, electric models are made widely available, and electric vehicle benefits are broadly realized in China.

These results also call for sustained action beyond regulations to support electric vehicles, including extending fiscal incentives, expanding charging infrastructure, and improving consumer awareness. Fiscal incentives can be designed to bridge the price gap between combustion and electric vehicles, and also could be used more selectively over time. For example, incentives could be targeted toward specific vehicle classes and prospective buyers with special conditions (e.g., regarding higher annual driving, home charging availability, and vehicle work functions). This analysis also shows the complex trade-offs that consumers are likely to face between lower-cost, shorter-range electric vehicles and higher-cost electric versions with less charging inconvenience. For example, a car buyer in 2026 may be able to purchase a 250-km BEV at less cost than a comparable gasoline version, or pay a 20% higher purchase price for a 500-km BEV or a PHEV. This suggests that expanding home and public charging infrastructure (i.e., making short-range BEVs more attractive) could be an important approach to help make cost parity occur sooner for many prospective car buyers.

This analysis also points to several rich areas for future research. Future research would ideally analyze how electric vehicle residual values change as the new technology matures, as incentives are phased down, as consumer understanding improves, as charging infrastructure availability improves, and as the electric vehicle stock achieves an order-of-magnitude increase. Analysis that incorporates the cost, use, and variation in electric charging prices for public charging infrastructure would improve the consumer and societal analysis conducted here. In addition, building from this national-level analysis, regional analyses that account for local conditions (e.g., other important vehicle classes, different driving patterns, varied charging conditions, high-mileage vehicles like taxis) could better inform regional policies that are in development within China. Finally, while this analysis focused on direct quantifiable consumer effects, a more comprehensive analysis would also include emission-reduction benefits of improving local air quality and mitigating climate change effects.

As the world's largest vehicle market and also the largest electric vehicle market, China plays a special role globally. This work suggests that China has an opportunity to continue to expand its electric vehicle and battery production capacity, and thus help electric vehicles reach cost parity sooner. As 100% zero-emission goals for 2030–2040 are being established in Europe and North America, setting a similar electric vehicle target in China would ensure the country is on an accelerated path toward 100% zero-emission vehicle sales and can capture the associated benefits. Such a commitment would signal to both domestic industry and global manufacturers that China will remain a world leader in electric vehicles and batteries.

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APPENDIX

The tables below provide additional details related to information provided in the body of the paper. Table A1 provides data sources related to Figure 1. Note that these sources have various differences in data terminology, whether they refer to cost or price (including whether various indirect supplier costs are included), aspects of pack-level costs that are included, currency years, specific battery technology or a market average, and global or China-specific conditions. Table A2 provides the vehicle prices corresponding to Figure 4.

Table A1. Data sources for battery pack cost estimates (2015–2020) and forecasts (2020–2035).

	2015	2016	2017	2018	2019	2020	2025	2030	2035
CAEV 2020 (low end)						0.8	0.7	0.65	0.6
CAEV 2020 (high end)						1.2			
CATARC 2019 (estimate for CATL)	1.9	1.5	1.3	1.2	1.1	1.0			
CATARC 2019 (estimate for Volkswagen)		1.61		1.21		0.83			
CATARC 2019 (low end)			1.58	1.22	1.05	0.94	0.69	0.58	0.51
CATARC 2019 (high end)			1.55	1.27	1.16	1.07	0.88	0.78	0.72
GGII 2019 (low end)					1.15				
GGII 2019 (high end)					1.3				
Ma 2020 (CATL)	1.33				0.67				
Ma 2020 (BYD)					0.85				
Ma 2020 (LFP)						0.75			
Ma 2020 (NMC/NCA)						0.9			
Miao 2020 (low end)					0.6				
Miao 2020 (high end)					1				
MIIT 2017a						1			
MIIT 2017b						1			
National Advisory Committee for Manufacturing Power Strategy 2018						1	0.9	0.8	
Ren, Lian and Guo 2019 (LFP)					1.05				
Ren, Lian and Guo 2019 (NMC)					1.1				
SAE China 2016						1	0.9	0.8	
SAE China 2020							0.45	0.4	0.35
Shi 2020 (LFP, low end)					0.86				
Shi 2020 (LFP, high end)					1.0				
Shi 2020 (NMC/NCA, low end)					1.1				
Shi 2020 (NMC/NCA, high end)					1.3				
Su & Zou 2020 (CATL)	1.33	1.13	0.91	0.76					
Su & Zou 2020 (CATL, price)	2.28	2.06	1.41	1.15					
Su & Zou 2020 (Guoxuan)		1.06	1.02	0.8	0.7				
Su & Zou 2020 (Guoxuan, price)		2.06	1.69	1.12	1				
Su & Zou 2020 (Funeng)		1.31	1.19	1.13	0.83				
Su & Zou 2020 (Funeng, price)		1.61	1.43	1.17	1.01				
Berckmans 2017 (high cost, reference graphite anode)						195	120	80	
Berckmans 2017 (low cost, graphite-silicon anode)						131	85	50	
Witter 2018 (Volkswagen)		236	200	165	134	106			
P3 2020 (Tesla)						115	50		
Lutsey & Nicholas 2019 (ICCT U.S.)						152	106	74	
This 2021 analysis (ICCT China)						123	84	58	51

Numbers in Chinese yuan/watt-hour, except numbers in **blue**, which are in U.S. dollars per kilowatt-hour (6.8985 yuan = 1.0 U.S. dollars). Where the date not provided, cell-level battery costs are converted to pack-level costs by multiplying by a factor of 1.3.

Table A2. Vehicle prices (in 2019 U.S. dollars) for conventional and electric vehicles for 2020–2035.

	Technology	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Small car	Gasoline	11,486	11,521	11,555	11,590	11,625	11,659	11,694	11,730	11,765	11,800	11,835	11,871	11,907	11,942	11,978	12,014
	BEV250	15,284	14,459	13,722	13,063	12,473	11,943	11,491	11,115	10,785	10,500	10,259	10,134	10,046	9,978	9,927	9,892
	BEV300	16,310	15,400	14,586	13,855	13,199	12,609	12,103	11,675	11,299	10,972	10,692	10,545	10,440	10,358	10,297	10,255
	BEV400	18,700	17,590	16,592	15,693	14,883	14,153	13,517	12,971	12,487	12,061	11,690	11,492	11,346	11,231	11,145	11,085
	BEV500	20,893	19,603	18,438	17,387	16,437	15,578	14,824	14,170	13,585	13,068	12,613	12,368	12,184	12,039	11,930	11,853
	PHEV40	16,748	16,247	15,808	15,425	15,089	14,794	14,560	14,384	14,240	14,128	14,046	14,015	14,007	14,005	14,008	14,016
	PHEV60	17,430	16,873	16,384	15,953	15,574	15,240	14,969	14,760	14,585	14,445	14,337	14,292	14,273	14,262	14,258	14,261
	PHEV80	18,101	17,489	16,949	16,472	16,050	15,677	15,370	15,128	14,923	14,755	14,622	14,563	14,532	14,512	14,501	14,500
	PHEV100	18,774	18,106	17,514	16,990	16,525	16,112	15,769	15,494	15,259	15,063	14,904	14,831	14,789	14,760	14,742	14,736
Compact car	Gasoline	17,782	17,835	17,889	17,943	17,996	18,050	18,105	18,159	18,213	18,268	18,323	18,378	18,433	18,488	18,544	18,599
	BEV250	23,139	21,915	20,831	19,871	19,019	18,263	17,637	17,136	16,708	16,351	16,064	15,916	15,826	15,757	15,708	15,677
	BEV300	24,283	22,963	21,792	20,752	19,827	19,004	18,316	17,759	17,279	16,875	16,544	16,373	16,263	16,178	16,118	16,079
	BEV400	26,603	25,089	23,740	22,536	21,462	20,502	19,688	19,016	18,431	17,931	17,512	17,291	17,140	17,024	16,939	16,883
	BEV500	29,225	27,497	25,951	24,566	23,325	22,212	21,257	20,456	19,752	19,142	18,622	18,345	18,150	17,997	17,885	17,808
	PHEV40	25,127	24,273	23,532	22,888	22,329	21,842	21,465	21,194	21,042	20,985	20,934	20,934	20,941	20,954	20,973	20,998
	PHEV60	25,906	24,989	24,190	23,492	22,883	22,352	21,933	21,624	21,437	21,347	21,267	21,251	21,244	21,247	21,259	21,278
	PHEV80	26,674	25,693	24,836	24,085	23,427	22,851	22,391	22,045	21,823	21,702	21,592	21,560	21,541	21,533	21,537	21,551
	PHEV100	27,443	26,398	25,482	24,677	23,971	23,349	22,848	22,464	22,207	22,054	21,915	21,867	21,834	21,817	21,813	21,821
Mid-size car	Gasoline	33,572	33,673	33,774	33,875	33,977	34,078	34,181	34,283	34,386	34,489	34,593	34,697	34,801	34,905	35,010	35,115
	BEV250	42,791	40,538	38,561	36,824	35,298	33,955	32,875	32,049	31,364	30,816	30,404	30,197	30,093	30,017	29,968	29,942
	BEV300	44,302	41,922	39,829	37,987	36,364	34,932	33,770	32,870	32,116	31,506	31,036	30,797	30,667	30,571	30,506	30,470
	BEV400	47,373	44,737	42,409	40,351	38,530	36,917	35,589	34,536	33,643	32,905	32,318	32,013	31,830	31,692	31,594	31,534
	BEV500	50,734	47,832	45,258	42,972	40,941	39,135	37,627	36,410	35,365	34,486	33,770	33,394	33,153	32,969	32,837	32,752
	PHEV40	46,186	44,416	42,885	41,560	40,414	39,423	39,003	38,923	38,853	38,794	38,744	38,767	38,800	38,842	38,892	38,949
	PHEV60	47,204	45,351	43,743	42,349	41,138	40,088	39,614	39,484	39,369	39,267	39,178	39,181	39,197	39,225	39,265	39,315
	PHEV80	48,206	46,270	44,587	43,123	41,849	40,740	40,212	40,033	39,873	39,730	39,603	39,585	39,584	39,599	39,628	39,671
	PHEV100	49,211	47,191	45,431	43,897	42,558	41,391	40,809	40,580	40,374	40,190	40,025	39,985	39,967	39,969	39,988	40,023
Sport utility vehicle	Gasoline	24,781	24,855	24,930	25,005	25,080	25,155	25,230	25,306	25,382	25,458	25,534	25,611	25,688	25,765	25,842	25,920
	BEV250	33,138	31,309	29,697	28,277	27,023	25,915	25,011	24,305	23,712	23,227	22,850	22,655	22,545	22,462	22,404	22,368
	BEV300	34,747	32,783	31,049	29,515	28,158	26,955	25,964	25,179	24,512	23,961	23,522	23,294	23,156	23,051	22,976	22,928
	BEV400	38,314	36,055	34,049	32,266	30,679	29,267	28,083	27,122	26,293	25,593	25,018	24,713	24,514	24,360	24,247	24,172
	BEV500	41,837	39,321	37,074	35,065	33,269	31,660	30,294	29,162	28,176	27,329	26,618	26,240	25,982	25,781	25,633	25,534
	PHEV40	35,859	34,476	33,277	32,236	31,333	30,549	29,944	29,516	29,333	29,257	29,189	29,191	29,201	29,221	29,248	29,282
	PHEV60	36,894	35,426	34,149	33,037	32,068	31,224	30,565	30,086	29,857	29,738	29,631	29,611	29,604	29,610	29,627	29,654
	PHEV80	37,912	36,360	35,006	33,824	32,790	31,887	31,173	30,644	30,369	30,208	30,063	30,021	29,997	29,989	29,996	30,016
	PHEV100	38,932	37,296	35,864	34,610	33,511	32,548	31,779	31,199	30,879	30,675	30,491	30,428	30,387	30,365	30,361	30,374
Multi-purpose vehicle	Gasoline	18,007	18,061	18,115	18,170	18,224	18,279	18,334	18,389	18,444	18,499	18,555	18,610	18,666	18,722	18,778	18,835
	BEV250	24,737	23,352	22,127	21,042	20,080	19,226	18,519	17,954	17,473	17,072	16,750	16,582	16,479	16,399	16,342	16,305
	BEV300	26,176	24,671	23,335	22,149	21,094	20,156	19,371	18,736	18,189	17,728	17,351	17,153	17,025	16,926	16,854	16,806
	BEV400	29,367	27,597	26,019	24,609	23,350	22,223	21,266	20,473	19,781	19,187	18,688	18,422	18,239	18,096	17,990	17,917
	BEV500	32,547	30,543	28,745	27,131	25,681	24,377	23,254	22,307	21,473	20,747	20,126	19,793	19,556	19,371	19,233	19,139
	PHEV40	26,704	25,718	24,860	24,113	23,464	22,899	22,458	22,141	21,888	21,698	21,571	21,521	21,515	21,518	21,527	21,543
	PHEV60	27,630	26,568	25,641	24,831	24,123	23,504	23,014	22,651	22,356	22,128	21,967	21,897	21,876	21,866	21,866	21,875
	PHEV80	28,541	27,404	26,408	25,535	24,769	24,096	23,558	23,151	22,815	22,549	22,353	22,264	22,228	22,206	22,197	22,199
	PHEV100	29,455	28,241	27,175	26,238	25,414	24,688	24,101	23,648	23,271	22,967	22,736	22,628	22,576	22,542	22,524	22,520

BEV = Battery electric vehicle; PHEV = Plug-in hybrid electric vehicle (number refers to the official test cycle electric range in kilometers)