Modeling Climate, Health, and Economic Benefits of Faster New Energy Vehicle Deployment in China

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EXECUTIVE SUMMARY

Across China in the decade spanning 2005 to 2015, air pollution from transportation increased premature deaths from 8 percent to 14 percent,[1] despite some of the world's most stringent standards for passenger vehicle fuel consumption. Petroleum fuel use in vehicles is a major source of the carbon dioxide emissions driving climate change, and has made China the world's largest importer of crude oil.

Domestic policies to accelerate new energy vehicle (NEV) deployment in China's transportation sector can benefit public health, climate, and the pace of innovation while reducing oil demand.

The vast majority of NEVs[i] are battery-powered electric vehicles (EVs), which can replace vehicles powered by conventional internal combustion engines (ICEs) that burn petroleum-derived fuels like gasoline and diesel.

Energy Innovation used the China Energy Policy Simulator (EPS) to analyze the effects of policies that can accelerate NEV deployment, and to quantify these benefits.[2]

To explore the effects of even faster NEV deployment, we developed an EPS policy scenario accelerating the transition to 100 percent NEV sales for a range of vehicle types, including commercial vehicles.[ii] In our scenario, new sales of

[i] "New energy vehicles" are defined to include all-electric, plug-in hybrid, and hydrogen-fueled vehicles. This terminology aligns with Chinese transportation policy conventions.

[ii] Covering vehicles with at least four wheels for on-road use, i.e., excluding two- and three-wheelers and off-road vehicles.

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passenger cars, sport-utility vehicles (SUVs), and buses reach 100 percent NEVs in 2035. New sales of freight trucks grow to 100 percent NEVs in 2040.

Our EPS results indicate that faster NEV deployment in China would prevent billions of tons of climate pollution, improving air quality and saving hundreds of thousands of lives. Accelerated NEV deployment would also create millions of new domestic jobs while lessening oil dependence.

Policy recommendations

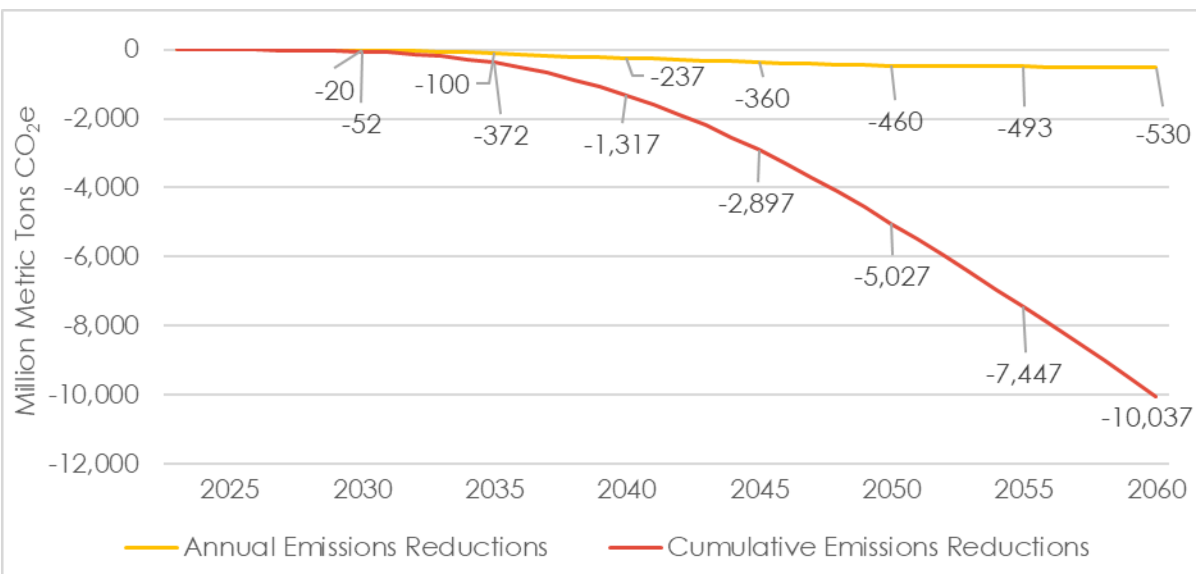
China EPS results show benefits from the accelerated deployment of NEVs across all types of on-road vehicles. However, we recommend that domestic Chinese policy prioritize additional support for new energy trucks considering their outsized benefits to human health and because the current NEV policy framework for commercial vehicles is less developed than for cars and SUVs. While China has targeted 50 percent NEV sales for cars and SUVs by 2035 and recently extended to 2025 its "Dual Credit" policy that sets annual NEV sales targets for cars and SUVs, similar policies do not yet exist for commercial vehicles.[3] The Dual Credit policy has been called "the main driver for [NEV] market growth in China."[4]

Based on this research, we suggest Chinese policymakers establish a NEV sales requirement for freight trucks consistent with a 2030 trajectory for NEV sales to reach 56 percent of light-duty truck sales and 46 percent share of heavy-duty truck sales (i.e., those with a gross vehicle weight of 12 metric tons or greater). The International Council on Clean Transportation (ICCT) has determined that these even faster NEV deployment levels are feasible for China.[5]

Decarbonization benefits

Rapid NEV deployment in our policy scenario reduces greenhouse gas (GHG) emissions by 20 million metric tons of carbon dioxide equivalent (MMT of CO_2e) in 2030. These emissions reductions grow steadily to 530 MMT of CO_2e in 2060, as shown in Figure ES-1.

Figure ES-1. CO_2e emissions reductions from faster NEV deployment, annual & cumulative



Since battery-electric vehicles are expected to be the preferred NEV technology, the pollutant emissions intensity of electricity generation used to charge batteries is factored into NEV benefits. Our modeling results include indirect electricity sector emissions based on projections of China's electricity generation mix in the EPS's "Business as Usual" scenario. In 2030, the electricity mix is projected to be 23 percent renewable energy and 47 percent zero-emission technologies, including sources like hydroelectric and nuclear.

Our modeling also examined changes in direct emissions from ICE vehicles, including discharges of CO2 as well as pollutants such as nitrogen oxides, particulate matter, sulfur oxides, and volatile organic compounds. Rapid NEV deployment in our modeled scenario ultimately eliminates 98 to 99 percent of direct vehicle emissions. Reductions in direct vehicle emissions never reach 100 percent due to the remaining combustion emissions from plug-in hybrid vehicles. .

Health benefits

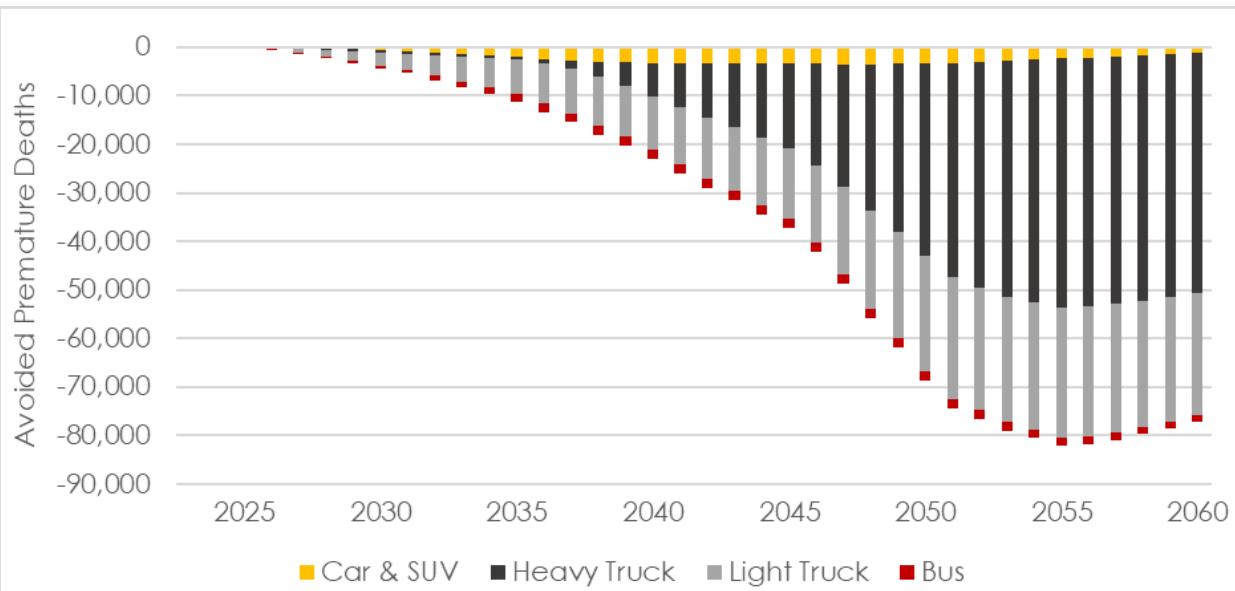
Table ES-1 presents improvements in several health-related metrics from rapid NEV deployment. Avoided premature deaths reach about 4,400 in 2030 and grow to 77,000 in 2060, with 130,000 avoided asthma attacks in 2030, growing to 2.3 million in 2060.

Table ES-1. Health improvements due to faster NEV deployment

	2030	2040	2050	2060
Reduced premature mortality (lives saved)	-4,400	-22,000	-69,000	-77,000
Reduced asthma attacks	-130,000	-690,000	-2,100,000	-2,300,000
Reduced work loss days	-550,000	-2,600,000	-7,400,000	-8,200,000
Reduced activity restriction days	-3,200,000	-15,000,000	-41,000,000	-46,000,000

Figure ES-2 reveals that health gains are largely attributable to new energy trucks, responsible for 84 percent of annual avoided premature deaths on average. Health gains from rapid new energy truck deployment are disproportionately large because trucks are the main vehicles using diesel engines and because diesel engine exhaust is especially damaging to human health. The current slower deployment of electric trucks also means rapid NEV uptake will have a larger impact relative to present trends.

Figure ES-2. Lives saved attributed to vehicle category (annual avoided premature deaths)

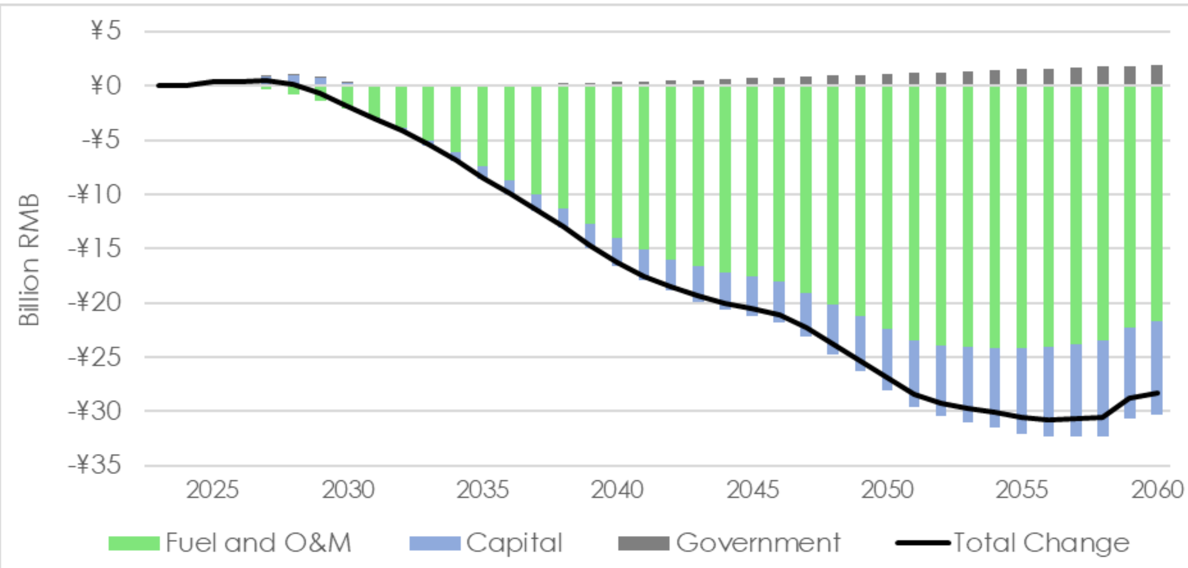


Economic impacts

Transportation electrification is being driven by innovations in battery-electric storage technology, which has revolutionized EV economics. Already, in many circumstances, total ownership costs for NEVs are less than that of ICE vehicles due to fuel and maintenance savings.[6] With battery metal prices having largely normalized after COVID-19 supply chain-induced disruptions,[7] NEVs will soon be cheaper to buy than conventional ICE vehicles.[8] Chinese policymakers can be confident that, within several years, EVs will pass this last up-front price milestone, becoming less expensive to purchase due to the promise of continuing innovation and economies of scale as this industry expands. Implementing additional policies to spur faster NEV deployment can increase certainty about future market conditions, boosting domestic investment and stimulating additional innovation.

Figure ES-3 presents results of impacts on CapEx and OpEx, referring to effects on capital (i.e., equipment[iii]) costs and operational (i.e., energy and maintenance) expenses. China EPS finding point to large operational costs savings due to greater fuel efficiency and lower maintenance costs of NEVs. Over time, as NEV purchase prices fall below those of conventional vehicles, CapEx savings add to total savings. Higher CapEx expenditures (shaded blue in Figure ES-3) in early years reflect higher NEV purchase prices, as well as associated investment costs for building charging infrastructure and for increased electric power capacity to serve added transportation demand.

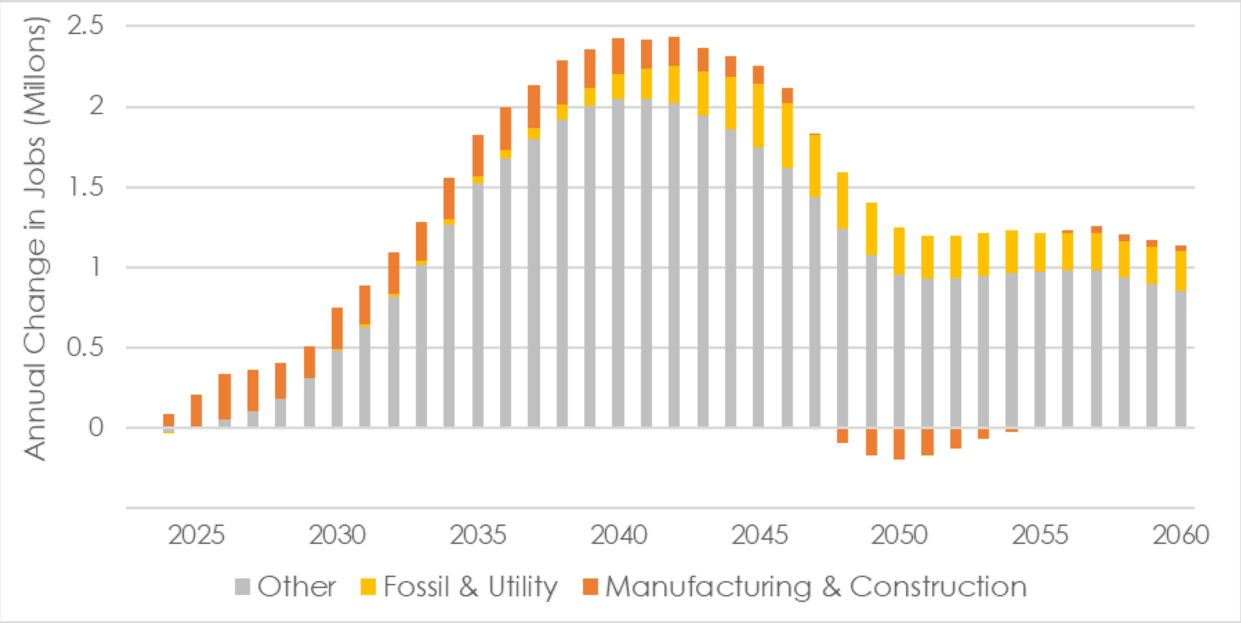
Figure ES-3. CapEx and OpEx impacts due to faster NEV deployment



Our study finds faster NEV deployment could create millions of new domestic jobs, as shown in Figure ES-4, peaking at a net gain of 2.4 million jobs in 2032. The increase in the "Other" jobs category is greatest, mainly caused by re-spending of fuel and maintenance savings. Employment in "Fossil & Utility" sectors also expands steadily over time. EPS results indicate initial gains in "Manufacturing & Construction," decreasing over time. Lower capital spending is due to savings on new vehicles as NEV purchase prices fall below those of conventional vehicles.

[iii] Modeling accounts for electricity and charging infrastructure costs related to faster NEV uptake, including investment for the equivalent of 2.8 million chargers for cars and SUVs and 4.8 million chargers for light-duty and heavy-duty trucks and buses.

Figure ES-4. Employment effects (annual change in full-time equivalent jobs in millions)



Oil dependence

China has been the world's largest oil importer since 2017.[9] Growing demand for petroleum-based fuels like gasoline and diesel have driven the country's increasing dependence on crude oil.[10] Our modeling finds rapid NEV deployment could lower China's petroleum fuel demand significantly: by 28 percent in 2035, 81 percent in 2045, and 97 percent in 2060 compared to business-as-usual demand for petroleum fuels from cars, SUVs, trucks, and buses.

Conclusion

Three years ago, China pledged to reach net-zero emissions by 2060. Our research provides new insights into the level of NEV deployment needed in the transportation sector to help make that pledge a reality. Stronger ambition and faster, more effective policy implementation are required for China to get on track for its decarbonization goals.

Net-zero emissions globally by mid-century is achievable, but only if China—the world's largest emitter of climate pollution—leverages the most mature and cost-effective climate solutions. The International Energy Agency has identified passenger vehicle and commercial vehicle electrification as the third- and fifth-most important technologies for reaching carbon neutrality.[11] Because China is the world's largest market for new motor vehicles overall as well as for EVs,[12] its success on NEV deployment is crucial to global transportation decarbonization. A rapid transition to NEVs will not be without its challenges, but our China EPS modeling indicates the effort will provide significant domestic health, energy security, and economic benefits.

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INTRODUCTION

This research analyzes the emissions, health, economic, and energy security impacts for China of rapid NEV deployment, considering an accelerated transition to 100 percent NEVs for all on-road vehicles. We model cars, SUVs, and buses fully transitioning to NEVs by 2035 with freight trucks and other commercial vehicles doing so in 2040.

In China, as elsewhere, NEV sales thus far have consisted almost entirely of all-electric vehicles or plug-in hybrid EVs.[iv] Battery innovations have improved EV economics, increased sales and industry investments, and boosted government commitments, increasing hopes for transportation's role in economy-wide decarbonization. The International Energy Agency's (IEA) analysis finds passenger vehicle and commercial vehicle electrification to be the third- and fifth-most important technologies for reaching carbon neutrality.[13]

Never have so many climate solutions been available and cost-effective, but the urgency of progress also has never been so self-evident. China's record-breaking heat in summer 2023 is one of many climate extremes making headlines, drawing new attention to the exigency of decarbonization. Global emissions increased in 2022, but they need to begin decreasing in short order. According to a recent United Nations report: "Much more ambition in action and support is needed in implementing domestic mitigation measures and setting more ambitious targets in [nationally determined contributions] to realize existing and emerging opportunities across contexts."[14]

For China, rapid NEV deployment is also important for public health. Motor vehicle emissions are disproportionately released in densely populated urban areas, leading to a higher rate of exposure and intake. China has increasingly urbanized and has controlled pollution from coal power plants, causing an uptick in transportation's share of ambient air pollution—and the associated damage is on the rise. The percentage of premature deaths from air pollution exposure attributed to transportation rose from 8 percent in 2005 to 14 percent in 2015.[15]

BACKGROUND

UPDATE ON BATTERY COST AND NEW ENERGY VEHICLES

Rapid innovation and falling battery prices have changed the economics of EVs because batteries are the main driver of purchase price differences between EVs and conventional ICE vehicles.[16] Technological progress and economies of scale reduced the inflation-adjusted cost of batteries 89 percent from 2010 to 2021.[17]

In 2022, pandemic-induced economic turbulence increased battery pack prices 7 percent,[18] but these price increases were transient. Raw material input cost pressures on battery production have normalized, indicating a return to the trend of falling prices.[19] Declining costs for battery metals have caused cell prices to drop to levels last seen in early 2021.[20] In August, Benchmark Mineral Intelligence reported the price of advanced lithium-ion cells in China declined to $82.6 per kilowatt-hour,[21] approaching the thresholds below which EVs are cheaper than equivalent ICE cars and SUVs.[22]

Turning to NEV sales, the Chinese market is the world's largest for not only EVs but also conventional new cars, SUVs, and commercial vehicles. NEV sales have experienced strong global growth for years, reaching

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[iv] Plug-in hybrid electric vehicles have both a battery-electric powertrain and a conventional combustion engine.

25.6 percent of new car and SUV sales in China[23] in 2022.[24] In the first half of 2023, NEVs accounted for 32 percent of sales, with 23 percent all-electric and 9 percent plug-in hybrid electric.[25]

In another economic signal of gathering momentum, clean tech investment topped $1 trillion for the first time in 2022, with electrified transport growing faster than any other category. For the first time, investment in electrified transport came close to dethroning renewables, with 2022 investment amounting to $466 billion, 54 percent more than in 2021.[26]

THE ECONOMIC OUTLOOK FOR NEW ENERGY VEHICLES

Today, in many circumstances, NEV ownership costs—purchase cost plus fuel and maintenance—are less than that of ICE vehicles.[27] Moreover, while the unsubsidized purchase price for EVs remains above that of conventional vehicles on average, continued learning curve effects provide confidence that most NEVs will be less expensive to purchase within several years. Additionally, Chinese car buyers are increasingly financing vehicle purchases, which can render initial cost differences irrelevant.[28]

Learning curves are a robust phenomenon that has been observed for more than 50 kinds of clean technologies.[29] Learning curves, sometimes referred to as Wright's Law or experience curves, capture the innovation and cost-lowering effects of learning by doing and economies of scale that follow increased deployment. Learning by doing refers to the fact that the more batteries and NEVs people produce, the more they discover how to make them better, faster, and cheaper.

Confidence that learning curve effects will remain significant is based on underlying trends in investment and technology. For instance, the IEA forecasts that global battery production capacity will expand at least fivefold between 2020 and 2030. Such an expansion provides added certainty that future cost reductions will follow from manufacturing economies of scale.[30]

Another factor underlying confidence in future learning curve effects is an increasingly diverse set of battery chemistries. Two new battery chemistries—sodium-ion and lithium-sulfur—are nearing commercial availability,[31] and BloombergNEF estimates growth in sodium-ion battery market share could lower lithium demand by 40 percent in 2035.[32]

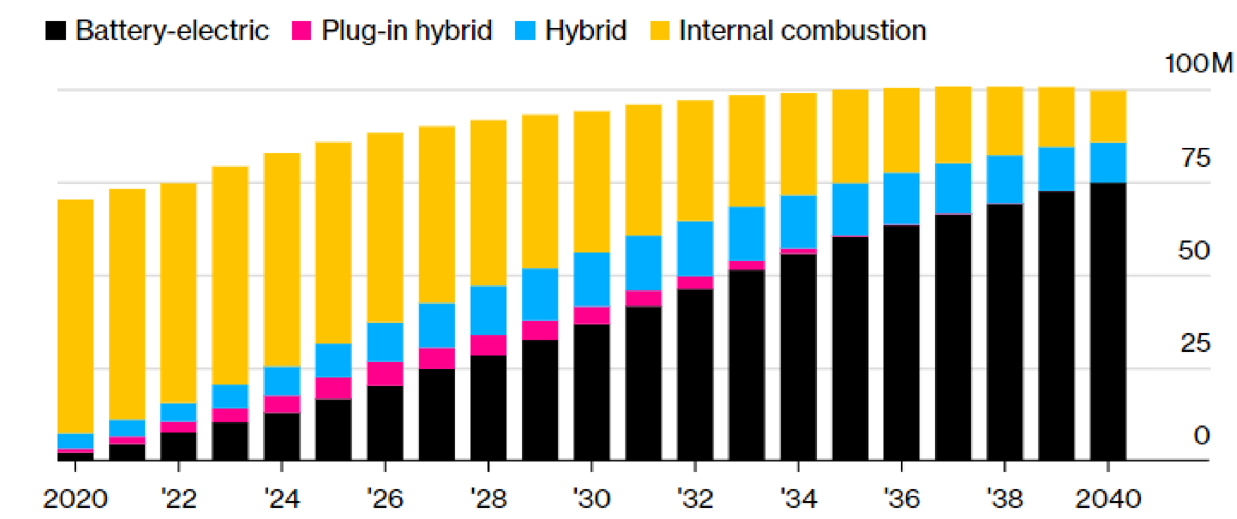
A greater number of commercially viable battery technologies increases the possibilities for technological progress. More battery diversity creates new options for resource substitution that push prices down, lower producer profit margins, and improve consumer economics. Framed another way, more battery chemistry options spread material demand across a greater array of raw inputs, reducing demand-side pressure and the risk of supply bottlenecks.

The rise of lithium-ion phosphate batteries provides a case study in the benefits of more diverse battery chemistries. Lithium-ion phosphate batteries require no cobalt, and offer an affordable alternative, albeit at the cost of lower energy density.[33] Lithium-ion phosphate battery market share has exceeded 40 percent in 2023, up from 25 percent in 2022 and less than 10 percent in 2019.[34] At the same time, cobalt demand has fallen, and in June 2023 cobalt prices were 65 percent lower than their 2022 price peak.[35] BloombergNEF estimates global demand for cobalt will be 52 percent lower in 2030 than it would have been otherwise as a result of the shift in demand to lithium-ion phosphate batteries.[36]

Another promising technology is solid-state batteries, which use thin layers of solid electrolytes to replace the conventional liquid electrolytes found in today's lithium-ion batteries.[37] Solid-state batteries can hold more energy than liquid lithium-ion batteries, enabling greater EV range. The technology promises shorter charging times, and solid-state batteries are safer because they are less volatile and flammable. Several major companies and startups intend to ramp up production and expand commercial use in the next several years.[38]

Global ICE car sales have remained below pre-pandemic levels and are expected to continue shrinking—the world likely passed peak ICE vehicle demand in 2017.[39] Meanwhile, EV sales expanded strongly during the pandemic. Driven by the underlying economics, the growing consensus is that EVs are on track to become the preferred transportation technology.[40] BloombergNEF is unequivocal in its prediction: "The Future Will be Battery-Electric."[41]

Figure 1. BloombergNEF global outlook for vehicle sales by technology



Source: BloombergNEF[42]

THE DANGERS OF DIESEL EXHAUST

Diesel engine emissions are much more harmful to human health than emissions from gasoline-fueled vehicles, and contribute to respiratory disease, cancer, and even premature death. The World Health Organization has identified diesel exhaust as a known carcinogen since 2012.[43] Diesel exhaust contains 40 cancer-causing substances and high levels of particulate matter, or fine soot.[44] Particulate matter varies in size from coarse particulates (less than 10 microns in diameter, known as PM10) to fine particulates (less than 2.5 microns, known as PM2.5) to ultrafine particulates (less than 0.1 microns). Ultrafine particulates, which are small enough to penetrate the cells of the lungs, make up 80 to 95 percent of diesel soot pollution.

Diesel trucks are also a disproportionately large source of nitrogen oxides (NOx) emissions. NOx is a double threat—both a pollutant itself and a chemical precursor to fine particulate and ground-level ozone pollution.[45] Exposure to NOx pollution inflicts respiratory health issues, including reduced lung function and inflammation.[46] Long-term exposure to NOx emissions has been directly linked to the development of asthma, while short-term exposure can trigger asthmatic symptoms.[47]

METHODOLOGY

THE CHINA ENERGY POLICY SIMULATOR

This research is based on the China EPS,[48] a free, open-source, peer-reviewed model that analyzes the impacts of climate and energy policy. EPS models have been developed for more than a dozen countries, 48 U.S. states, and several other subnational regions, including multiple Chinese provinces. EPS models now cover 58 percent of global GHG emissions in total.[49]

The EPS covers every major economic sector: transportation, energy supply, buildings, industry, agriculture, and land use. The model's structure includes detailed representations of technologies, policies, capital stock turnover, cash flow, and macroeconomics. Model outputs provide visibility into how policies affect a host of emissions, economic, and public health measures. The model's online documentation provides a deeper introduction to the EPS's methods.[50]

Table 1. Vehicle category definitions and gross vehicle weight ratings

	Vehicle Categories	Gross Vehicle Weight
Cars & SUVs	Light-duty passenger vehicles	≤ 6 metric tons
Buses	Heavy-duty passenger (buses & long-distance coaches)	> 6 metric tons
Light Trucks	Light- and medium-duty freight trucks & vocational vehicles	≤ 6 metric tons
Heavy Trucks	Heavy-duty freight trucks & vocational vehicles	> 6 metric tons

The research focuses on the four EPS vehicle categories covering on-road motor vehicles with at least four wheels, a subset of the transportation sector.[v] Within each vehicle category, the model specifies several technology types. New vehicle technology choice in the EPS is a function of the net present value of ownership cost for different technology options. Lower vehicle ownership cost leads to a greater market share of new vehicle sales.[51] However, non-economic factors also affect the mix of NEVs and conventional technology in new vehicle sales, including range anxiety and availability of charging infrastructure. The model also accounts for "rebound effects"—the increase in driving that follows from the adoption of more efficient vehicles that reduce the cost per kilometer traveled.

China EPS vehicle choice modeling principally leads to the adoption of all-electric vehicles to satisfy NEV sales standard requirements. The China EPS's preference for EVs is consistent with historical trends. Most experts also expect EVs to dominate the NEV market due to their technological maturity and cost advantages.[52]

SCENARIOS

Scenarios are economy-wide representations of energy use and travel demand along with emissions characteristics of different fuels and technologies, which combine to provide a complete picture of emissions and energy-related spending (covering private spending on capital, fuel, and other operational and maintenance expenses, as well as government budget impacts).

Each EPS scenario is defined by its specification of more than 50 different types of policies. Varying policy settings change behaviors, investments, and system dynamics represented in the EPS; scenarios provide detailed information about technology use, energy demand, prices, and capital stock for all major energy-

[v] Included vehicles are on-road motor vehicles with at least four wheels. Off-road vehicles and those with two or three wheels are outside of this analysis's scope.

using and -producing sectors of the economy. By calculating the difference in such variables between scenarios, the EPS enables policy impact analysis. Note that scenarios are representations of plausible futures, not predictions. Nonetheless, scenario analysis using the EPS offers valuable insights for Chinese domestic policymaking through its quantitative, interdisciplinary system dynamics framework.

1. Business-as-Usual (BAU) Scenario

For this study, we developed two scenarios. The first is the BAU Scenario, which models a more moderately paced transition, with NEV deployment aligning with NEV sales shares in the ICCT's "Momentum Scenario" for China through 2030. [53] The Momentum Scenario considers policy developments through March 2023.[54] It does not consider some more recent developments, such as China's extension of favorable sales tax treatment through 2028.

After 2030, our BAU Scenario assumes some economic adoption occurs, reflecting expectations of continuing improvement in the cost competitiveness of EVs. This assumption of some market-driven NEV adoption is similar to BloombergNEF's economic transition scenario, "which is driven by the economic competitiveness of technologies and assumes no new policies are introduced."[55] Though economic factors increase NEV sales shares above the levels in the Momentum Scenario, they are below BloombergNEF's Economic Transition Scenario.

Only some existing policies supporting NEV adoption are accounted for in our BAU Scenario, similar to the Momentum Scenario. Specifically, the BAU Scenario includes only policies already in effect or with a specific implementation plan and timetable. Defined in this way, neither the BAU Scenario, nor the ICCT's Momentum Scenario, are intended to reflect China's target of 50 percent NEVs for cars and SUVs, nor its pledge to reach net-zero emissions by 2060.[vi] [56]

Table 2. Percentage of NEVs in new vehicle sales—BAU Scenario

	2030	2035	2040	2050	2060
Cars and SUVs	42%	46%	51%	69%	77%
Buses	50%	60%	70%	79%	84%
Light Trucks	21%	34%	43%	57%	66%
Heavy Trucks	17%	20%	22%	28%	33%

2. Added Policy (AP) Scenario

To analyze the effects of policies that accelerate NEV deployment, we created the Added Policy (AP) Scenario, aligning with the ICCT's "Ambitious Scenario" for China.[57] As the ICCT explains: "The Ambitious Scenario is designed to push the envelope but stay within our judgment of technical feasibility. For this we considered progressive positions put forth by governments, our own assessment of technically feasible scale up of NEV production and policy-driven market uptake, and assessments by us and other researchers of how fast the NEV transition needs to be to align with the Paris Agreement."[58]

Table 3. Percentage of NEVs in new vehicle sales—Added Policy (AP) Scenario

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[vi] Our BAU Scenario and the ICCT's Momentum Scenario are akin to the "Stated Policies Scenario" in the IEA's modeling. In contrast, the IEA's "Announced Policies Scenario" assumes policy commitments are achieved even if yet unbacked by implemented policies or specific plans. In the ICCT's Momentum Scenario for China, 42.7 percent of car and SUV sales are NEVs in 2030 and 49.5 percent in 2060; bus sales grow to 55.6 percent NEVs in 2060, when new energy truck sales top out at 25.6 percent (for a weighted average metric covering all types of trucks over 3.5 metric tons). The Momentum Scenario is said to consider "announcements, proposals, consultations, and goals from global coalitions, regional entities such as the European Union, individual nations, and subnational entities. The Political Momentum scenario assumes each of the considered policy targets is reached within its stated time period."

	2030	2035	2040	2050	2060
Cars and SUVs	75%	100%	100%	100%	100%
Buses	90%	100%	100%	100%	100%
Light Trucks	56%	82%	100%	100%	100%
Heavy Trucks	46%	68%	100%	100%	100%

Since NEVs use electricity instead of petroleum-based fuels, their emissions reduction benefits depend on the pollutant emissions intensity of the electricity system. Electricity pollutant emissions intensity is determined by the share of renewable and zero-emission generation sources in the electricity mix. We assume the same shares of renewable and zero-emissions sources across both our scenarios, as detailed in Table 4.

Table 4. Renewable and zero-emission technology shares of electricity generation[vii]

	2030	2040	2050	2060
Renewable Electricity Generation	23%	34%	47%	58%
Zero-Emission Electricity Generation	47%	60%	74%	85%

ADDED INFRASTRUCTURE INVESTMENTS WITH FASTER DEPLOYMENT

The AP Scenario accounts for electric power supply and EV charging infrastructure costs. In the electricity sector, our modeling accounts for added demand for electricity from greater NEV deployment, incorporating the cost of electricity procured as well as investments in expanded electric power generating capacity to supply greater demand. The amount of EV charging infrastructure investment needed is a function of extra NEVs sold.

Table 5. Additional chargers installed in AP Scenario (millions)[viii]

For Cars & SUVs

	2030	2040	2050	2060
Level 2	1.2	1.7	2.1	2.4
Direct Current Fast Charging (60 KW)	0.2	0.3	0.4	0.4
Total	1.4	1.8	2.5	2.8

For Light-Duty Trucks, Heavy-Duty Trucks, and Buses

	2030	2040	2050	2060
Direct Current Fast Charging (20KW-150KW)	1.4	3.8	4.3	4.5
Direct Current Fast Charging (350 KW-1,500KW)	0.1	0.2	0.2	0.2
Total	1.4	4.0	4.5	4.8

The AP Scenario reflects the investment needed to build the equivalent of 2.8 million chargers for cars and SUVs and 4.8 million chargers for buses, light-duty trucks, and heavy-duty trucks. For cars and SUVs, charger installation costs and charger types draw on a study by Chinese researchers analyzing data from China.[59] For trucks and buses, installation costs are based on a study of commercial vehicles in the Chinese context,

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[vii] Renewable technologies are defined as including solar photovoltaic, solar thermal, onshore wind, offshore wind, and geothermal. Zero-emission technologies are defined as inclusive of renewables plus hydroelectric, nuclear, biomass, and municipal solid waste type electric power generating plants.

[viii] In some cases, the components of this table intentionally do not add to the sum, due to rounding.

while estimation of the required number and types of chargers in the future employs a recent California Energy Commission analysis.[60, 61]

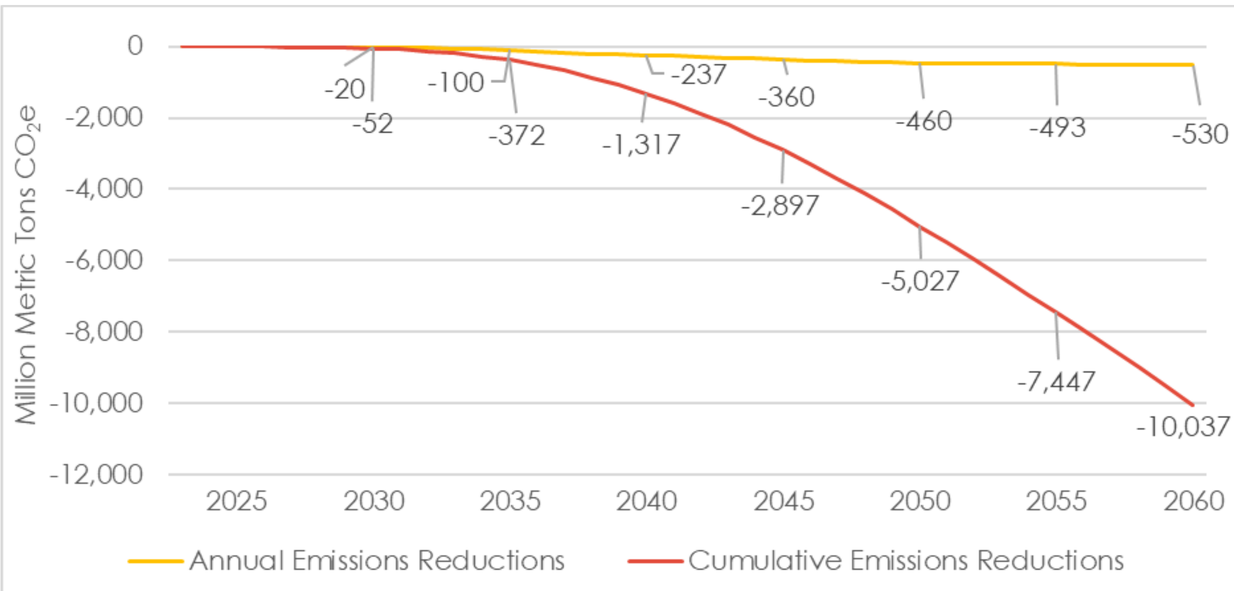
RESULTS

The following results compare the AP Scenario to the BAU Scenario. Results are economy-wide in scope, except for the results of direct vehicle emissions analysis in Figures 4 and 5 and Table 6.

CLIMATE AND HEALTH IMPACTS

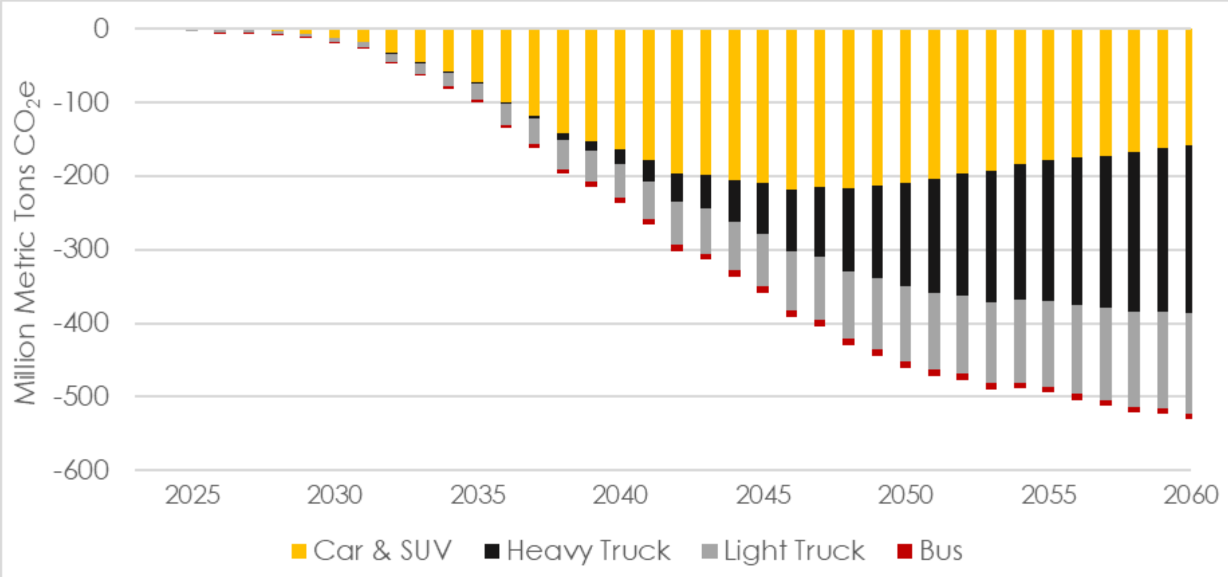
Faster NEV deployment in the AP Scenario reduces GHG emissions by 20 MMT of CO_2e in 2030. These emissions reductions grow steadily to 530 MMT of CO_2e in 2060, as shown in Figure 2. Cumulative emissions reductions are 52 MMT of CO_2e through 2030 and reach 10,000 MMT of CO_2e in 2060. These emissions impacts include the indirect emissions from electricity needed to meet new transportation demand as well as reduced emissions from petroleum refining due to lower demand for gasoline and diesel.

Figure 2. CO_2e emissions reductions in AP Scenario, annual and cumulative



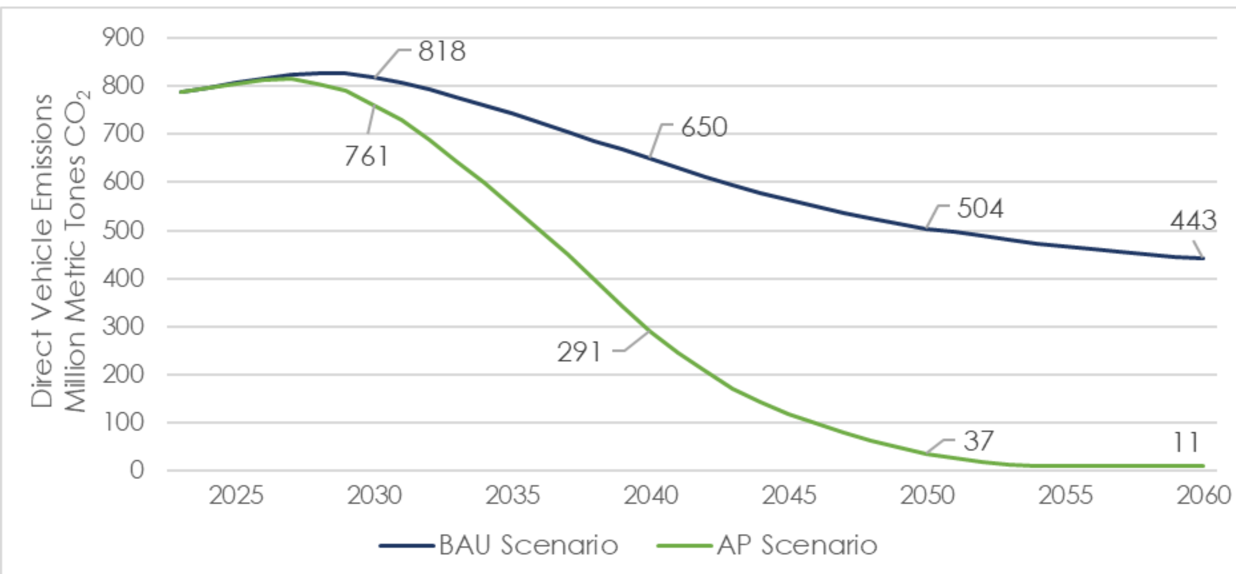
Error! Not a valid bookmark self-reference., next, disaggregates decarbonization impacts by vehicle category—Cars & SUVs, Light Trucks, Heavy Trucks, and Buses. The Appendix offers more detailed numerical results.

Figure 3. CO_2e emissions reductions by vehicle category



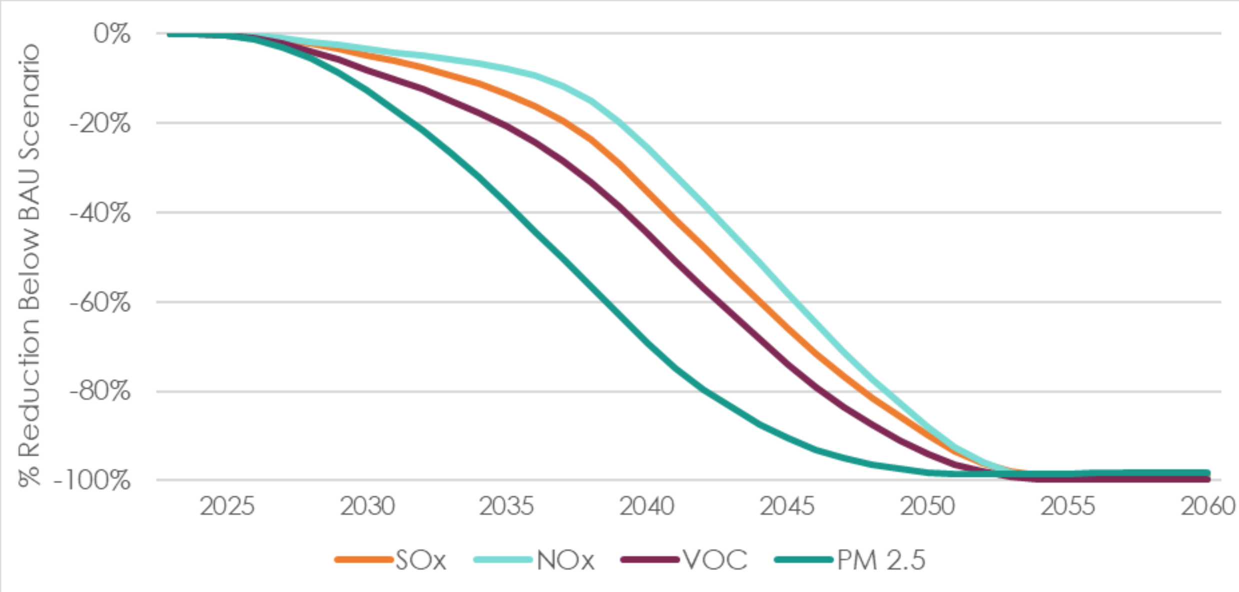
Direct vehicle emissions include those for which vehicles themselves are the source (e.g., tailpipe emissions from combustion of diesel, gasoline, natural gas, and liquefied petroleum gas). Direct vehicle emissions exclude increased electricity sector emissions from greater demand for electricity caused by faster NEV deployment in the AP Scenario. The different emissions sources account for why emissions reductions in Figure 4, below, are greater than the totals presented in Figure 2 and Figure 3, above.

Figure 4. Direct vehicle emissions of CO_2 in BAU vs. AP scenarios[ix]



[ix] Direct vehicle emissions include transportation sector impacts, while excluding changes in other sectors.

Figure 5. Reductions in direct vehicle co-pollutant emissions (% reduction below BAU Scenario)



As detailed in Table 6, below, the AP Scenario ultimately eliminates 98 to 99 percent of direct vehicle emissions compared to the BAU Scenario. Reductions in direct vehicle emissions never reach 100 percent due to the remaining combustion emissions from plug-in hybrid vehicles.

Table 6. Impact on direct vehicle pollutant emissions (% reduction below BAU Scenario)

	2030	2040	2050	2060
CO_2 (carbon dioxide)	-7%	-55%	-93%	-98%
NO_x (nitrogen oxides)	-5%	-35%	-90%	-98%
PM 2.5 (particulate matter 2.5 micron or less)	-3%	-26%	-88%	-98%
SO_x (sulfur oxides)	-8%	-45%	-94%	-99%
VOC (volatile organic compounds)	-13%	-69%	-98%	-99%

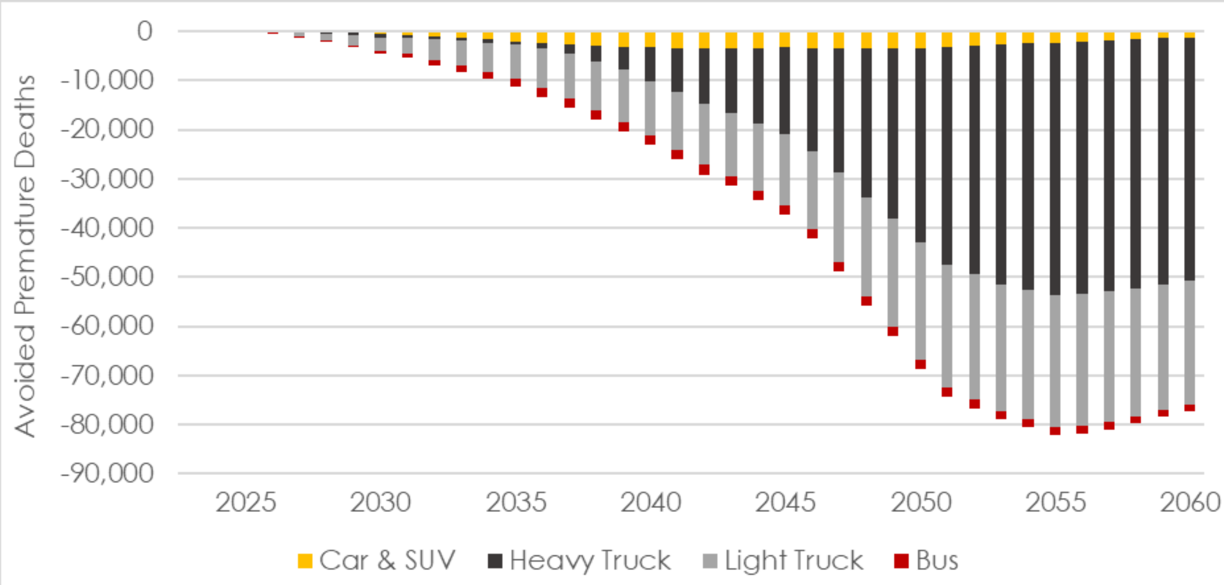
Next, returning to the economy-wide perspective, we present estimates of the public health benefits in the AP Scenario. Reduced negative health effects result from the improved air quality produced by lower air pollutant emissions. The China EPS quantifies 10 types of health impacts. Table 7 details four of these for the AP Scenario, starting with avoided premature deaths, which are estimated to reach 4,400 in 2030 and 77,000 in 2060.

Table 7. Health improvements from reduced air pollution exposure in the AP Scenario

	2030	2040	2050	2060
Reduced premature mortality (lives saved)	-4,400	-22,000	-69,000	-77,000
Reduced asthma attacks	-130,000	-690,000	-2,100,000	-2,300,000
Reduced work loss days	-550,000	-2,600,000	-7,400,000	-8,200,000
Reduced activity restriction days	-3,200,000	-15,000,000	-41,000,000	-46,000,000

Error! Not a valid bookmark self-reference. attributes avoided premature deaths to different vehicle categories, illustrating that new energy freight trucks deliver the largest health benefits. In fact, China EPS results find faster adoption of new energy light- and heavy-duty trucks are responsible for an average of 84 percent of annual avoided premature deaths.

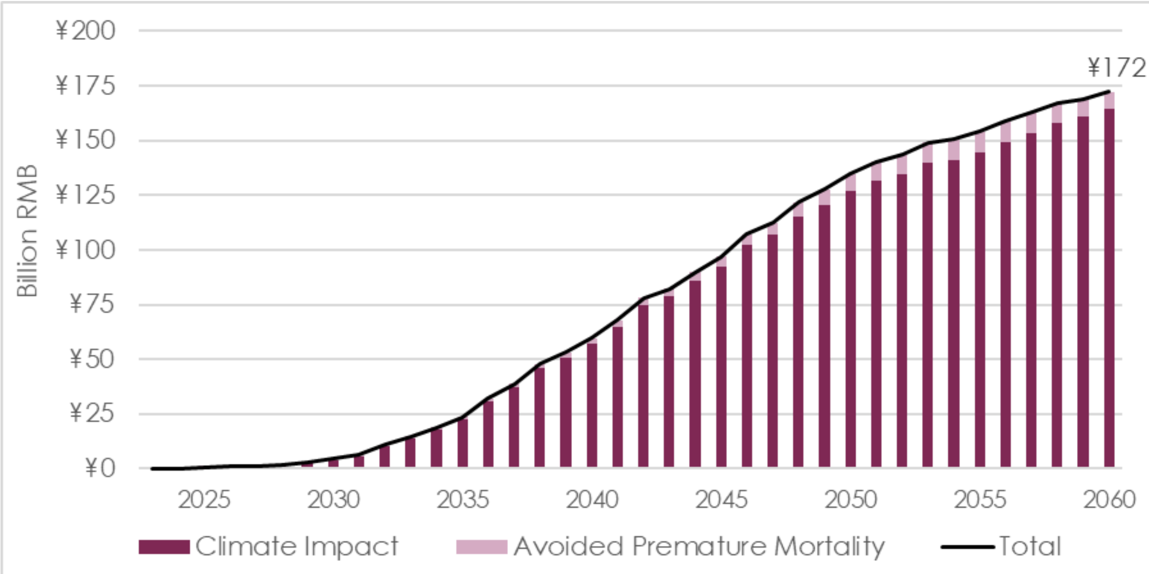
Figure 6. Lives saved by vehicle category (annual avoided premature deaths)



Disproportionate health gains from accelerated NEV truck deployment arise from two causes. First, diesel engine exhaust is more damaging to human health, and in China as in other nations, most of the diesel vehicles on roads are trucks. Second, the current slower deployment of NEV trucks in the BAU Scenario means there is a greater potential for emissions reductions from faster NEV adoption. Similarly, faster uptake of NEV cars and SUVs in the BAU Scenario reduces the scope of the transformation required, moderating AP Scenario impacts attributable to these vehicles. Still, the sheer number of cars and SUVs in China's fleet and their fuel demand mean cars and SUVs drive the majority of GHG reductions through 2049, observable above in Error! **Not a valid bookmark self-reference.**, next, disaggregates decarbonization impacts by vehicle category—Cars & SUVs, Light Trucks, Heavy Trucks, and Buses. The Appendix offers more detailed numerical results.

Figure 3. CO_2e emissions reductions by vehicle category

Figure 7. Monetization of climate and health impact



Economic valuation techniques make it possible to calculate the monetary value effects of carbon emissions reductions and avoided deaths, which is the only health impact the EPS monetizes currently. Figure 7 charts China EPS monetized estimates of climate benefits and reduced premature mortality resulting from faster NEV adoption in the AP Scenario.

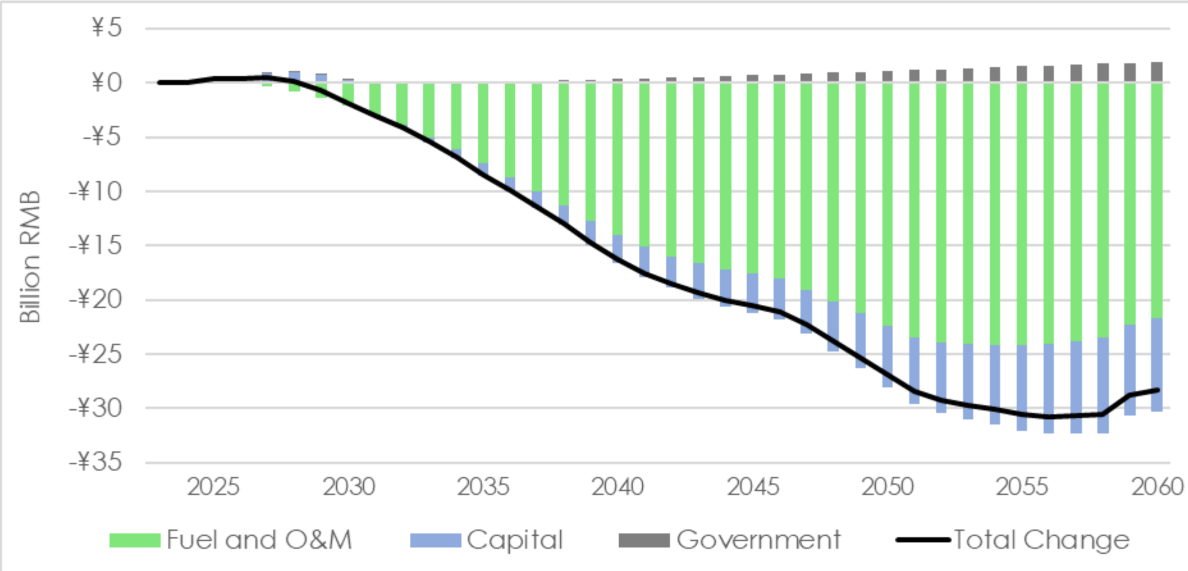
ECONOMIC IMPACTS

To investigate economic impacts, we first, present the AP Scenario's impacts on the direct costs of faster NEV adoption. Direct costs refer to capital expenses ("CapEx"; i.e., equipment), operating expenses ("OpEx"; i.e., related to operational cost, such as energy use, and maintenance), and government transfers.[x]

China EPS modeling finds large operational costs savings, following from NEVs' fuel efficiency advantage and lower maintenance costs. In the first few years, increases in capital costs, reflecting initially higher NEV purchase prices, lead to net added costs. Within several years, in 2028, operational savings grow large enough to outweigh capital cost increases. Over time, NEV purchase prices fall below those of conventional vehicles, yielding savings on capital expenditures, even accounting for additional investment in electricity capacity and charging infrastructure. Figure 8 shows CapEx and OpEx results, illustrating that net cost reductions are the dominant trend.

[x] Government transfers account for changes in subsidies and taxes in the AP Scenario as compared to the BAU Scenario.

Figure 8. Annual change in CapEx and OpEx



Our study finds faster NEV deployment could create millions of new jobs. The employment impact peaks at a net gain of 2.4 million jobs in 2032, as shown in Figure 9. Growth in the "Other" jobs category is greatest, mainly caused by re-spending of fuel and maintenance savings. Employment in the "Fossil & Utility" sectors also expands steadily over time. EPS results indicate initial gains in "Manufacturing & Construction," decreasing over time because of lower capital spending. Lower capital spending is due to savings on new vehicles as NEV purchase prices fall below those of conventional vehicles.

Figure 9. Employment effects (annual change in full-time equivalent jobs in millions)

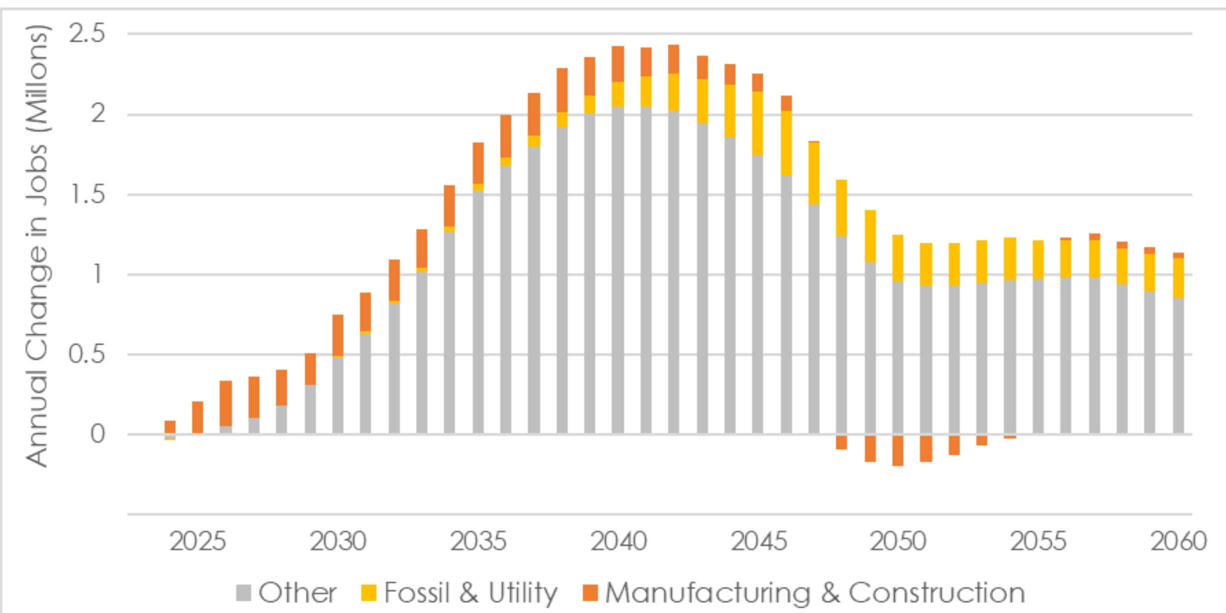


Figure 10. Gross domestic product effects

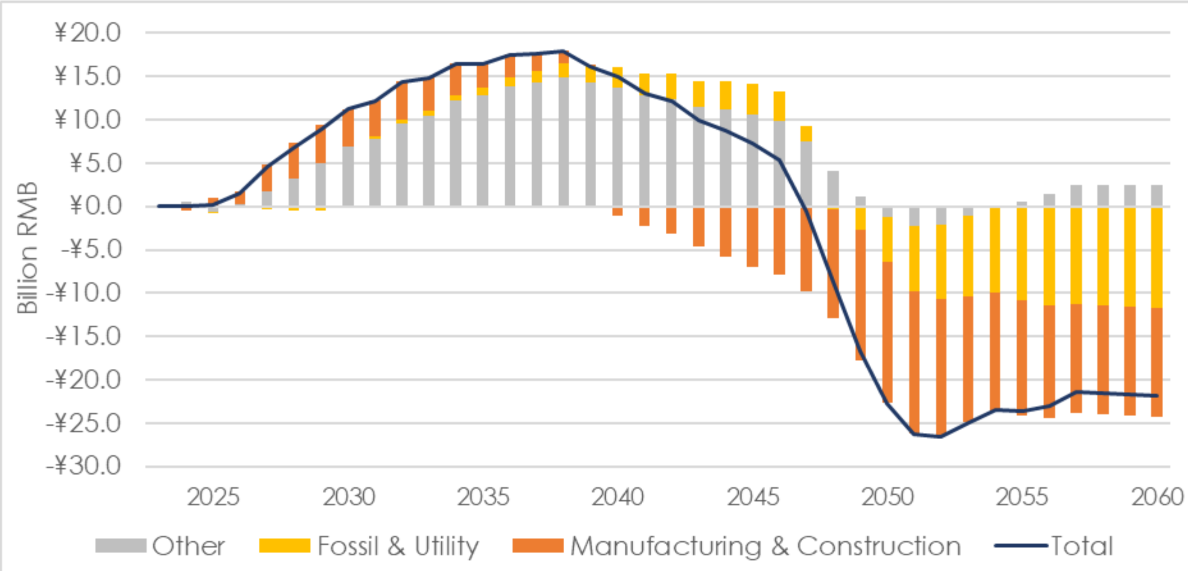
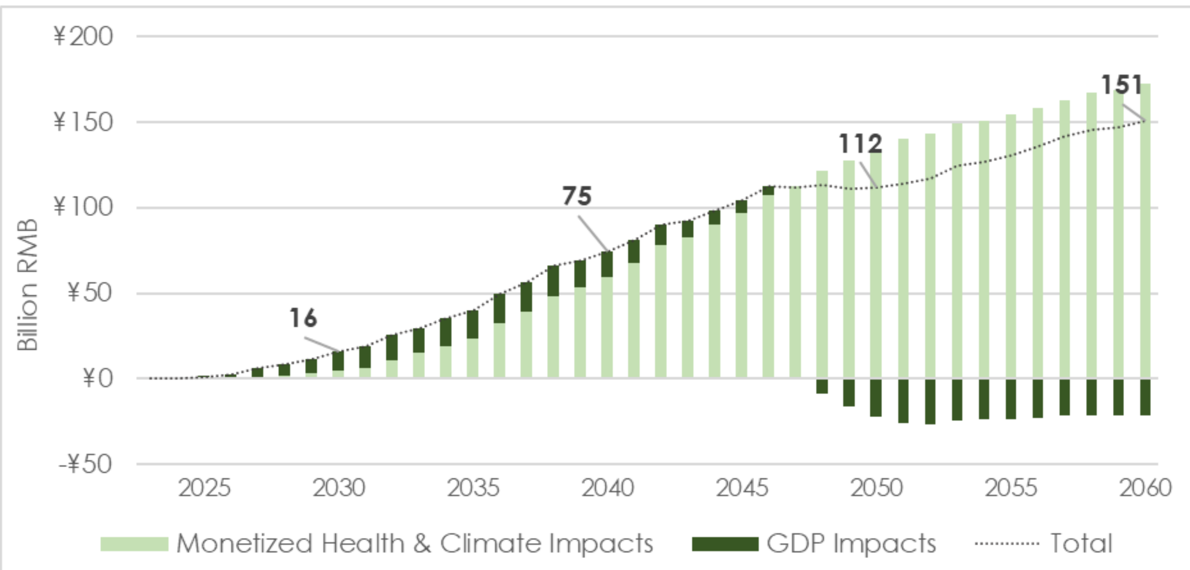


Figure 10 shows overall positive gross domestic product effects through 2047. Figure 11 takes a broader view, combining gross domestic product effects with monetized climate and health benefits.

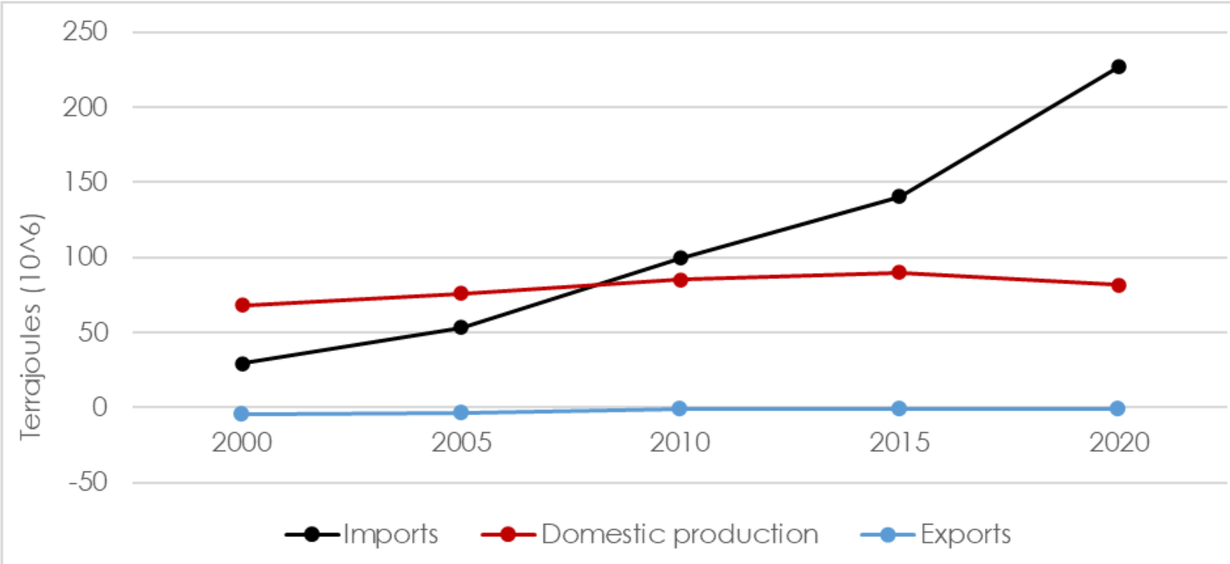
Figure 11. Aggregating gross domestic product impacts and monetized health and climate effects



DEPENDENCE ON IMPORTED OIL

China surpassed the United States to become the world's largest oil importer in 2017.[62] Gasoline and diesel are the principal outputs from crude oil refining, representing about 70 percent of petroleum refinery production by volume in China.[63] Thus, there is a clear linkage between the fuel China's conventional vehicles demand and the country's dependence on imported petroleum.

Figure 12. Crude oil imports, exports, and production for China, 2000-2020[64]

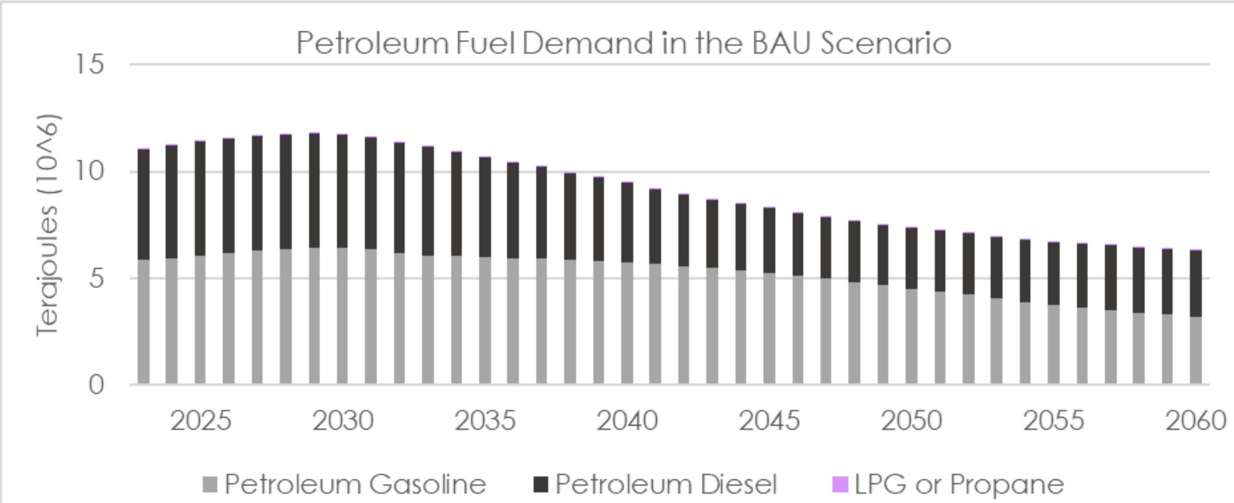


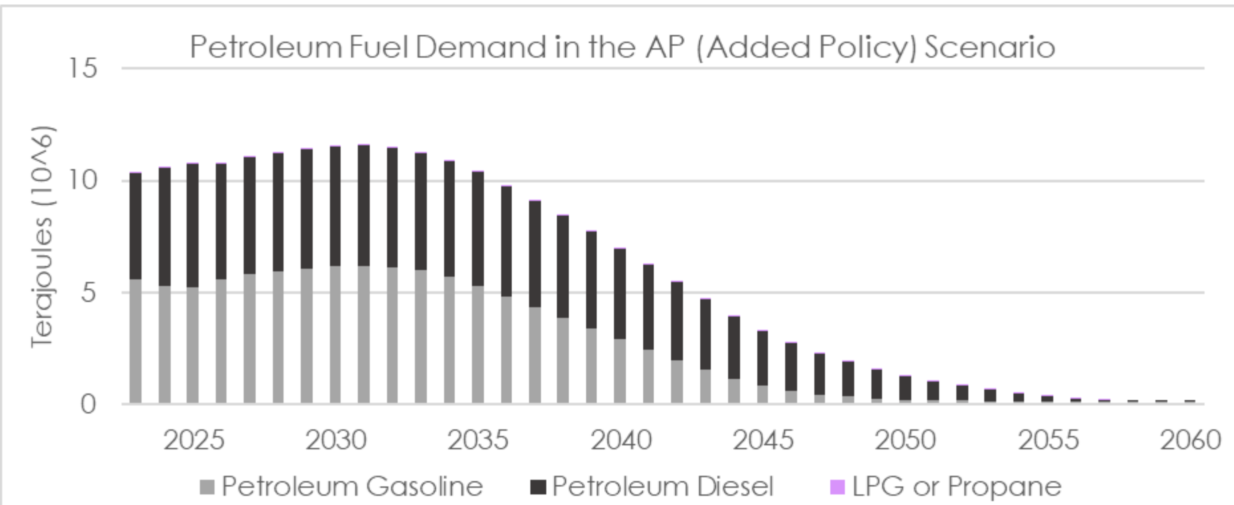
Source: International Energy Agency[65]

Chinese producers supply most of the NEVs demanded by its domestic market, including the battery packs that power EVs.[66] Additionally, battery-electric vehicles pose lower risk of consumer price shocks.. Price spikes in refined petroleum products like gasoline or diesel immediately affect all conventional vehicles, no matter how new or old. Continued use of conventional ICE vehicles requires regular refueling, with most of that supply being imported. In contrast, China domestically sources most its electricity. Moreover, an EV price spike, such as could occur due to battery mineral input price fluctuations, is likely to have no impact on most consumers because only a fraction will be looking to buy a new vehicle at a given time. China has more than 200 million motor vehicle owners[67] and around 25 million new car buyers annually[68]—almost an order of magnitude fewer. Some vehicle buyers might also have the option of delaying their purchase if EV prices were to jump, further dampening the disutility of EV-related market variability.

Another advantage for NEVs concerns battery recyclability. It may be possible to recover and recycle upwards of 99 percent of battery metals at the end of an EV's lifetime.[69] In contrast, the ICEs powering conventional vehicles convert fuels into kinetic energy (the vehicle's motion), waste heat, and air pollution—none of which can be recycled. Thus, as a nation accumulates more and more EVs, the share of resource demands related to motor vehicle ownership and operation that may be met through domestic recycled resources also increases. Petroleum-fueled ICE vehicles do not offer this advantage.

Figure 13. Petroleum transportation fuel use in BAU Scenario vs. AP Scenario[xi]



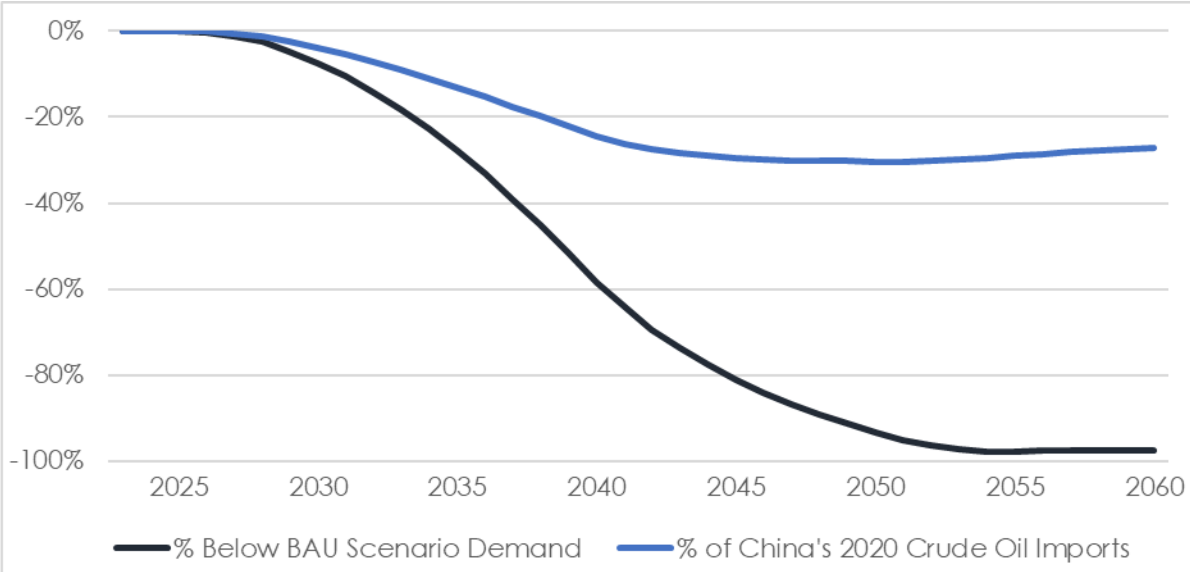


To explore effects on China's dependence on imported oil, we first calculate reductions in petroleum-derived transportation fuels due to faster NEV adoption. Figure 13 shows on-road vehicle demand for gasoline, diesel, or liquefied petroleum gas (LPG) in the BAU Scenario and AP Scenario.

Deriving annual petroleum-fuel demand reductions from the results above, we next provide an economy-wide comparison for these effects to contextualize their importance to China's overall demand for oil. Figure 14 presents two perspectives on petroleum-fuel demand reductions: the first metric calculates reductions as a fraction of demand for petroleum fuels from cars and SUVs, buses, and light- and heavy-duty trucks in the BAU Scenario; the second metric compares the petroleum-fuel demand reductions for each year as a percentage of 2020 crude oil imports.

[xi] Demand for LPG or propane is small enough that it is difficult to distinguish in the graph, but it is included for completeness.

Figure 14. Petroleum fuel demand reduction in AP Scenario[xii]



Sources: China EPS results and International Energy Agency[70]

Faster NEV deployment in the AP Scenario would cause refined motor vehicle petroleum fuel demand for cars and SUVs, buses, and trucks to fall by 28 percent in 2035, 81 percent in 2045, and 97 percent in 2060. The figure also shows petroleum-fuel demand in the AP Scenario as a percentage of 2020 crude oil imports. AP Scenario reductions as a percentage of 2020 crude oil imports grow to a maximum of 30 percent in 2051. The percentage reduction falls in 2052 and later years because of declining BAU Scenario demand. Lower demand correspondingly reduces the maximum potential reduction compared to 2020 crude oil imports.[xiii]

China EPS results indicate the more rapid NEV deployment represented in the AP Scenario could significantly lessen China's reliance on oil imports. However, painting a complete picture requires acknowledging other factors influencing petroleum imports. For example, China is a net exporter of refined petroleum products like gasoline and diesel, providing an alternative source of domestic demand for oil. Furthermore, other products such as jet fuel and petrochemical feedstocks also rely on crude oil as a production input. So, while domestic petroleum fuel demand for motor vehicles is a key determinant of oil demand, other factors are also relevant. Therefore, the preceding numerical results are not directly translatable to quantitative estimates of future oil import reductions.

POLICY RECOMMENDATIONS

Over the past decade, China has implemented a wide range of policies at all government levels—national, provincial, county, and city—to encourage NEV adoption. These efforts have established China as the world's largest EV market. Recently, China's battery-swapping pilot projects for new energy heavy-duty

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[xii] "% Below BAU Scenario" is calculated as the difference between demand for diesel, gasoline, and LPG in the AP and BAU scenarios divided by BAU Scenario demand. "% of China's 2020 Crude Oil Imports" is calculated by dividing the same numerator—estimated demand reduction—by the quantity of oil China imported in 2020.

[xiii] "% Below BAU Scenario" grows continuously, even after 2051, because it is measured relative to BAU Scenario fuel use. That is to say, the calculation of "% Below BAU Scenario" has BAU Scenario demand for any given year in the denominator.

trucks grew to around 50 percent of new energy heavy-duty truck sales in 2022.[71] From this preface recognizing China's extensive NEV policy portfolio, we offer our two main domestic policy recommendations:

1) Set clear and ambitious long-term targets for NEV truck sales.

Our first recommendation is for China's policymakers to establish clear, ambitious, long-term goals for NEV truck sales. We provide two existing examples for cars and SUVs: one, China's State Council called for battery-electric vehicles to become the "mainstream" technology for passenger automobiles by 2035,[72] and two, the China Society of Automotive Engineers' *Technology Roadmap 2.0* endorses a 2035 target of 50 percent for new car and SUV sales.[73]

We suggest aiming for the AP Scenario levels modeled in our study: In 2030, NEV sales of 56 percent for light-duty trucks and 46 percent for heavy-duty trucks; in 2035, NEV sales of 82 percent for light-duty trucks and 68 percent for heavy-duty trucks. The ICCT deems these targets realistically achievable.[74, 75]

New energy truck sales trends in recent years are another reason NEV deployment as modeled in the AP Scenario should be considered achievable. The new energy truck market is exhibiting rapid progress like that of new energy cars and SUVs as they began to takeoff, and if new energy truck sales in China continue to follow a similar year-over-year growth pattern, actual truck sales would exceed the recommended levels in 2030.

California's market demonstrates the potential for rapid adoption. A recent California Air Resources Board study shows the state is already shattering its targets for electric medium- and heavy-duty truck sales, which made up 7.5 percent of statewide truck sales in 2022.[76] That represents significant progress beyond the 6 percent threshold set for 2024 by the state's Advanced Clean Trucks policy.[77] California is offering a case study of the rapid progress possible when policy, innovation, and market forces align.

2) Undertake immediate implementation of supportive policies to help reach these targets. A priority is establishing a "Dual Credit"-type policy for commercial vehicles.

We understand a commercial vehicle Dual Credit-type policy is under consideration, and we suggest that instituting it should be a priority. While China recently extended its Dual Credit policy for cars and SUVs to 2025, a similar policy does not exist for commercial vehicles.[78] The ICCT deems the existing Dual Credit policy for light-duty vehicles "the main driver for [NEV] market growth in China."[79]

While these recommendations spotlight the urgency of new energy truck progress, China EPS results support the accelerated deployment of NEVs across all on-road vehicles. One cross-cutting design recommendation is to aim for longer-range policy horizons. The pace of change in NEV technology and markets makes it challenging to stay fully abreast of global developments, and even more so to plan far into the future. One way to manage uncertainty is through price caps on the tradable NEV credits used for compliance. These are easily implemented by offering unlimited NEV credits at the desired price cap.[xiv] [80] Long-term NEV policy amid rapid technological change is challenging, but manageable and worthwhile. Increased long-term certainty about the future shape of NEV demand will boost investment and stimulate additional innovation.[81]

[xiv] Rather than allowing excess NEV credits to be used for compliance with vehicle fuel efficiency requirements, we suggest a separate policy directly targeting vehicle fuel efficiency.

CONCLUSION

Three years ago, China pledged to reach net-zero emissions by 2060.[82] Growing policy commitments, the expanding toolbox of mature decarbonization technologies, and these technologies' rising commercial success are positive developments. Yet other signs point to the urgency of accelerated action.[83] China's record-breaking heat in summer 2023 is one of many recent examples of alarming climate extremes. Even so, the country's GHG emissions grew again in 2022, when they need to fall sharply by the end of the next decade.[84] Even stronger ambition and faster, more effective near-term implementation are required from policymakers for the world to get on track for international goals.

China's pledge to reach carbon neutrality by 2060 makes the choice clear. A successful net-zero strategy must include maximizing the opportunities provided by mature, commercially available, and cost-effective climate solutions, such as EVs.[85] Given the scale of the Chinese market, these measures will significantly boost global efforts to decarbonize transportation. By accelerating the transition to NEVs, China's policymakers can induce rapid innovation and lower costs, supporting greater international action.

While the global benefits are impressive, our study also illustrates that China's rapid development of NEVs will generate invaluable domestic benefits: better air quality, improved health outcomes, job creation, and other economic benefits.

APPENDIX: MORE MODELING RESULTS

Table 8. Emissions reductions by vehicle category (MMT of CO_2e)[xv]

	2030	2035	2040	2045	2050	2055	2060
Cars & SUVs	-12	-73	-160	-210	-209	-180	-160
Heavy Truck	-1	-1	-20	-69	-140	-190	-230
Light Truck	-5	-22	-46	-72	-100	-120	-136
Bus	-1	-4	-7	-9	-9	-8	-7
Total	-20	-100	-240	-360	-460	-490	-530

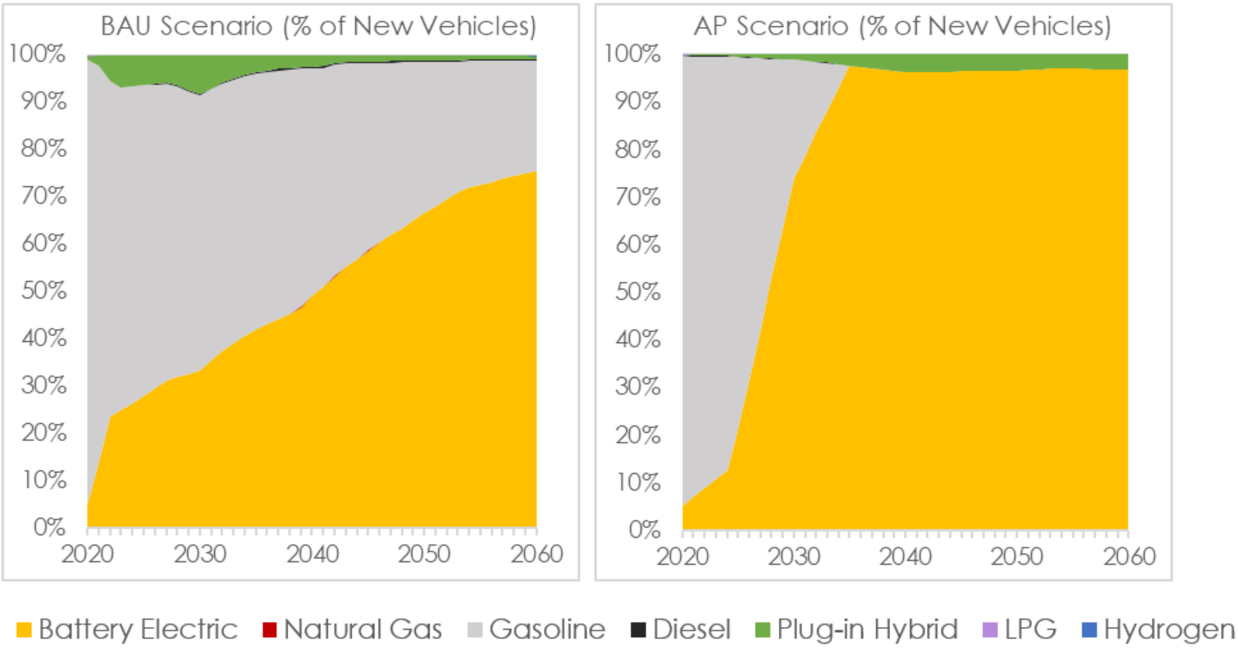
Table 9. Lives saved by vehicle category (annual avoided premature deaths)[xvi]

	2030	2035	2040	2045	2050	2055	2060
Cars & SUVs	-590	-2000	-3,300	-3,300	-3,460	-2,300	-1,300
Buses	-580	-580	-6,800	-17,000	-40,000	-51,000	-50,000
Light Truck	-2,300	-7000	-11,000	-15,000	-24.000	-27,000	-25,000
Heavy Truck	-570	-1500	-1,900	-1,800	-2,000	-1,700	-1,300
Total	-4,400	-11,000	-23,000	-37,000	-69,000	-82,000	-77,000

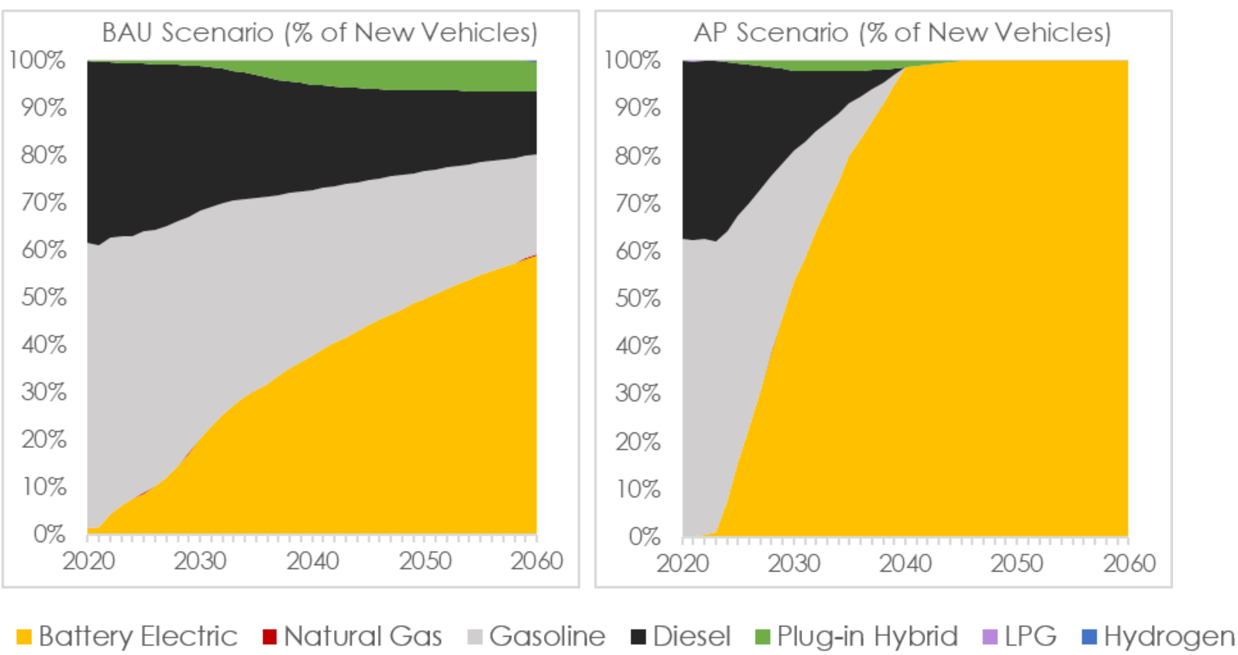
[xv] Totals may not equal sum of component parts due to rounding.
[xvi] Totals may not equal sum of component parts due to rounding.

Figure 15. NEV sales share by vehicle category in BAU and AP scenarios

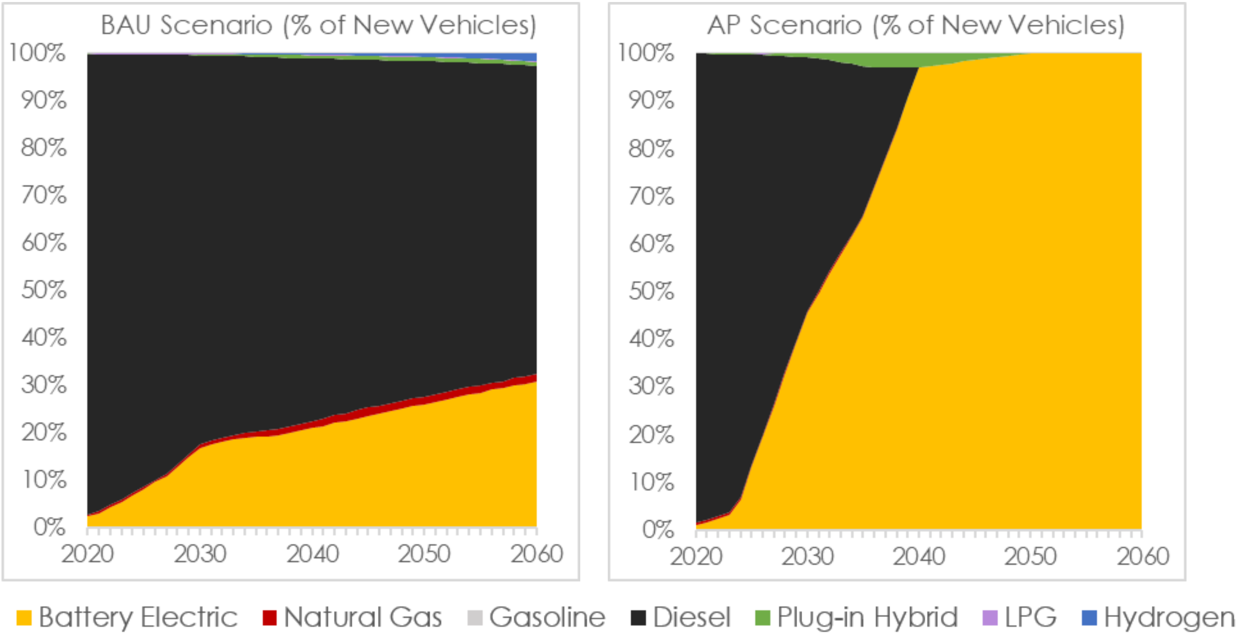
Cars and SUVs



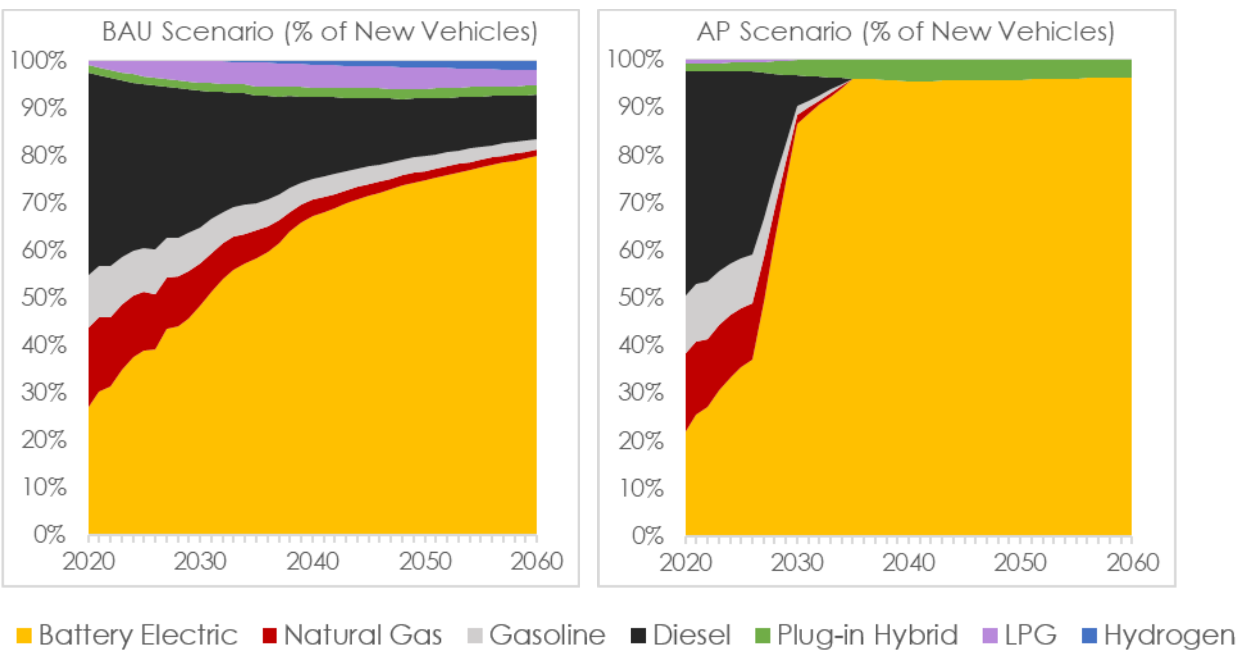
Light-Duty Trucks



Heavy-Duty Trucks



Buses



REFERENCES

[1] Haotian Zheng et al., "Transition in Source Contributions of PM2.5 Exposure and Associated Premature Mortality in China during 2005–2015," *Environment International* 132 (November 1, 2019): 105111, https://doi.org/10.1016/j.envint.2019.105111.

[2] innovative Green Development Project and Energy Innovation, "China Energy Policy Simulator," 2023, https://energypolicy.solutions/home/china-igdp/en.

[3] Zhinan Chen and Hui He, "How Will the Dual-Credit Policy Help China Boost New Energy Vehicle Growth?" (International Council on Clean Transportation, February 10, 2022), https://theicct.org/china-dual-credit-policy-feb22/.

[4] Peter Mock and Zifei Yang, "A 2022 Update on Electric Car Sales: China Taking the Lead, the U.S. Catching up, and Europe Falling Behind," *International Council on Clean Transportation* (blog), August 19, 2022, https://theicct.org/2022-update-ev-sales-us-eu-ch-aug22/.

[5] Arijit Sen and Josh Miller, "Vision 2050: Update on the Global Zero-Emission Vehicle Transition," White Paper (International Council on Clean Transportation, 9/23), https://theicct.org/wp-content/uploads/2023/09/Global-ZEV-update_final.pdf.

[6] Chris Harto, "Electric Vehicle Ownership Costs: Today's Electric Vehicles Offer Big Savings for Consumers" (Consumer Reports, October 2020), https://advocacy.consumerreports.org/wp-content/uploads/2020/10/EV-Ownership-Cost-Final-Report-1.pdf.

[7] Benchmark Mineral Intelligence, "Global Cell Prices Fall below $100/kWh for First Time in Two Years," *Benchmark Source: Supply Chain Intelligence* (blog), September 6, 2023, https://source.benchmarkminerals.com/article/global-cell-prices-fall-below-100-kwh-for-first-time-in-two-years.

[8] David Fickling, "Climate: Solar, EV Boom While Wind Struggles in Net-Zero Race - Bloomberg," *Bloomberg*, September 13, 2021, https://www.bloomberg.com/opinion/articles/2023-09-13/climate-solar-ev-boom-while-wind-struggles-in-net-zero-race.

[9] Energy Information Administration, "China Surpassed the United States as the World's Largest Crude Oil Importer in 2017" (U.S. Department of Energy, December 2018), https://www.eia.gov/todayinenergy/detail.php?id=37821.

[10] International Energy Agency, "Oil Information - Data Product," https://www.iea.org/data-and-statistics/data-product/oil-information.

[11] International Energy Agency, "Net Zero by 2050" (Paris: IEA, 2021), https://www.iea.org/reports/net-zero-by-2050.

[12] International Energy Agency, "Global EV Outlook 2023," accessed August 4, 2023, https://www.iea.org/reports/global-ev-outlook-2023.

[13] International Energy Agency, "Net Zero by 2050."

[14] United Nations Framework Convention on Climate Change, Secretariat, "Synthesis Report by the Co-Facilitators on the Technical Dialogue of the First Global Stocktake," September 8, 2023, https://unfccc.int/documents/631600.

[15] Zheng et al., "Transition in Source Contributions."

[16] "Evaluating Electric Vehicle Costs and Benefits in China in the 2020–2035 Time Frame," *International Council on Clean Transportation* (blog), accessed September 12, 2023, https://theicct.org/publication/evaluating-electric-vehicle-costs-and-benefits-in-china-in-the-2020-2035-time-frame/.

[17] BloombergNEF, "Battery Pack Prices Fall to an Average of $132/kWh, But Rising Commodity Prices Start to Bite," November 30, 2021, https://about.bnef.com/blog/battery-pack-prices-fall-to-an-average-of-132-kwh-but-rising-commodity-prices-start-to-bite/.

[18] BloombergNEF, "A Year of Breakthroughs and Setbacks for the Race to Net Zero," December 29, 2022, https://about.bnef.com/blog/a-year-of-breakthroughs-and-setbacks-for-the-race-to-net-zero-in-five-charts/.

[19] David Fickling, "We're Not Even Close to Running Out of Green Minerals," *Bloomberg.com*, February 6, 2023, https://www.bloomberg.com/opinion/articles/2023-02-06/energy-transition-we-re-not-close-to-running-out-of-green-minerals.

[20] Benchmark Mineral Intelligence, "Global Cell Prices Fall below $100/kWh."

[21] Benchmark Mineral Intelligence, "Global Cell Prices Fall below $100/kWh."

[22] Fickling, "Climate: Solar, EV Boom."

[23] China Association of Automobile Manufacturers, "Sales of New Energy Vehicles in January 2023," February 9, 2023, http://en.caam.org.cn/Index/show/catid/66/id/2050.html.

[24] International Energy Agency, "Global EV Data Explorer," May 23, 2022, https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer.

[25] China Association of Automobile Manufacturers, "Sales of New Energy Vehicles in June 2023," July 12, 2023, http://en.caam.org.cn/Index/show/catid/66/id/2045.html.

[26] BloombergNEF, "Global Low-Carbon Energy Technology Investment Surges Past $1 Trillion for the First Time," *BloombergNEF* (blog), January 26, 2023, https://about.bnef.com/blog/global-low-carbon-energy-technology-investment-surges-past-1-trillion-for-the-first-time/.
[27] Harto, "Electric Vehicle Ownership Costs."
[28] Robbie Orvis, "Most Electric Vehicles Are Cheaper to Own Off the Lot Than Gas Cars" (Energy Innovation: May 2022), https://energyinnovation.org/wp-content/uploads/2022/05/Most-Electric-Vehicles-Are-Cheaper-Off-The-Lot-Than-Gas-Cars.pdf.
[29] Rupert Way et al., "Empirically Grounded Technology Forecasts and the Energy Transition," *Joule*, September 13, 2022, https://doi.org/10.1016/j.joule.2022.08.009.
[30] International Energy Agency, "Energy Technology Perspectives 2023," Flagship Report, January 2023, https://www.iea.org/reports/energy-technology-perspectives-2023.
[31] Mingqiang Wang et al., "Multifactorial Engineering of Biomimetic Membranes for Batteries with Multiple High-Performance Parameters," *Nature Communications* 13, no. 1 (January 12, 2022): 278, https://doi.org/10.1038/s41467-021-27861-w.
[32] Colin McKerracher, "EV Sales Are Soaring and Oil Use Is About to Peak: Hyperdrive," *Bloomberg.com*, June 8, 2023, https://www.bloomberg.com/news/articles/2023-06-08/ev-sales-are-soaring-and-oil-use-is-about-to-peak-hyperdrive.
[33] Kim Heejin, "Korea's Battery Makers Embrace LFP Cells as China Strides Ahead," *Bloomberg.com*, May 15, 2023, https://www.bloomberg.com/news/articles/2023-05-15/korea-s-battery-makers-embrace-lfp-cells-as-china-strides-ahead.
[34] Annie Lee and Gabriela Coppola, "How Tesla's Quest for Cheaper Batteries Boosts China," *Bloomberg.com*, April 4, 2023, https://www.bloomberg.com/news/articles/2023-04-04/how-tesla-s-quest-for-cheaper-batteries-buoys-china-quicktake.
[35] Sophie Caronello, "Five Key Charts to Watch in Global Commodity Markets This Week," *Bloomberg.com*, June 11, 2023, https://www.bloomberg.com/news/articles/2023-06-11/five-key-charts-to-watch-in-global-commodity-markets-this-week.
[36] BloombergNEF, "Race to Net Zero: The Pressures of the Battery Boom in Five Charts," July 21, 2022, https://about.bnef.com/blog/race-to-net-zero-the-pressures-of-the-battery-boom-in-five-charts/.
[37] Luhan Ye and Xin Li, "A Dynamic Stability Design Strategy for Lithium Metal Solid State Batteries," *Nature* 593, no. 7858 (May 2021): 218–22, https://doi.org/10.1038/s41586-021-03486-3.
[38] "Explainer: How Could Solid-State Batteries Improve Next-Gen EVs?," *Reuters*, June 13, 2023, https://www.reuters.com/business/autos-transportation/how-could-solid-state-batteries-improve-next-gen-evs-2023-06-13/.
[39] Nathaniel Bullard, "Rapid EV Growth Hastens the Peak, Then Fall, of Internal Combustion," *Bloomberg*, July 1, 2022, https://www.bloomberg.com/news/articles/2022-06-01/when-will-gas-cars-be-phased-out-sales-peaked-and-soon-the-fleet-will-too.
[40] Nathaniel Bullard, "Decarbonization: The Long View, Trends and Transience, Net Zero," January 2023, https://www.nathanielbullard.com/presentations.
[41] Monica Raymunt, William Wilkes, and Stefan Nicola, "Tesla and China Risk Leaving Volkswagen on a Road to Nowhere," *Bloomberg.com*, September 10, 2023, https://www.bloomberg.com/news/features/2023-09-10/volkswagen-s-ev-strategy-comes-under-intense-focus-amid-german-economic-gloom.
[42] Raymunt, Wilkes, and Nicola, "Tesla and China Risk Leaving Volkswagen on a Road to Nowhere."
[43] International Agency for Research on Cancer, "Diesel Engine Exhaust Carcinogenic" (World Health Organization, June 12, 2012), https://www.iarc.who.int/wp-content/uploads/2018/07/pr213_E.pdf.
[44] Research Division, California Air Resources Board, "Diesel Particulate Matter Health Impacts Summary," https://ww2.arb.ca.gov/resources/summary-diesel-particulate-matter-health-impacts.
[45] Physics News, "NOx Gases in Diesel Car Fumes: Why Are They so Dangerous?," *Phys.org*, September 2015, https://phys.org/news/2015-09-nox-gases-diesel-car-fumes.html.
[46] W. S. Beckett, "Ozone, Air Pollution, and Respiratory Health," *The Yale Journal of Biology and Medicine* 64, no. 2 (1991): 167–75.
[47] Jamie T. Mullins, "Ambient Air Pollution and Human Performance: Contemporaneous and Acclimatization Effects of Ozone Exposure on Athletic Performance," *Health Economics* 27, no. 8 (August 2018): 1189–1200, https://doi.org/10.1002/hec.3667.
[48] innovative Green Development Project and Energy Innovation, "China Energy Policy Simulator."
[49] Energy Innovation, "Energy Policy Simulator Homepage," https://energypolicy.solutions/.
[50] Energy Innovation, "Energy Policy Simulator Documentation," March 5, , https://docs.energypolicy.solutions/.
[51] Energy Innovation, "Calculating the Number of New Vehicles | Transportation Sector | Energy Policy Simulator Documentation," https://docs.energypolicy.solutions/transportation-sector-main.
[52] Shiyue Mao et al., "Total Cost of Ownership for Heavy Trucks in China: Battery-Electric, Fuel Cell Electric and Diesel Trucks" (International Council on Clean Transportation, November 2021), https://www.theicct.org.cn/wp-content/uploads/2022/01/ze-hdvs-china-tco-EN-nov21-1.pdf.

[53] Arijit Sen and Josh Miller, "Vision 2050: Update on the Global Zero-Emission Vehicle Transition," (International Council on Clean Transportation, September 2023), https://theicct.org/wp-content/uploads/2023/09/Global-ZEV-update_final.pdf.
[54] Sen and Miller, "Vision 2050."
[55] BloombergNEF, "A Year of Breakthroughs and Setbacks for the Race to Net Zero."
[56] Sen and Miller, "Vision 2050."
[57] Sen and Miller, "Vision 2050."
[58] Sen and Miller, "Vision 2050."
[59] China Electric Vehicle Charging Infrastructure Promotion Alliance **中国**电动汽车充电设施促进联盟, "2019-2020**年度中国充**电基础设施发展报告；2019-2020 China Charging Infrastructure Development Report," January 2020, http://en.caam.org.cn/Uploads/File/2020-09-10/5f59ce29d1d17.pdf.
[60] Feiqin Zhu et al., "Does the Battery Swapping Energy Supply Mode Have Better Economic Potential for Electric Heavy-Duty Trucks?," *eTransportation* 15 (January 1, 2023): 100215, https://doi.org/10.1016/j.etran.2022.100215.
[61] Adam Davis et al., "Second Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment: Analyzing Charging Needs to Support Zero-Emission Vehicles in 2030 and 2035," (California Energy Commission, August 2023), https://efiling.energy.ca.gov/GetDocument.aspx?tn=251866&DocumentContentId=86859.
[62] Energy Information Administration, "China Surpassed the United States as World's Largest Oil Importer."
[63] International Energy Agency, "Oil Information - Data Product."
[64] International Energy Agency, "Oil Information - Data Product."
[65] International Energy Agency, "Oil Information - Data Product."
[66] International Energy Agency, "Energy Technology Perspectives 2023."
[67] innovative Green Development Project and Energy Innovation, "China Energy Policy Simulator."
[68] International Energy Agency, "Global Car Sales by Key Markets, 2005-2020," May 18, 2020, https://www.iea.org/data-and-statistics/charts/global-car-sales-by-key-markets-2005-2020.
[69] Casey Crownhart, "This Is Where Tesla's Former CTO Thinks Battery Recycling Is Headed," *MIT Technology Review*, January 17, 2023, https://www.technologyreview.com/2023/01/17/1066915/tesla-former-cto-battery-recycling/.
[70] International Energy Agency, "Oil Information - Data Product."
[71] Hongyang Cui, Yihao Xie, and Tianlin Niu, "China Is Propelling Its Electric Truck Market by Embracing Battery Swapping," (International Council on Clean Transportation, August 9, 2023), https://theicct.org/china-is-propelling-its-electric-truck-market-aug23/.
[72] State Council of the People's Republic of China, "New Energy Vehicle Industry Development Plan (2021-2035)," 2020, http://www.gov.cn/zhengce/content/2020-11/02/content_5556716.htm.
[73] Society of Automotive Engineers (China), "Energy-Saving and New Energy Vehicle Technology Roadmap 2.0," October 27, 2020, http://en.sae-china.org/a3967.html.
[74] Sen and Miller, "Vision 2050."
[75] Yihao Xie, Tim Dallmann, and Rachel Muncrief, "Heavy-Duty Zero-Emission Vehicles: Pace and Opportunities for a Rapid Global Transition," (International Council on Clean Transportation, May 2022), https://theicct.org/wp-content/uploads/2022/05/globalhvsZEV-hdzev-pace-transition-may22.pdf.
[76] California Air Resources Board, "Advanced Clean Trucks Credit Summary Through the 2022 Model Year," October 13, 2023, https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-trucks-credit-summary-through-2022-model-year.
[77] Office of Governor Gavin Newsom, "California Hit Zero-Emission Vehicle Truck Sales Goal Two Years Ahead of Schedule," October 23, 2023, https://www.gov.ca.gov/2023/10/23/california-hit-zev-truck-sales-goal-two-years-ahead-of-schedule/.
[78] Ceh and He, "How Will the Dual-Credit Policy Help China Boost New Energy Vehicle Growth?," (International Council on Clean Transportation, February 2022), https://theicct.org/china-dual-credit-policy-feb22/.
[79] Mock and Yang, "A 2022 Update on Electric Car Sales."
[80] Hal Harvey, Robbie Orvis, and Jeffrey Rissman, *Designing Climate Solutions: A Policy Guide for Low-Carbon Energy* (Island Press, 2018), https://islandpress.org/books/designing-climate-solutions.
[81] Chris Busch and Anand Gopal, "Electric Vehicles Will Soon Lead Global Auto Markets, But Too Slow to Hit Climate Goals Without New Policy" (Energy Innovation, November 3, 2022), https://energyinnovation.org/publication/electric-vehicles-will-soon-lead-global-auto-markets-but-too-slow-to-hit-climate-goals-without-new-policy/.
[82] Net Zero Tracker, "Data Explorer - Net Zero Target Status," https://zerotracker.net/.
[83] United Nations Framework Convention on Climate Change, Secretariat, "Technical Synthesis - First Global Stocktake."
[84] United Nations Framework Convention on Climate Change, Secretariat, "Technical Synthesis - First Global Stocktake."
[85] International Energy Agency, "Energy Technology Perspectives 2023."