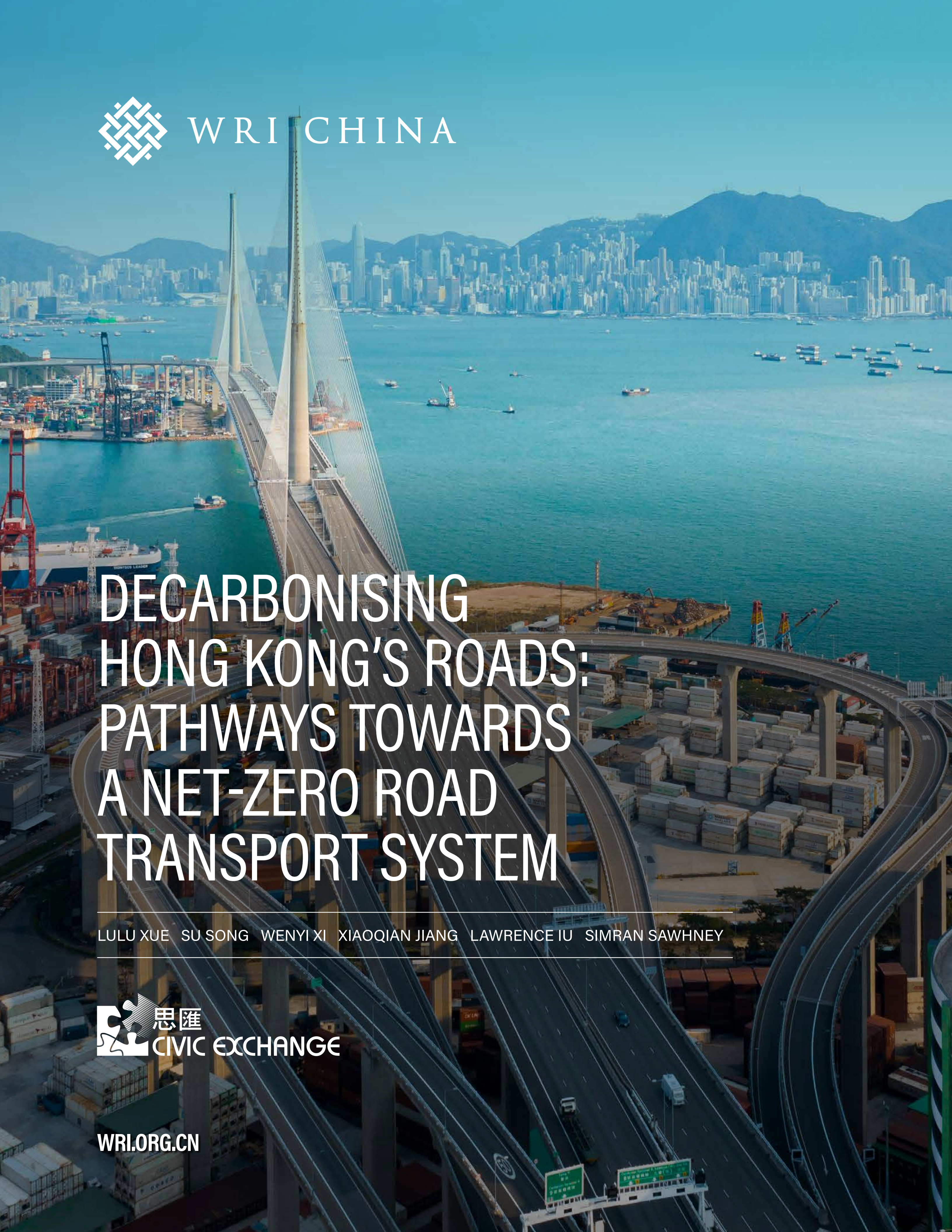

WRI CHINA

DECARBONISING HONG KONG'S ROADS: PATHWAYS TOWARDS A NET-ZERO ROAD TRANSPORT SYSTEM

LULU XUE   SU SONG   WENYI XI   XIAOQIAN JIANG   LAWRENCE IU   SIMRAN SAWHNEY

思匯 CIVIC EXCHANGE

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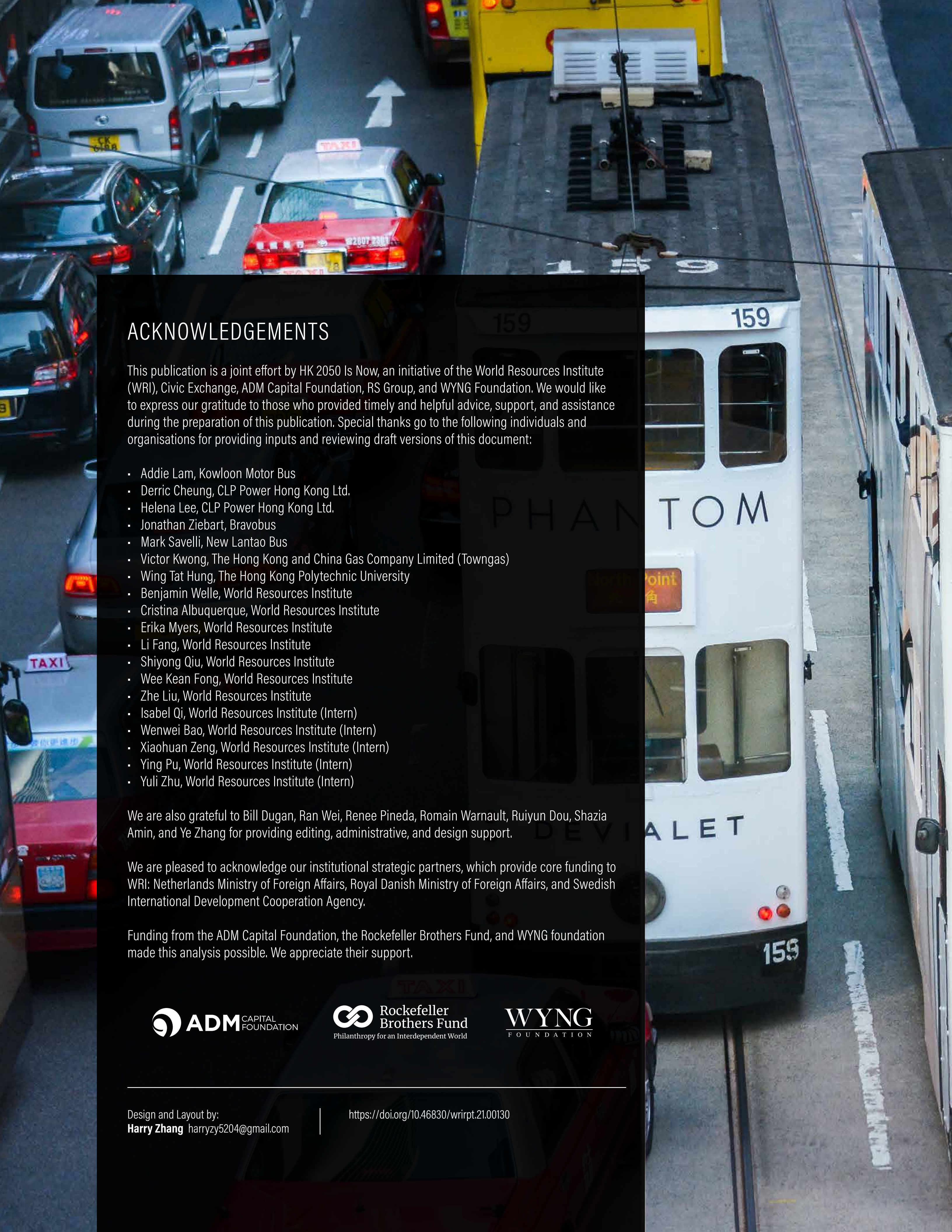

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Design and Layout by:
Harry Zhang harryzy5204@gmail.com

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聖安娜餅
ETH ZÜRICH

FOREWORD

Where there is transportation, there is life. Life has progressively changed as we work to achieve carbon neutrality. It is vital that Hong Kong is able to retain its interconnectedness while preserving a sustainable environment for future generations. Decarbonisation of the transport sector provides a unique opportunity to reach these goals that we must grasp now.

The central goal of the Paris Agreement is to limit global temperature rise to "well below 2°C above pre-industrial levels and to pursue efforts to limit temperature increase to 1.5°C." The latest science shows that to achieve this goal, global greenhouse gas emissions need to be halved by 2030 and reach net-zero by 2050. This transformation requires ambitious action across all levels of government and sectors of society — including countries, states and provinces, cities, companies, investors, and the public.

As global trends shift towards zero emission transportation, Hong Kong has committed to achieve carbon neutrality by 2050 and will ban the new registration of Internal Combustion Engine ("ICE") private cars (including plug-in hybrid vehicles) by 2035. All sectors of the society should welcome this initiative.

Transportation is the second-largest source of greenhouse gas emissions in Hong Kong. Road transport accounts for 89 percent of total transport emissions and is also a major source of pollution. Currently, Hong Kong, as a Special Administration Region, is the first Chinese city that has committed to carbon neutrality by 2050 and launched a clear fossil fuel ban on private cars.

Decarbonising the transport sector is critical to combatting climate change, but it also poses particular challenges for a economically prosperous and densely populated port city. With oil prices remaining high, the need to decarbonise Hong Kong's public transportation system is stronger than ever.

The breakthrough of power battery and hydrogen fuel cell technology and continuous cost reductions have brought new opportunities for emission reductions in road transport. Hong Kong now has a wealth of technological tools at its disposal to support a net-zero vehicular transition.

Despite the rigorous changes and major efforts required, Full decarbonisation requires an action-oriented long-term plan, and will require momentous changes—commensurate with those already underway in Mainland China and globally. This report provides a feasibility analysis on Hong Kong's decarbonisation of road transport and offers recommendations for the government, private sector, and civil society. The message is clear: we can only achieve net-zero in the transportation sector if government together with society takes collective action immediately.

As a wealthy city, Hong Kong has an environmental and social responsibility to contribute to collective climate action in the transportation sector. Together, we have the resources to JOINTLY BUILD a city that is thriving, healthy, and fully decarbonised. Let us begin that journey now.

Li Fang
Chief Representative,
Beijing Representative Office, ***WRI China***

Evan Auyang Chi-Chun
Chairman of the Board,
Civic Exchange

EXECUTIVE SUMMARY

HIGHLIGHTS

- The transport sector is the second-largest greenhouse gas (GHG) emission source in Hong Kong after the power sector, and road transport is the largest source of transport emissions. Decarbonising road transport is important for realising the city's net-zero emission goal. This report focuses on the top road transport emitters—private cars, freight vehicles, and buses.

- The Total Cost of Ownership (TCO) parity of zero-emission buses could be reached before 2030. We recommend banning the registration of diesel buses by 2030~2033 with a major acceleration in the testing of zero-emission double-deckers in intensively operated bus routes and rolling out zero-emission bus-specific policy safeguards and transition plans.

- TCO parity of electric private cars (PCs) is close in sight due to generous vehicle registration tax concessions and high petrol prices in Hong Kong. Hong Kong has the opportunity to advance the PCs' fossil fuel ban from the current 2035 to 2026–2030, while managing overall car ownership and usage.

- Hong Kong should prioritise electric trucks in all sizes, including a certain share of hydrogen fuel cell heavy-goods vehicles. Hong Kong should ban new registration of internal combustion engine (ICE) light-goods vehicles by 2030, and ICE medium- and heavy-goods vehicles by 2039.

Introduction

In November 2020, Hong Kong pledged to achieve carbon neutrality before 2050, making it the first city in China with a time-specific carbon neutrality goal. As the transport sector is the second-largest direct greenhouse gas (GHG) emission source (18.1 percent) in Hong Kong, after electricity generation (65.6 percent) (Environmental Protection Department 2021a), decarbonising the transport sector is important for reaching the city's carbon neutrality target.

In the recently released "Hong Kong's Climate Action Plan 2050" and in "Hong Kong Roadmap on Popularisation of Electric Vehicles" from 2021, electrification of vehicles (and ferries) is listed as the primary decarbonisation measure. To this end, the Hong Kong government aims that (1) the new registration of fuel-propelled private cars (including plug-in hybrid electric vehicles [PHEVs]) will be banned by 2035 or earlier (Hong Kong Environment Bureau 2021); (2) for commercial vehicles, the government aims to promote electric vehicles (EVs) at a large scale and test out hydrogen fuel cell electric buses and heavy vehicles in the next three years. However, Hong Kong's current vehicle electrification plan is not sufficient to meet the city's carbon neutrality target; banning the sale of internal combustion engine (ICE) private cars (26.9 percent of road transport emissions) is not sufficient to achieve the 2050 carbon neutrality goal.

To enhance Hong Kong's zero-emission vehicle adoption goals, this study aims to explore ways to promote zero-emission vehicles—battery electric vehicles (BEVs) and hydrogen fuel cell vehicles (FCEVs)—at scale in Hong Kong. Three key vehicle segments—buses, private passenger vehicles, and trucks with the largest GHG emissions (87 percent of road transport emissions) and fleet sizes (87 percent of the vehicle stock) (Hong Kong Environment Bureau 2021)—are chosen for in-depth analysis.

Zero-emission transition of franchised buses: More than e-bus trials

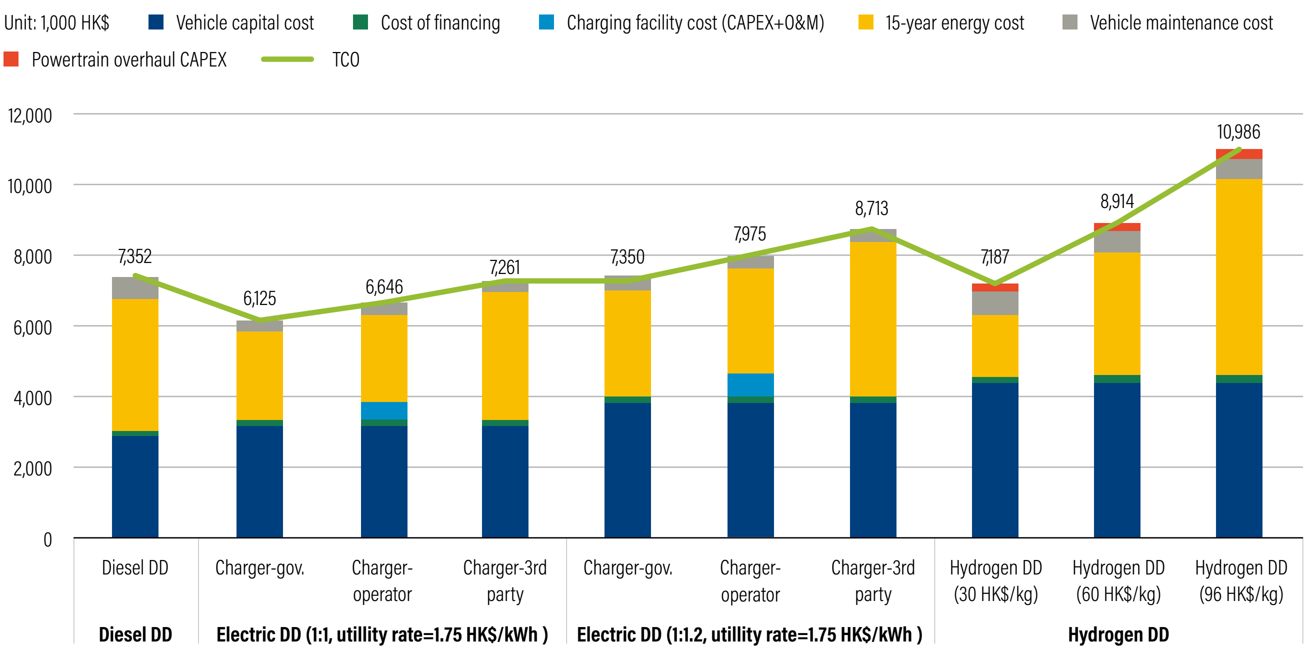
It is crucial to foster Hong Kong's franchised bus electrification without compromising high operational efficiency, passenger comfort, and market competitiveness, particularly considering Hong Kong's bus electrification faces unique challenges: first, 95 percent of the franchised bus fleet are 3-axle double-deckers (DDs)[1] (gross vehicle weight over 24 tonnes) with limited zero-emission model availability, insufficient ranges (in terms of Hong Kong's intense operation mileages), prohibitive prices, and less passenger capacity. Second, Hong Kong's buses are operated under the franchise scheme. Private bus operators are responsible for bus acquisition.

The study first calculates the total costs of ownership for double-deckers under different scenarios—varying charging infrastructure–funding mechanisms, electric vehicle availability rates, and electricity/hydrogen costs. The results show the following (Figure ES-1):

- Due to high vehicle prices and costly infrastructure investments, the total cost of ownership (TCO) parity between diesel double-deckers and electric double-deckers is not yet achieved in 2022. In the future, with lower vehicle prices and improved vehicle energy efficiency, TCO cost parity may be reached in (or before) 2030. If replacing a diesel DD requires extra (20 percent) electric DDs and charging infrastructure is built without the government's support, the TCOs of electric DDs will be HK$605,000 (8 percent) to HK$1,195,000 (15 percent) higher than the TCOs of diesel DDs.

- For hydrogen double-deckers, TCOs of hydrogen and diesel double-deckers may possibly converge by 2030. However, the TCOs of hydrogen DDs would vary considerably more than the TCOs of electric DDs, because of uncertainties in future hydrogen costs. If hydrogen has supply bottlenecks, and hydrogen cost is above HK$60 per kilogram (kg), the TCO parity of hydrogen buses will be reached by 2030. The TCO of hydrogen DDs would be HK$1,562,000 (21 percent, hydrogen cost is HK$60/kg) to HK$3,633,000 (49 percent, hydrogen cost is HK$96/kg) higher than diesel DDs' TCO in 2030.

Figure ES-1 | **Double-Deckers' TCO Comparisons as of 2030**



Notes: DD = Double-decker; kWh = Kilowatt-hours; kg = Kilogram; O&M = Operations and maintenance; TCO = Total cost of ownership.
"Charger-gov." indicates government-invested e-bus charging facilities. "Charger-operator" is bus operators—invested e-bus chargers. "Charger-3rd party" is other private investor—funded e-bus chargers. 1:1 and 1:1.2, respectively, indicate one diesel bus is replaced by one e-bus and 1.2 e-buses.
Source: Chapter 2 of this study.

The study further proposes possible "diesel bus ban" time lines/scenarios, based on possible TCO parity timeliness as well as the measures taken by various stakeholders. The study assumes three-to-five-year transition periods from the timing of TCO parity to the "diesel bus bans" and, therefore, proposes three possible "diesel bus ban" time lines: 2026, 2030, and 2033.

The socioenvironmental impact analysis shows that to balance public financial viability and environmental, social, and health benefits, banning new registration of diesel buses around 2030–2033 is viable for Hong Kong. In comparison, a diesel bus ban by 2026 requires considerable public expenditure (Table ES-1). Although the environmental benefits justify these public expenditures, strong political determination and firm support from franchised operators are also needed.

To turn the above scenarios into reality, Hong Kong needs dedicated zero-emission bus trials, a long-term electrification roadmap, and sustainable policy safeguards.

First, in the near term, Hong Kong's e-bus trials could be improved with the following recommendations:

- The government could play a more proactive role in the trials by providing necessary enablers, including support on land planning rezoning, coordination of charging facility installation at terminals and depots, and secure hydrogen supply, as well as removing existing regulatory barriers (such as requirements on the maximum gross vehicle weight of double-deckers).

- A dedicated fund for zero-emission bus promotion could be established, where bus operators are allowed large procurements to reinforce commitments.

- An advisory group could be established to synthesize the trial results and resolve potential vested interests. The advisory group could help in evaluating trial results, building consensus among different stakeholders, informing policymaking, advising bus operators' operations adjustments, and more.

Table ES-1 | **Comparisons of Policy Measures and Socioenvironmental Impact of Diesel Bus Bans in 2026, 2030, and 2033**

		DIESEL BUS BAN 2026	DIESEL BUS BAN 2030	DIESEL BUS BAN 2033
Policy safeguards	Electric buses	• Purchase subsidy • Supports on charging infrastructure delivery • Credit enhancement	• Purchase subsidy • Supports on charging infrastructure delivery • Credit enhancement	None
	Hydrogen buses	• Purchase subsidy • Operational subsidy • Supports on hydrogen supply • Credit enhancement	• Purchase subsidy • Operational subsidy • Supports on hydrogen supply • Credit enhancement	• Purchase subsidy • Operational subsidy • Supports on hydrogen supply
Private sector efforts	Electric buses	• Demand charge avoidance • Eco-driving training • Green finance	• Demand charge avoidance • Eco-driving training • Green finance	None
	Hydrogen buses	• Manpower training • Green finance	• Manpower training • Green finance	• Manpower training • Green finance
Cumulative GHG emissions reduction (2021–2050) (compared to diesel bus ban 2033)		2.4 million tonnes CO_2e	1.5 million tonnes CO_2e	n/a
Cumulative economic benefits from avoided emissions (2021–2050) (compared to diesel bus ban 2033)		HK$2.0 billion	HK$1.2 billion	n/a
Cumulative public expenditure (2021–2050)		HK$452 million–HK$1.21 billion	HK$31–HK$592 million	HK$0–HK$211 million

Notes: GHG = Greenhouse gas; n/a = Not applicable; CO_2e = Carbon dioxide equivalent.
Electric bus = Battery electric bus; Hydrogen bus = Hydrogen fuel cell electric bus.
Source: Chapter 2 of this study.

Further, given the long service life of buses, Hong Kong needs to plan the phase-in of zero-emission buses early on, to be on track to attain Hong Kong's 2050 carbon neutrality target:

- Minibuses and single-deckers (SDs) are technologically ready for wider adoption, and the adoption of electric single-deckers can now also help franchised bus operators to ease the sharp learning curve and become prepared. Starting from 2026, zero-emission double-deckers may be ready for wider adoption.
- Double-decker electrification can be prioritised: double-deckers travelling in urban centres with short daily mileages, low speeds, and frequent idling would become increasingly ready for EV transition. Double-deckers travelling long-distance to serve new towns on the outskirts (like the Express Service Route with a route length over 40 kilometres [km] and average speed up to 70 kilometre per hour [km/h]) may well be electrified at scale around 2026–2030, if the technology advances occur as expected. The latter type of double-decker is also a niche application for hydrogen.

Sustainable policy incentives must succeed the temporary e-bus trials to continue incentivising the adoption of zero-emission buses:

- Vehicle purchase and operational subsidies: The vehicle purchase subsidy is important to reduce zero-emission buses' TCOs and make them affordable for private franchised operators. For hydrogen DDs, apart from a vehicle purchase subsidy, an operational subsidy may also be needed, contingent on at-pump hydrogen prices.

- Public support on e-buses' charging infrastructure delivery: Although charging facilities can be delivered by the private sector or through public-private partnerships (PPPs), public support is essential. This public support takes the form of land zoning and land acquisition for new bus depots as well as capital grants to install e-bus charging facilities, specifically: First, a proactive role by the government to plan for large pockets of land for new bus depots and to manage land rents is particularly important. Further, in bus terminals where e-bus chargers are shared among multiple bus operators, the government can fund the installation of shared chargers (from grid expansion and space planning to the construction of chargers) to avoid redundant investments and reduce zero-emission buses' TCOs.

- Public support on hydrogen supply: Public support on hydrogen imports, reservoir construction, inland transportation, and construction of hydrogen-refuelling stations (HRSs) (as well as land rezoning and acquisition) is necessary. Particularly, securing sustained hydrogen supply is important for continued operation of hydrogen DDs.

- Bus financing mechanisms such as concessional loans, green bonds, and leasing are needed to avoid large up-front investments on vehicle purchase. If necessary, the government could also consider providing guarantees on loans or bonds.

- Plans on grid integration: With increasing adoption of EVs (including e-buses),the government needs to systematically evaluate the grid impacts of EV charging and ensure efficient grid integration and minimise impact to the grid (after the deployment of necessary peak-shifting measures such as smart charging devices).

Further, proactive efforts are needed from franchised operators, including optimising vehicle procurement and asset management strategy (such as negotiation for favourable warranty terms and to cultivate long-term partnerships with original equipment manufacturers [OEMs]); adopting smart charging–capable chargers and load management systems, and installing on-site renewable energy to reduce electricity expenses; optimising the operation of zero-emission vehicles (coordinated with charging and refuelling time); and improving zero-emission vehicles' energy efficiency by providing eco-driving training for bus drivers.

Private car electrification: “Shift“ policies (from private cars to green transport modes) are essential

Hong Kong is more proactive with private car (PC) electrification: it is the city's aspiration to prohibit new registration of internal combustion engine (ICE) private cars by 2035 or earlier. Unlike global front-runners in EV promotion, Hong Kong has the potential of creating a new electrification paradigm by enhancing its vehicle electrification ambition, while controlling overall car ownership and usage. The new paradigm will be achieved by encouraging the rapid electrification of the existing in-use PC fleet, while managing the ownership and usage of electric PCs through travel demand management (TDM) measures.

Car ownership and usage in Hong Kong are subject to intensive policy interventions to alleviate traffic congestion and avoid inefficient land use. Such policies, known as TDM policies, include vehicle First Registration Tax (FRT), annual licence fees (ALFs), parking space purchase costs, and road (tunnel) tolls (Hong Kong Legislative Council 2020). As a result, Hong Kong's car ownership levels are low. Under this TDM policy regime, tax concessions are important policy instruments to incentivise EV adoption. Unlike Norway, which also relies on tax benefits to promote EVs, Hong Kong's tax benefits are more favourable for in-use PCs. Under Hong Kong's "One-for-One

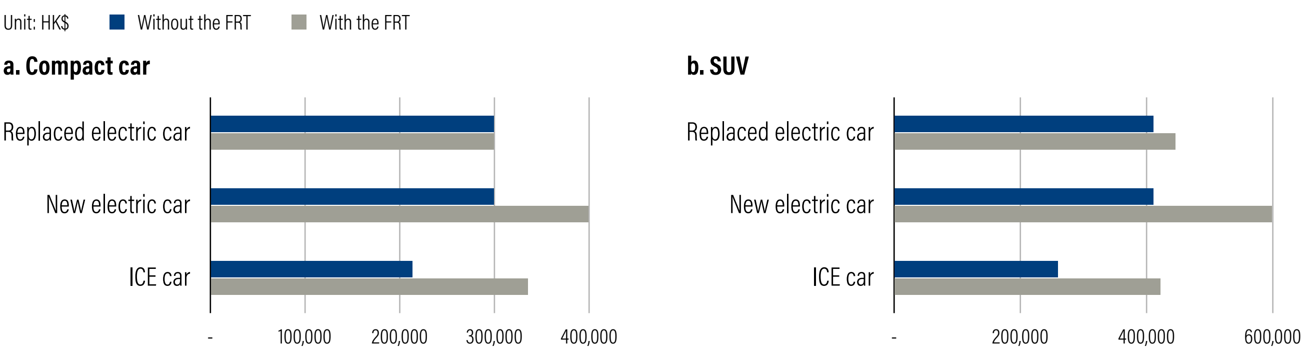
Replacement" Scheme, existing car owners who scrap their ICE cars and switch to electric cars (short as “replaced EVs”) enjoy a maximum of tax concessions at HK$287,500, tripling the maximum tax concession of new electric PCs. The approach is compatible with Hong Kong’s well-established tradition to temper overall growth in car ownership, including electric PC ownership.

Therefore, it is crucial to design Hong Kong’s PC electrification policies to meet its multifaceted goals: (1) promoting vehicle electrification and mitigating emissions; (2) controlling car ownership growth, relieving traffic congestion, reining in urban sprawl; (3) maintaining fiscal sustainability; and (4) avoiding subsidising the wealthy.

Due to preferential tax concessions to replace EVs, the capital cost (vehicle prices plus FRT) of replaced EVs is nearly breakeven with that of ICE cars in 2021: for compact cars, replaced EVs have lower capital costs than ICE cars; and for sport utility vehicles (SUVs), the replaced EVs are only HK$37,000 (9 percent) costlier than ICE cars (Figure ES-2). This is a considerable benefit because, without any tax interventions, the study predicts the retail prices of electric compact cars will reach price parity with ICEs around 2025–2026, and for SUVs around 2029–2030.

For the TCO, the study reveals that unlike elsewhere, because of the high fuel prices and low electricity costs in Hong Kong and generous tax concessions for electric PCs, compact cars and replaced EVs in Hong Kong achieved cost parity in 2021. With continued tax concessions, the TCO parity of new electric SUVs is also rapidly approaching (before 2024) (Table ES-2).

Figure ES-2 | **Vehicle Capital Costs as of 2021**



Note: The capital cost includes the vehicle retailer prices and First Registration Tax concessions. Some electric SUVs are equipped with autonomous driving functions; therefore, it is not an apples-to-apples comparison between electric SUVs and ICE SUVs.
SUV = Sport utility vehicle; ICE = Internal combustion engine; FRT = First Registration Tax.
Source: Authors.

Table ES-2 | **Time Line of TCO Parity for Electric PCs under Current Tax Concessions**

TYPES OF PCS		CAPITAL COST PARITY	TCO PARITY
Compact car	New EVs	2021	2021
	Replaced EVs	Before 2021	Before 2021
SUV	New EVs	2025~2026	2023–2024
	Replaced EVs	2021–2022	Before 2021

Notes: Red colour denotes parity is not achieved; green colour denotes parity is achieved.
TCO = Total cost of ownership; PC = Private car; SUV = Sport utility vehicle; EV = Electric vehicle.
Source: Authors.

The study further evaluates three scenarios that balance EV promotion and growth of overall car ownership: On the one hand, with preferential EV tax concessions, Hong Kong has room to further advance the time line of the ICE vehicle ban on PCs from 2035 to 2028. Additional measures to increase EV adoption will be important in this scenario, such as the subsidy on charging facilities. On the other hand, the continued decline of EV capital costs and TCOs will make EVs a compelling option. These cost advantages of electric PCs would spur car ownership and also make the path to the fossil fuel ban more funding-intensive.

Using the Hong Kong Energy Policy Simulator (EPS) model (WRI and Civic Exchange 2019), three scenarios are simulated for 2050:

- Hong Kong's car ownership will steadily grow to 809,000, spurred by either ICE car growth resulting from limited TDM measures (the Current Policy Scenario), or by electric PC growth resulting from dropped EV prices (the High PC Stock Scenario).
- Hong Kong's car ownership will grow to 670,000, resulting from the adoption of more proactive TDM policies to manage both EV and ICE growth, such as introducing zero-emission zones, increasing parking fees (or congestion charge), and even direct control on car ownership (the Low PC Stock Scenario).

The socioenvironmental impact analysis shows that the scenarios—the High PC Stock Scenario (0.88 million PCs by 2050) and the Low PC Stock Scenario (0.73 million PCs by 2050)—aiming to increase Hong Kong's PC electrification ambition, would result in comparable emission reduction potentials. However, the two scenarios differ in the amount of public spending. With a smaller PC stock due to TDM policies, in the Low PC Stock Scenario, public spending on infrastructure—charge points, roadways, and public parking spaces—can be saved. This saving can be mobilised to improve public transit, walking, and cycling environments for low- and middle-income groups (Table ES-3).

Based on the analysis, the study recommends the following:

First, Hong Kong has an important opportunity to advance the current ICE vehicle ban time line (2035) to 2028 or earlier and create a new global

Table ES-3 | **Comparisons on Policy Measures and Socioenvironmental Impacts of Different PC Electrification Scenarios**

	LOW PC STOCK SCENARIO	HIGH PC STOCK SCENARIO	CURRENT POLICY SCENARIO
Policy interventions	• ICE vehicle ban 2028 • Proactive TDM measures on both ICEs and EVs	• ICE vehicle ban 2028 • Current TDM measures	• ICE vehicle ban 2035 • Limited TDM measures
Cumulative GHG emissions reduction (2021–2050) (compared to the Current Policy Scenario)	6.0 million tonnes CO_2e	4.8 million tonnes CO_2e	n/a
Cumulative economic benefits from avoided emissions (2021–2050) (compared to the Current Policy Scenario)	HK$3.4 billion	HK$2.7 billion	n/a
Cumulative public expenditure (2021–2050)	HK$5.9 billion	HK$6.5 billion	HK$4.6 billion

Notes: PC = Private car; GHG = Greenhouse gas; TDM = Travel demand management; ICE = Internal combustion engine; EVs = Electric vehicles; n/a = Not applicable; CO_2e = Carbon dioxide equivalent.
Source: Authors' calculations.

paradigm in vehicle electrification—prioritising electrification of the existing fleet on the road.

Second, in the near term, tax concessions should be gradually phased out, to offset the continuous drop in EV prices and to avoid boosting car ownership. If tax concessions are not reduced/eliminated in a timely manner, the capital cost of a new electric compact car in 2030 would be HK$163,000 cheaper (47 percent reduction) than of ICE cars, and the TCO would be HK$220,000 less (45 percent reduction) than for ICE cars. This means the cost of purchasing an ICE compact car would be equal to the cost of purchasing two electric compact cars. The study further shows that tax concessions for new electric vehicles could be reduced from 2021~2023, and completely phased out during 2026~2027. Because tax concessions for replaced EVs are more desirable to accelerate vehicle electrification, the time line to reduce tax concessions for replaced EVs is contingent on the government's trade-off between EV promotion and fiscal revenues.

Apart from reducing tax concessions, proactive TDM options could be considered by the city (Table ES-4) to manage car ownership as EV prices drop. By evaluating vehicle electrification potential, extent of control over growth in car ownership, public revenue generation, and implementation feasibility, the study shows four TDM policies can be added to Hong Kong's future policy arsenal, including implementation of zero-emission zones, increased parking fees (or congestion charge), carbon pricing on fuels, and direct car ownership control.

Third, to unlock vehicle electrification potential, government could enhance charging infrastructure provisions in the following ways:

- By increasing the adoption of private home chargers through institutionalising the building code to mandate all parking spaces of new and retrofitted buildings be 100 percent charging-ready; encouraging shared and managed chargers; introducing time-of-use residential rates (to replace current tiered rates); and issuing right-to-charge regulations.

Table ES-4 | **Scorecards of Different Travel Demand Management Policies on Vehicle Electrification, Car Ownership Control, and Public Revenue Generation**

	EV REGISTRATION TAX CONCESSION	EV PURCHASE SUBSIDY	VEHICLE REGISTRATION QUOTA	ACCESS INCENTIVES (ZERO EMISSION ZONE)	INCREASED PARKING FEES (OR CONGESTION CHARGES)	PARKING INCENTIVE	CHARGING FACILITY INCENTIVE	CARBON PRICE
Effects on promoting vehicle electrification	Positive	Positive	Positive	Positive	Positive	Positive	Positive	Positive
Car ownership control	Negative	Negative	Positive	Neutral	Positive	Negative	Neutral	Neutral
Public revenue generation	Negative	Negative	Neutral	Neutral	Positive	Negative	Negative	Positive
Implementation easiness	Negative	Positive	Negative	Positive	Negative	Positive	Positive	Neutral
Recommendation of this study	✓		◯	◯	◯		✓	◯

Note: ✓ denotes the TDM policy has been implemented in Hong Kong; ◯ represents new TDM policies that can be considered by the city.
EV = Electric vehicle; TDM = Travel demand management.
"Positive" indicates the TDM policy has positive impacts on the indicator, while "Negative" and "Neutral" mean the TDM policy has negative or neutral impacts.
Source: Authors.

- By increasing the coverage of public charging stations, where the number of EVs per public charging point could be set to 5–10 (T&E 2020), and build an open, public data platform to facilitate locating charging stations.

Freight vehicle decarbonisation

We defined three scenarios to analyse how to decarbonise Hong Kong's freight vehicles: the Business-as-Usual (BAU) Scenario, the Battery Electric Vehicle (BEV) Scenario, and the Hydrogen Scenario. In the BEV Scenario, all light-goods vehicles (LGVs) and 50 percent of heavy-goods vehicles (HGVs) (medium-goods vehicles [MGVs] included) will be BEVs in 2050 or earlier, while the other 50 percent of HGVs will be hydrogen fuel cell electric vehicles (FCEVs). In the Hydrogen Scenario, all HGVs and 50 percent of LGVs will be FCEVs, while 50 percent of LGVs will be BEVs. The study then assessed and compared the impact of different scenarios against climate impact, public health impact, impact on freight companies, and impact on infrastructure (Table ES-5).

Table ES-5 | **Comparing Greenhouse Gas Emissions, Social and Economic Impacts of Different Scenarios for Freight Vehicles (2020–2050)**

	BAU SCENARIO	BEV SCENARIO	HYDROGEN SCENARIO
Cumulative GHGs (million tCO_2e)	61.6	41.4	44.2
Cumulative social benefits from GHGs saving (@3.0% discount rate) (billion HK$ 2020)	n/a	11.8	10.3
Cumulative life savings	n/a	277.0	239.0
Cumulative social benefits from life savings (@ billion HK$ 2020)	n/a	6.6	5.7
Annual financial support needed on trucking industry (million HK$ 2020)	n/a	60 annually, before meeting a breakeven point around 2025	70 annually, before meeting a breakeven point around 2028
Cumulative financial support needed on infrastructure (billion HK$ 2020)	n/a	10	30
Annual additional fuel cost compared with the BEV Scenario (million HK$ 2020)	n/a	n/a	31

Notes: BAU = Business as usual; BEV = Battery electric vehicle; GHG = Greenhouse gas; tCO_2e = Tonnes of carbon dioxide equivalent.
Source: Authors.

Analysis shows that the BEV Scenario produces less GHG emissions and air pollutants and higher social, health, and climate benefits.

Recommendations for the electrification of trucks include the following:

Advance the current fossil fuel ban time line and expand the coverage to freight vehicles. Ban new registration of ICE light goods trucks in 2030 or earlier. Ban new registration of ICE medium- and heavy-goods trucks in 2039 or earlier.

BEV and FCEV together with clean electricity and green hydrogen are the ultimate solutions for road transport decarbonisation. BEV technology is mature and the TCO has reached parity for some types of vehicles and would reach cost parity for the remaining types before 2030, which is earlier than for hydrogen vehicles. For the midterm (2025–2030), we recommend BEV as the solution for light-goods trucks. For the long term (2030–2050), both technologies can be considered for medium- and heavy-goods trucks.

Finance the expansion of public charging/alternative fuel–refuelling network.

Either of the technology roadmaps—BEV or FCEV—will need significant amounts of financial support. This could be from government subsidies, public-private partnerships (PPPs), or leveraged capital from the private sector such as green loans and bonds from financial organisations.

For freight vehicles, our analysis shows that about 56,000 chargers and 213 HRSs are needed for the BEV Scenario by 2050, and 22,000 chargers and 819 HRSs are needed for the Hydrogen Scenario by 2050. Government can enable continuous financial support through the PPP mechanism. Government should also use the New Energy Transport (NET) Fund (and other budgets) to leverage capital from the private sector to cofinance the infrastructure for zero-emission vehicles (ZEVs). Government should prioritise building hydrogen-refuelling stations with the help of commercial green loans (zero carbon loans).

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CHAPTER 1

INTRODUCTION

Transportation is the second-largest source of greenhouse gas emissions in Hong Kong. Road transport accounts for 89 percent of total transport emissions and is also a major source of pollution. Decarbonising road transport is vital for the city's carbon neutrality targets, air pollution reduction, and public health.

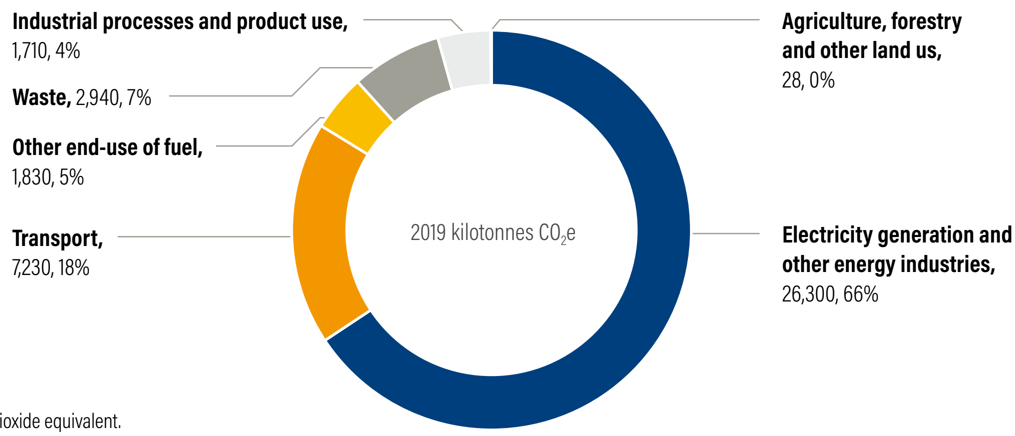
Necessities

Achieve carbon neutrality and improve air quality

In November 2020, Hong Kong pledged to achieve carbon neutrality before 2050, making it the first city in China with a time-specific carbon neutrality goal. On 6 October 2021, "Hong Kong's Climate Action Plan 2050" was published. It set an interim target of reducing Hong Kong's carbon emissions by 50 percent before 2035 compared to 2005 levels. In the action plan, green transport is raised as one of the four strategies to achieve carbon neutrality along with net-zero electricity generation, energy-saving green buildings, and waste reduction.

The transport sector is the second-largest direct GHG emission source[2] (18 percent) in Hong Kong, after electricity generation (66 percent) (Environmental Protection Department 2021a) (see Figure 1). Within the transport sector, road transport (i.e., motor vehicles) is the largest source, accounting for 89 percent of GHG emissions. Further, roadside pollutants caused by motor vehicles are also a major source of air pollutants (GovHK 2021). In 2019, motor vehicles accounted for 16 percent, 23 percent, and 50 percent of the city's total nitrogen oxide (NO_x), volatile organic compound (VOC), and carbon monoxide (CO) emissions, respectively, (Environmental Protection Department, 2021b) (Table 1). Therefore, decarbonising transport is vital for the city's carbon neutrality targets, air pollution reduction, and public health.

Figure 1 | **Greenhouse Gas Emissions in Hong Kong in 2019 by Sector**



Note: CO_2e = Carbon dioxide equivalent.
Source: Environmental Protection Department 2021a.

Table 1 | **Air Pollutant Emissions of Motor Vehicles in Hong Kong (2019)**

	SO_2	NO_x	PM_{10}	$PM_{2.5}$	VOC	CO
Motor vehicles (t)	40	12,700	330	300	4,900	30,100
Total emissions (t)	8,430	77,620	3,480	2,630	21,130	60,440
Share (%)	0.47	16.36	9.48	11.41	23.19	49.80

Notes: t = Tonnes; SO_2 = Sulfur dioxide; NO_x = Nitrogen oxides; PM_{10} = Particulate matter; $PM_{2.5}$ = Fine particulate matter; VOC = Volatile organic compounds; CO = Carbon monoxide.
Source: Environmental Protection Department 2021b.

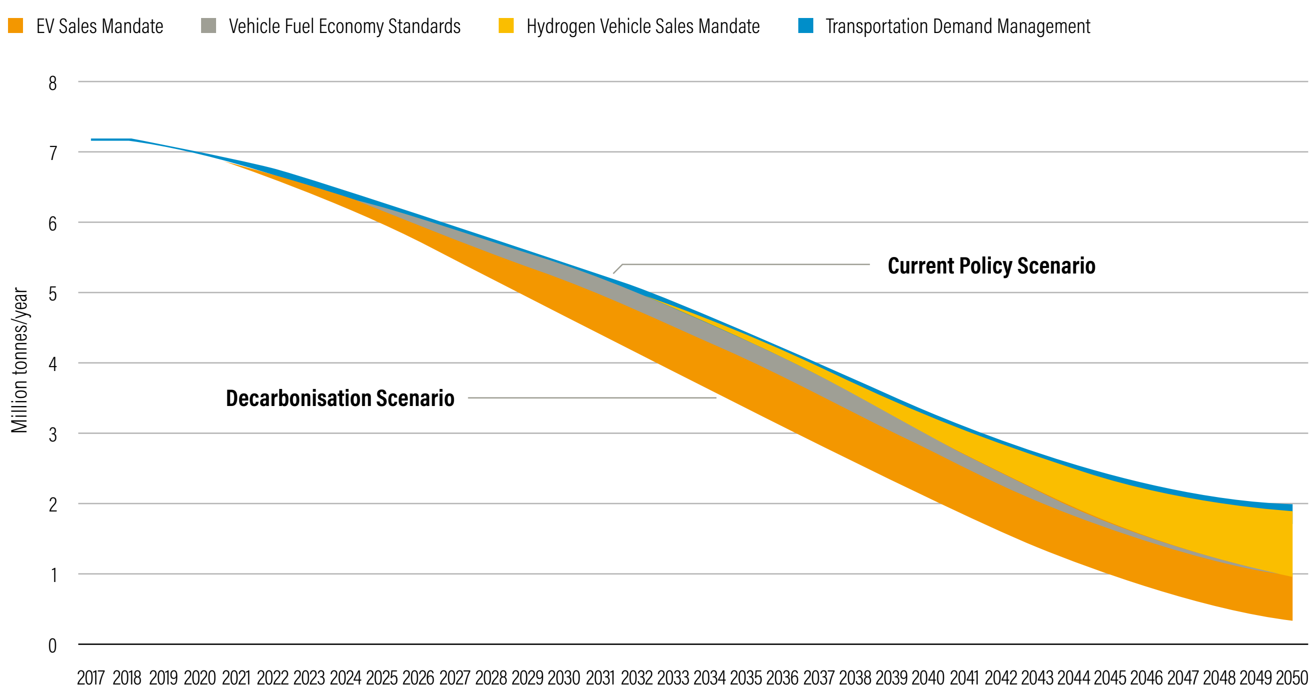
Preserve global leadership in sustainable transport

The transport sector's goal in "Hong Kong's Climate Action Plan 2050" is to achieve zero vehicular emissions before 2050. To this end, vehicle (and ferry) electrification is identified as the central approach: for private cars, the Hong Kong government aims to cease new registration of fuel-propelled and hybrid private cars (including plug-in hybrid electric vehicles [PHEVs]) in 2035 or earlier; for commercial vehicles, the government aims to promote electric vehicles at a large scale and test out hydrogen fuel cell electric buses and heavy vehicles in the next three years.

This means that Hong Kong is ramping up efforts on "improve" measures, which, combined with "avoid" and "shift" measures, are forging a complete green transport strategy around the ASI (avoid-shift-improve) framework.[3] In the past, Hong Kong has been a global leader in "avoid" and "shift" measures: the city is a model for transit-oriented development (TOD) (Suzuki et al. 2015). it is also well-known for its highly developed public transit network and large transit dependency.

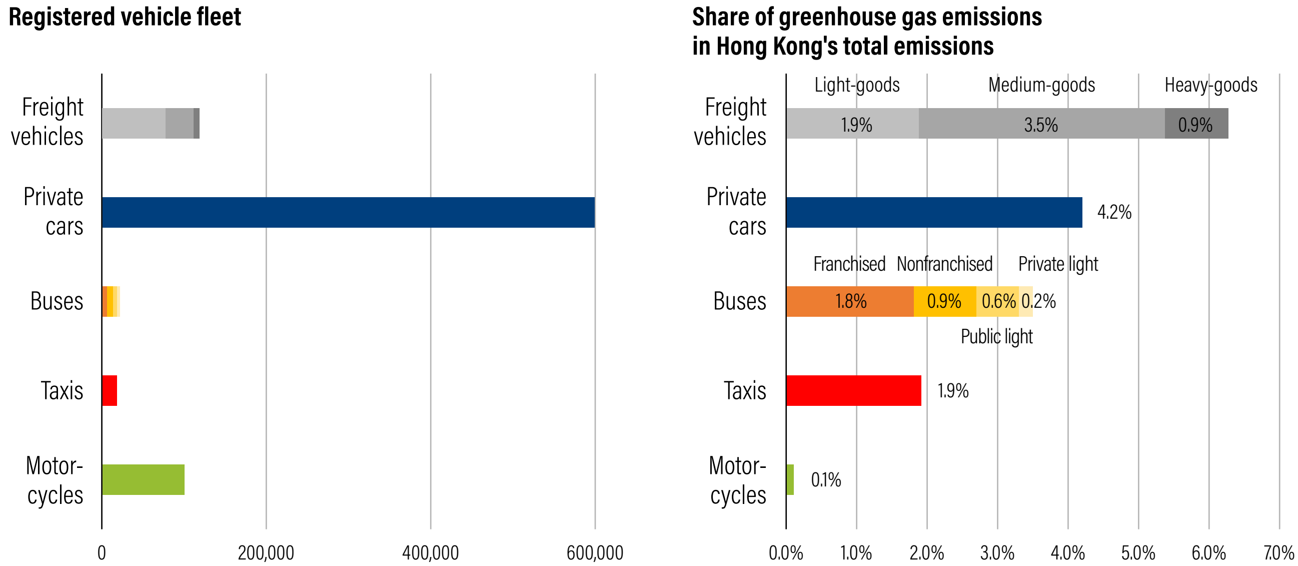
Although the legacy on "avoid" and "shift" should be sustained, the city needs reinforced efforts on "improve" measures. Based on WRI's calculation (WRI et al. 2020), "improve" measures—especially the switch from internal combustion engine (ICE) vehicles to zero-emission vehicles (including EVs and hydrogen fuel cell vehicles)—offer the largest decarbonisation potential (Figure 2). Zero-emission vehicle sales mandates could contribute to about 98 percent of transport's emission reduction potential for Hong Kong in 2050. Nonetheless, Hong Kong is slow in the global race of "improve," especially in vehicle electrification: for the commercial fleet, Hong Kong remains at the early stage of vehicle electrification; by the end of 2021, Hong Kong only had 80 electric single-decker buses and zero electric taxis—fewer than its neighbour city, Shenzhen (where 100 percent of the buses and taxis had been electrified). As a well-known global leader in sustainable transport, Hong Kong needs to remain competitive and preserve its leadership.

Figure 2 | **Effects of Decarbonisation Policies on the Transport Sector**



Note: Under the Decarbonisation Scenario, Hong Kong has high potential to achieve net-zero emissions by 2050 at reasonable cost, if more ambitious action is taken now.
Source: Hong Kong Energy Policy Simulator (EPS) (https://hongkong.energypolicy.solutions/).

Figure 3 | **Current Vehicle Stocks and Greenhouse Gas Emissions by Vehicle Segments in Hong Kong**



Note: Vehicle fleet is 2021 data, GHG emissions are 2018 data. Most updated total emissions for the transport sector are for 2019, but there is no information for the breakdown, so 2018 emissions data are used.

Source: Adapted from Hong Kong Environment Bureau 2021; Transport Department n.d. (c).

Status quo

At the end of 2021, there were 926,238 registered vehicles in Hong Kong, including 656,973 private cars (70.9 percent), 119,895 trucks (12.9 percent), 21,799 buses (2.4 percent), 18,163 taxis (2.0 percent), and 100,557 motorcycles (10.9 percent).[4] Although private cars consist of the largest vehicle fleet, because of the integrated transit and land-use planning and well-developed public transit system, Hong Kong's vehicle ownership is low: only 111 vehicles (excluding motorcycles and special purpose vehicles) per 1,000 people,[5] compared to 288 in Beijing, and 325 in London.[6] Over 90 percent of Hong Kong's passenger trips were completed by transit (Transport and Housing Bureau 2017).

Although private cars account for the highest share of the fleet, trucks emitted the largest emissions, contributing 6.3 percent of Hong Kong's total GHG emissions, followed by private cars (4.2 percent), buses (3.5 percent), and taxis (1.9 percent), as shown in Figure 3.

Status quo of zero-emission vehicle adoption

At the end of 2021, the total number of EVs in Hong Kong is 27,855 (Transport Department n.d. [c]).

However, the EV penetration of total vehicle stocks is still low—only about 3 percent (Table 2):

- The electrification of private cars has performed the best due to technological readiness, model availability, and ample incentives in the promotion of private cars. Hong Kong's market share of electric private cars in new sales has jumped from 0.3 percent in 2017 to 34.0 percent in December 2021 (Transport Department 2016–2021).

- Contrary to conventional thinking, buses and taxis—usually at the forefront of vehicle electrification—are least electrified in Hong Kong. Only 34 franchised buses were electrified at the end of 2021, the same number as in 2020; and there are no electric taxis or public light buses (PLBs or minibuses). Although technology barriers can be one explanation, financial barriers, limited make-and-model availability, charging facility availability, and limited public awareness are other reasons.

- Electrification of trucks is mixed. Light-goods trucks are better performing, while the electrification of medium- and heavy-goods

Table 2 | **Electrification of Different Types of Registered Vehicles in Hong Kong in 2021**

	PETROL	DIESEL	ELECTRIC	LP GAS	OTHERS	TOTAL	EV PENETRATION (%)
Private car	617,599	11,906	**27,358**	0	110	656,973	**4.2**
Buses	0	16,993	**47**	4,759	0	21,799	**0.2**
Franchised buses	0	6,133	**34**	0	0	6,167	**0.6**
Nonfranchised buses	0	6,990	**5**	0	0	6,995	**0.1**
Public light buses	0	755	**0**	3,594	0	4,349	**0.0**
Private light buses	0	3,115	**8**	1,165	0	4,288	**0.2**
Taxis	3	0	**0**	18,160	0	18,163	**0.0**
Trucks	562	119,120	**213**	0	0	119,895	**0.2**
Light-goods vehicles	562	76,401	**211**	0	0	77,174	**0.3**
Medium-goods vehicles	0	35,633	**2**	0	0	35,635	**0.0**
Heavy-goods vehicles	0	7,086	**0**	0	0	7,086	**0.0**
Motorcycles	100,438	0	**119**	0	0	100,557	**0.1**
Special purpose vehicle	63	1,787	**118**	193	2	2,163	**5.5**
Total	718,665	149,806	**27,855**	23,112	112	919,550	**3.0**

Notes: LP = Liquefied petroleum; EV = Electric vehicle.
Source: Transport Department n.d. (c).

trucks has not yet started. There are currently only two medium-goods vehicle deployed in Hong Kong. The Hong Kong Productivity Council is working to research and develop electric truck specifications for waste collection, to be produced in 2021 and trialled in 2022.

Current policy landscape

The "Hong Kong Roadmap on Popularisation of Electric Vehicles" has mapped out the zero-emission vehicle (ZEV) transition pathways for different vehicle classes. The roadmap is a living policy, to be reviewed every five years, to adapt targets and policy measures to technology advances and changing conditions.

To facilitate the implementation of the roadmap, Hong Kong's government has promulgated dedicated policies for different vehicle classes.

Private cars in Hong Kong are heavily taxed to control car ownership. Preferential tax concessions are offered to electric private cars to promote EV adoption. Especially, under the "One-for-One Replacement" Scheme, replaced electric private cars are favourably treated—when ICE car owners replace their existing cars with an EV, they receive higher First Registration Tax (FRT) concessions. This scheme has been highly effective for promoting the electrification of existing in-use private cars, and for this reason, the government has opted to extend the scheme from its original end date in March 2021 to March 2024.

Compared to tax benefits, subsidies are often administered on commercial fleets. The HK$800 million New Energy Transport Fund (previously named Pilot Green Transport Fund [PGTF]) has been in place to encourage trials of low-carbon technologies—including electric vehicles, hybrid vehicles, and plug-in hybrid vehicles—for commercial vehicles (Hong Kong Environment Protection Department 2020).

Numerous commercial vehicles–including buses, public light buses, taxis, and trucks–are eligible. Moreover, another HK$180 million subsidy was dedicated for franchised bus companies to procure electric single-deckers. In addition to subsidies, enterprises are entitled to 100 percent profit tax deductions for capital expenditure on EV acquisition in the first year of procurement. Further, the FRT is fully waived for commercial electric vehicles (such as buses, light buses, taxis, and special purpose vehicles).

Concerning charging infrastructure, the installation of home chargers is prioritised, and various incentives have been sought to equip Hong Kong's high-density, multidwelling units with charging facilities:

- For new buildings, gross floor area concession was used to incentivise real estate developers to equip parking spaces of new constructions with charging facilities since 2011.
- For existing buildings, government rolled out a HK$2 billion pilot subsidy scheme—EV-Charging at Home Subsidy Scheme (EHSS) in 2020—to retrofit 60,000 existing parking lots in residential communities to be charging-ready (Hong Kong Environmental Protection Department 2022b). Due to the effectiveness of this scheme, an additional sum of HK$1.5 billion has been injected to extend the scheme for four years to 2027–28. It will further support the installation of EV charging-enabling infrastructure for about 140,000 parking spaces, accounting for approximately half of the eligible parking spaces in Hong Kong (Government of Hong Kong 2022).

Further, a 2019–2020 budget of HK$120 million was created to extend the public charging network at government car parks. Table 3 summarizes the public incentives on zero-emission vehicle promotion in Hong Kong.

Table 3 | **Public Incentives on Zero-Emission Vehicle Promotion**

	INCENTIVES ON ZEV PURCHASE	INCENTIVES ON CHARGING INFRASTRUCTURE PROVISION
Private cars	• Tax benefits, such as vehicle registration tax concessions (including the "One-for-One Replacement" Scheme)	• Gross floor area concessions for real estate developers • EV-Charging at Home Subsidy Scheme (EHSS) (retrofit 60,000 private parking spaces) • Public charging network subsidy (government car parks)
Taxis	• Subsidy for ZEV trials—New Energy Transport Fund • Corporate profit tax benefit • Waiver of vehicle registration tax	• Subsidy for ZEV trials—New Energy Transport Fund
Public light buses	• Subsidy for ZEV trials—New Energy Transport Fund and HK$80 million for electric public light bus trials • Euro IV diesel commercial vehicle scrappage subsidy • Corporate profit tax benefit • Waiver of vehicle registration tax	• Subsidy for ZEV trials—New Energy Transport Fund
Franchised buses	• Subsidy for ZEV trials—New Energy Transport Fund and HK$180 million for electric single-decker trials • Corporate profit tax benefit • Waiver of vehicle registration tax	• Subsidy for ZEV trials—New Energy Transport Fund
Trucks	• Subsidy for ZEV trials—New Energy Transport Fund • Euro IV diesel commercial vehicle scrappage subsidy • Corporate profit tax benefit • Waiver of vehicle registration tax	• Subsidy for ZEV trials—New Energy Transport Fund

Notes: Orange-colored policies are subsidies.
ZEV = Zero-emission vehicle.
Source: Authors' summary.

Challenges

Multiple challenges stand in the way to electrify Hong Kong's vehicle fleet, including common challenges like high costs of EVs as well as Hong Kong–specific challenges such as limited availability of EV models.

High costs and technological unreadiness of some vehicle segments

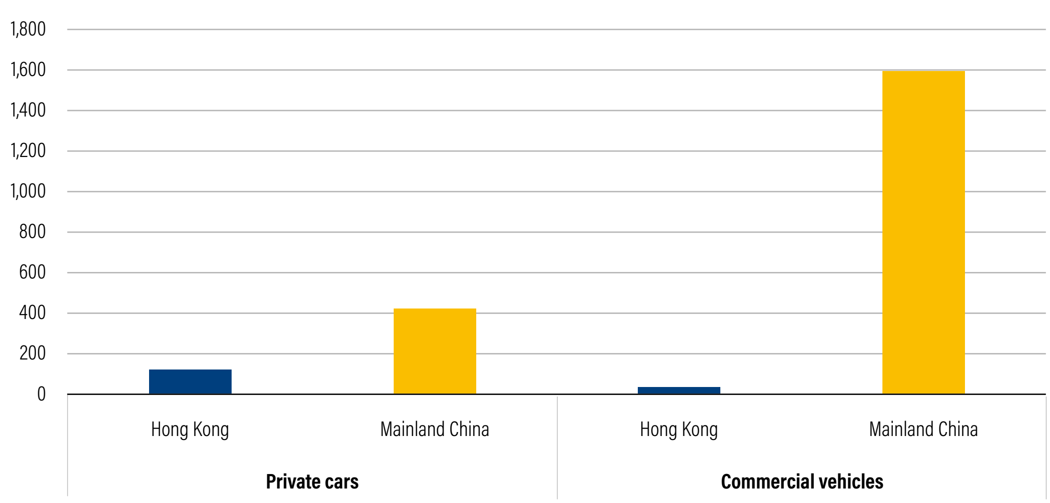
Although private cars, taxis, (public and private) light buses, and light-goods trucks are ready for widespread transition to zero-emission vehicles, there are complications with double-decker buses and heavy-goods trucks. For example, many of Hong Kong's franchised buses are 3-axle double-deckers. The technology of these double-deckers is still developing and there are very few ZEV models available. The TCOs of zero-emission heavy commercial vehicles would possibly reach parity around 2025–2035 (Phadke et al. 2021; California Air Resources Board 2019; Mao et al. 2021). Moreover, their passenger carrying capacity and energy efficiency still cannot meet the operational needs in Hong Kong (Hong Kong Legislative Council 2019).

Although the Hong Kong government plan to test the FCEV technology for 3-axle double-deckers in recent years, the cost of FCEVs is higher than BEVs at present. Current heavy-duty FCEV technology also have limitations: for example, the fuel cell system's 5,000~15,000 hours lifetime for heavy-goods vehicles is too short, smaller than the interim target of 25,000 hours set for fuel cell systems by the U.S. Department of Energy for class-8 tractor trailers (Marcinkoski et al. 2019);[7] further, the current power ratings of the fuel cell system is below 200kW, less than (at least) 300kW power ratings that are common for heavy-duty vehicles; therefore, FCEVs are unsuitable for a hilly driving cycle.

Limited make-and-model availability

Although limited make-and-model availability for EVs is a global phenomenon, the problem is more acute in Hong Kong. Without local original equipment manufacturers (OEMs), Hong Kong's vehicle market relies on imports. The government has been proactive in approving new EV models for entry into Hong Kong's market, as long as the models meet basic safety and functional requirements. At present, 164 EV models have been type-approved by the Transport Department, including 126 electric models for private cars and 38 models for commercial vehicles (Hong Kong Environmental Protection Department 2022b, Transport Department n.d. [b]). However, in mainland China, there were 425 BEV models for private cars and 1,603 models for commercial vehicles in 2021 (MIIT 2021) (Figure 4). Because no suitable electric public light bus (e-PLB, i.e., minibuses) models are available, the city still does not have an e-PLB.

Figure 4 | **Numbers of BEV Models Type-Approved by Hong Kong and Mainland China**



Note: BEV = Battery electric vehicle.
Source: Hong Kong Environmental Protection Department 2022b, MIIT 2021.

The reasons for Hong Kong's shortage in EV models could be the following: (1) with limited market demands, vehicle dealers or corporates may lack leverage with manufacturers to diversify EV models in Hong Kong's market; (2) the government's regulation on EV models appropriate for Hong Kong's roads is too stringent to introduce more EV models (see explanation in subsection "Lack of government determination and policy safeguards" below); and (3) the unique vehicle models used in Hong Kong—especially public light buses (PLBs) and 3-axle double-deckers are less common in the global market, and few OEMs are developing zero-emission buses with these characteristics.

Public interventions are essential to resolve the challenge. To tackle the problem of few OEMs producing the PLB models used in Hong Kong, the government has asked the Hong Kong Productivity Council—responsible for fostering market-oriented research and development (R&D) and commercialisation of R&D prototypes—to develop e-PLB specifications and identify local businesses to design and manufacture the vehicles. When e-PLB models are available, the Hong Kong government plans to trial e-PLBs in 2023 and from there devise an electrification roadmap for e-PLBs (Hong Kong Legislative Council 2021).

Lack of government determination and policy safeguards

The EV roadmap launched in 2021, although setting a time line to phase out the new registration of ICE private cars, still lacks the ambition to match its carbon neutrality vision.

- Commercial vehicles need a clearer roadmap besides EV trials. In Hong Kong, private cars, buses, taxis, and freight vehicles consist of 26.9 percent, 12.9 percent, 17.6 percent, and 42.2 percent, respectively, of road transport-related carbon dioxide (CO_2) emissions (Hong Kong Environment Bureau 2021). Therefore, only banning the sales of ICE private cars (26.9 percent of the road transport emissions) is not sufficient to attain Hong Kong's 2050 carbon neutrality goal. Further, current small-scale trials on e-buses and light-goods trucks are insufficient to create commitments from operators. For example, although the Pilot Green Transport Fund was established in 2011 to promote the trials of electric single-deckers, over a decade, it led to the adoption of 34 electric single-deckers and did not create the momentum for their continuous adoption.

- Interdepartmental coordination, which is important in promoting zero-emission vehicles, is lacking. Promotion of zero-emission vehicles in Hong Kong involves multiple departments, including the Transport Department, Environmental Protection Department, Environment Bureau, and Housing Department. Without concerted action from all the departments, it is difficult to address the challenges enumerated in this chapter.

To implement the roadmap, current regulatory obstacles need to be overcome, including, but not limited to, the following:

- The "Road Traffic Regulations" on maximum weights and lengths of vehicles hinder the adoption of zero-emission vehicles. Only vehicles meeting the regulations can be imported to Hong Kong. However, the regulations were originally designed for ICE vehicles and are not appropriate for BEVs, especially considering BEVs tend to have greater lengths and weights than ICE vehicles. Because many electric double-deckers and e-PLBs do not meet these regulations, they face market entry barriers.

- Hong Kong's existing safety standards and guidelines on the handling of hydrogen are outdated. Hong Kong's Dangerous Goods Regulation (Cap. 295, Section 5) states that compressed or refrigerated liquid hydrogen, as well as fuel cell cartridges, are only permitted in Hong Kong at the general level at 75 litres, and at the industrial level of 150 litres (Hong Kong e-Legislation 2012). The maximum package size for fuel cell cartridges is 120 millilitres (ml) (Hong Kong e-Legislation 2012).

Unwilling private operators

Since Hong Kong's buses and light-goods trucks are primarily privately owned and operated, without clear returns on investments, it is challenging for cost-conscious corporate decision-makers to switch to ZEVs, even though they acknowledge the importance of the zero-emission transition. The COVID-19 pandemic further reinforced this reluctance. Our interviews show that private operators running at low margins are concerned that the transition to EVs may undermine financial resilience in times of crises.

Barriers with infrastructure deployment

Lack of charging/hydrogen refuelling infrastructure is a crucial barrier for users and corporates to switch to ZEVs.

However, Hong Kong has limited land spaces. The ratio of parking spaces to private cars in Hong Kong had declined from 1.51 to 1.1 from 2006 to 2019, the lowest point during the decade (Hong Kong Legislative Council 2019). Similar challenges can be found for buses and trucks. For example, Hong Kong's bus terminals or bus interchanges are often located in buildings owned by large estates; finding spaces to accommodate extra zero-emissions buses (due to operational inefficiency), charging/refuelling facilities, and electrical equipment is challenging and expensive.

Further, for BEVs, the capacity of distribution grids poses another constraint. Upgrading a transformer costs millions of Hong Kong dollars. Without a smart charging management system, the growth of BEVs will stress out Hong Kong's grid.

Energy transition should occur simultaneously

Hong Kong's zero-emission vehicle transition also places requirements on the sources of energy:

- For electricity, around 75 percent of Hong Kong's electricity is sourced from fossil fuels—50 percent from natural gas and 25 percent from coal. Further, Hong Kong's power system has unique characteristics: the potential of domestic renewable energy is limited, due to limited land spaces. Therefore, Hong Kong needs to seek new ways to decarbonise its power system.

- For hydrogen, because Hong Kong has limited land spaces or renewable energy to produce hydrogen, it relies on imports from Australia, the Middle East, and mainland China. Finding affordable and stable sources of (green) hydrogen would be important for Hong Kong's hydrogen bus trials and future day-to-day operation.

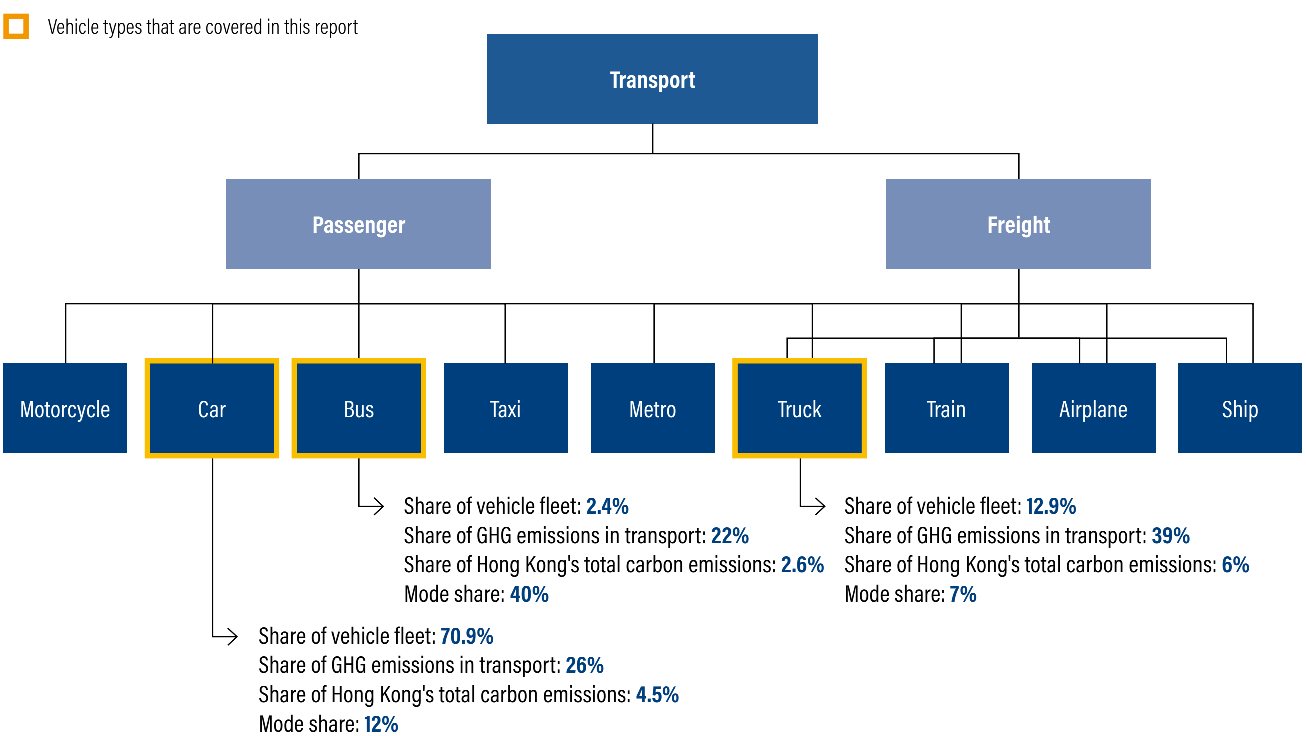
Research scope and framework

This study aims to explore ways to promote zero-emission vehicles on scale in Hong Kong. In this report, we will only focus on three key vehicle segments: buses, private vehicles, and trucks (Figure 5). These three vehicle classes are the largest carbon emitters in the road transport sector, consisting of 87 percent of the total vehicle population, serving 52 percent of passenger journeys and 7 percent of freight movements (in tonnes).[8]

The zero-emission vehicle technologies considered in the study include battery electric vehicles (BEVs) and hydrogen fuel cell electric vehicles (FCEVs) (Table 4). Other low-carbon options such as hybrid vehicles (including PHEVs), biofuels, and e-fuels are not considered, due to the following reasons:

- Hybrid vehicles: The Hong Kong government's attitude towards hybrid vehicles is varied by vehicle classes. For private cars, the recently

Figure 5 | **Vehicle Segments Covered by the Study**



Note: GHG = Greenhouse gas.
Sources: WRI, based on data sources from Hong Kong Environment Bureau 2021; Transport Department 2021.

announced fossil fuel ban stipulates that PHEVs and ICE vehicles will be banned before 2035 or earlier. This is because PHEVs are not zero-emission–their emissions depend on whether car owners turn on the EV mode. Moreover, hybrid vehicles use more fuel than conventional vehicles (Kao 2016; Ockenden 2020). According to the monitoring and evaluation of Hong Kong's hybrid vehicle trial between 2018 and 2020, with government subsidy support, the hybrid light bus spent more than twice as much on fuel and operating costs than LPG light buses and had more downtime due to maintenance (Lo Ka Wah et al. 2020). Therefore, if the cost of ZEVs drops further, ZEVs will be cost-competitive. Given that limited public funding must be prioritised, the study focuses on BEVs and FCEVs.

- Biodiesel: With advances in technology, second-generation biodiesel from plant cellulose and food waste has the advantages of eliminating the need of vehicle and infrastructure upgrades and of alleviating food security risks that commonly arise around first-generation biodiesel. However, biodiesel's supply remains limited, and there is risk that an increase in demand for biodiesel may result in accelerated loss of biodiversity as rainforests, etc., are felled. At present, a total of three petrol stations in Hong Kong supply biodiesel (Government of Hong Kong 2019). Moreover, the mandatory usage of biodiesel is only limited to nonroad construction machinery in all newly tendered public works projects. In the future, using waste feedstock to produce second-generation biofuels faces supply bottlenecks in Hong Kong because the most sustainable waste management strategy is to reduce (food) wastes. Furthermore, besides biofuel, waste feedstock has competing uses—for instance, compost production (Royal Academy of Engineering 2017, de Blas et al. 2020). On the other hand, considering the rapid evolution of zero-emission vehicle technology, the technology will be better poised to decarbonise motor vehicles (Ziegler and Trancik 2021). Therefore, this report does not consider biofuel.

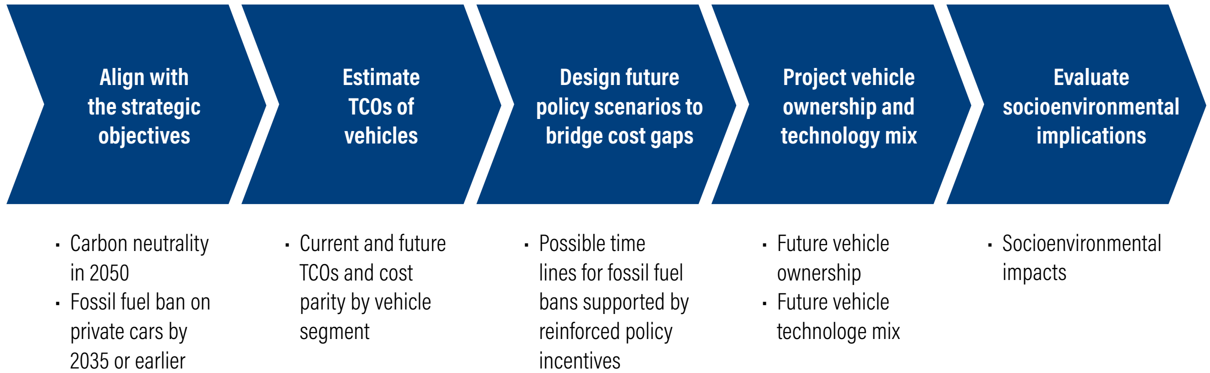
- E-fuel: e-fuel is hydrocarbon fuel synthesised from hydrogen and CO_2. It has the advantage of reducing emissions without vehicle switch or infrastructure upgrade. However, e-fuel is expensive and has limited decarbonisation potential. For example, significant conversion losses of e-fuel could potentially lead to three to four times more emissions than would fossil fuel (Ueckerdt et al. 2021). Therefore, this long-term solution is not considered in the study.

Table 4 | **Zero-Emission Vehicle Technologies Covered by This Study**

	PRESENT 2021	POSSIBLE LOW-CARBON ALTERNATIVES	CURRENT POLICY FOCUS	THIS STUDY
Private car	• Petrol (94.0%) • Diesel (1.8%) • EV (4.2%)	BEV, FCEV, Hybrid, Biodiesel, E-fuel	BEV	BEV
Bus	• Diesel (78.0%) • LPG (21.8%) • EV (0.2%)		BEV, FCEV, Hybrid	BEV, FCEV
LD truck	• Diesel (99.0%) • Petrol (0.7%) • EV (0.3%)		BEV, FCEV, Hybrid	BEV, FCEV
MD & HD truck	• Diesel (100.0%) • EV (0%, with only 1 MD truck)		BEV, FCEV, Hybrid	BEV, FCEV

Notes: LD = Light duty; MD = Medium duty; HD = Heavy duty; EV = Electric vehicle; LPG = Liquified petroleum gas; BEV = Battery electric vehicle; FCEV = Fuel cell electric vehicle.
Source: Table is authors' summary, and data are from Transport Department 2021.

Figure 6 | **Research Framework**



Note: TCOs = Total cost of ownership.
Source: Authors.

The analytical framework of this study is illustrated in Figure 6. The objective of the research is to enhance Hong Kong's zero-emission vehicle ambition in alignment with the city's climate change targets, while not significantly increasing public fiscal burden, worsening traffic congestion, compromising businesses' (such as franchised bus operators') viability, or affecting public access to transit and logistic services.

Because the cost aspect is the key driver to affect zero-emission vehicles' market shares, the study first calculates the current and future total costs of ownership (TCOs) of ZEVs to identify the cost differences with ZEVs and ICE vehicles. The study further explores contextualised policy options that can close the cost gaps. Based on the timing of cost parity between ZEVs and ICEs as well as the time cycles for vehicle turnovers, the study proposes possible time lines for "ICE vehicle bans" for different vehicle segments, where new registrations of vehicles will be 100 percent zero tailpipe emissions. It further evaluates the socioenvironmental implications of the proposed time lines of "ICE vehicle bans." The detailed methodology is explained below.

Total cost of ownership estimation

The total cost of ownership (TCOs) for zero-emission buses and private cars is estimated by the authors, using the methodologies explained below. Due to limited data availability, the TCO estimation of trucks is based on literature review.

The TCO includes the vehicle capital cost (including taxes and fees, cost of financing), cost of charging (including charging infrastructure delivery costs and electricity bills), and maintenance costs incurred over the vehicle service life, and the residual value of the vehicle when the vehicle is scrapped (Lutsey et al. 2021; Mao et al. 2021; EBRD 2021).

$$TCO = Cost_{capital} + \sum_{t=1}^{T} \frac{Cost_{operation_t}}{(1+r)^{t-1}}$$

$$Cost_{operation_t} = Cost_{energy_t} + Cost_{maintenance_t}$$

Where:
TCO is the present value of the total cost of ownership for the ownership period.
$Cost_{capital}$ is the purchase cost, which can be paid one time at procurement or financed over the lifetime of the bus, and includes taxes and fees.
$Cost_{operation_t}$ includes insurance and fees, electricity or fuel cost, and annual maintenance cost.
r is the annual discount rate.
T is the service life.

Vehicle capital cost: The capital cost of ZEVs is affected by multiple factors, including battery sizes, subsidies and tax exemptions, and extra vehicle accessory requirements (Lutsey et al. 2021). The current vehicle capital costs in this study are obtained based on retail prices of mainstreamed ZEV models, interviews with Hong Kong local stakeholders, and literature review. The future vehicle capital cost of BEVs is projected using the method outlined in Appendix A, considering the continuous reduction in battery pack costs, R&D expenses, warranty costs, and improvement in energy efficiency (Lutsey and Nicholas 2019), while the future capital cost of FCEVs is forecasted based on literature review.

Energy costs: ZEVs' energy costs hinge on the infrastructure delivery costs, local electricity tariff structures, and hydrogen production costs.

Among all the cost elements, infrastructure delivery costs—including the capital expenditure (CAPEX) and operational (and maintenance) expenditure (OPEX) of charging/refuelling stations (and sometimes including grid upgrade and land acquisition investments)—are crucial but highly variable. For simplicity, the study assumes the investments on hydrogen-refuelling infrastructure are recouped by at-pump hydrogen costs that are available at hydrogen refuelling stations. However, charging infrastructure delivery costs have a variety of forms (Table 5). This study classifies the charging infrastructure delivery mechanisms into four ways:

- Government-invested public chargers: City government contracts with a supplier to install the charging facilities and operate them for a set period. The capital cost is funded by the government; in this case, the infrastructure delivery costs are the lowest for EV users.
- Public chargers under public-private partnership (PPP): City government sets up a concession with a supplier to install e-bus charge points and operate them for a set period. The capital cost is jointly funded by the government and private investors. Charging

Table 5 | **Comparisons of Different Charging Infrastructure Delivery Mechanisms**

	PRIVATE HOME CHARGERS	PUBLIC CHARGERS: GOVERNMENT INVESTMENT	PUBLIC CHARGERS: PPP	PUBLIC CHARGERS: PRIVATE INVESTMENT	
				FLEET OPERATOR INVESTMENT	THIRD-PARTY INVESTMENT
Investor	Individual EV owners	Government	Government and private entities	Fleet operators	Utility companies or commercial charging point operators (CPOs)
Advantage	• Simple to implement	• Improved coordination among departments, leading to fast network expansion	• Improved coordination among departments, leading to fast network expansion • Expertise on charging facility supply and management (such as smart charging)	• Eased public burdens	• Eased public burdens • Expertise on charging facility supply and management (such as smart charging)
Disadvantage	• Slowed infrastructure delivery due to land	• Heavy public burdens	• Slowed infrastructure delivery due to contractual negotiations	• Slowed infrastructure delivery due to land and grid constraints	• Slowed infrastructure delivery due to land and grid constraints • Demonstrated project financial viability
Examples	Many regions	UK, the Netherlands	UK, the Netherlands	Mainland Chinese cities	Santiago, Chile Mainland Chinese cities
Energy costs	**• Electricity bills** **• CAPEX for charge point installation**	**• Electricity bills**	**• Electricity bills** **• A fraction of CAPEX and OPEX for charge point installation and grid upgrades** **• Regulated charging service surcharges**	**• Electricity bills** **• CAPEX and OPEX for charge point installation and grid upgrades**	**• Electricity bills** **• Charging service surcharges**

Notes: EV = Electric vehicle; PPP = Public-private partnership; kWh = Kilowatt-hours; CAPEX = Capital expenditure; OPEX = Operational expenditure.
Source: Authors based on literature review and interviews.

service surcharges are usually imposed in addition to utility tariffs for EV users, to recoup private investments.

- Private-invested public chargers: Private investors fund the installation and operation of chargers. If utility companies or charging point operators (CPOs) invest, service surcharges will be imposed on EV users. If fleet operators invest, charging facilities' CAPEX and OPEX will be included.
- Private home chargers: EV users pay up-front costs of the charger unit and electrical wiring costs.

Different charging infrastructure delivery mechanisms are chosen for different vehicle segments, as explained in the following chapters.

Other costs: maintenance costs of different vehicle classes are based on literature review. The study assumes the residual value of zero-emission vehicles is zero, and the residual values of ICE vehicles are based on local interviews.

Projection on vehicle ownership and technology mix

The projection of future vehicle ownership by vehicle class is performed in the Energy Policy Simulator (EPS) model, based on assumptions of population growth, mode shift, and travel demand management measures outlined in the report "Towards a Better Hong Kong: Pathways to Net Zero Carbon Emissions by 2050" (WRI and Civic Exchange 2020).

The future market share of zero-emission vehicles in annual sales and the zero-emission fleet penetration ratios in vehicle stocks are predicted based on TCOs, using the "vehicle turnover" approach in EPS that takes vehicle age profiles, stock turnover cycles (vehicles' useful life), and proposed "ICE vehicle bans" into account.

Socioenvironmental impact analysis

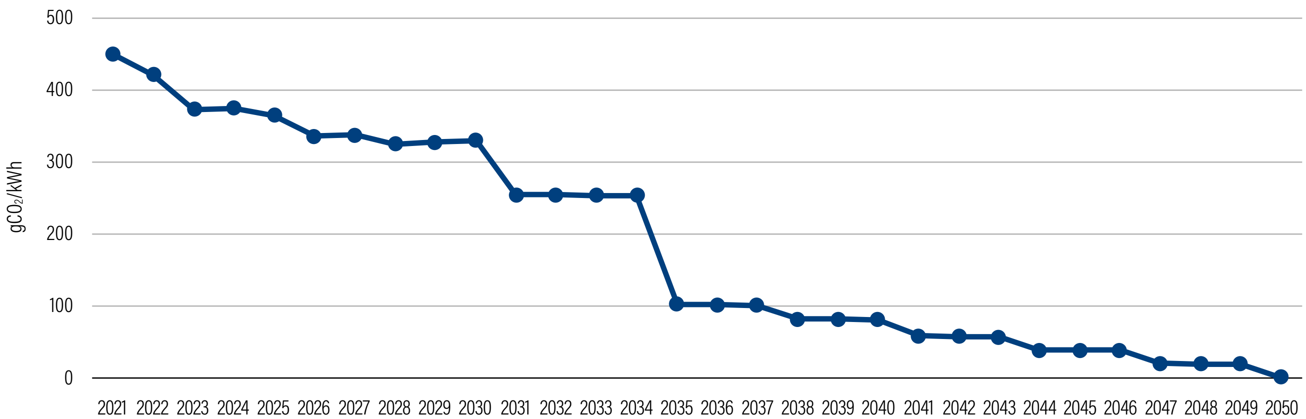
Socioenvironmental impacts in this study include reductions in GHG emissions and air pollutants, benefits of avoided climate damages and premature deaths, and impacts on public expenditure. The impacts on public expenditure are calculated based on the TCO estimation and future market share of ZEVs, while the GHG emission and air pollutant reduction benefits are computed in EPS using the methods and assumptions outlined below:

Reductions in GHG emissions and air pollutants: GHG emissions in this study are well-to-wheel (WTW) emissions, including tank-to-wheel emissions (i.e., tailpipe emissions) and well-to-tank (WTT) emissions (i.e., emissions from power generation, hydrogen production, and oil refineries). In contrast, air pollutant emissions only include tailpipe emissions because the WTT emissions are not entirely within Hong Kong.

Since WTW CO_2 emissions of ZEVs hinge on upstream emissions from power generation and hydrogen production, this study assumes the following:

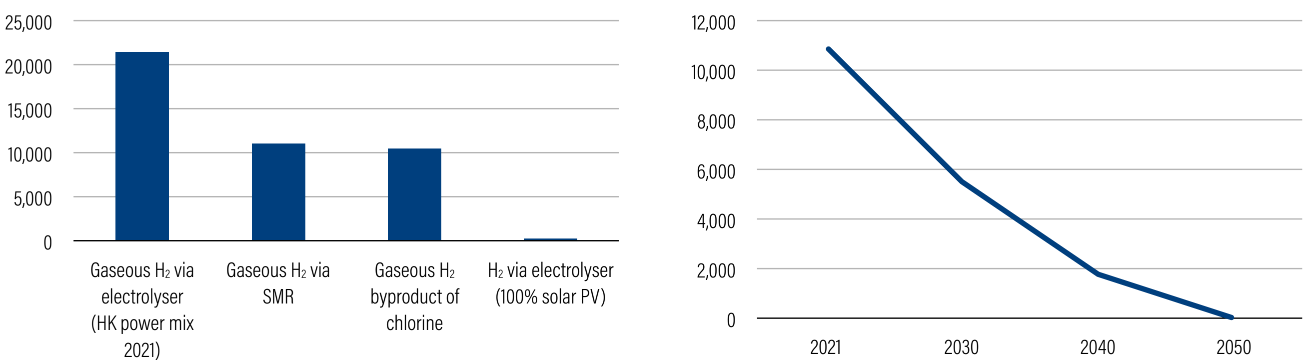
- Emission factors for power generation: Hong Kong is still heavily relying on fossil-based power. In 2020, 71 percent of electricity was sourced from fossil fuels—48 percent from natural gas and 23 percent from coal, and the remaining 29 percent from imported nuclear power (27 percent) and other sources (2 percent). In this study, the future power mix and emission factors of power generation in Hong Kong are built on the World Resources Institute (WRI) and Civic Exchange study "Powering a Carbon-Free Hong Kong: Pathways towards a Net-Zero Emissions Power System for Hong Kong" (WRI and Civic Exchange 2021), in which the most ambitious Fossil-Free Scenario is selected that ensures the achievement of zero-emissions in 2050. In the scenario, the power mix in 2050 will comprise 60 percent imported nuclear, 30 percent hydrogen-based power, and 10 percent local renewable energy. The projected emission factors of power generation in this study are shown in Figure 7.
- Emission factors for hydrogen production: The study assumes that in the near term (2021–2030), the cost-effective solution is to source 100 percent (gaseous) hydrogen from adjacent cities in the Greater Bay Area (GBA) with hydrogen generated as a by-product from industrial processes (such as from chlorine) or from stream methane reforming (SMR). In 2030, when liquefied hydrogen becomes

Figure 7 | Projected CO_2 Emission Factors of Power Generation in Hong Kong



Notes: g = Grams; kWh = Kilowatt-hours; CO_2 = Carbon dioxide.
Source: 2021 data are provided by CLP Power Hong Kong, and the rest of the data are calculated by WRI.

Figure 8 | CO_2 Emission Factors of Different Hydrogen-Generation Approaches (Unit: g CO_2/kg H_2)



Note: The emissions from transportation and distribution of H_2 are not included. Using Hong Kong's local grid power to produce hydrogen (H_2) (through electrolyser) emits highest amount of CO_2 emissions; therefore, this approach is not considered in the study.
g = Grams; CO_2= Carbon dioxide; kg = Kilograms; H_2 = Hydrogen; HK = Hong Kong; SMR = Stream methane reforming; PV = Photovoltaic.
Source: Authors' calculation using Hong Kong 2021 power mix and GREET 2.0.

economically viable, imports of hydrogen from global or regional markets will be feasible, the study assumes 50 percent (liquid) hydrogen will be sourced from green hydrogen; that is, centralised water electrolyser with 100 percent renewable energy (Figure 8). In 2050, 100 percent of hydrogen will be green hydrogen. The emission factors for different hydrogen production methods are estimated using GREET 2.0 (ANL 2014).

Benefits of avoided climate damages and premature deaths: Based on the projected emission reductions, the monetised benefit from GHG emission reductions is calculated by multiplying the amount of emission reductions—in comparison to a reference scenario—with the future social cost of carbon (U.S. Government 2015). The reduced air pollutant emissions could also lead to less premature mortality, which could be calculated by multiplying the health-related incident factor and projected pollutant emissions reductions. The economic benefits from avoided health impacts are obtained by multiplying the localised Value of Statistical Life (VSL)[9] and avoided premature death. The detailed methodology is documented in the technical note, "Hong Kong Energy Policy Simulator: Methods, Data, and Scenario Results for 2050" (WRI and Civic Exchange 2019).


#MISSIONZERO
零排放
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CHAPTER 2

ZERO-CARBON BUS FLEET AND ENABLING MECHANISMS

Bus services accounted for 40 percent of Hong Kong's mode-share for mechanised trips (excluding walking and cycling) in the most recent travel survey (Transport Department 2014), outnumbering rail transit and private cars. Hong Kong needs dedicated zero-emission bus trials, a long-term electrification roadmap, and sustainable policy safeguards to decarbonise bus-related emissions.

Figure 9 | **The Status Quo of the Bus Services in Hong Kong**

Double-decker

Single-decker

Minibus

	TYPE OF BUSES	# OF BUSES	# OF ROUTES	ANNUAL MILEAGE PER BUS	ANNUAL PASSENGER TRIPS PER BUS
Public light bus service	Minibuses	4,350	360	87,984 km	540,200,000
Franchised bus service*	Single-deckers	282	702	65,327 km	1,544,680,000
	Double-deckers	5,760		84,249 km	

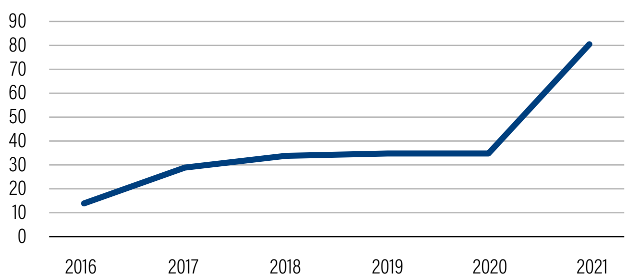
Notes: *Although MTR is not among the franchised bus companies, there are 15 bus routes operated by MTR Corporation to complement its railway services with a fleet of 142 buses (131 double-decker; 11 single-decker).
km = kilometres.
Source of data: Transport Department 2021c. Hong Kong Extras n.d.
Source of pictures: WSJ https://www.wsj.com/video/riding-on-a-hong-kong-double-decker-bus/BB5BFF1A-DB53-4224-A06C-27D84699D31E.html; Hong Kong photos http://www.hongkongphotos.info/hong-kong-tram-120.html; Hong Kong Extras http://www.hongkongextras.com/busservices.html; Wikiwand. https://www.wikiwand.com/en/Public_light_bus.

To meet the large and unevenly distributed demands, Hong Kong's bus services and vehicle types are diversified (Figure 9) and include (1) franchised bus services that capture the majority of Hong Kong's bus ridership and consist of 27 percent of the mode-share. The operation of the franchise bus routes is granted to five private bus operators. To accommodate large ridership, only high-capacity double-deckers[10] are deployed for franchise services; and (2) public light bus services, which capture the remaining bus ridership, account for 13 percent of Hong Kong's mode-share. The services are carried out solely by minibuses.

The pace of e-bus adoption in Hong Kong is lagging (Figure 10):

- Minibuses: Before 2022, no electric minibuses had been introduced in Hong Kong because of limited make-and-model availability. The situation is improved: an electric minibus will be available for trial in 2022, and the government plans to purchase 40 minibuses for a 12-month trial from 2023.
- Single-deckers: Since the first trial of single-decker e-buses in 2015, the number of electric franchised single-deckers registered in Hong Kong has been stagnant at 34 (0.6 percent of the franchised bus fleet).
- Double-deckers: Before 2020, no electric double-deckers were procured. In 2021, 46 electric double-deckers were purchased and confirmed for delivery. The number is equivalent to one-third of the franchised bus procurements in 2021.

Figure 10 | **Number of e-Buses Registered in Hong Kong**



Note: The statistics on single-deckers and double-deckers refer only to franchised services.
Source: Transport Department 2016–2021.

TCO analysis

For the total cost of ownership (TCO) analysis, typical franchised bus models—the 3-axle double-deckers and 12-metre single-deckers—are chosen (Table 6). Because there are cost and technology barriers obstructing the electrification of minibuses, they are not emphasised in this analysis.

Compared to other cities, Hong Kong's transition to zero-emission buses is confounded by unique challenges, including the following:

- **The large share of the heavy-duty and high-capacity 3-axle double-deckers.** 95 percent of the franchised bus fleet is composed of 3-axle double-deckers[11] (gross vehicle weights over 24 tonnes), with the remaining 5 percent of single-deckers. However, the availability of electric makes-and-models is limited on the market. For those that are available—3-axle double-deckers like the BYD ADL Enviro500EV, vehicle ranges (240–280 km[12])—for Hong Kong's over 230 kilometres (km) daily operating mileages, the prices are prohibitive. According to a few local bus operators, electric 3-axle double-deckers could also have the issue of lower passenger capacity.
- **Intensive operation of Hong Kong's franchised buses.** Although intensive operation is critical to maintain the city's bus operation efficiency, this hampers bus electrification; the annual mileage of diesel double-deckers is 84,294 km, over 20 percent higher than 67,970 km in the United Kingdom (EBRD 2021) and 66,000 km in Shenzhen (World Bank 2021). To meet the high annual mileage requires either larger battery capacities[13] or more rapid charging speeds.[14]
- **Hong Kong's bus franchise system.** As with London and Singapore, Hong Kong's buses are operated under the franchise scheme (Table 7). Private bus operators are responsible for capital investments on bus acquisition and for operating them for a maximum of 18 years, while the city government adjusts bus fares to ensure operators have sufficient revenues to recover their costs. However, if the current practice persists where private bus operators take on the risks associated with zero-emission

Table 6 | **Technical Characteristics of Representative Single-Deckers and Double-Deckers in Hong Kong**

Parity is not reached   Parity is reached

	SINGLE-DECKER (12M) (SD)		3-AXLE DOUBLE-DECKER BUS (DD)		
	Battery electric bus	Diesel bus	Battery electric bus	Hydrogen bus	Diesel bus
Bus length (metres)	12.2	12.0	13.5	X	12.0
Gross vehicle weight (kg)	19,000	18,000	27,800	X	24,000
Maximum passengers or seats	90/32	95-100/10-46	144/92	X	140/91
Annual mileage (km)	66,000	65,327	66,000	84,294	84,294

Notes: Seat numbers of 137/90 mean 90 seats, with a total passenger capacity (including standing passengers and the driver) of 137. Annual mileage of electric single-decker is derived from the 1:1.2 replacement rate used in the Hong Kong Legislative Council (2019), and the annual mileage of electric double-decker is derived from the 1:1.5 replacement rate assumed by the authors.
m = Metres; kg = Kilograms; km = Kilometres; X = Not available.
Source: Transport Department 2020, Alexander-Dennis, BYD, and Yutong websites.

Table 7 | **Comparisons of Bus Contracting Models between Hong Kong and Other Cities**

	HONG KONG	SINGAPORE	LONDON	SANTIAGO (before the introduction of e-buses)
Bus contracting model	**Net-cost contract**	**Gross-cost contract**	**Gross-cost contract**	**Mixed model**
Bus capital risks	Operators purchase the buses to meet requirements set by government.	Government retains ownership of the buses and leases to the operators.	Operators purchase the buses to meet requirements set by government.	Operators purchase the buses to meet requirements set by government.
Demand/revenue risks	Operators are renumerated based on passengers transported.	Operators are renumerated based on vehicle miles travelled.	Operators are renumerated based on vehicle miles travelled.	& Operators are renumerated based on vehicle miles travelled and passengers transported.

Note: denotes "governments", and denotes "bus operators."
Source: Authors' summary based on London information from http://content.tfl.gov.uk/uploads/forms/lbsl-tendering-and-contracting.pdf; Santiago information from https://www.itf-oecd.org/sites/default/files/docs/reforming-bus-concessions-santiago-de-chile.pdf.

vehicle procurement and charging equipment supply, the switch to zero-emission buses will either erode operators' financial sustainability or raise bus fares. Therefore, franchise reforms or other policy safeguards may be warranted.

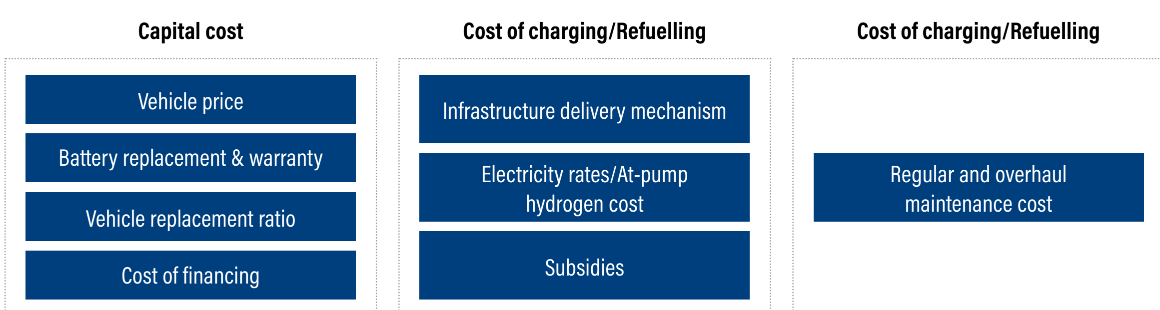
Key TCO considerations

Assuming the existing bus franchise remains unchanged, the section first calculates the TCOs of zero-emission buses (including electric buses and hydrogen buses) for zero-emission bus owners—that is, private franchised operators.

The cost breakdowns of zero-emission-buses' TCOs are listed in Figure 11. Of note, a crucial cost item—the large land acquisition/leading costs for bus depots and hydrogen-refuelling stations are not included in the TCO calculation. The study assumes the government will take on the costs; if not, the cost burden on bus operators will increase and further deter the zero-emission bus transition.

Capital cost of buses: The capital cost of zero-emission buses is affected by a basket of factors, including battery ranges, the replacement

Figure 11 | **TCO Cost Breakdowns for Zero-Emission Buses**



Notes: Land acquisition costs are not included. TCO = Total cost of ownership.
Source: Authors.

Box 1 | Considerations on Vehicle and Charging Technologies

The study considers two zero-emission vehicle technologies—the battery electric bus (shortened to "e-bus") and the hydrogen fuel cell bus (shortened to "hydrogen bus"). Globally, with dropped prices and proven technologies, e-buses have emerged as a viable solution ready for large deployment. In contrast, the deployment of hydrogen buses remains at the early stage, given the technology uncertainty and high costs.

E-buses have several variants in terms of charging technologies. Based on different charging technologies' impacts on bus operation, costs of infrastructure delivery, and public objection, the study recommends plug-in charging (see Table B1.1).

Table B1.1 | Comparison of Different Zero-Emission Bus Charging Technologies

	BATTERY ELECTRIC BUS			HYDROGEN FUEL CELL BUS
	Plug-in charging or pantograph charging in terminals and depots	On-road pantograph charging	Battery swapping at battery swapping stations	
Impacts on operation	Depends (charging time—3 minutes to 5 hours—will affect operation)	Depends (charging time—3 to 10 minutes—will affect high frequency operation)	Depends (limited number of battery swapping stations will affect operation)	Depends (refuelling time—10–20 minutes—will affect high frequency operation)
Capital investments on infrastructure	Pantograph charging is 2–3 times the capital investment of plug-in charging	2–3 times the capital investment of plug-in charging	Higher than plug-in charging due to extra battery reserves needed	Higher than plug-in charging facilities due to weak supply chains
Land space requirements	Moderate to large land spaces needed to accommodate chargers and substations.	Moderate land spaces (especially public spaces) needed to accommodate chargers and substations.	Large land spaces needed to accommodate battery swapping stations.	Moderate to large land spaces needed to accommodate hydrogen storage, refuelling stations, and safety zones.
Range	Current BEB technology requiring plug-in charging does not provides sufficient range for certain intensively operated routes in HK.	BEB technology requiring on-road pantograph charging could provide sufficient range for HK.	BEB technology requiring battery swapping could provide sufficient range for HK.	Hydrogen FCEBs could provide sufficient range for HK.
Other considerations		• Public objection (not-in-my-backyard challenges) and lengthy approval (visual appearance and grid connection) can impede on-street charger installation.	• Limited land spaces affect the supply of battery-swapping stations.	• Safety operation of refuelling stations and buses is a concern. • Green hydrogen supply is challenging.
Applicability to Hong Kong	✓			✓

Notes: Induction charging is not considered due to limited global adoption. Charging time duration refers to the charging time in the actual operation—it would be a full charge or partial charge.
BEB = Battery electric bus; HK = Hong Kong; FCEBs = Fuel cell electric buses.
Source: Authors.

ratio between diesel buses and electric buses, procurement sizes (bulk procurement tends to receive large discounts), extra vehicle accessory requirements, and subsidies and tax exemptions.

This study assumes the following: first, both single-deckers and double-deckers will have 250 km ranges, and replacing one diesel single-decker would require 20 percent additional e-buses (Legislative Council of Hong Kong 2019), whereas replacing one diesel double-decker would require 50 percent additional e-buses due to loading capacity and operating mileage loss. For hydrogen buses, the study assumes one hydrogen fuel cell bus would replace one diesel bus squarely. Second, the prices of e-buses in this study are assumed to be the prices for small purchases, which is in keeping with the current situation. Therefore, the prices are higher than bulk procurement prices. If the Hong Kong government or bus operators pool the procurement in large sizes, the prices would be lower.

Additionally, the useful life of a bus is 17 to 18 years in Hong Kong, whereas battery packs have only five to eight years. Therefore, an e-bus would require battery replacement two to three times. To manage battery replacement investments, bus operators have three procurement strategies (Table 8 and Figure 12):

- Scheme 1. Bus operators operate the e-buses for eight years and then scrap the vehicle. Thus, one diesel bus is replaced by two e-buses over the lifetime, not accounting for operational efficiency loss. This scheme is only adopted by mainland Chinese cities because of the mandatory eight-year scrappage limit.

- Scheme 2. Bus operators operate the e-bus for 12 to 18 years, and batteries are replaced two to three times in the bus's lifetime. Because currently in the European market, where the scheme is common, Scheme 2 has a warranty period of two to five years, bus operators undertake the battery replacement costs (EBRD 2021).

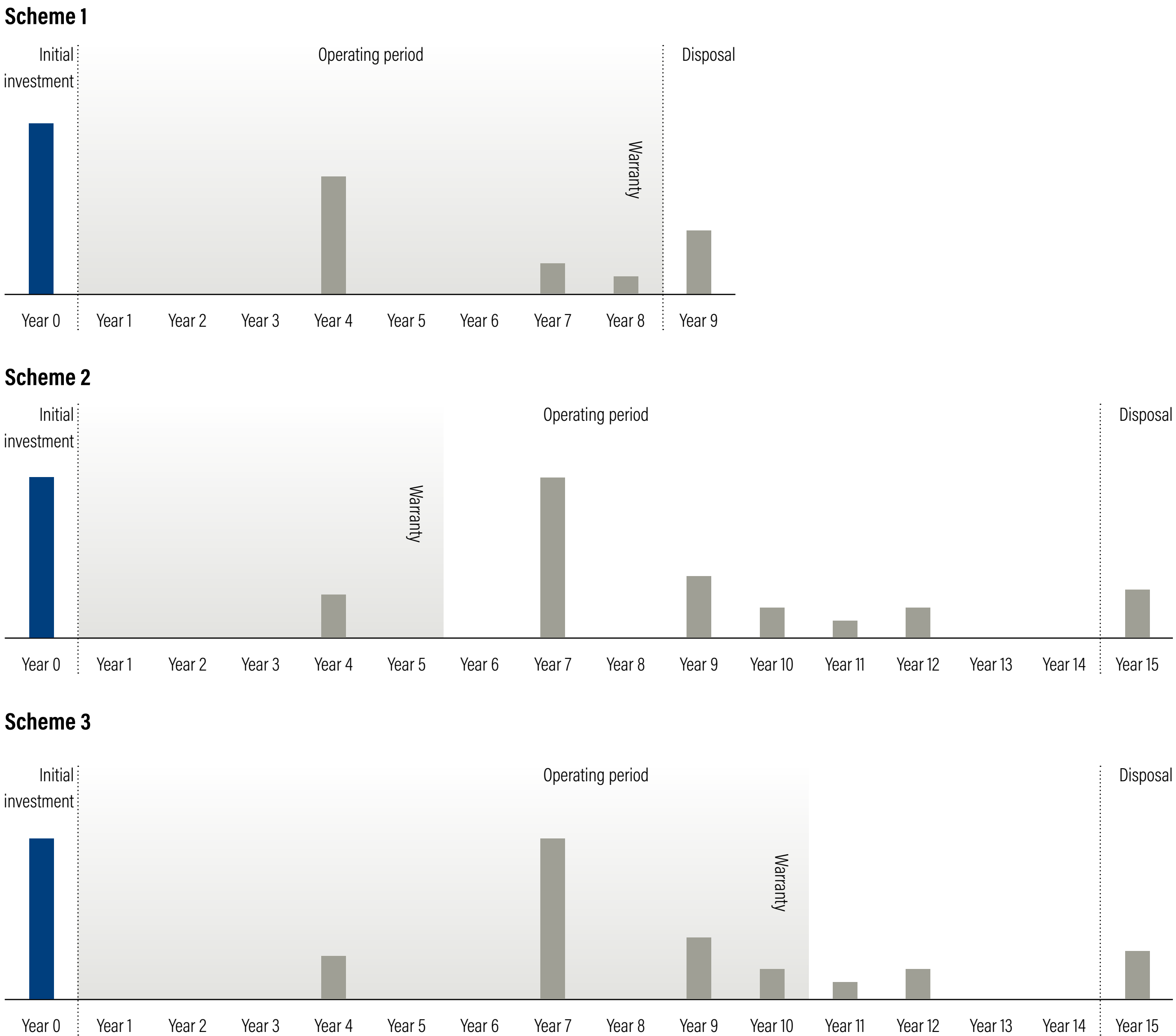
- Scheme 3. Differing from Scheme 2, original equipment manufacturers (OEMs) provide long-term warranties, either at an additional cost or for free. Therefore, few battery replacement costs are imposed on bus operators.

Table 8 | **Three Procurement Strategies of e-Buses**

	SCHEME 1	SCHEME 2	SCHEME 3
E-bus service life	8 years	12–15 years	12–15 years
Warranty periods	8 years	2–5 years	8–10 years
Battery replacement for operators	0–1 replacement	2–3 replacements	0–1 replacement
Examples	Mainland Chinese cities such as Shenzhen	London and European cities	Hong Kong

Source: Authors updated based on EBRD 2021.

Figure 12 | **Bus Operator Procurement Strategies to Manage Battery Replacement Investments (2)**



Note: The graphs are for illustrative purposes only.
Source: Authors updated based on EBRD 2021.

The TCO in Scheme 2 and Scheme 3 is lower than for Scheme 1 because of the maximum utilisation of the vehicle chassis and lower battery costs when they are replaced. Although Scheme 2 is more common, operators need to ensure compatible battery packs are available. As battery durability improves, Scheme 3 will become more prevalent. Based on the survey of recent e-bus procurement in Hong Kong, Scheme 3 is chosen—it is also recommended that franchised bus operators in Hong Kong negotiate for better warranty terms at the procurement stage.

Cost of financing: E-bus procurement would require financing mechanisms to ease capital investments as e-bus prices are high, and their cost of financing could be higher than the cost of financing for diesel buses.

However, zero-emission buses are also entitled to low-cost financing options, such as lower-interest concessional loans and green bonds. At present, no low-cost financing mechanisms are available for Hong Kong's bus operators. This study assumes the annual interest rate for both diesel buses and zero-emission buses is 5.5 percent, and the loan amount is 50 percent of vehicle prices for a three-year period. However, if Hong Kong bus operators could access green finance, the concessional loan would have a 2.5 percent annual interest rate for zero-emission buses.

Energy efficiency: Zero-emission buses' energy efficiency—particularly e-buses—varies with speeds, the usage of air conditioning, the slope of the road, drivers' driving habits, and other factors (Table 9). The issue with energy inefficiency is prominent in Hong Kong—the hilly terrains, air-conditioning usage, and local driving cycles increase e-buses' energy consumption.

Based on literature reviews, the study assumes that in 2021, the energy efficiency of electric single-deckers (SDs) and double-deckers (DDs) in Hong Kong was 135 kilowatt-hours per 100 kilometres (kWh/km) (the median of Hong Kong test results) and 234 kWh/100 km (the median of Singapore test results), respectively. The energy efficiency of hydrogen double-deckers is 9.3 kilograms (kg)/100 km (UK test results). In 2030, the electric DD's energy efficiency will be improved to 165 kWh/100 km (London test result), and that for hydrogen double-deckers will be improved to 7.5 kg/100 km (London test result).

Cost of charging and refuelling: The cost of charging for e-buses hinges on the charging infrastructure delivery mechanisms and the local electricity tariff structures (Table 10).

For charging infrastructure delivery mechanisms, the study considers two extreme cases—government investments and private investments (see Section 1.4).

For electricity tariff structure, Hong Kong's rate design has different tariff rates to cater to the various customer segments. For the category of large energy and power users, which includes bus operators, the bulk tariff or large power tariff may apply. The time varying rates (time-of-use rates) with additional demand charges

Table 9 | **Summary of Real-World Energy Intensities of Zero-Emission Buses in Literature**

LOCATION	ELECTRIC SD (kWh/100 km)	ELECTRIC DD (kWh/100 km)	HYDROGEN DD (kg/100 km)	SOURCES
London and other UK cities	• Median: 112	• Median: 165	X	EBRD 2021; WRI based on interviews
	X	• Median: 256	• Median: 9.3	EU NewBusFuel project 2020
	X	X	• Range: 6.3–7.9	Doyle et al. 2020
Shenzhen	• Range: 94–126	X	X	World Bank 2021
Singapore	• Median: 160 • Median absolute deviation (MAD): 24 • Range: 110–220	• Median: 234 • MAD: 34 • Range: 160– 320	X	Gallet et al. 2018
Ontario, Canada	X	• Light traffic: 230 • Congested traffic: 248	X	El-Taweel et al. 2020
Hong Kong	• Median: 135 • Range: 125–192	X	X	Hong Kong Legislative Council 2019

Notes: SD = Single-decker; DD = Double-decker; kWh = Kilowatt-hours; km = Kilometres; X = Not available.
Source: Authors' summary based on literature review.

Table 10 | **The Levelised Cost of Charging for Bus Operators under Different Delivery Mechanisms**

	GOVERNMENT INVESTMENTS	PRIVATE INVESTMENTS: BUS OPERATORS	PRIVATE INVESTMENTS: THIRD-PARTY INVESTMENTS
Types of cost of charging for bus operators	· Electricity bills	· Electricity bills · CAPEX and OPEX for charging points and grid upgrades	· Electricity bills · Charging service surcharges
Charger capital cost per bus (1,000 HK$)	0	230	0
Charger O&M cost per bus (1,000 HK$)	0	291	0
Charger service surcharge (HK$/kWh)	0	0	0.8
Levelised cost of charging (HK$/kWh)	**1.14–1.75**	**1.35–2.16**	**1.94–2.75**

Notes: Assumes the charge point to vehicle ratio is 1:2 and annual electricity consumption of an e-bus is 164,286 kWh.
kWh = Kilowatt-hours; O&M = Operations and maintenance; CAPEX = Capital expenditure; OPEX = Operational expenditure.
Sources: Charger's capital and O&M costs are from World Bank 2021. The rest are authors' assumptions.

Table 11 | **The Levelised Cost of Hydrogen Refuelling for Bus Operators under Different Market Conditions**

	2020 Hydrogen supply mix=100% industrial by-products		2030 Hydrogen supply mix=50% industrial by-products + 50% green hydrogen	
	Market equilibrium	Under supply	Market equilibrium	Under supply
Levelised cost of refuelling (HK$/kg)	60	96	30–60	96

Notes: Kg = Kilograms; FCEV = Fuel cell electric vehicle.
Sources: Interviews with FCEV bus operators and FCEV light-duty truck operators in the Greater Bay Area conducted by WRI authors; Hope-Morley et al. 2019.

imposed on peak hours (and off-peak hours) cause variability in operators' electricity bills. Using the CLP's tariff rates as an example, if all e-buses are charged during night hours using the bulk tariff rate structure, the tariff would be 1.14 HK$/kWh. In contrast, some e-buses charging during daytime peak hours (such as 30 percent of e-buses' energy consumption) using the bulk tariff rate structure would lead to a rate around 1.75 HK$/kWh. This study considers two possible extremes of utility rates—1.14 HKW/kWh and 1.75 HK$/kWh.

The study assumes the investments to hydrogen-refuelling infrastructure are recouped by at-pump hydrogen costs, known as "levelised cost of refuelling." Because Hong Kong's local generation is insufficient to meet the demand, the city's at-pump hydrogen cost is affected by the global or regional supply of hydrogen, the maturity of green hydrogen production technology, and hydrogen transport and distribution costs. Therefore, in addition to the costly green hydrogen production costs and expensive shipment costs for gaseous hydrogen, the import dependency and the exposure to international market fluctuations would pose a challenge to Hong Kong's hydrogen availability and price affordability (Fraunhofer 2020).

In this study (Table 11):

- The hydrogen cost in 2021 is between 60 and 96 HK$/kg, based on the authors' interview with FCEV bus operators and FCEV light-duty truck operators in the Greater Bay Area.

- The hydrogen cost in 2030 is between 30 and 96 HK$/kg, based on the assumption that 50 percent of the hydrogen is sourced from green hydrogen. The cost varies due to uncertainties in hydrogen supply and the costs of "green hydrogen."

Maintenance cost: Because the electric powertrain is simple, the maintenance cost of e-buses—including regular and overhaul maintenance—is lower than for diesel buses. Further, e-buses' maintenance cost is closely related to the warranty periods. Under the extended warranty period of 10 years, most maintenance work is undertaken by OEMs, and the remaining maintenance costs fall on operator labour (World Bank 2021). Based on the literature review, the maintenance cost of e-buses is estimated to be 50 percent of that for diesel buses (Quarles et al. 2020; Deliali et al. 2021).

The case differs for hydrogen buses (Eudy and Post 2018). Because reliable supply chains for spare vehicle components are lacking, the maintenance cost for hydrogen buses remains high (NREL 2021). Without any pilot on hydrogen buses and localised maintenance data, the study assumes current maintenance costs for hydrogen buses are 30 percent higher than for diesel buses based on literature review (Deliali et al. 2021), and that future maintenance costs will be the same as for diesel buses.

TCO calculation for 2021

The TCO calculation follows the method outlined in Section 1.4. Given that under Hong Kong's franchise system, zero-emission buses are procured by private operators, Table 12 lists the key assumptions for the TCOs borne by private operators. In the TCO calculation, the discount rate is set at 7 percent.

Table 12 | **Assumptions for Hong Kong Zero-Emission Buses' TCO Calculation in 2021**

	SINGLE-DECKER (12-METER) (SD)		3-AXLE DOUBLE-DECKER BUS (DD)		
	Electric bus	Diesel bus	Electric bus	Hydrogen bus	Diesel bus
CAPITAL COST					
Vehicle price (in 1,000 HK$)	2,500	1,500	4,450	5,670	2,890
Present value of battery/fuel cell powertrain replacement CAPEX (in 1,000 HK$)	0	n/a	0	332	n/a
Cost of financing (in 1,000 HK$)	192	261	311	436	503
Additional vehicle required	0	n/a	20%	0	n/a
ENERGY COSTS					
Utility rate/hydrogen price	1.14HK$/kWh or 1.75 HK$/kWh	12.5 HK$/L	1.14HK$/kWh or 1.75 HK$/kWh	60 HK$/kg or 96 HK$/kg	12.5 HK$/L
Energy intensity	135 kWh/100 km	32 L/100 km	234 kWh/100 km	9.3 kg/100km	39 L/100 km
MAINTENANCE COST					
Annual maintenance cost (in 1,000 HK$)	32.7	65.4	32.7	85.0	65.4

Notes: Under the asset management Scheme 3, the battery replacement cost is covered by the warranty.
TCO = Total cost of ownership; n/a = Not applicable; kWh = Kilowatt-hours; L = Litres; kg = Kilograms; CAPEX = Capital expenditure.
Source: Authors' summary based on Section 2.1.1, World Bank 2020, and World Bank 2021.

The results show the following:

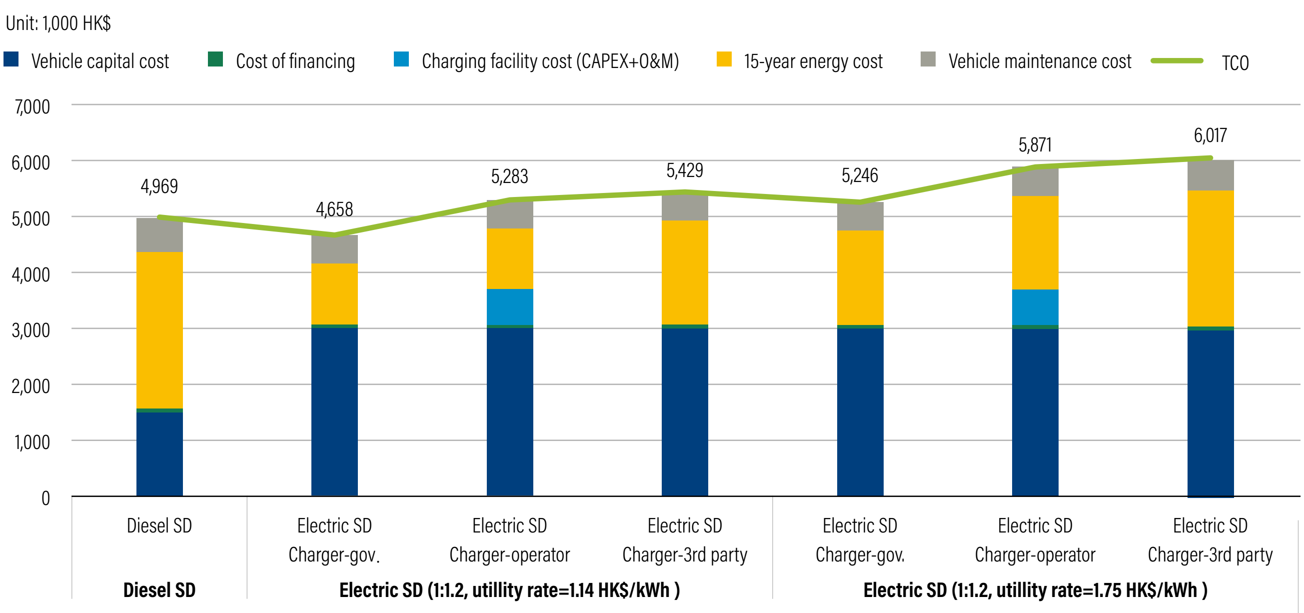
For single-deckers, the TCO cost parity would be reached in the case where the government is responsible for funding e-buses' charging facility installation, and e-buses avoid charging at daytime peak hours (Figure 13). However, in most cases—when the responsibility of e-buses' charging facility installation falls on bus operators and e-buses charge at daytime peak hours, the TCO of e-buses would be from HK$314,000 (6 percent) to HK$1,048,000 (21 percent) higher than the TCO of diesel buses.

For double-deckers, the TCO cost parity between diesel and zero-emission double-deckers is far from being achieved (Figure 14).

For electric double-deckers, the TCO as of 2021 is around HK$714,000 (10 percent) to HK$3,246,000 (44 percent) higher than the TCO of diesel buses. The relatively high TCO of electric double-deckers is due to the following reasons:

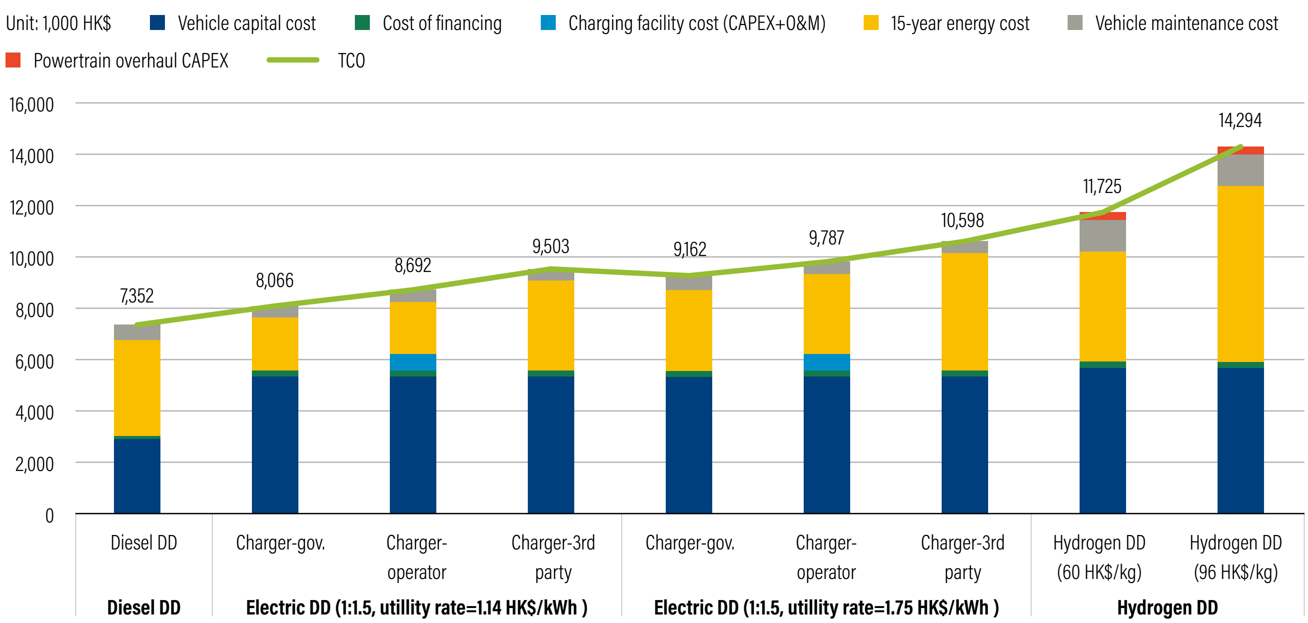
- High vehicle capital costs: The price of electric double-deckers is greater than that of diesel buses. In addition, it takes 1.5 electric double-deckers to replace one diesel bus. Altogether, the capital cost of electric double-deckers is about two times the capital cost of diesel buses.
- Charging infrastructure delivery: Different charging infrastructure delivery mechanisms lead to different TCOs. By this study's estimates, the overall cost burden of charging infrastructure delivery for bus operators varies from zero to about one million Hong Kong dollars per e-bus. Among all options, the government-led charging infrastructure investment incurs almost no cost for bus operators, since the costs are covered by the government. If bus operators fund the installation of charging facilities, the infrastructure capital and O&M costs would rise to around HK$521,000 per e-bus during the 15 years of the bus's lifetime, and even higher when land acquisition cost is included. Charging infrastructure provided by profit-driven third parties, such as charge point operators (CPOs), is the most expensive option for bus operators.
- Potential high demand charges: The variations in e-buses' total charging costs are affected by Hong Kong's electricity rate design. Hong Kong's

Figure 13 | **Single-Deckers' TCO Comparisons as of 2021**



Notes: TCO=Total cost of ownership; SD = Single-decker; kWh = Kilowatt-hours; O&M = Operations and maintenance; CAPEX = Capital expenditure.
"Charger-gov." indicates government-invested e-bus charging facilities. "Charger-operator" is bus operator–invested e-bus chargers. "Charger-3rd party" is other private investor–funded e-bus chargers. 1:1.2 indicates one diesel bus is replaced by 1.2 e-buses. The electricity rate of 1.75 HK$/kWh is authors' estimation by assuming that 30% electricity consumption is during peak hours.
Source: Authors' calculations.

Figure 14 | **Double-Deckers' TCO Comparisons as of 2021**



Notes: TCO = Total cost of ownership; DD = Double-decker; kg = Kilogram; kWh = Kilowatt-hours; O&M = Operations and maintenance; CAPEX = Capital expenditure. "Charger-gov." indicates government-invested e-bus charging facilities. "Charger-operator" is bus operators–invested e-bus chargers. "Charger-3rd party" is other private investor–funded e-bus chargers. 1:1.5 indicates one diesel bus is replaced by 1.5 e-buses. The electricity rate of 1.75 HK$/kWh is authors' estimation by assuming that 30% electricity consumption is during peak hours.
Source: Authors' calculations.

electricity tariff (low-end of the utility rate = 1.14 HK$/kWh) is not high. However, when many e-buses charge at high power rates during peak hours, demand charges and peak-hour charges will increase. Without the deployment of smart chargers and the choice of an appropriate utility rate structure, the rate of 1.75 HK$/kWh could lead to a surge of HK$80,171 in electricity bills (per bus annually).

For hydrogen double-deckers, the TCO differences with diesel buses are larger, with the 2021 TCO about HK$4,373,000 (59 percent) to HK$6,942,000 (94 percent) higher than diesel buses' TCOs. The higher TCO of hydrogen DDs is attributable to the following: First, the vehicle capital cost is high. However, because hydrogen buses more efficiently replace diesel buses (assuming 1:1 replacement with diesel buses in this study) than electric buses do,[15] the capital cost of hydrogen double-deckers is about the same as electric double-deckers. Second, hydrogen fuel is expensive. Unlike the energy cost savings potential of electric double-deckers, the 15-year energy cost (in 2021 present values) of a hydrogen DD is HK$541,000 to HK$3,110,000 higher than diesel buses' fuel costs.

TCO projections to 2030

This section focuses on the projection of the TCOs of 3-axle double-deckers.

First, the study assumes that even with rapid technology advances, vehicle prices of electric DDs and hydrogen DDs would still be higher than the prices of diesel DDs in 2030:

- The future price of electric DDs is forecasted using the methodology outlined in Appendix A. The result shows that the price of electric DDs will drop. However, the vehicle price of electric DDs would be about 10 percent higher than the price of diesel DDs in 2030, and probably approach the price of diesel DDs post-2030.

- The future price of hydrogen DDs is forecasted based on the report, "New Bus ReFuelling for European Hydrogen Bus Depots" (Hope-Morley et al. 2019) with the vehicle price about 50 percent higher than the price of diesel buses in 2030.

Table 13 | **Assumptions for Zero-Emission Bus TCO Projection in 2030**

	3-AXLE DOUBLE-DECKER BUS (DD)	
	Electric DD	Hydrogen DD
CAPITAL COST		
Vehicle price (in HK$1,000)	3,200 (–28%)	4,400 (–22%)
Additional vehicle required	20% (–30%) 0 (–50%)	0
Present value of fuel cell powertrain replacement CAPEX (in HK$1,000)	0	266 (–20%)
COST OF CHARGING		
Energy cost	1.14 HK$/kWh or 1.75 HK$/kWh	30 HK$/kg, 60 HK$/kg, or 96 HK$/kg
Energy efficiency	185 kWh/100 km (–21%)	7.5 kg/100 km (–19%)
MAINTENANCE COST		
Annual maintenance cost (in HK$1,000)	32.7	65.4 (–50%)

Notes: The percentages in the parentheses are the changes compared to 2020 levels.
TCO = Total cost of ownership; kWh = Kilowatt-hours; km = Kilometres; kg = Kilograms; CAPEX = Capital expenditure.

- The price of electric DDs in 2030 is authors' own calculation (Appendix A).
- The prices of hydrogen DDs and fuel cell powertrain replacement CAPEX in 2030 are from the report "New Bus ReFuelling for European Hydrogen Bus Depots" (Hope-Morley et al. 2019).
- The energy costs and energy efficiency of electric DDs and hydrogen DDs in 2030 are explained in Section 2.1.1.
- Annual maintenance cost of hydrogen DDs in 2030 is authors' own assumption.

Sources: Authors' summary based on own calculations, Hope-Morley et al. 2019, and Gallet et al. 2018.

Second, 2030 TCOs of electric DDs and hydrogen DDs are estimated based on the assumptions outlined in Table 13.

The results show the following (Figure 15):

For electric DDs, even at the utility rate of HK$1.75 per kWh, in some cases, TCO parity will be reached in (or before) 2030. The future decline of electric DDs' TCOs is due to the following:[16]

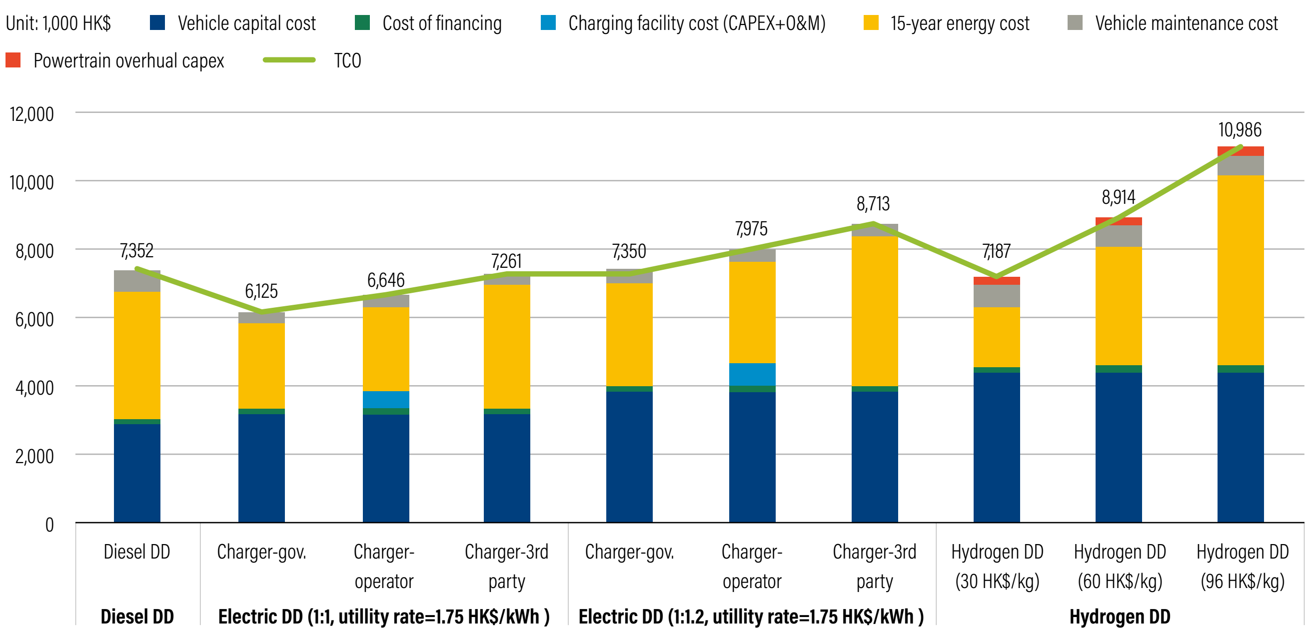
- Lower vehicle capital costs: First, the price of electric DDs is expected to drop due to improved cost, durability of batteries, and energy-efficiency improvement. Further, the increased energy density and 300-km range of batteries will allow for more efficient replacement of diesel buses (1:1 or 1:1.2 replacement).
- Improved energy efficiency: Leapfrogged efficiency improvements will be expected in the future that will result in lower energy costs and larger battery ranges.

However, if replacing a diesel DD still requires extra (20 percent) electric DDs, and charging infrastructure is built without the government's support, the TCO of electric DDs will likely be HK$623,000 (8 percent) to HK$1,361,000 (19 percent) higher than the TCO of diesel DDs.

TCOs of hydrogen and diesel DDs will possibly converge by 2030. The decline in hydrogen DDs' TCOs is due to lower vehicle capital costs and reduced maintenance costs.

However, TCOs of hydrogen DDs would vary more considerably than TCOs of electric DDs, resulting from uncertainties in future hydrogen costs. If hydrogen is in abundant supply and the levelised cost of hydrogen drops below HK$30 per kilogram, the TCO of hydrogen DDs—similar to e-buses—will be reached by 2030. However, if the hydrogen supply has bottlenecks and the hydrogen cost is above HK$60 per kilogram, the TCO of hydrogen DDs would be HK$1,562,000 (21 percent, hydrogen cost is 60 HK$/kg) to HK$3,633,000 (49 percent, hydrogen cost is 96 HK$/kg) higher than diesel DDs'

Figure 15 | **Double-Deckers' TCO Comparisons as of 2030**



Notes: TCO = Total cost of ownership; DD = Double-decker; kg = Kilograms; kWh = Kilowatt-hours; O&M = Operations and maintenance.
"Charger-gov." indicates government-invested e-bus charging facilities. "Charger-operator" is bus operators–invested e-bus chargers. "Charger-3rd party" is other private investor–funded e-bus chargers. 1:1 and 1:1.2, respectively, indicate one diesel bus is replaced by one e-bus and 1.2 e-buses. The electricity rate of 1.75 HK$/kWh is authors' estimation by assuming that 30% electricity consumption is during peak hours.
Source: Authors' calculations.

TCO in 2030. The future cost and supply of hydrogen will be the key determinant of hydrogen DDs' TCOs.

Discussions

The above TCO estimations are not perfectly accurate. The possible caveats with the calculations include, but are not limited to, the following:
For the TCOs of zero-emission buses in 2021:

- First, the land costs for acquiring new bus depots (to accommodate extra e-buses) or extra land spaces (to install charging stations and/or hydrogen-refuelling stations) as well as grid expansion costs are not considered in this study. Given that Hong Kong land costs are exceptionally high, the omission of land costs may lead to large underestimation of TCOs for zero-emission buses. But as mentioned earlier, the costs should be undertaken by the government. Similarly, the grid expansion costs are usually high. Because the study does not consider the case when the distribution grid capacity is augmented, the e-buses' TCOs in this study would be underestimated.

- Second, another key issue affecting TCO is the extent to which an assumption of 1:1.5 replacement of diesel DDs by electric DDs and an assumption of 1:1 replacement of diesel DDs by hydrogen DDs are valid. The assumptions are yet to be confirmed by the trials of zero-emission DDs in high-intensity routes. If more zero-emission buses are required to replace a diesel DD, the TCOs of zero-emission DDs would be higher.

- Third, the initial learning curve for zero-emission buses would be high for some local operators. Bulk procurement prices of zero-emission buses are much lower than prices for small quantity procurements, and the maintenance costs of electric DDs are lower than diesel DDs. However, for operators with limited experiences in purchasing and running zero-emission buses, additional costs and labour time would be needed to overcome the initial learning curves. Therefore, the TCOs of electric DDs would be higher than this study's estimation.

For the projected TCOs of zero-emission buses in 2030:

- There are still large uncertainties with technology development with zero-emission DDs. For example, vehicle prices may not drop as rapidly as assumed. Further, energy-efficiency electric DDs may not be improved as expected. In these cases, TCOs of zero-emission DDs are unlikely to achieve cost parity by 2030.

To make up for the above caveat—particularly for the near-term TCO estimation, the authors recommend the government and local bus operators accelerate pilots on zero-emission double-deckers. The above TCO calculation can be continuously updated through real-world on-road testing results from different bus operators (with different bus procurement and operation strategies).

Future policy scenarios

This section identifies possible measures undertaken by both government and private stakeholders to bridge TCO gaps between diesel buses and zero-emission buses. The section further evaluates different "diesel bus ban" time lines that are instrumental to achieving Hong Kong's carbon neutrality commitment, while not compromising private bus operators' balance sheets or government financial sustainability.

Current policy gaps

At present, given the large TCO gaps between zero-emission DDs and diesel DDs, comprehensive action should be jointly undertaken by the government and relevant stakeholders to bring TCOs of zero-emission DDs to reach parity with TCOs of diesel DDs.

For electric DDs, the current measures include, but are not limited to, the following (Figure 16):

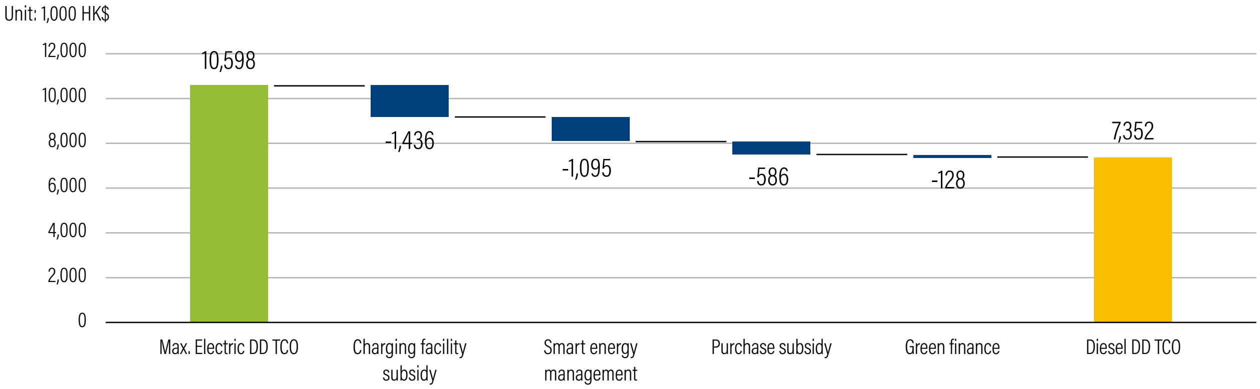
- Public support for e-bus charging infrastructure delivery along with land acquisition: If the government can mobilise land resources and public funding to support charging infrastructure delivery, the TCO of an electric DD would decline by at least HK$1.43 million. These public supports can take the form of land zoning and land acquisition for new bus depots as well as capital grants for installation of e-bus charging facilities. Particularly, considering that a larger number of e-buses are needed to replace diesel buses, the government could plan for large pockets of land for new bus depots in advance and acquire/lease the land. Further, in bus terminals, where chargers may be shared among multiple e-bus operators, the government could consider fully funding the installation of these chargers (from grid expansion to space planning and the construction of chargers) to avoid redundant investments. Further, the government needs to systematically forecast the grid impacts from EV charging and plan for grid capacity expansion.

- E-bus purchase subsidy: Even with public support on charging infrastructure delivery in place, the TCO gap still exists. Therefore, a purchase subsidy up to about HK$586,000 per electric DD is needed to fill the remaining TCO gap. Of note, the actual size of the purchase subsidy depends on how bus operators, utility companies, and government work together to reduce charging infrastructure costs, land costs, and utility costs.

- Smart energy management by bus operators: If bus operators avoid charging at peak hours, the 15-year electricity cost (at a 1.14 HK$/kWh rate) per bus can be around HK$1 million lower than the cost at a 1.75 HK$/kWh rate. Electricity costs can be better managed by private bus operators through smart charging management coordinated with e-buses' operation schedules and bus drivers' eco-driving trainings. If charging at peak hours is unavoidable—particularly when large numbers of e-buses are deployed in the future—the TCO gap can be filled either by increased public purchase subsidies or through concessional charging rates for bus operators.

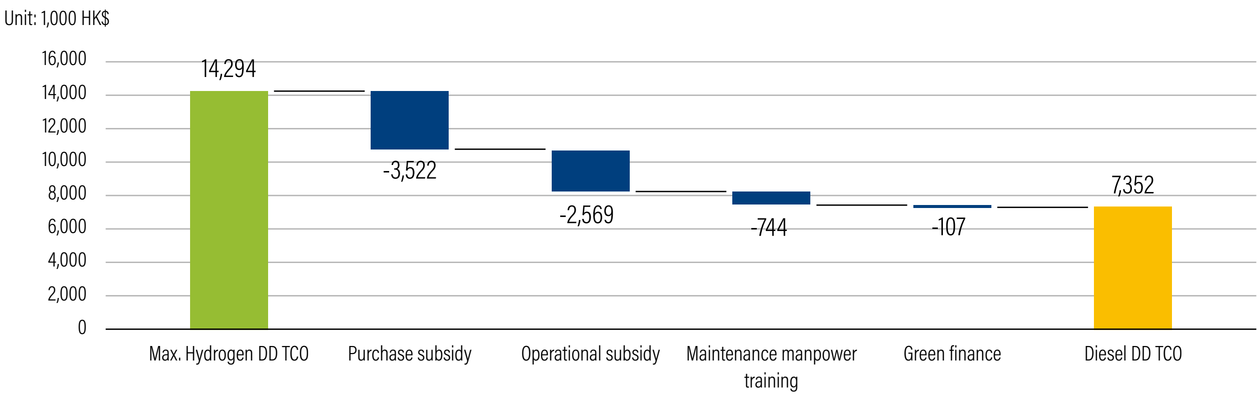
- Although green finance would lower e-bus TCOs by a small amount, it is necessary because the large up-front capital investments for vehicle acquisition will strain private bus operators' cash flows even when TCO parity is reached. Therefore, new financing mechanisms—including concessional loans, green bonds, and leasing—are helpful (WRI and Civic Exchange 2019). Hong Kong's local financial institutions could make these low-cost financing options available to bus operators. To incentivise low-cost green

Figure 16 | **TCO Reduction Potentials for Electric Double-Deckers in 2021**



Notes: DD = Double-decker; kWh = Kilowatt-hours; TCO = Total cost of ownership.
Source: Authors' calculations.

Figure 17 | **TCO Reduction Potentials for Hydrogen Double-Deckers in 2021**



Notes: For hydrogen double-deckers, operational subsidy and maintenance improvement are 15-year costs.
DD = Double-decker; TCO = Total cost of ownership.
Source: Authors' calculations.

financing, the Hong Kong government could consider providing public guarantees.

For hydrogen DDs, the measures include, but are not limited to, the following (Figure 17):

- Operational subsidy and purchase subsidy: The operational subsidy and purchase subsidy are crucial to reduce hydrogen DDs' TCO. Of note, Figure 17 is only for illustrative purposes, the actual size of the public subsidy would still depend on the levelised cost of hydrogen and vehicle prices.

- Public support on hydrogen supply: Although it is challenging to estimate an explicit cost, given limited hydrogen production in Hong Kong, public support on hydrogen imports, reservoir construction, inland transportation, and the construction of hydrogen-refuelling stations (as well as land acquisition) are necessary. Particularly, planning for sustained hydrogen supply is important to ensure the continued operation of hydrogen DDs.

- Maintenance manpower improvement and green finance: The two measures would be helpful to reduce hydrogen DDs' TCOs. If overcoming the initial learning curve, the maintenance cost of hydrogen DDs would drop to the level of diesel DDs, leading to HK$744,000 cost-savings per bus. Similarly, through green finance, the cost of capital could be reduced by HK$107,000 per bus. However, of note, the public operational subsidy and purchase subsidy remain the key measures in making hydrogen DDs affordable.

Future policy scenarios

The section proposes possible "diesel bus ban" time lines based on the TCO gaps between zero-emission buses and diesel buses as well as the measures taken by various stakeholders.

This study assumes that once TCO cost parity is reached, the market shares of e-bus sales would rapidly increase and even become the mainstream vehicle technology; then, a time line of "diesel bus bans" would be feasible. However, a short transitional period would be expected between the time of TCO parity and the time of diesel bus bans, to allow for the market to react. The study assumes three-to-five year transition periods from the timing of TCO parity to the diesel bus ban and, therefore, proposes three possible diesel bus ban time lines:

- **Diesel bus ban 2033**, where the city will acquire only zero-emission buses from 2033. Considering the 17-year service life of diesel buses, the time line is conservative to ensure Hong Kong is on track to reach its 2050 carbon neutrality target. For the diesel bus ban to be effective as of 2033, the TCO parity of zero-emission buses would be achieved around 2030. As not in Section 2.1.3, without public support or only limited support, the TCO parity for electric DDs will be reached around 2030, and hydrogen buses' TCO parity will also possibly be reached then. Therefore, the scenario is a low-cost pathway for all parties, where the Hong Kong government and local bus operators could take limited measures and wait for technologies to improve.
- **Diesel bus ban 2030,** where the city will acquire only zero-emission buses from 2030. Accounting for transitional years between the time of TCO parity to the time of diesel bus bans to allow for the market to react, TCO parity would be reached by 2026–2027. To advance the TCO parity time line to this date, proactive interventions are needed (see Table 14).
- **Diesel bus ban 2026**, where Hong Kong will acquire only zero-emission buses from 2026. To achieve this ambition, considerable efforts are needed to bring TCOs to parity by 2021–2023. This scenario is a high-cost pathway for all parties (see Table 14).

Table 14 | **Comparisons on Diesel Bus Ban in 2026, 2030, and 2033**

		DIESEL BUS BAN 2026	DIESEL BUS BAN 2030	DIESEL BUS BAN 2033
TCO PARITY		**2021-2023**	**2026-2027**	**2030**
Policy safeguards	Electric buses	• Purchase subsidy • Supports on charging infrastructure delivery • Credit enhancement	• Purchase subsidy • Supports on charging infrastructure delivery • Credit enhancement	None
	Hydrogen buses	• Purchase subsidy • Operational subsidy • Supports on hydrogen supply • Credit enhancement	• Purchase subsidy • Operational subsidy • Supports on hydrogen supply • Credit enhancement	• Purchase subsidy • Operational subsidy • Supports on hydrogen supply
Private sector efforts	Electric buses	• Demand charge avoidance • Eco-driving training • Green finance	• Demand charge avoidance • Eco-driving training • Green finance	None
	Hydrogen buses	• Manpower training • Green finance	• Manpower training • Green finance	• Manpower training • Green finance

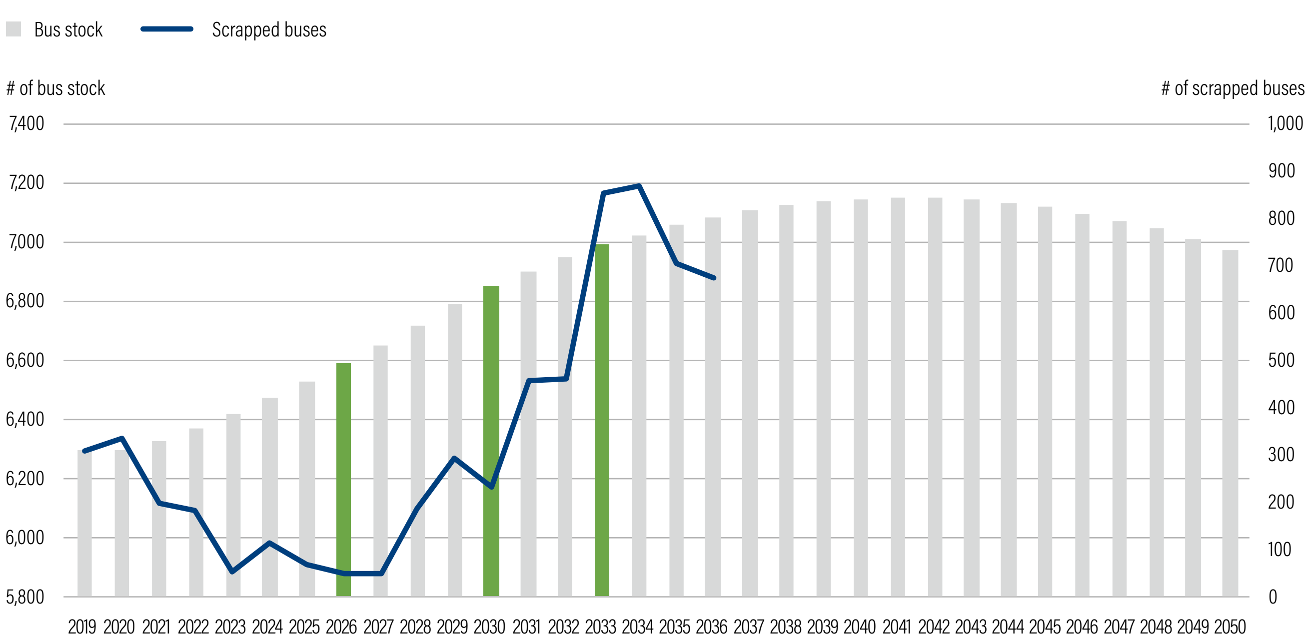
Source: Authors.

The proposed time lines of "diesel bus bans" also match the bus stock turnover pace (Figure 18). Zero-emission buses are usually introduced to the fleet under either of two conditions: (1) new vehicles are added to augment the fleet's service capacities; or (2) existing buses are retired and replaced with new ones. For new additions, the study considers the most favourable scenario—the Decarbonisation Scenario in the Hong Kong EPS model, where under proactive travel demand management policies, Hong Kong's transit demand and the size of the bus fleet will take off from 2026, as the city's population grows and more people take public transit. For the retired and replaced fleet, based on the current age profile of the franchised bus fleet in Hong Kong, two-thirds will be retired and replaced after 2030—if no early retirement takes place. Therefore, the diesel bus bans of 2026 and 2030 match the bus stock turnover pace.

Further, in the three scenarios, the franchised bus fleet in Hong Kong will grow from 6,000 in 2019 to over 8,500 in 2050 to meet the increasing population growth and the growing transit demands resulting from mode shift measures (corresponding to the Low PC Stock Scenario discussed in Section 3.2).

For the 8,500 franchised bus fleet in 2050, this study assumes that BEV buses will comprise 65 percent of the fleet by 2050, with the remaining 35 percent made up of hydrogen buses. This is because despite higher costs and emissions of hydrogen DDs, hydrogen buses have a "niche" application—long-haul Express Routes in Hong Kong. These Express Routes connecting the Central Business District (CBD) to surrounding new towns are often characterised by (1) long route lengths (e.g., Route 962 between Causeway Bay and Moreton Terrace has a route length of 40 km) (WikiRoutes 2017); and (2) high speeds—with few stops, the speed of buses can reach the speed limit of 70 km/hour (h). For these routes, e-bus challenges with range limits and energy inefficiency would persist (Wager et al. 2016). According to statistics from one of Hong Kong's local bus operators—KMB—the buses serving such intensive routes represent one-third of the total fleet, and the study assumes that this ratio would be stable over time; therefore, hydrogen buses would consist of 35 percent of the bus fleet in Hong Kong by 2050 to complement e-bus inadequacy in these routes.

Figure 18 | **Bus Fleet Growth and Turnovers during 2021 and 2050**

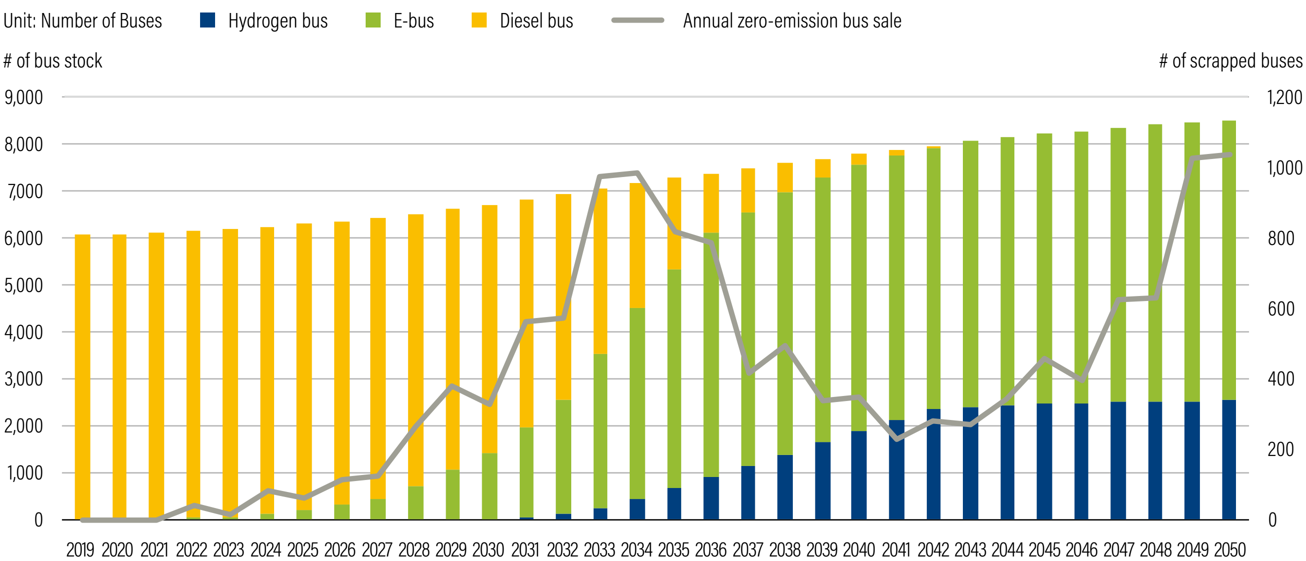


Source: Authors' calculations.

Socioenvironmental implications

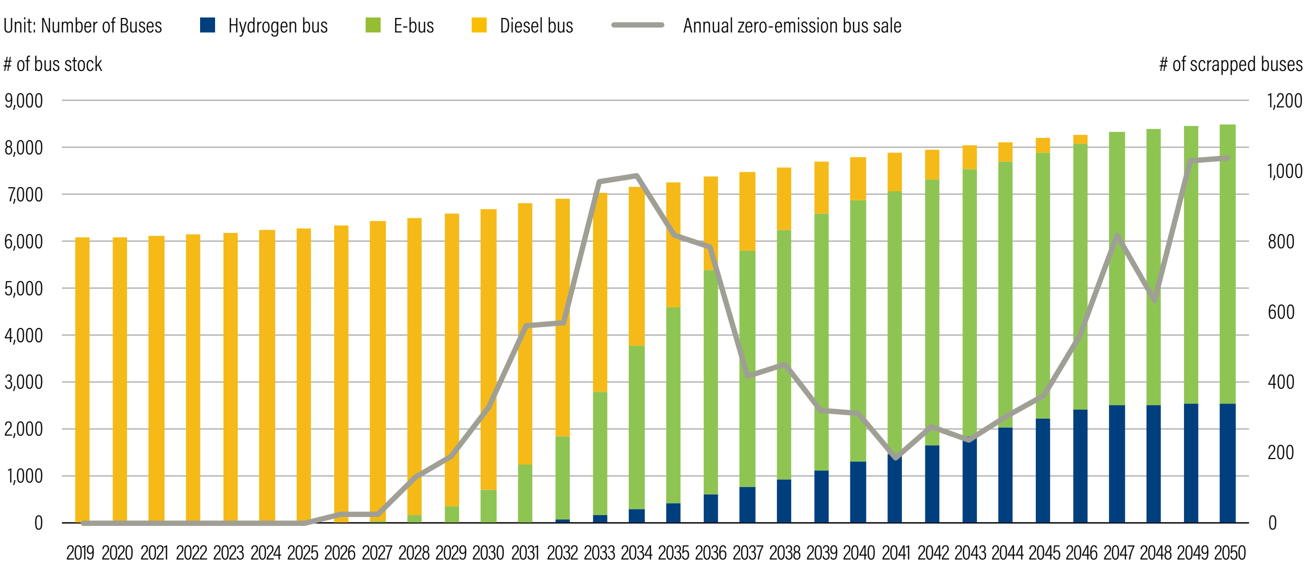
The earlier the diesel bus ban takes effect, the earlier the bus fleet will be completely zero-emission (Figures 19, 20, and 21). For example, in the "diesel bus ban 2026" scenario, the bus fleet will be completely zero-emission in 2043. This section evaluates the social and environmental impacts of the three scenarios.

Figure 19 | **Diesel Bus Ban 2026 Scenario**



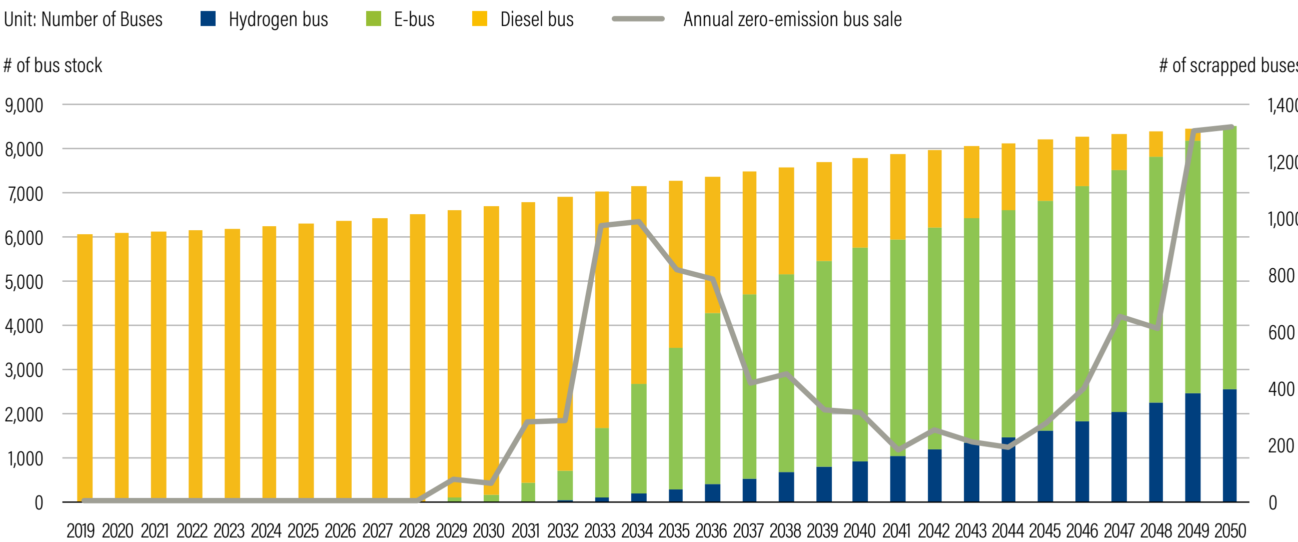
Source: Authors' calculations.

Figure 20 | **Diesel Bus Ban 2030 Scenario**



Source: Authors' calculations.

Figure 21 | **Diesel Bus Ban 2033 Scenario**



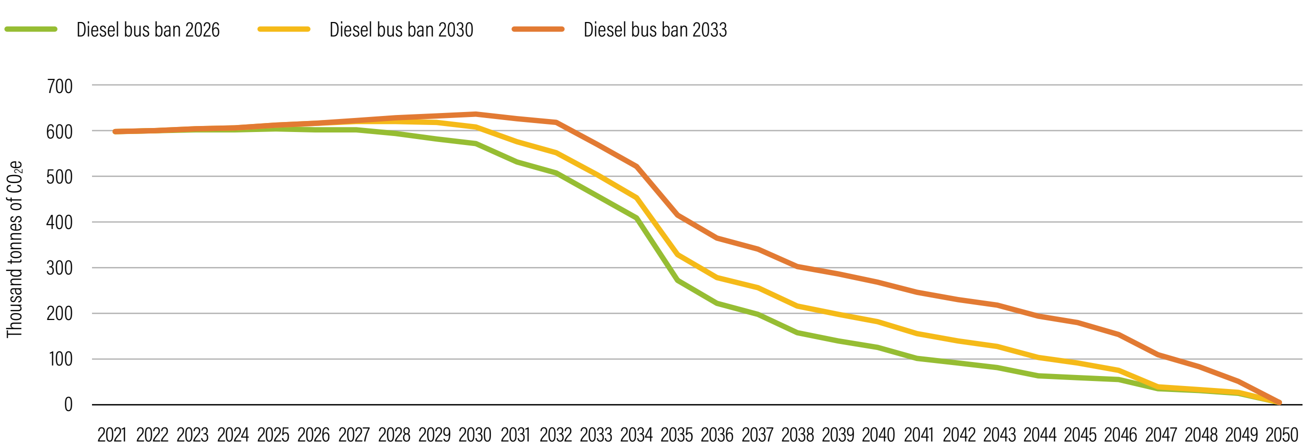
Source: Authors' calculations.

GHG emissions and air pollution

Banning the new registrations of diesel buses earlier has greater GHG emissions and air pollutant abatement potential:

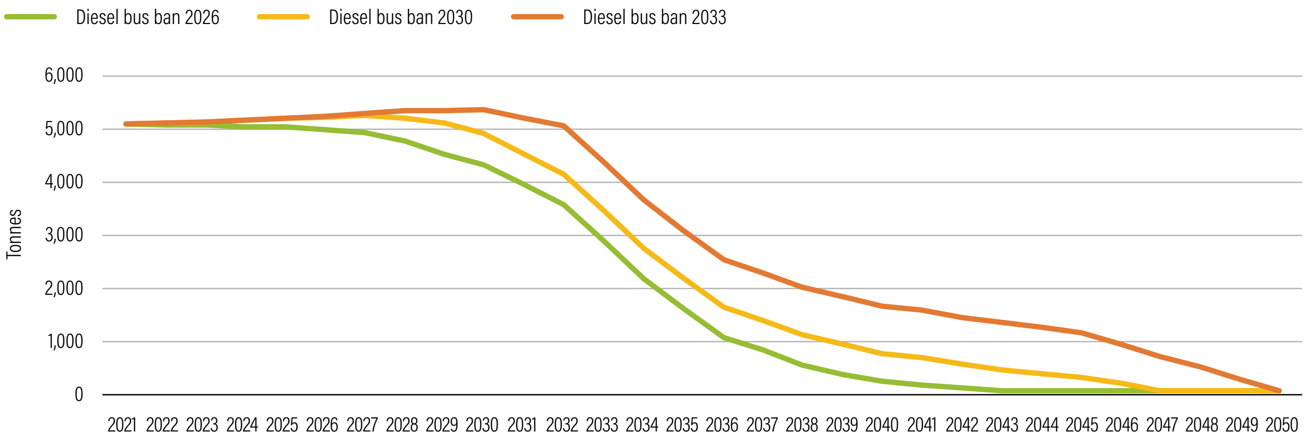
- For GHG emissions, across the three scenarios, the emissions of the bus fleet would peak around 2025–2030 and then drop close to zero before 2050 (Figure 22). Banning the new registration of diesel buses in 2026 can save 2.4 million tonnes of cumulative GHG emissions compared to banning the diesel buses in 2033, and 1.0 million tonnes of GHG emissions compared to banning the diesel buses in 2030.
- Air pollutants also show a rapid reduction trend (Figure 23). Because Hong Kong local driving cycle's and vehicle degradation's impacts on nitrogen oxides (NO_x) emissions are not considered in the study, the pollutant abatement potential of zero-emission buses could be underestimated.

Figure 22 | **Well-to-Wheel Greenhouse Gas Emissions Projection for Franchised Buses**



Note: CO_2e = Carbon dioxide equivalent.
Source: Authors' calculations.

Figure 23 | **Tailpipe Nitrogen Oxides Emissions Projection for Franchised Buses**



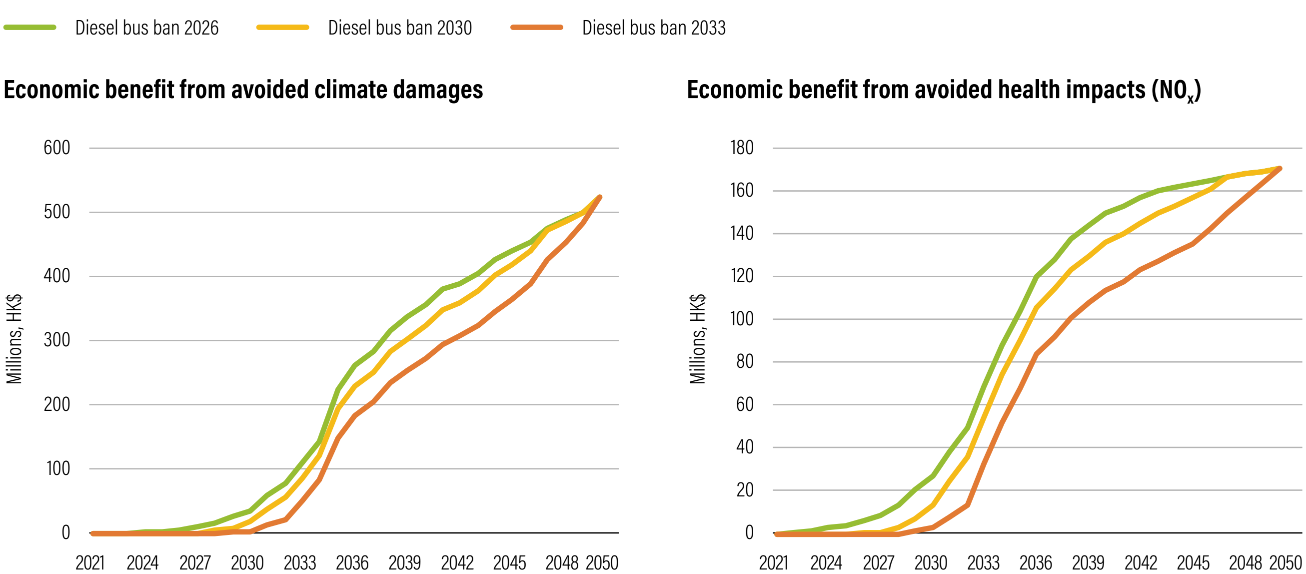
Source: Authors' calculations.

Economic benefits from avoided climate damages and health impacts

The "diesel bus ban in 2026" could avoid about HK$7 billion (at 2020 constant prices) in climate damages between 2021 and 2050, compared to the reference scenario, where buses are 100 percent diesel. This avoided cost is HK$500 million higher than for the "diesel bus ban in 2030," and HK$1,366 million higher than for the "diesel bus ban in 2033" (Figure 24).

The health benefits from improved air quality (focusing on NO_x) are comparable to the climate benefits. Banning the new registration of diesel buses in 2026, 2030, and 2033 could prevent about 115, 105, and 88 premature deaths during the years from 2021 to 2050, in comparison to the reference scenario (Figure 24). And it shows the "diesel bus ban in 2026" could deliver an economic gain of HK$650 million compared to the "diesel bus ban in 2033," and HK$252 million economic gain compared to the "diesel bus ban in 2030."

Figure 24 | **Economic Benefits Compared to the Reference Scenario**



Source: Authors' calculations.

Figure 25 | **Cumulative Public Expenditures under Different Diesel Bus Ban Scenarios**

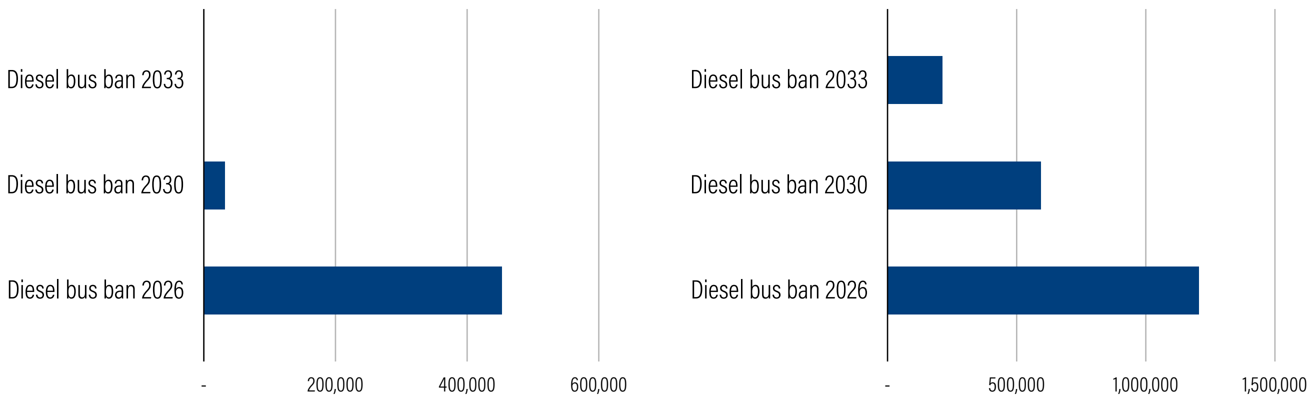
Unit: 1,000 HK$ 2021 Present Value

a. Rapid technology development

TCO of electric DDs in 2030: HK$6.6 million
TCO of hydrogen DDs in 2030: HK$7.2 million

b. Slow technology development

TCO of electric DDs in 2030: HK$8.0 million
TCO of hydrogen DDs in 2030: HK$8.9 million



Notes: Assume net present value (NPV) rate is 3 percent.
TCO = Total cost of ownership; DD = Double-decker.
Source: Authors' calculations.

Public expenditure by 2050

Cumulative public expenditure on zero-emission bus promotion is defined as government funding used to bridge TCO gaps during 2021 to 2050, including subsidies on charging infrastructure construction, vehicle purchase subsidy, and other forms of funding supports.

The results show the following (Figure 25):

First, the speed of technology advances in zero-emission DDs would have a bearing on future public expenditure of zero-emission bus promotion. If the technology for zero-emission DDs develops as expected, and TCOs drop to reach parity with TCOs of diesel DDs in (or before) 2030—particularly for electric DDs that consist of over a half of the bus fleet—public expenditure across all scenarios would be less: the cumulative expenditure would be between zero to HK$452 million. However, if the technology for zero-emission DDs does not advance as expected, and TCOs of zero-emission remain above the TCOs of diesel DDs in 2030, public support should be sustained even post-2030. As a result, the cumulative expenditure for zero-emission bus promotion would be between HK$212 million and HK$1.21 billion.

Second, public expenditure varies significantly across scenarios.

- Diesel bus ban in 2026 leads to the largest amount of public expenditure—around HK$452 million to HK$1.21 billion—because of the larger number of double-deckers that need to be electrified before TCO parity is reached and due to the large TCO gaps of e-buses in the early years. However, this spending, although tremendous, is outweighed by HK$0.8 to HK$2 billion additional climate and health benefits of the 2026 diesel bus ban.

- Diesel bus ban in 2030 has fewer public burdens. Banning the new registrations of diesel buses in 2030 requires around HK$31 million to HK$592 million public expenditure—that is, a 51–90 percent reduction from the expenditure of the "diesel bus ban 2026" scenario, while experiencing a 1.0 million-tonne carbon dioxide equivalent (CO_2e) increase in cumulative GHG emissions and 8 percent reduction in climate and health benefits compared with the "diesel bus ban in 2026."

- Diesel bus ban in 2033 is the least costly option for the government. Banning the new registrations of diesel buses in 2033 requires around zero to HK$211 million public expenditure—that is, 82–100 percent reduction from the expenditure of the "diesel bus ban 2026" scenario. The scenario would see around 2.5 million-tonne CO_2e increase in cumulative GHG emissions and 21 percent reduction in climate and health benefits compared with the "diesel bus ban in 2026."

Summary

Balancing public financial viability and environmental, social, and health benefits, **banning the new registration of diesel buses around 2030–2033 may be feasible for Hong Kong.** In comparison, the diesel bus ban by 2026 requires considerable public expenditure. Although the environmental benefits may justify the public expenditures, strong political determination and supports from franchised bus operators are needed.

Recommendations

To turn the above scenarios into reality, Hong Kong needs dedicated zero-emission bus trials, a long-term electrification roadmap, and sustainable policy safeguards.

Improve e-bus trials

"Hong Kong Roadmap on Popularisation of Electric Vehicles" has emphasised e-bus trials as the primary way to inform the decision on a concrete time line for the diesel bus ban in 2025. To carry out the trials, HK$180 million funding for franchised single-deckers and a HK$800 million New Energy Transport Fund for a wider variety of commercial vehicles has been in place.

However, existing trials of zero-emission bus technologies lack sustainability in the following ways:

- First, there is no dedicated programme to support the trials of zero-emission buses—the existing fund targets either commercial vehicles or single-deckers. In fact, the adoption of zero-emission buses is challenging (from land shortage to grid capacity constraints and hydrogen shortages) that cannot be resolved solely by "bus operators" or "the funds." All relevant government departments such as the Environment Bureau, Transport Department, and Planning Department should steer attention towards this vehicle segment and create enabling mechanisms.
- Second, the trials with procurement limits (limits of procurement equal 15 vehicles) and large time intervals may not create commitments from bus operators. Small ad hoc and infrequent procurements would not allow sustainable partnerships to be created between bus operators and original equipment manufacturers (OEMs) for continuous technology improvements—the recent e-bus trial occurred in 2015 with four to fourteen e-buses for each operator. Further, the size of procurements may be insufficient for bus operators to overcome the initial sharp learning curves to adjust their operations and maintenance to the optimal level.
- Third, an independent group of technical experts to evaluate the results of zero-emission bus trials and inform policymaking is missing. Because bus operators face varying degrees of challenges and the e-bus trials would have diverse outcomes, comprehensive information collection of the e-bus trials, benchmarking against global best practices, and generating unbiased policy recommendations are crucial. Further, considering conflicted interests among stakeholders on zero-emission bus technology pathways, a technical advisory group would be helpful to build consensus and create synergies.

Learning lessons from existing e-bus trials, the government needs more comprehensive goals for the zero-emission bus trials, not only in testing different zero-emission technologies' performances, but also by creating commitments from franchised operators and designing sustainable policy incentives to accelerate adoption of zero-emission buses. Therefore, the trials of zero-emission buses could be improved in the following ways:

- The government could play a more proactive role in the trials by providing necessary enablers, including support on land planning rezoning, coordination of charging facility installation at terminals and depots, and securing hydrogen supply as well as removing existing regulatory barriers (such as the requirement on the maximum gross vehicle weights of double-deckers).

- A dedicated fund for zero-emission bus promotion should be established, where bus operators are allowed large procurements to reinforce commitment. Through these large procurements, operators would be encouraged to form long-term partnerships with OEMs, step up manpower training, and optimise operations.

- An advisory group could be established to synthesize trial results and resolve potential vested interests. The advisory group could support evaluation of trial results, consulting different stakeholders, informing policymaking, advising bus operators' operation adjustments and energy-efficiency improvements, and more.

Plan the sequence for the adoption of zero-emission buses

Hong Kong needs to plan the phase-in of zero-emission buses early on, to be on track to attain Hong Kong's 2050 carbon neutrality target, given the long service life of buses.

Solely relying on the trials of different zero-emission bus technologies to inform the development of a long-term plan for the zero-emission bus transition is insufficient, considering the technologies are rapidly evolving—the performance of zero-emission buses in 2021–2022 cannot represent their performance a decade later. To this end, Hong Kong could take inspiration from global peer cities, combined with the trial results, to formulate a long-term plan of zero-emission bus transition.

The goal of the long-term plan for zero-emission bus transition could be to ban the sale of diesel buses from 2030 to 2033 onwards to be on track to achieve Hong Kong's carbon neutrality target, improve local air quality, and avoid social welfare losses. Further, the goal is also to take proactive measures to save costs. As more buses get electrified, more land spaces and grid capacities will be needed. The government could take proactive action to update bus depot plans and make necessary infrastructure investments and reduce retrofit investments in bus terminals/interchanges. Franchised bus operators can also save by pooling bus procurement in large quantities.

To facilitate achievement of the goal, concrete steps towards a zero-emission bus transition plan could be taken by the bus segment with policy safeguards (see Section 2.4.3):

- At present, minibuses and single-deckers are technologically ready for wider adoption, and the adoption of electric single-deckers can also help franchised bus operators ease the sharp learning curve and be prepared. Starting from 2026, zero-emission double-deckers may be ready for wider adoption.

- For the double-deckers, electrification priorities can be set: Double-deckers that travel in urban centres with low speeds, frequent braking, and relatively short mileage are ready for e-bus trials. Double-deckers travelling long distance to serve new towns on the outskirts (like the Express Services with a route length over 40 kilometres and average speed up to 70 kilometres per hour) may be transitioned at scale post-2026. Depending on the trials, the latter type of double-deckers would possibly be a niche application for hydrogen DDs.

Devise sustainable policies

Sole reliance on zero-emission bus trials is inadequate to accelerate the adoption of zero-emission buses. Sustainable policy incentives are needed to succeed the temporary e-bus trials to continuously incentivise the zero-emission bus adoption, including the following:

- **Vehicle purchase and operational subsidies:** The vehicle purchase subsidy is important to reduce zero-emission buses' TCOs and make them affordable for private franchised operators. For hydrogen DDs, operational subsidies may also be useful.

- **Public support on e-buses' charging infrastructure delivery:** This public support can take the form of land zoning and land acquisition for new bus depots as well as capital grants for the installation of e-bus charging facilities. Particularly, the government could plan for large pockets of land for new bus depots and acquire/lease the land. Further, in bus terminals where chargers may be shared among multiple e-bus operators, the government could consider fully funding the installation of shared chargers (from grid expansion to space planning, and to the construction of chargers) to avoid repetitive investments and reduce zero-emission buses' TCOs.

- **Public support for hydrogen supply:** Public support for hydrogen imports, reservoir construction, inland transportation, and the construction of hydrogen-refuelling stations (as well as land rezoning and acquisition) is necessary. Particularly, securing sustained hydrogen supply is important for continued operation of hydrogen DDs.

- **New financing mechanisms:** mechanisms such as concessional loans, green bonds, and leasing are needed to avoid large up-front investments on vehicle purchases. If necessary, the government could also consider providing public guarantees on loans or bonds.

- **Plans for grid capacity expansion:** With increasing adoption of EVs (including e-buses), the government needs to systematically evaluate the grid impacts of EV charging and plan for grid capacity augmentation (after the deployment of necessary peak-shifting measures such as smart charging devices).

Proactive efforts are also needed from franchised operators, including the following:

- Optimising vehicle procurement and asset management strategy (such as negotiation for favourable warranty terms and cultivating long-term partnerships with OEMs).

- Adopting smart charging–capable chargers and load management systems, and installing on-site renewable energy to reduce electricity expenses.

- Optimising operation of zero-emission vehicles (coordinated with charging and refuelling time) and improving zero-emission vehicles' energy efficiency by bus drivers' eco-driving training.

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CHAPTER 3

DECARBONISING PRIVATE CARS AND SUPPORTING MECHANISMS

Private cars are the largest vehicle fleet in Hong Kong, and contribute to road transport GHG emissions as the second-largest emitter. Inspired by global front-runners in EV promotion, the private cars in Hong Kong have the potential of creating a new electrification paradigm by enhancing its vehicle electrification ambition, and achieving a net-zero emission pathway well ahead of 2050.

By the end of April 2021, Hong Kong had 657,609 registered private cars (578, 843 of them were licenced), accounting for 71 percent of the fleet (Transport Department 2016–2021). However, they only accounted for 12 percent of Hong Kong's mode-share for mechanised trips (excluding walking and cycling) (Transport Department 2014).

Hong Kong's electric vehicle fleet has been dominated by private cars (PCs). By the end of April 2021, the number of registered electric PCs had rapidly grown to almost 20,000, taking up 98 percent of the EV fleet and 3 percent of the total registered private car fleet (Transport Department 2021) (Figure 26). Unlike with the bus segment, Hong Kong is more proactive with PC electrification. It is the city's aspiration to prohibit new registration of internal combustion engine (ICE) private cars by 2035 or earlier.

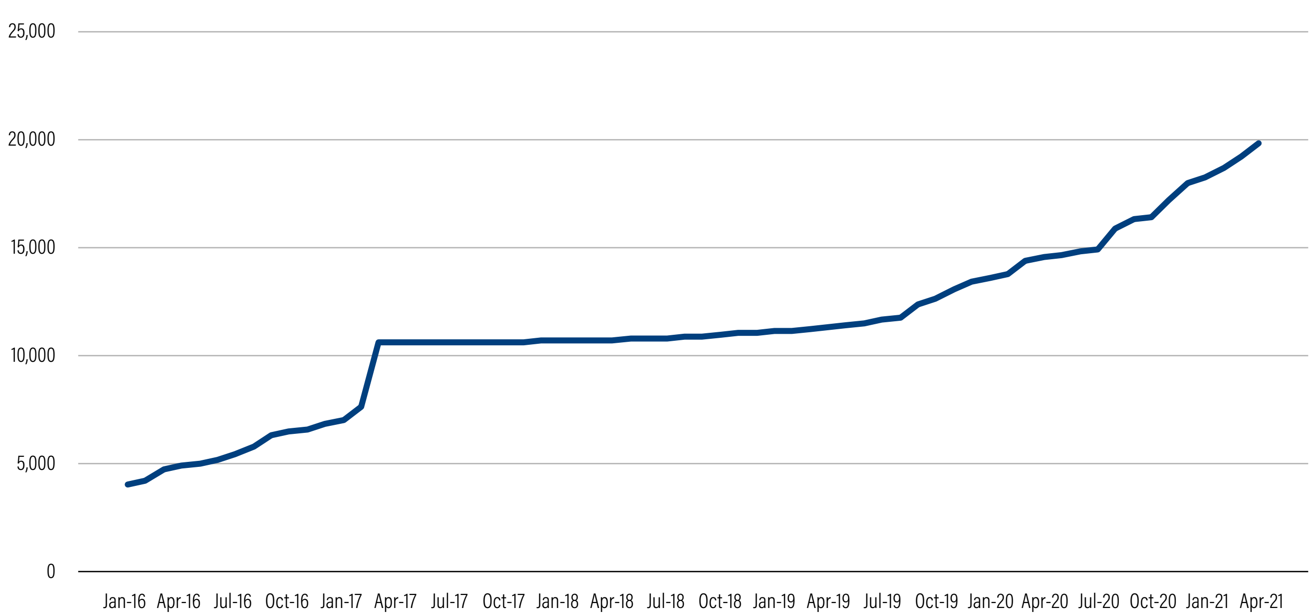
TCO analysis

Multiple factors influence the deployment of zero-emission technologies, such as consumer-centric TCOs, vehicle make-and-model availability, charging convenience, and public awareness. Given the important role played by TCOs, this section first elaborates the methods used by the study to estimate TCOs.

The TCOs of electric private cars (PCs) and ICE cars are calculated for representative vehicle classes in Hong Kong's market. Hong Kong categorises PCs into three board classes, namely, saloon (equivalent to "compact cars"), station wagon (equivalent to "SUVs"), and convertibles. Compact cars and SUVs amount to 99 percent of new registrations, with SUVs making up a larger market share of 60–70 percent. Therefore, the study focuses on compact cars and SUVs, while luxury "convertibles" are omitted.

Given Hong Kong's less intensive car usage (annual mileage around 11,200 km), the study assumes the battery ranges of 400 km for compact cars and 500 km for SUVs are sufficient at present (2021) and in the future (2030). Because SUVs are typically more

Figure 26 | **Total Number of Electric Private Cars in Hong Kong between January 2015 and April 2021**



Note: Years are abbreviated as the last two digits (e.g., 15 for 2015).
Source: Transport Department 2016–2021.

Table 15 | **Technical Characteristics of Representative Electric Vehicles and Internal Combustion Engine Vehicles (ICE)**

	COMPACT CAR		SUV	
	Battery electric vehicle (BEV)	ICE	Battery electric vehicle (BEV)	ICE
Assumed service life	10 years	10 years	10 years	10 years
Battery range (km)	400km	n/a	500km	n/a
Annual VKT (km)	11,200	11,200	11,200	11,200

Notes: SUV = Sport utility vehicle; ICE = Internal combustion engine; km = Kilometres; VKT = Vehicle kilometres travelled; n/a = Not applicable.
Source: Ccarprice website (https://www.ccarprice.com/hk); Transport Advisory Committee 2014.

energy-intensive than compact cars, the range of SUVs is 100 km more than for compact cars in the analysis (Table 15).

Unlike global front-runner cities in EV promotion, Hong Kong's PC electrification has some unique features. Car ownership and usage in Hong Kong are subject to intensive policy interventions, to alleviate traffic congestion and avoid inefficient land use. Such policies, known as travel demand management (TDM) policies, include Vehicle First Registration Tax (FRT), annual licence fees (ALFs), parking space purchase costs, parking fees, and road (tunnel) tolls (Hong Kong Legislative Council 2020). As a result, Hong Kong's car ownership levels are low, with only 111 vehicles per 1,000 people,[17] compared to 288 in Beijing, and 325 in London.

Under this TDM policy regime, instead of relying on public subsidies to promote EVs (as in the United States and mainland China), Hong Kong relies on tax concessions to incentivise EV adoption (Table 16). Unlike Norway, which also relies on tax benefits to encourage EV purchase, Hong Kong's tax benefits are designed to encourage electrification of the

Table 16 | **Public Incentives to Promote Electric Private Cars in Hong Kong, Norway, and Mainland China**

	HONG KONG	NORWAY	MAINLAND CHINA
Private car ownership	• Concessions on the First Registration Tax (FRT)	• Exemption on one-off registration tax • Exemption on Value-Added Tax (VAT)	• Exemption on vehicle purchase tax • Local government: percentage of new registrations should be electric cars[a] • National and local vehicle purchase subsidies
Private car usage	• Concessions on the annual licence fees	• Exemption on road traffic insurance tax • Concessions on toll roads • Concessions on parking fees • Access to bus lane	• Waived parking fees • Right-of-way and exempt from traffic restrictions
Charging infrastructure installation	• EV-Charging at Home Subsidy Scheme (EHSS) • Free charging at public parking lots	• Government support for fast charging facilities • Free charging at public parking lots	• Local charging subsidies to recover CAPEX

Notes: EV = Electric vehicle; CAPEX = Capital expenditure; NEVs = New energy vehicles.
[a]. Getting a licence plate for a new vehicle is restrictive and requires a competitive lottery or bidding process in some Chinese cities like Beijing, Shanghai, and Guangdong. However, to incentivise EV stock, these cities have removed this restriction for private NEVs (including ride-hailing NEVs).
Source: Authors' summary based on Fridstrøm 2021; Transport Department.

existing car stock—that is, scrapping the in-use ICE cars and replacing them with EVs. The approach is in keeping with Hong Kong's well-established tradition of avoiding boosting overall car ownership (including electric PC ownership).

Key TCO considerations

The study first estimates electric PCs' TCOs, based on the TCO breakdowns listed in Figure 27. Importantly, because TDM policies—particularly the FRT and annual licence fees—have a strong bearing on TCOs, the effects of both policies are estimated.

Figure 27 | **TCO Cost Breakdowns for Electric Private Cars**

Capital cost	Cost of charging
Vehicle price	CAPEX of home charger
First registration tax	Home charging subsidies
	Electricity rates
	Annual licence fee

Note: Maintenance costs are not included due to the lack of localised data. Because the maintenance cost of electric PCs is lower than for ICE PCs, the exclusion of maintenance costs could lead to relatively higher TCOs for electric PCs.
Source: Authors.

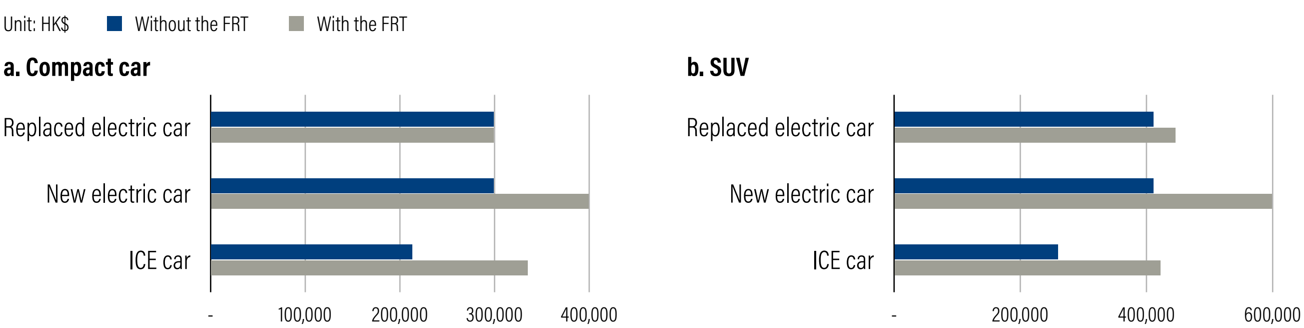
Capital cost of PCs

Hong Kong's First Registration Tax (FRT) is a major tax imposed on the sales of new cars that amounts to 50 or 200 percent of vehicle retail prices. Hence, the FRT has a multiplier effect: without tax concessions, FRT can widen price gaps between less expensive PCs (like ICE vehicles) and expensive PCs (like EVs).

To avoid multiplier effects on electric PCs, starting from 1994, electric car owners in Hong Kong received preferential tax concessions. At present, the maximum tax concession for new electric PCs is HK$97,500—so as not to widen the price gaps between EVs and ICEs (Transport Department 2021a). Further, Hong Kong's FRT concession is preferential to replaced EVs. Under the "One-for-One Replacement" Scheme, existing car owners who scrap their old ICE cars[18] and switch to electric cars enjoy a maximum tax concession of HK$287,500, nearly triple that for new electric PCs.

This tax benefit brings the capital cost of replaced EVs to nearly breakeven with that of ICE cars in 2021: for compact cars, replaced EVs have lower capital costs than ICE cars; and for SUVs, the replaced EVs are only HK$37,000 (9 percent) higher than ICE cars (Figure 28).

Figure 28 | **Vehicle Capital Costs as of 2021**



	COMPACT CAR			SUV		
	ICE	Replaced EV (400 km)	New EV (400 km)	ICE	Replaced EV (500 km)	New EV (500 km)
Vehicle price (in 1,000 HK$)	213	300	300	260	410	410
FRT (in 1,000 HK$)	123	0	100	164	37	227
Capital cost (in 1,000 HK$)	336	300	400	424	447	637

Notes: Capital cost includes the vehicle retail prices and the First Registration Tax. Some electric SUVs are equipped with autonomous driving functions; therefore, it is not an apples-to-apples comparison between electric SUVs and ICE SUVs.
SUV = Sport utility vehicle; ICE = Internal combustion engine; EV = Electric vehicle; km = Kilometres; FRT = First Registration Tax.
Source: Authors calculated based on the current FRT scheme (Transport Department 2021a).

Table 17 | **Numbers of Registered Private Cars That Are Entitled to the "One-for-One Replacement" Scheme**

	HAS BEEN REGISTERED FOR SIX YEARS OR MORE			
	Owner has owned the PC for three years or more without interruption		Owner has owned the PC for one year or more without interruption	
	Number of PCs	Percentage of PCs registered	Number of PCs	Percentage of PCs registered
Number of PCs as of March 31, 2018	186,498	30	270,769	44
Estimated number of PCs as of March 31, 2019	255,614	41	382,576	61
Estimated number of PCs as of March 31, 2020	345,526	53	427,066	66
Estimated number of PCs as of March 31, 2021	474,077	73	474,077	73

Notes: The number of PCs is estimated by assuming there is no change in the number of registered PCs since March 31, 2018. The percentage in total PCs registered is calculated using the registered PCs in 2018–2020. For 2021, the total registered PCs is assumed to be the same as in 2020.
PCs = Private cars.
Source: https://gia.info.gov.hk/general/201810/24/P2018102400326_295822_1_1540354381575.pdf.

This policy to accelerate electrification of the existing stock is crucial for Hong Kong. With the restriction on car ownership, Hong Kong has witnessed modest annual increases in newly registered cars (10,000–23,000 between 2016 and 2020; i.e., 2–4 percent of car ownership) (Transport Department 2019). In contrast, many in-use PCs are getting older and face increasing demands for scrappage and replacement. By 2020, PCs registered for more than six years—likely to be entitled to the "One-for-One Replacement" Scheme—accounted for 73 percent of the fleet.

Given the differentiated policy treatment on replaced cars, the TCO calculation (Table 17) distinguishes between new EVs and replaced EVs.

Cost of charging

Because parking spaces in existing buildings in Hong Kong are not often charge-ready, the installation of home chargers is an important expense.[19] Overall, home charger installation costs include charger unit costs, electrical wiring costs, and sometimes grid augmentation costs. For simplicity, only charger unit costs and electric wiring costs are included in this study and are generally between HK$20,000 and HK$80,000 per unit (EV Power Group n.d.). With up to HK$30,000 "EV-Charging at Home Subsidy" for each parking space, the study assumes that the installation cost per home charger is HK$50,000 (Table 18).

Table 18 | **Assumptions on Hong Kong Electric Private Cars' Charging Costs**

	COMPACT CAR			SUV		
	ICE	Replaced EV (400 km)	New EV (400 km)	ICE	Replaced EV (500 km)	New EV (500 km)
Installation cost of home chargers	n/a	HK$50,000	HK$50,000	n/a	HK$50,000	HK$50,000
Energy cost	21.0 HK$/L	1.16 HK$/kWh	1.16 HK$/kWh	21.0 HK$/L	1.16 HK$/kWh	1.16 HK$/kWh
Annual licence fees (in 1,000 HK$)	7.5	0.94	0.94	7.5	1.19	1.19

Notes: The fluctuation of petrol prices in the recent decade (2011~2021) is considered.
TCO = Total cost of ownership; SUV = Sport utility vehicle; ICE = Internal combustion engine; EV = Electric vehicle; km = Kilometres; L = Litres; kWh = Kilowatt-hours; BEV = Battery electric vehicle; n/a = Not applicable.
Source: Petrol prices are from TradingEconomics 2021. EVs' charging costs are based on CLP residential rates and the cost of Tesla superchargers. Annual licence fees for ICE cars and BEV cars are from the Transport Department 2021b. The installation cost of home chargers is authors' estimation.

In addition to the CAPEX of home charger installation, PCs' cost of charging also includes electricity bills and charging service surcharges. This study assumes the average case of home charging, using the residential utility rate of 1.16 HK$/kWh (CLP residential rate) (Table 18), considering home charging is lower compared to public charging[20] (the cost is up 2.90 HK$/kWh at maximum based on the survey conducted by HK01 [2019]).

Apart from charging costs, the Hong Kong government also imposes an annual licence fee (ALF) that is different for ICE vehicles than it is for electric vehicles (Transport Department 2021b). For ICE cars, ALFs consist of 50–90 percent of annual fuel costs. Because ALFs have favourable rates for electric PCs, they only comprise 20–50 percent of annual charging costs (Table 19).

TCO analysis for 2021

TCO calculation follows the method outlined in Section 1.4, with the net present value (NPV) rate of 6 percent assumed for private cars and key assumptions listed in Table 20.

The result reveals that unlike elsewhere, several passenger-vehicle classes in Hong Kong have

Table 19 | **Annual Licence Fees as of 2021 (in HK$)**

ICE CARS				BEV CARS		
Cylinder capacity of the engine	Petrol	Diesel	Percentage of annual energy cost	Unladen weight	BEV	Percentage of annual energy cost
Not exceeding 1,500cc	5,074	6,972	50–90	Not exceeding 1 tonne	572	20–50
1,500cc to 2,500cc	7,498	9,396		an additional fee for each 250kg unladen weight	124	

Notes: ICE = Internal combustion engine; BEV = Battery electric vehicle; cc = cubic centimetres; ALFs = Annual licence fees; PC = Private car.
1. According to the Transport Department's registered PC statistics, around 80 percent of private cars in Hong Kong have cylinder capacities below 2,500 cc; therefore, the table only shows ALFs up to this point.
2. The percentage of annual energy cost is authors' calculation. Because energy costs vary according to the costs of charging and the fluctuation of petrol prices, the result is a range.

Source: Annual licence fees for ICE cars and BEV cars are from the Transport Department 2021b. The percentage of annual energy cost is authors' calculation.

Table 20 | **Assumptions for Hong Kong Electric Private Cars' TCO Calculation in 2021**

	COMPACT CAR			SUV		
	ICE	Replaced EV (400 km)	New EV (400 km)	ICE	Replaced EV (500 km)	New EV (500 km)
Vehicle price (1,000 HK$)	213	300	300	260	410	410
FRT (in 1,000 HK$)	123	0	100	164	37	227
Energy cost	21.0 HK$/L	1.16 HK$/kWh	1.16 HK$/kWh	21.0 HK$/L	1.16 HK$/kWh	1.16 HK$/kWh
Energy intensity	5 L/100km	12 kWh/100km	12 kWh/100km	8.2 L/100km	16 kWh/100km	16 kWh/100km
Annual VKT (km)	11,200	11,200	11,200	11,200	11,200	11,200
Annual licence fees (in 1,000 HK$)	7.5	0.94	0.94	7.5	1.19	1.19

Notes: Assume the NPV rate is 6 percent for private cars.
TCO = Total cost of ownership; SUV = Sport utility vehicle; ICE = Internal combustion engine; EV = Electric vehicle; FRT = First Registration Tax; L = litres; kWh = Kilowatt-hours; km = Kilometres; VKT = Vehicle kilometres travelled; NPV = Net present value.

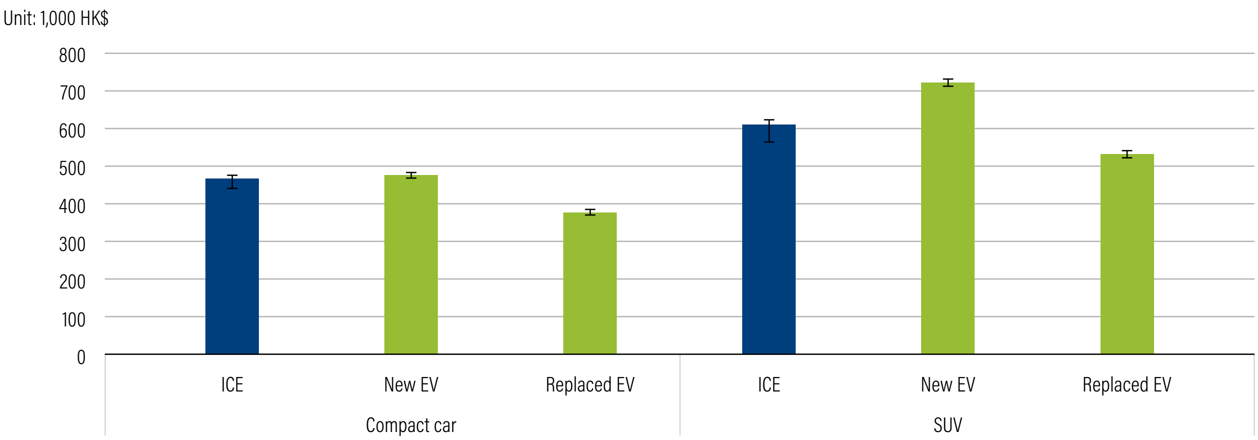
Source: Authors.

achieved cost parity in 2021 (Figure 29):

- For compact cars: TCOs for electric cars under the "One-for-One Replacement" Scheme (HK$371,000–HK$385,000) have reached cost parity with ICE cars (HK$443,000–HK$478,000). TCOs of new electric cars (HK$472,000– HK$486,000) have reached cost parity in some circumstances (such as home charging).
- For SUVs: TCOs for replaced electric SUVs (HK$525,000–HK$544,000) have achieved cost parity with ICE SUVs (HK$566,000–HK$626,000), while TCOs for new electric SUVs (HK$715,000–HK$734,000) are still 14–30 percent more expensive than their ICE counterparts.

Despite the higher vehicle prices, the early attainment of TCO cost parity is attributed to factors highlighted in Figures 30 and 31 and the discussion that follows.

Figure 29 | **Comparisons of TCOs as of 2021**



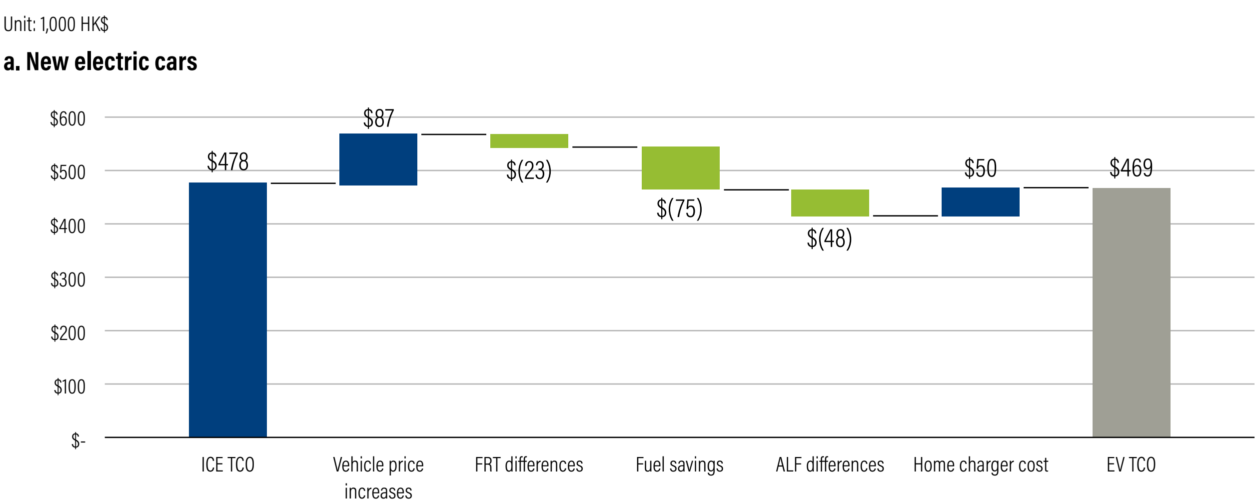
Notes: ICE = Internal combustion engine; EV = Electric vehicle; SUV = Sport utility vehicle; TCOs = Total costs of ownership; L = Litres; kWh = Kilowatt-hours.

a. Variations on TCOs for each vehicle class are affected by fluctuations of petrol prices in recent years (12.5–21.0HK$/L) and different electricity rates (due to different levels of energy consumption for households) (1.16–2.90HK$/kWh).

b. Ten years of ownership for the first owner of the vehicle is assumed for the TCO calculation.

Source: Authors' calculations.

Figure 30 | **Attribution Analysis of TCO Differences between ICE and Electric Passenger Cars: Compact Cars (1)**



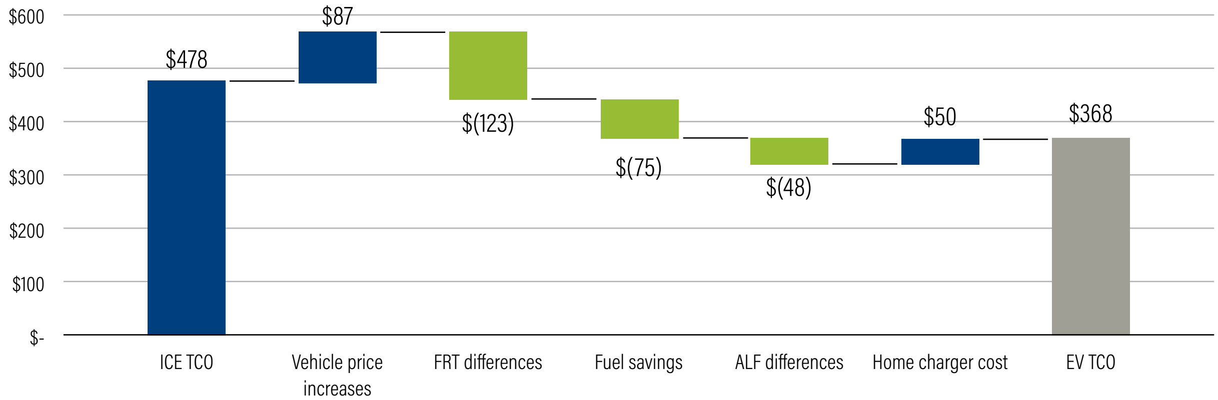
Notes: ICE = Internal combustion engine; TCO = Total cost of ownership; FRT = First Registration Tax; ALF = Annual licence fee; EV = Electric vehicle.

Source: Authors' calculations.

Figure 30 | **Attribution Analysis of TCO Differences between ICE and Electric Passenger Cars: Compact Cars (2)**

Unit: 1,000 HK$

b. Replaced electric cars

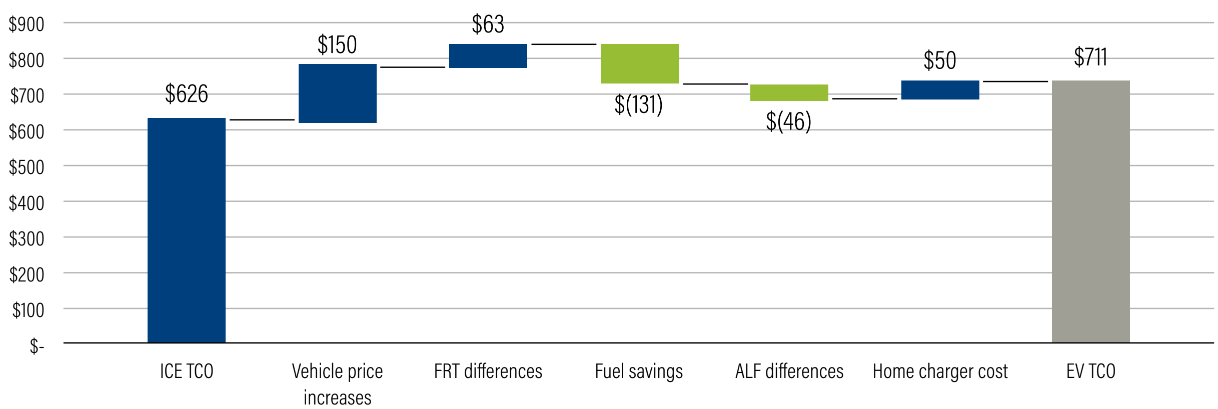


Notes: ICE = Internal combustion engine; TCO = Total cost of ownership; FRT = First Registration Tax; ALF = Annual licence fee; EV = Electric vehicle.
Source: Authors' calculations.

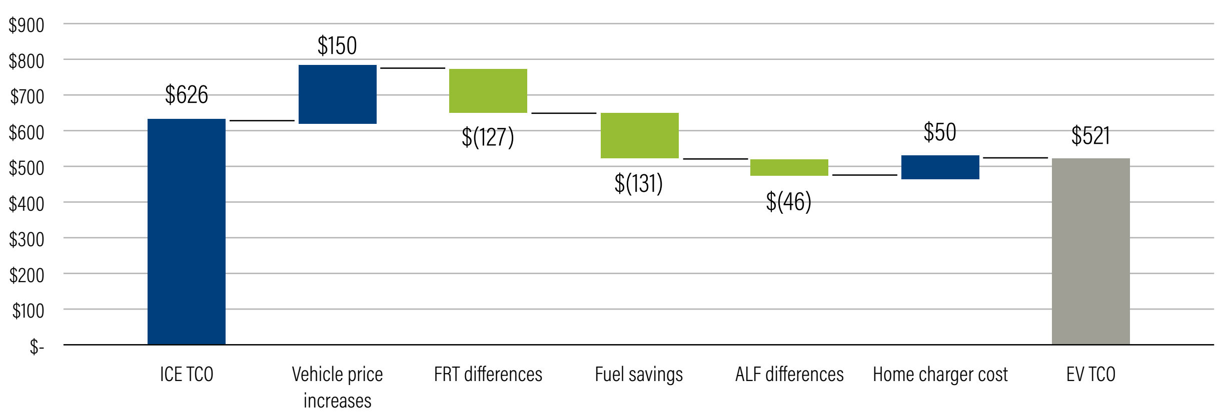
Figure 31 | **Attribution Analysis of the TCO Differences between ICE and Electric Passenger Cars: SUV**

Unit: 1,000 HK$

a. New electric cars



b. Replaced electric cars



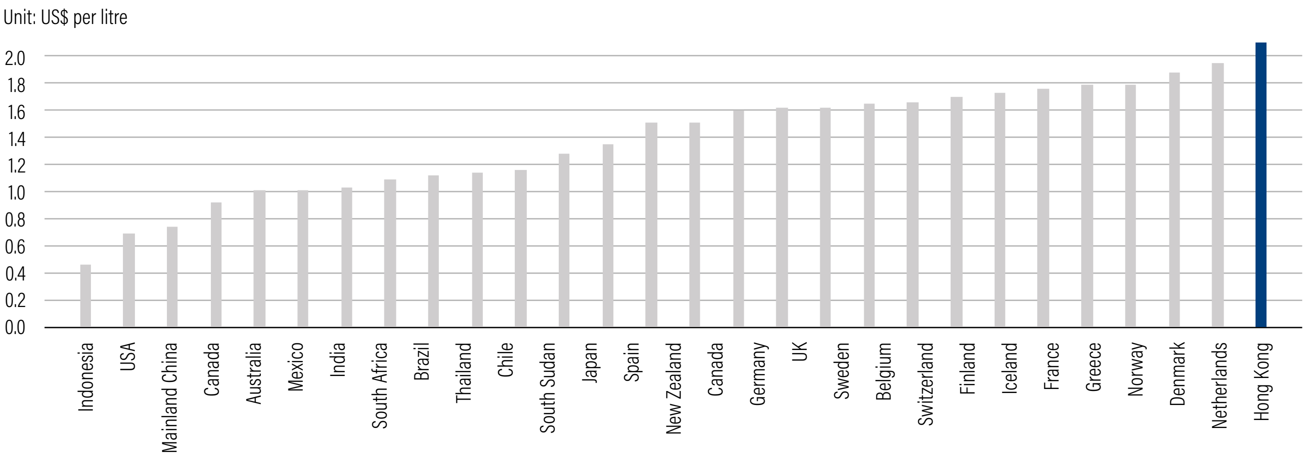
Notes: TCO = Total cost of ownership; ICE = Internal combustion engine;; FRT = First Registration Tax; ALF = Annual licence fee; EV = Electric vehicle.
Source: Authors' calculations.

First, **cumulative energy cost savings** from BEVs are significant, ranging from HK$75,000–HK$131,000 throughout the vehicles' useful life.

It is important to note that cost savings are attributable to not only the higher efficiency of electric powertrains but also the extremely high petrol prices in Hong Kong. Without local refineries, Hong Kong auto fuel depends on imports. Due to the high cost of land to build fuelling stations, government taxes on fuel, and the free market economy (Competition Commission 2017), Hong Kong's petrol prices are among the highest globally (Figure 32).[21] In contrast to high auto fuel costs, Hong Kong has relatively affordable electricity prices (Figure 33). Its utility rates are capped to a level that allows private utility companies to recover all their operating costs while making a regulated rate of return (IPA 2015). The city also ensures utility rates are stable, by requiring utility companies to maintain a tariff stabilisation fund, to "cushion" possible electricity price increases (IPA 2015).

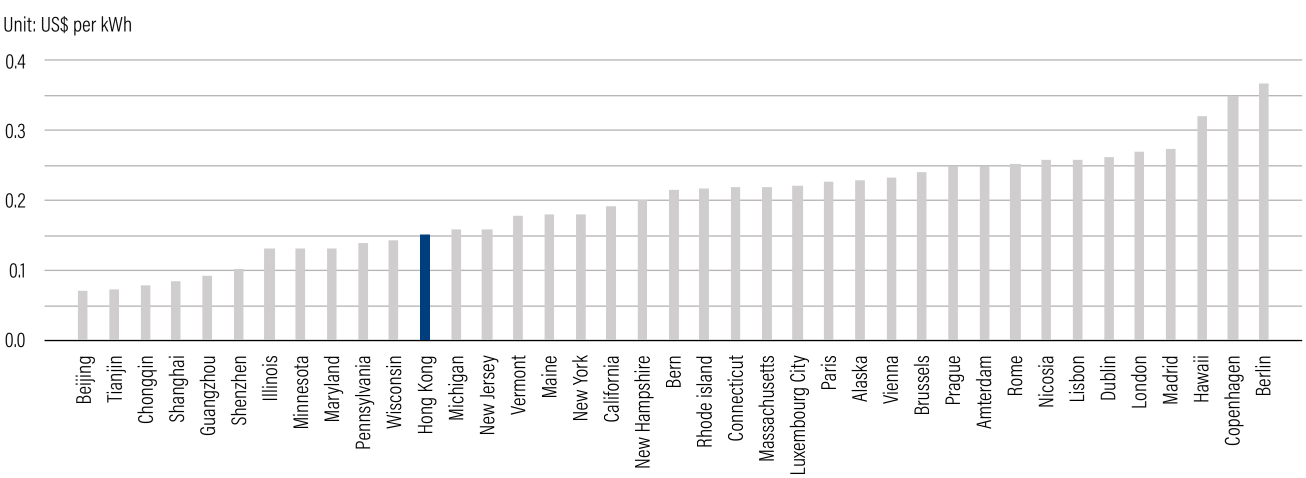
Because of high fuel prices and low electricity costs, energy cost savings from vehicle electrification is greater in Hong Kong than

Figure 32 | **Petrol Price Comparisons: Hong Kong and Global Peers**



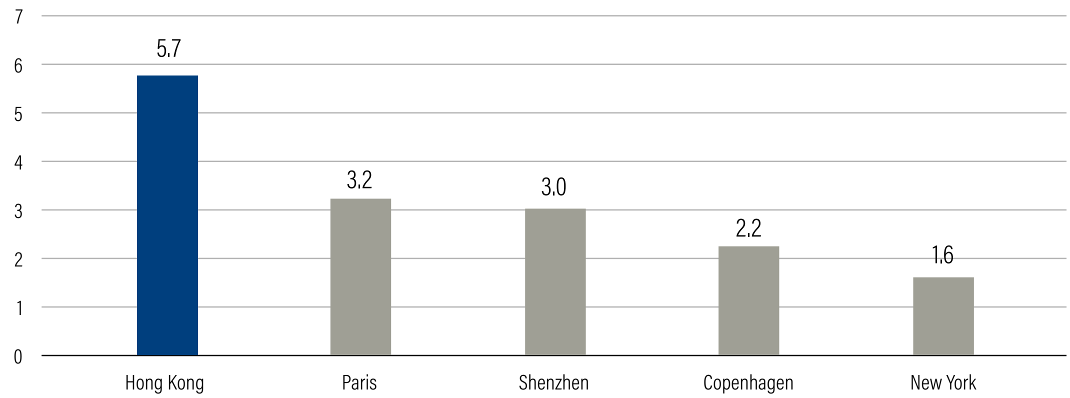
Note: Data were effective in 2019.
Source: TradingEconomics 2019.

Figure 33 | **Residential Utility Rate Comparisons: Hong Kong and Global Peers**



Note: kWh = Kilowatt-hours.
Sources: CLP 2020; China National Energy Administration 2018; U.S. EIA. 2019; European Commission 2019.

Figure 34 | **The Ratio of ICE Car's Petrol Cost to Electric Vehicle's Electricity Cost per 100 km Travelled (Compact Car)**



Sources: TradingEconomics 2019; CLP 2020; China National Energy Administration 2018; U.S. EIA. 2019; Europe Commission 2019.

elsewhere. By this study's estimate, for 100 kilometres travelled, the petrol cost of a compact ICE car in Hong Kong is almost sixfold that of the electricity cost (Figure 34). In contrast, cost-savings are not as obvious elsewhere, with the petrol-electricity ratios of 3.2 in Paris, 3.0 in Shenzhen, and 1.6 in New York.

Second, FRTs offer the largest cost benefits for replaced EVs, but they differ greatly between new EVs and replaced ones. For new electric PCs, the FRT of new SUVs is HK$63,400 higher than for ICE counterparts. However, for replaced electric PCs, FRTs offer considerable cost advantages. They are around HK$123,000~HK$127,000 lower than the ICE counterparts.

Third, ALF concessions also provide considerable cost benefits, regardless of new registrations or replacements. The lifetime cost benefits of ALF concessions would amount to HK$46,400–HK$48,200.

TCO projections to 2030

This study projects future TCO trajectories until 2030. The purpose of this analysis is to identify the timing of TCO parity and future adjustments on tax concessions. To this end, the section first forecasts future vehicle prices resulting from battery cost reductions, and then calculates the lifetime TCOs of private cars. Because cost parity of replaced EVs is achieved, the section focuses on new EVs.

First, utilising the learning curve method outlined in Appendix A, the study projects future retail prices and capital costs of electric compact cars and SUVs in 2030. The result shows the following:

- Without any tax interventions, retail prices of electric compact cars will reach price parity with ICEs around 2025–2026, and with SUVs around 2029–2030. These time lines agree with existing studies (Lutsey and Nicholas 2019; Lutsey et al. 2021).

- If current FRT tax concessions persist, the capital cost of new electric compact cars will reach capital cost parity with ICEs around 2021, while SUVs will achieve parity around 2025–2026.

Second, lifetime TCOs of new electric compact cars and SUVs are projected based on future cost assumptions in Table 21.

The results show that without any tax benefits, electric compact cars will reach TCO parity by 2025, and electric SUVs by 2025–2026 (Figure 35). However, with continued tax concessions, TCO parity will occur rapidly. For example, with the current level of tax concessions for compact cars, TCO parity was achieved in 2021; for SUVs, with the tax benefits, TCO parity will move ahead to 2023–2024 (Figure 35).

Table 21 | Assumptions for Hong Kong Electric Private Cars' TCO Calculation in 2030

	COMPACT CAR		SUV	
	ICE	New EV (400 km)	ICE	New EV (500 km)
Vehicle price (in 1,000 HK$)	219	184	260	261
Energy cost	21.0 HK$/L	1.16 HK$/kWh	21.0 HK$/L	1.16 HK$/kWh
Energy intensity	5 L/100km	11 kWh/100km	8.2 L/100km	15 kWh/100km
Annual VKT (km)	11,200	11,200	11,200	11,200

Notes: Assume the NPV rate is 6 percent for private cars.
TCO = Total cost of ownership; SUV = Sport utility vehicle; ICE = Internal combustion engine; EV = Electric vehicle; L = Litres; kWh = Kilowatt-hours; VKT = Vehicle kilometres travelled; km = Kilometres; NPV = Net present value.
Source: Authors.

Figure 35 | Projected TCOs of New Electric Cars

Unit: 1,000 HK$

a. Compact cars **b. SUV**

Notes: TCO = Total cost of ownership; SUV = Sport utility vehicle; EV = Electric vehicle; ICE = Internal combustion engine; FRT = First Registration Tax; ALF = Annual licence fee.

1. "TCO without taxes" includes vehicle prices, energy costs, and charger costs. "TCO with taxes" includes vehicle prices, energy costs, charger costs, First Registration Taxes, and annual licence fees.
2. "EV_TCO_current_policy" and "ICE_TCO_current_policy" denote that both the EVs and ICEs' TCOs are calculated based on current levels of FRT and ALF rates and concessions, while "EV_TCO_new_policy" denotes that EVs' TCOs are calculated based on dynamically reduced tax concessions.

Source: Authors' calculations.

Importantly, recent attainment of cost parity in Hong Kong implies that pro-EV policy interventions should be gradually phased out, to offset the continuous drops in EV prices and to avoid boosting car ownership. If tax concessions are not reduced, the capital cost of a new electric compact car would be HK$163,000 lower (47 percent reduction) than for ICE cars in 2030, and its TCO would be HK$220,000 less (45 percent reduction) than the ICE vehicle. This means the cost of purchasing an ICE compact car equals the cost of purchasing two electric compact cars. Although electric SUVs are not as advantageous as electric compact cars, they still offer significant cost savings over ICE SUVs. Without adjusting tax concessions, the capital cost and the TCO of a new electric SUV will be, respectively, HK$110,000 (25 percent reduction) and 215,000 (34 percent reduction) lower than for the ICE SUVs.

As for timings to reduce tax concessions for new EVs, there are two possibilities: (1) reduce the tax concessions when the capital cost parity is reached (compact cars are 2021, and SUVs are 2025–2026); or (2) reduce the tax concessions when TCO parity is reached (compact cars are 2021, and SUVs are 2023–2024). This study chooses the second option because the energy cost savings from EVs in Hong Kong is particularly large. Two policy scenarios are designed: "EV_TCO_current_policy" (and "ICE_TCO_current_policy") denote that TCOs are calculated based on current levels of tax concessions, while "EV_TCO_new_policy" denotes that TCOs are calculated based on reduced tax concessions. The results show that for new electric compact cars, from 2021, both FRT and ALF tax concessions need to be reduced and completely phased out after 2026. From 2023, for new electric SUVs, both FRT and ALF tax concessions can be reduced, and after 2027, tax concessions for new SUVs can be completely phased out.

The timing for reducing tax concessions for replaced EVs is more complicated because electrification of the existing fleet should be encouraged. The decision is contingent on the government's trade-offs between EV promotion and fiscal revenues.

Future policy scenarios

This section projects EVs' market share under three policy scenarios that balance EV promotion and overall car ownership growth.

First, Hong Kong has room to further advance the time line of the fossil fuel ban on PCs. This is due to the following: First, TCO cost parity of all electric PCs will be achieved before 2024. Particularly, for compact cars and replaced SUVs, the timing of TCO parity is in the near future (Table 22). Second, considering Hong Kong will not see large new additions of PCs in the future, and 70 percent of existing ICE PC stock are entitled to the "One-for-One Replacement" Scheme (see Table 17), the city's EV market shares will soon take off. In fact, the current growth trend of EV market shares suggests electric PCs are set for exponential growth—the ratio of electric PCs in annual sales soared from 0.3 percent in 2017 to 28.0 percent in September 2021 (Transport Department 2016-2021) (Figure 36).

Table 22 | **Time Line of TCO Parity for Electric PCs under Current Tax Concessions**

TYPES OF PRIVATE CARS		CAPITAL COST PARITY	TCO PARITY
Compact car	New vehicle	2021	2021
	Replaced vehicle	Before 2021	Before 2021
SUV	New vehicle	2025–2026	2023–2024
	Replaced vehicle	2021–2022	Before 2021

Notes: Orange colour denotes parity is not achieved; green colour denotes parity is achieved.
TCO = Total cost of ownership; SUV = Sport utility vehicle.
Source: Authors.

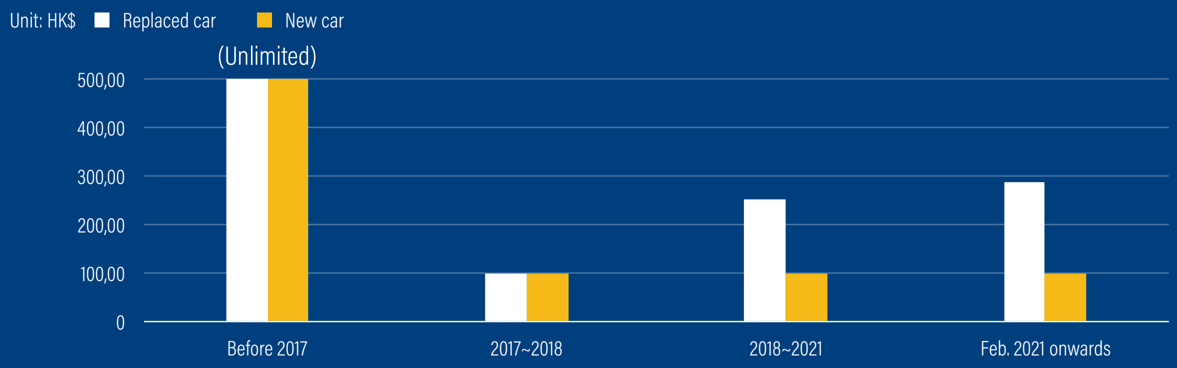
Box 2 | The adjustments on FRT

In the past, FRT adjustments had a strong bearing on annual sales of electric PCs. The FRT has experienced three major adjustments since implementation. Instead of incremental changes, some adjustments were radical. For example, the FRT was initially waived for EVs. However, fearing the waiver would boost car ownership and subsidise the wealthy, the government cut EVs' tax concession from "unlimited" to a maximum of HK$97,500 in early 2017.

The sudden surge of FRT for EVs led to 26–48 percent increases in TCOs and a sharp drop in registered electric PCs; as a result, a meagre 99 EVs registered in 2017. The registration of electric PCs was only restored after 2019.

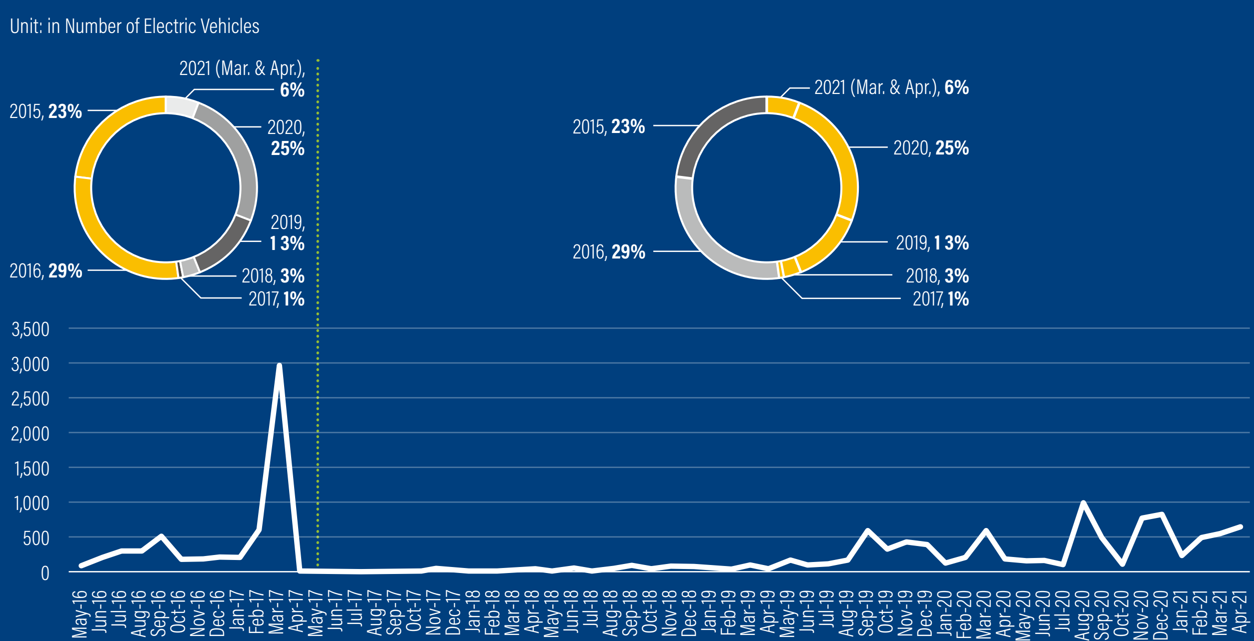
Since FRT tax concessions have a strong bearing on EV sales, future adjustments on tax concessions need to be treated with caution.

Figure B2.1 | Adjustments on the Maximum First Registration Tax Concessions for Electric Private Cars



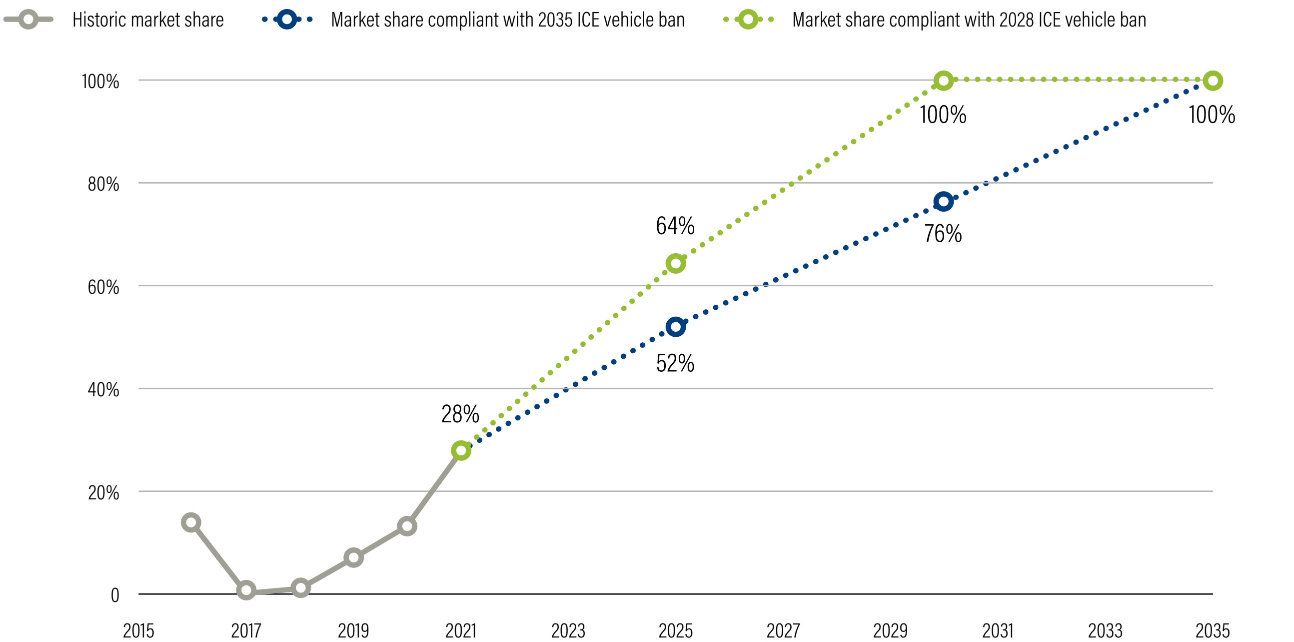
Source: Authors summary based on Hong Kong's Transport Department 2021a.

Figure B2.2 | Electric Private Cars Registered between May 2016 and April 2021



Note: Years are abbreviated as the last two digits (e.g., 15 for 2015).
Source: Authors' summary based on Hong Kong's Transport Department 2016–2021.

Figure 36 | **Projections on Hong Kong's Electric Private Car Market Share**



Note: The market share of electric PCs in 2021 was only for March to September 2021. Besides 2035's market share of 100 percent, the target market share is the linear extrapolation of the 2021 (March to September) market share and 2035 market share.
Sources: Historic observations are from Hong Kong's Transport Department 2016–2021. The future market shares (under 2028 and 2035 ICE vehicle bans) is authors' assumption.

With around 10 years of useful life for PCs, the study assumes that it is possible for Hong Kong to advance its ICE vehicle bans from 2035 to 2028. To further increase the EV market share in PC sales, the following measures will be important, including increasing the availability of charging facilities and diversifying vehicle make-and-models.

Second, affected by TDM policies and vehicle electrification, Hong Kong's car ownership would vary. Despite strong TDM policies that restrict car ownership, vehicle electrification would create a loophole. The continued decline of EV capital costs and TCOs will make EVs a compelling option. For example, as shown in Section 3.1.3, if current tax concessions persist, the cost of purchasing an ICE compact car could equal the cost of two electric compact cars. These cost benefits of electric PCs are large enough to spur car ownership and make the path to the fossil fuel ban more expensive: more EVs mean worse congestion, greater public resistance to car ownership restrictions, and more public expenses on tax concessions and charging network investments.

To evaluate different electric PC fleet sizes on public expenditure and emissions, the study uses the Hong Kong EPS model to simulate two car ownership growth pathways, including the "rapid car ownership increase" pathway and "slow car ownership increase" pathway (Table 23). The "rapid car ownership increase pathway" projects that Hong Kong's car ownership will steadily grow to 809,000 in 2050, spurred by either ICE car growth resulting from limited TDM measures (the Current Policy Scenario), or by electric PC growth resulting from lower EV prices (the High PC Stock Scenario). The slow car ownership increase pathway shows that Hong Kong's car ownership will grow to 687,000 vehicles in 2041 and stabilise at 670,000 in 2050, due to adoption of more proactive TDM policies to manage both EV and ICE growth (Low PC Stock Scenario). In particular, to control car ownership growth but not discourage vehicle electrification, new proactive TDM measures include introducing zero-emission zones, increasing parking fees (or congestion charges), and even placing direct controls on car ownership.

Table 23 | **Scenario Design of Private Car Ownership and Electrification**

	RAPID CAR OWNERSHIP INCREASES	SLOW CAR OWNERSHIP INCREASES
Rapid EV adoption	**High PC Stock Scenario** ▪ ICE vehicle ban 2028 ▪ Current TDM measures	**Low PC Stock Scenario** ▪ ICE vehicle ban 2028 ▪ Tightened TDM measures
Slow EV adoption	**Current Policy Scenario** ▪ ICE vehicle ban 2035 ▪ Limited TDM measures	

Notes: EV = Electric vehicle; ICE = Internal combustion engine; PC = Private car; TDM = Travel demand management.
Source: Authors.

Based on the above considerations on EV promotion and car ownership controls, the following three policy scenarios may be constructed:

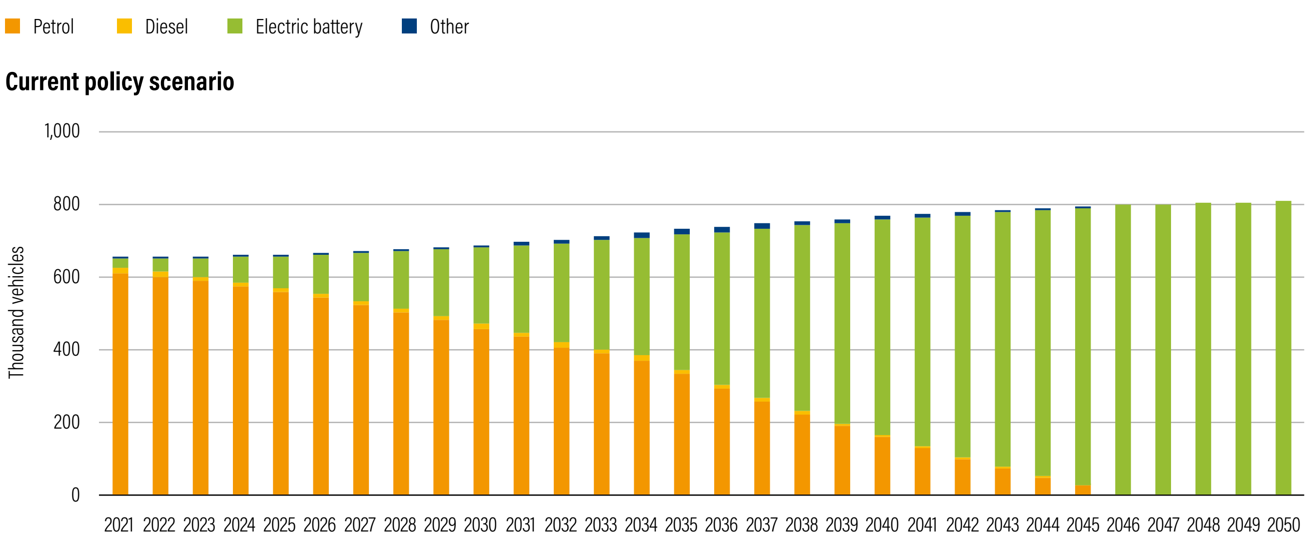
- Current policy scenario: This is in accordance with "Hong Kong Roadmap on Popularisation of Electric Vehicles". The city will witness rapid car ownership increases due to limited TDM policies.
- High PC stock scenario: Hong Kong will take proactive measures to promote EVs, and the ICE vehicle ban is moved ahead from 2035 to 2028. However, reduced EV prices and increased EV sales will increase overall car ownership.
- Low PC stock scenario: Hong Kong will advance the fossil fuel ban to 2028. Further, the city will tighten its TDM measures to control its car population growth and focus its policies on encouraging the electrification of in-use PCs.

Socioenvironmental implications

This section evaluates the social and environmental impacts of the above three scenarios.

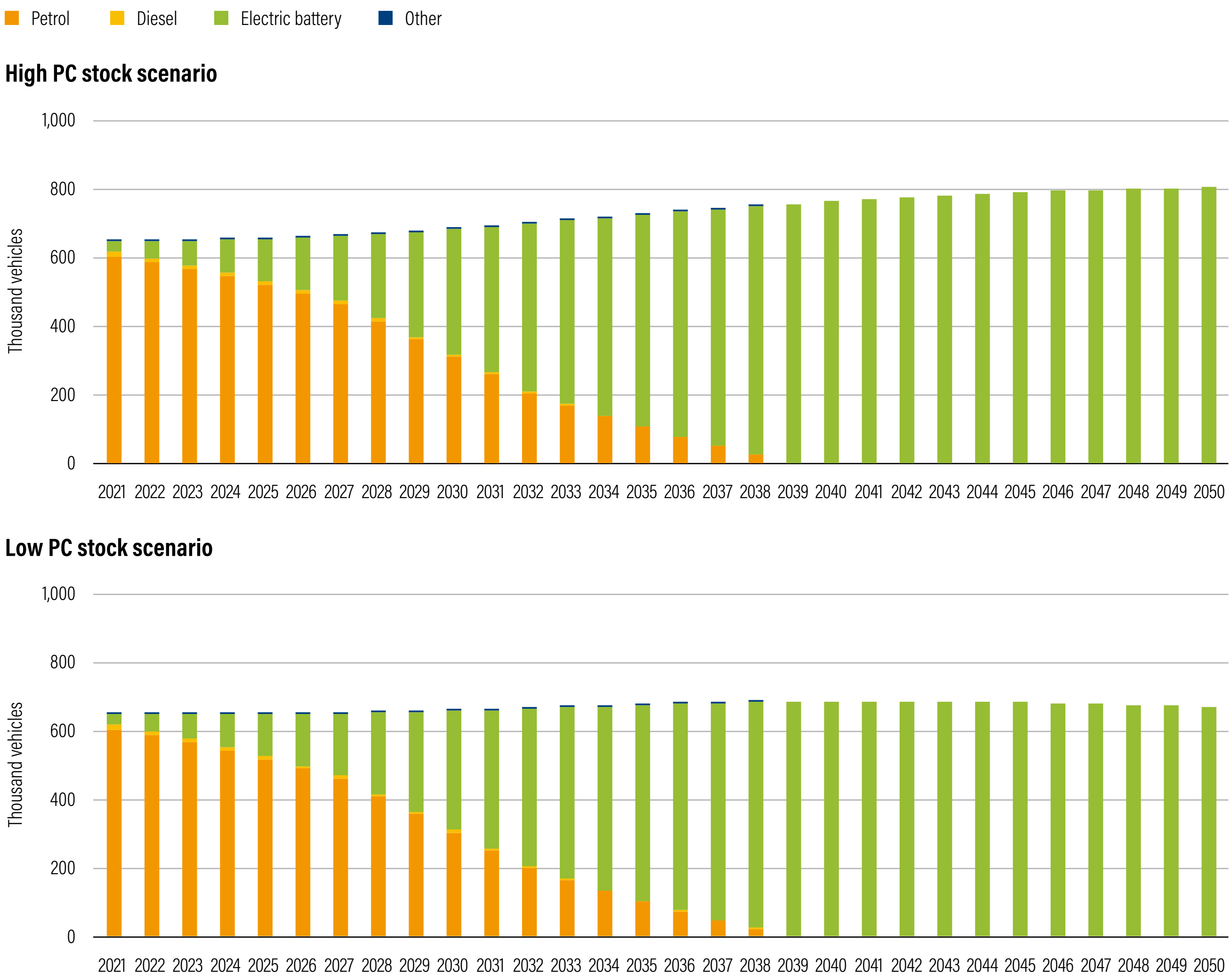
First, under all three scenarios, the PC stock will be completely zero-emission before 2046 (Figure 37). If new registration of ICE PCs is banned from 2028, PC stock will be completely electrified around 2040.

Figure 37 | **Private Car Fleet Composition under Different Scenarios (1)**



Note: PC = Private car.
Source: Authors' calculation using the Hong Kong EPS model.

Figure 37 | **Private Car Fleet Composition under Different Scenarios (2)**



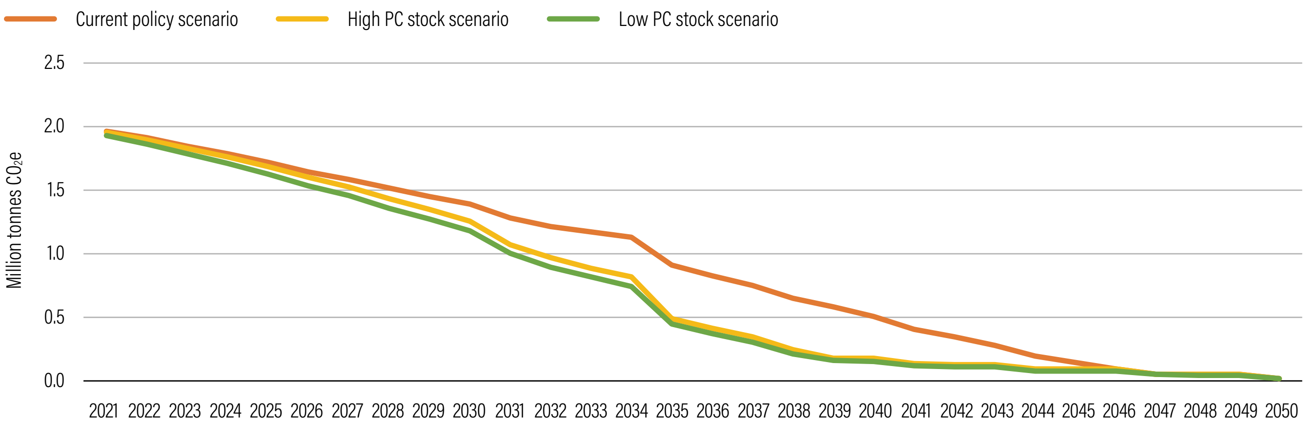
Note: PC = Private car.
Source: Authors' calculation using the Hong Kong EPS model.

GHG and air pollutant emissions and economic benefits

With the widespread adoption of electric PC and power sector decarbonisation, well-to-wheel GHG emissions of Hong Kong's private cars will steadily decrease from 2021 and achieve near-zero emissions around 2040–2050. With the sharp decline in GHG emissions, banning the new registration of ICE cars in 2028 would save 4.8~6.0 million tonnes CO_2e cumulative emissions, in comparison to the fossil fuel ban in 2035. Similar trends can be observed for air pollutants such as fine particulate matter ($PM_{2.5}$) (Figure 38). Since no more ICE cars will be permitted from 2039 onwards, under both High PC Stock and Low PC Stock Scenarios, there will be zero tailpipe pollutants after that point (Figure 39).

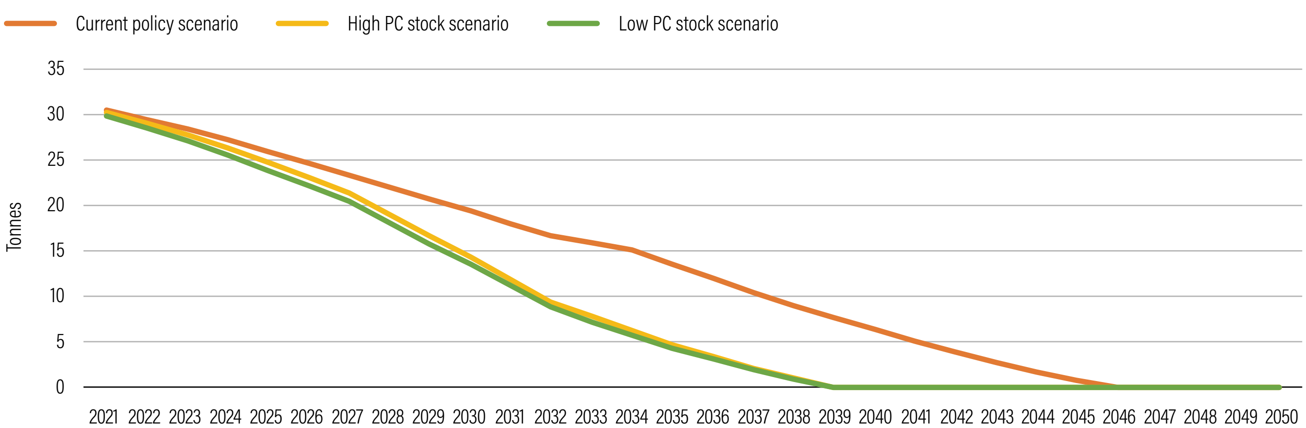
The cumulative economic benefits from the avoided climate damages between 2021 and 2050 are HK$2.6 billion and HK$3.2 billion in the High PC Stock scenario and Low PC Stock scenario, respectively. The benefits are higher than those in Current Policy Scenario (Figure 40). The economic benefits from avoided health impacts due to the reduction of $PM_{2.5}$ emissions) follow the same trend: the High PC Stock and Low PC Stock Scenarios offer HK$143 million and HK$156 million, respectively, in cumulative benefits (between 2021 and 2050)–higher than those of Current Policy Scenario.

Figure 38 | **Well-to-Wheel Greenhouse Gas Emissions for Private Cars**



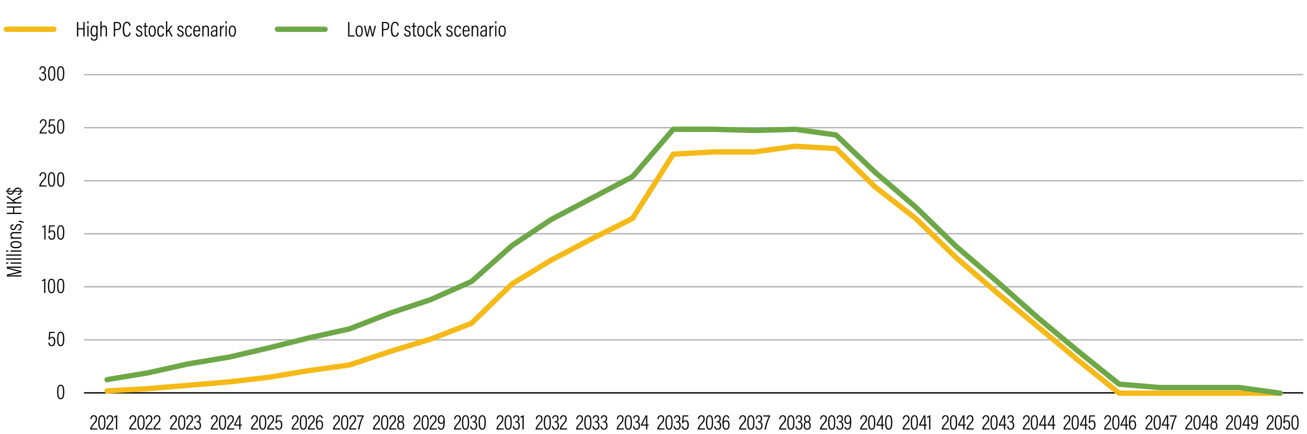
Note: PC = Private car. CO_2e = Carbon dioxide equivalent
Source: Authors' calculation using the Hong Kong EPS model.

Figure 39 | **Direct Tailpipe $PM_{2.5}$ Emissions for Private Cars**



Notes: $PM_{2.5}$ = Fine particulate matter; PC = Private car.
Source: Authors' calculation using the Hong Kong EPS model.

Figure 40 | **Economic Benefits from Avoided Climate Damages Compared to the Current Policy Scenario**



Note: PC = Private car.
Source: Authors' calculation using the Hong Kong EPS model.

Public expenditure

Cumulative public expenditure on electric PC promotion includes tax revenue losses due to First Registration Tax concessions and public grants to charging infrastructure delivery during 2021 and 2030. For simplicity, the study assumes First Registration Tax concessions are the same across all electric PCs (regardless of new additions or replaced vehicles) over time, and differences in tax revenues in the three scenarios are caused by variations in annual EV sales.

The result shows that public expenditure is the largest in the High PC Stock Scenario, due to tax revenue losses and increased subsidies to support a larger number of electric PC stock (Figure 41). If roadway expansion, additional parking spaces, and land acquisition investments for a larger PC fleet are considered, the public expenditure of the High PC Stock Scenario could be even higher and would possibly aggravate the city's traffic congestion: For example, 139,000 parking spaces would be needed if the scenario becomes a reality. In comparison, the Low PC Stock Scenario leads to less public expenditure, and this saving can be mobilised to improve public transit, walking, and cycling environments for low- and middle-income groups.

Summary

The above analysis shows that the scenarios—the High PC Stock Scenario and the Low PC Stock Scenario—aiming to increase Hong Kong's PC electrification ambition result in comparable emission reduction potentials. However, the two scenarios differ in the level of financial support needed from the government. With a smaller size PC stock due to the effects of TDM policies (in the Low PC Stock Scenario), public spending on infrastructure—chargers, roadways, and public parking spaces—can be curtailed, and revenues collected from FRT can be maintained.

Recommendations

Hong Kong has an important opportunity to advance the current fossil fuel ban time line (2035) to 2028 or earlier, given that the TCO parity and capital cost parity of several classes of electric PCs are reached.

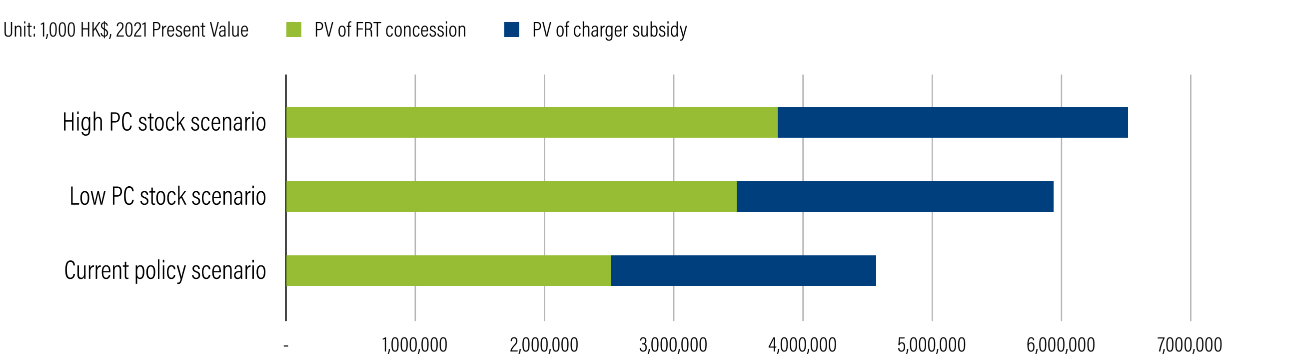
Further, the city has the potential to create a new electrification paradigm by enhancing its vehicle electrification ambition, while controlling overall car ownership. The new paradigm will be achieved by encouraging the rapid electrification of the existing in-use PC fleet, while properly managing the new additions of electric PCs through TDM measures.

To serve the above purposes, the city could consider the following measures:

Strengthen travel demand management measures

As EV prices continue to fall, the suite of Hong Kong's existing TDM policies needs to be regularly scrutinised and updated to avoid the rapid vehicle electrification that is inflating the car fleet.

Figure 41 | **Cumulative Public Expenditure between 2021 and 2050 under Different Scenarios**



Note: Assume NPV rate is 3 percent. Subsidy to each public charger is HK$40,000 in 2021, while it will be gradually reduced to HK$15,000 in 2050. The EV to public charger ratio is 10:1. PC = Private car; PV = Present value; NPV = Net present value; FRT = First Registration Tax; EV = Electric vehicle.
Source: Authors' calculations.

Table 24 | **Scorecards of Different TDM Policies on Vehicle Electrification, Car Ownership Control, and Public Revenue Generation**

	EV REGISTRATION TAX CONCESSION	EV PURCHASE SUBSIDY	VEHICLE REGISTRATION QUOTA	ACCESS INCENTIVES (ZERO EMISSION ZONE)	INCREASED PARKING FEES (OR CONGESTION CHARGES)	PARKING INCENTIVE	CHARGING FACILITY INCENTIVE	CARBON PRICE
Effects on promoting vehicle electrification	Positive	Positive	Positive	Positive	Positive	Positive	Positive	Positive
Car ownership control	Negative	Negative	Positive	Neutral	Positive	Negative	Neutral	Neutral
Public revenue generation	Negative	Negative	Neutral	Neutral	Positive	Negative	Negative	Positive
Implementation easiness	Negative	Positive	Negative	Positive	Negative	Positive	Positive	Neutral
Recommendation by this study	✓		◯	◯	◯		✓	◯

Note: ✓ denotes the TDM policy has been implemented in Hong Kong; ◯ represents new TDM policies that can be considered by the city.
EV = Electric vehicle; TDM = Travel demand management.
"Positive" indicates the TDM policy has positive impacts on the indicator, while "Negative" and "Neutral" mean the TDM policy has negative or neutral impacts.
Source: Authors.

New TDM policies in the vehicle electrification era must strike a balance among multifaceted goals (Table 24):

- Promoting vehicle electrification and mitigating GHG emissions and air pollution
- Controlling car ownership growth, relieving traffic congestion, and reining in urban sprawl
- Maintaining the sustainability of public fiscal revenues
- Refraining from subsidising the wealthy

First, the study shows that to avoid boosting car ownership, save public spending, and refrain from subsidising the wealthy, it is imperative to gradually reduce existing tax concessions for EVs. For new electric PCs, tax concessions can be reduced during 2021~2023, and completely phased out during 2026~2027.

Second, apart from reducing tax concessions, the city needs to consider alternative TDM options (Table 24). By evaluating vehicle electrification potential, extent of car ownership control, public revenue generation, and implementation feasibility, the study shows four TDM policies can be added to Hong Kong's future policy arsenal:

- Zero-emission zones: Zero-emission zones are areas that strictly regulate the access of ICE vehicles—ICE vehicles are either entirely banned from entering the areas or must pay for their environmental and social externalities to enter. Cities such as Amsterdam, London, and Paris aim to implement zero-emission zones between 2025 and 2030. Because the measure has low administrative cost, while being effective in incentivising vehicle electrification without stimulating car ownership growth, it can be a viable option for Hong Kong.
- Congestion charges: Hong Kong can further increase parking fees or introduce congestion charges (Electronic Road Pricing [ERP] scheme). The policy would have social equity implications, considering around 80 percent

of Hong Kong's mode-share was fulfilled by transit. Wealthy car owners (including EV owners) can pay for the externalities of driving (such as traffic congestion), and the revenue collected could be used to improve transit services. However, ERP implementation is challenging for Hong Kong: the ERP pilot scheme was initially proposed in the 1980s, but has not been implemented (Transport Department n.d. [a]).

- Carbon pricing: Carbon tax can be introduced on (1) transport fuels that target fuel distributors, and/or (2) vehicles at the purchase stage. Carbon pricing on fuels is relatively easier to implement; however, because Hong Kong's auto fuel retailers' market is highly competitive with varying degrees of discounts on pump prices, carbon taxes imposed on fuels may not be fully transferred to customers. Carbon taxes imposed at the vehicle purchase stage could avoid the problem, but such taxes would possibly trigger public resistance on the already high taxation and would experience possible delays in tax legislation. Further, carbon prices need to be regularly adjusted to reflect shadow prices and updated decarbonisation goals.

- Direct car ownership control: Hong Kong's existing vehicle registration tax (along with expensive parking costs) has effectively deterred car ownership increases. However, the falling prices of EVs in the future may undermine the tax's effectiveness. To counter this, the city could consider alternatives such as capping the number of new registrations. A typical example is Singapore's vehicle quota system (VQS), where the city sets annual quotas for new registrations and distributes them through auctions. However, compared with other measures, public objection to VQS is strong, and this policy should only be considered when other policy options have been tried.

Enhance charging infrastructure provisions

Increasing charging infrastructure is important to sustain Hong Kong's EV growth momentum, not just to serve the existing fleet but also to convince indecisive consumers. In addition to Hong Kong's current policies on gross floor area concessions and EV-Charging at Home Subsidy Scheme (EHSS), the government could strengthen efforts by doing the following:

Increasing the coverage of home chargers through:

- Institutionalising in the building code that all parking spaces of new and retrofitted buildings be 100 percent charging-ready,[22] and devising right-to-charge regulations to require property managers of existing buildings to allow tenants to install home chargers.

- Encouraging shared and managed chargers, introducing time-of-use residential rates, and systematically evaluating grid capacities of all existing buildings, to shift vehicle charging loads to off-peak hours.

Improving coverage and accessibility of public chargers through:

- Increasing the coverage of public charging stations, where the number of EVs per public charging point could be set to 5–10 (T&E 2020).

- Building an open, public data platform to facilitate the wayfinding for charging stations, and for utility companies to pinpoint areas in dire need of grid reinforcement.

- Adopting and enforcing e-roaming standards so that EV owners can experience seamless payments across public chargers operated by different charging service providers (Hardman et al. 2018).

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CHAPTER 4

GOODS VEHICLES DECARBONISATION POTENTIAL AND ACTION PLAN

Goods vehicles are the largest road transport emitter and the second-largest fleet. Hong Kong had 211 electric light-goods vehicles and 2 electric medium-goods vehicles by the end of 2021 (Transport Department 2021). Despite the challenges, it is highly possible for these goods vehicles to decarbonise their GHG emissions with support from the government and trucking industry.

Goods vehicles' stock and zero-emission vehicles' market share prediction

In this section, we define the business-as-usual scenario and two net-zero scenarios, as well as key assumptions—freight turnover, energy demand, and market shares within each scenario.

Scenarios

We define all the net-zero scenarios based on the following criteria: (1) the share of zero-emission vehicles (ZEVs) (i.e., BEVs and FCEVs) in the total truck fleet should be 100 percent by 2050 or earlier, which is in concert with the target in "Hong Kong's Climate Action Plan 2050" (Government of Hong Kong 2021) and EV Roadmap (Hong Kong Environment Bureau 2021); and (2) the total road freight demand (in tonne-kilometres), as an indicator of level of services, as projected in Section 4.1.2, should be met regardless of the fleet composition and technology options. We identified three scenarios in which the BEV Scenario and Hydrogen Scenario are the two "net-zero scenarios" that aim to realise carbon neutrality by 2050.

- ***BAU Scenario:*** Business-as-usual scenario was defined in the "Current Policy Scenario" mentioned in a previous World Resources Institute (WRI) and Civic Exchange Hong Kong study, "Towards a Better Hong Kong: Pathways to Net Zero Carbon Emissions by 2050" (WRI and Civic Exchange 2020). This scenario assumes that existing policies continue through 2050 without major changes. Measures to decarbonise mobility by improving fuel efficiency or encouraging EV sales will be limited (WRI and Civic Exchange 2020).

- ***BEV Scenario:*** In this scenario, all light-goods vehicles (LGVs) and 50 percent of heavy-goods vehicles (HGVs) and medium-goods vehicles (MGVs) will be battery electric vehicles (BEVs) by 2050 or earlier, while the other 50 percent of HGVs will be hydrogen fuel cell electric vehicles (FCEVs).

- ***Hydrogen Scenario:*** By 2050 or earlier, all HGVs and 50 percent of LGVs will be FCEVs, while 50 percent of LGVs will be BEVs.

Under both net-zero scenarios, Hong Kong can choose different powertrain technology pathways to reach its carbon neutrality goal by 2050. In extreme cases, Hong Kong can realise a full BEV or full hydrogen fleet by 2050 or earlier. However, in reality, this also depends on the net-zero strategy that the Hong Kong government (and the market) choose for their power sector. Based on findings from another WRI study, "Powering a Carbon-Free Hong Kong: Pathways towards a Net-Zero Emissions Power System for Hong Kong" (WRI and Civic Exchange 2021), an option exists for Hong Kong to use green hydrogen for its energy security and grid-balancing concerns, though with higher cost. Moreover, given that BEV technology is well-developed in LGVs and hydrogen is a promising option for HGVs, we developed compromise assumptions, as described in the above scenarios.

The study then assesses and compares the impacts of different scenarios against the following indicators:

- Climate impact (GHGs avoided in tonnes of carbon dioxide equivalent (tCO_2e) and associated benefits)

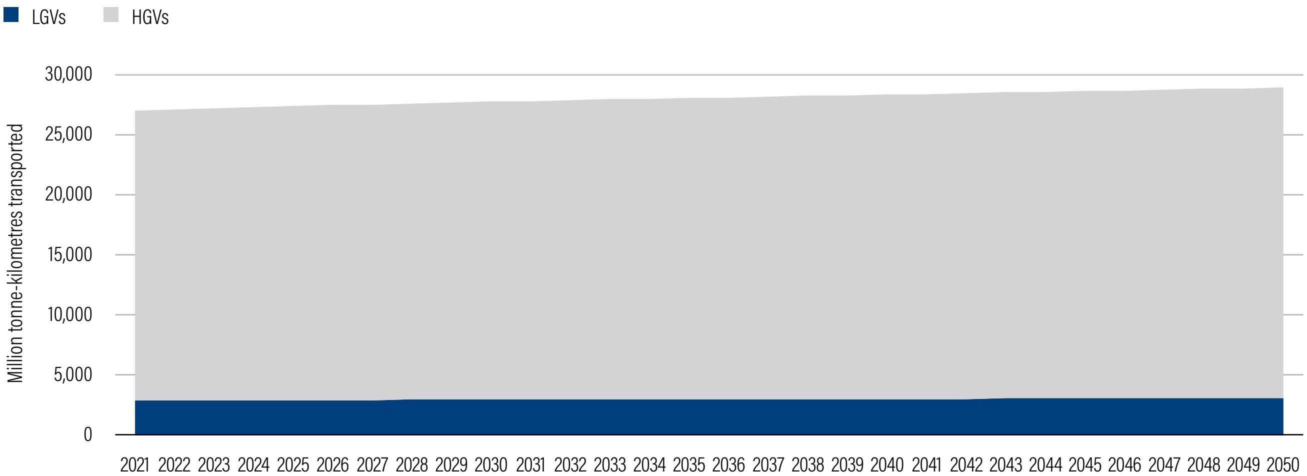
- Public health impact (premature deaths avoided and associated benefits due to air pollutants avoided)

- Impact on freight companies (costs or benefits for using different vehicle technologies)

- Impact on infrastructure (costs on new charging infrastructures and hydrogen-refuelling stations).

All impacts from the four indicators were monetised but not added up in the study. As in WRI's study "Powering a Carbon-Free Hong Kong: Pathways towards a Net-Zero Emissions Power System for Hong Kong" (WRI and Civic Exchange 2021), we compared the cost-effectiveness of different powertrain technology options in the different scenarios, in terms of meeting net-zero

Figure 42 | **Outlook for Hong Kong Road Freight Transport Demand**



Notes: LGVs = Light-goods vehicles; HGVs = Heavy-goods vehicles.
Source: Hong Kong Energy Policy Simulator (EPS) (https://hongkong.energypolicy.solutions/).

targets rather than an optimisation exercise to minimise the cost of options.

Road freight demand

We used the Energy Policy Simulator (EPS) tool to forecast the total road freight demand in Hong Kong. The road freight demand was represented by freight turnover in tonnes-kilometres transported (tkm) by trucks. Figure 42 shows the projection of total road freight demand in the BAU Scenario. It shows that the demand will have a slight growth of 7 percent by 2050 compared to the 2021 level, due to stable economic performance in Hong Kong and the hinterland. The road freight demand will increase to 29 billion tkm by 2050, in which HGVs (MGVs included) have the dominant share (89 percent) of total freight transport demand throughout the decades.

Energy demand

For all scenarios, the energy demand is reduced by between 40 and 60 percent (Table 25). This is due to higher energy efficiency from all low-emission powertrain technologies, including ICE vehicles. New battery electric vehicles and hydrogen fuel cell vehicles have much better energy economy performance than traditional ICE vehicles. This determines the large energy reduction throughout the years.

Table 25 | **Energy Demand for Each Scenario between 2020 and 2050**

SCENARIO	ENERGY CONSUMED 2020 (PJ)	ENERGY CONSUMED 2050 (PJ)	PERCENTAGE REDUCTION (2020–2050)
BAU	40	23	42
BEV	40	17	57
Hydrogen	40	19	52

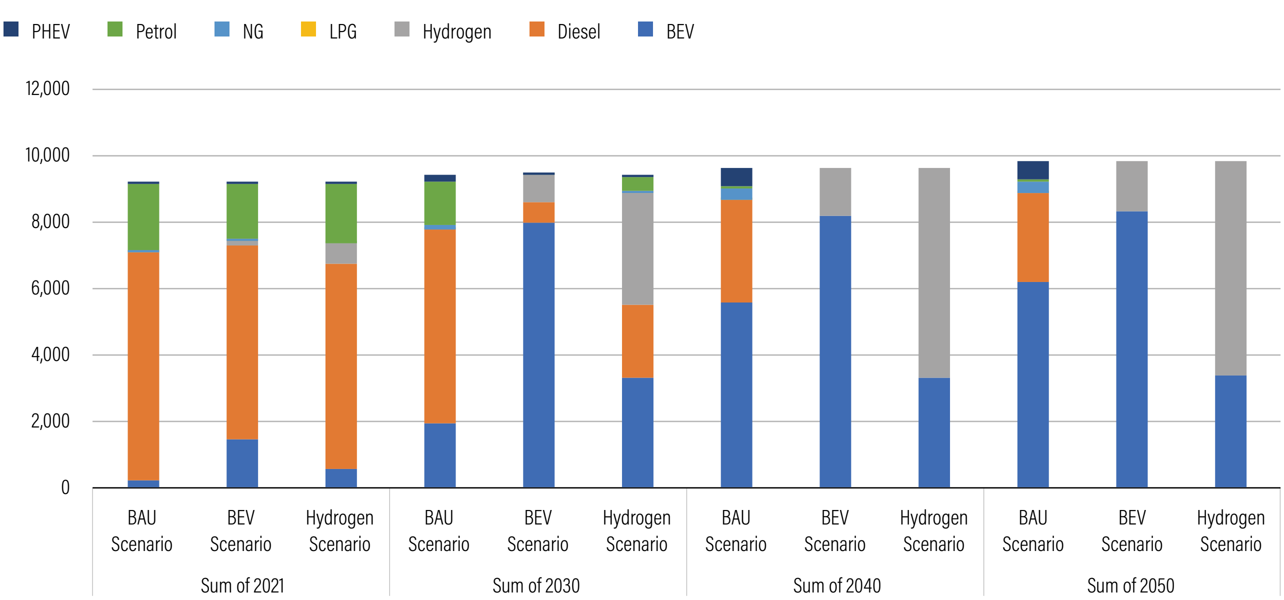
Note: PJ = Petajoules; BAU = Business as usual; BEV = Battery electric vehicle.
Source: Hong Kong Energy Policy Simulator (EPS) (https://hongkong.energypolicy.solutions/).

Market shares

To reach the net-zero emissions target by 2050 (ZEVs = 100%), new ICE trucks will not be sold in Hong Kong after 2035 if the service lifetime for the truck is within 15 years, as regulated in Hong Kong (TIC 2019). Based on ICCT's studies (ICCT 2019, 2021), we estimated that the Hong Kong trucking industry will see cost parity for battery electric LGVs by 2025 (or earlier), electric HGVs by 2030, and all hydrogen trucks after 2030, if there are no further policy incentives. If there are incentives on green hydrogen prices, hydrogen trucks will meet cost parity by about 2030 or a few years later. We assumed a linear market uptake of ZEVs by using the results from EPS, though in reality it would most likely be nonlinear and with rapid uptake once ZEVs reach cost parity with diesel ICEs (Ricardo Energy and Environment 2019). By using the EPS tool, with consideration (compromise) of the 2050 goal[23] and real situations,[24] we assumed that the time window for Hong Kong's new ICE truck ban could be (1) no new ICE LGVs sold in 2030 or earlier; and (2) no new ICE HGVs sold in 2039 or earlier, as long as the Hong Kong government and the trucking industry agree to phase out all existing ICE HGVs (before their retirement time) in the fleet by 2050. This restriction target for LGVs will be five years earlier than stipulated by Hong Kong's current policy on private cars (Hong Kong Environment Bureau 2021), while for HGVs, it will be four years later than for private cars.

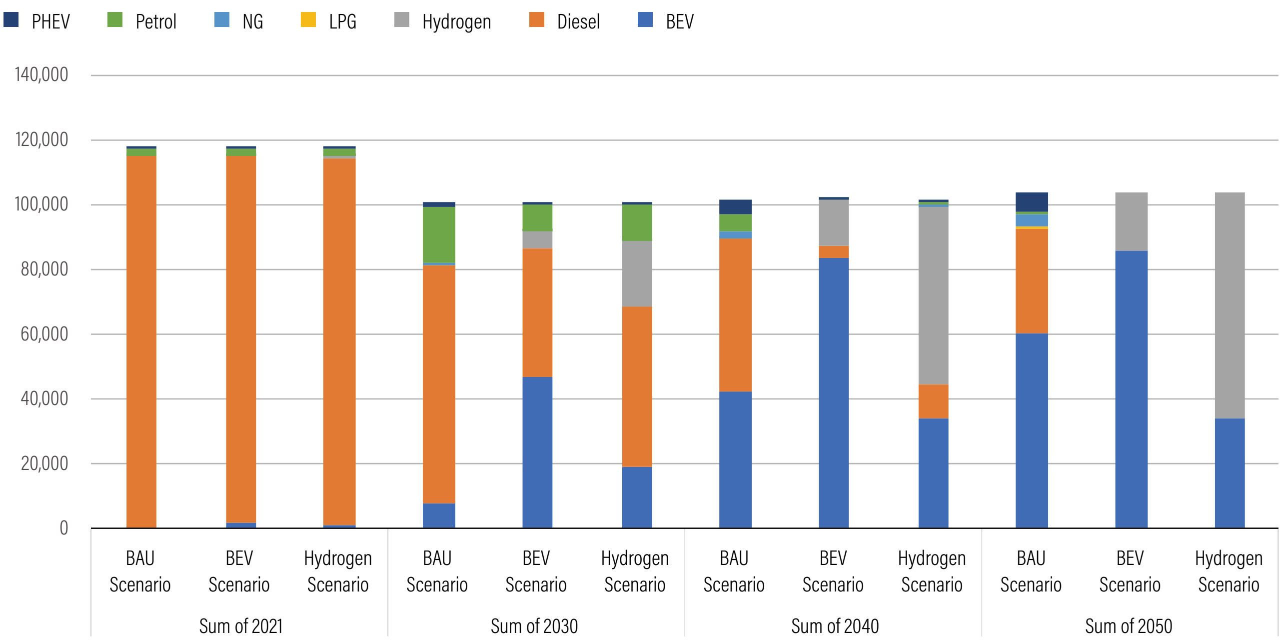
Following the assumptions above, we used the EPS to simulate the market shares of different vehicle powertrains for each scenario (Figure 43 and Figure 44). Each scenario presents a push towards a certain powertrain technology; that is, the BEV Scenario focuses on pushing towards battery electric technology in LGVs, while the Hydrogen Scenario promotes hydrogen technology in HGVs. However, there is no extreme case of 100 percent market share for either technology, as explained in Section 4.1.1. Both BEV and Hydrogen Scenarios consider a mix of ZEV powertrain technologies within the market shares. In the Hydrogen Scenario, we assumed half of the LGV fleet will still be BEVs in 2050, since the battery electric powertrains are already mature and suitable for light-goods vehicles used in urban environments. In the BEV Scenario,

Figure 43 | **Market Shares of Different Vehicle Powertrains, New Vehicle Sales**



Notes: PHEV = Plug-in hybrid electric vehicle; NG = Natural gas; LPG = Liquefied petroleum gas; BEV = Battery electric vehicle; BAU = Business as usual.
Source: Authors, based on the Hong Kong Energy Policy Simulator (EPS) (https://hongkong.energypolicy.solutions/).

Figure 44 | **Market Shares of Different Vehicle Powertrains, Total Number of Vehicles**



Notes: PHEV = Plug-in hybrid electric vehicle; NG = Natural gas; LPG = Liquefied petroleum gas; BEV = Battery electric vehicle; BAU = Business as usual.
Source: Authors, based on the Hong Kong Energy Policy Simulator (EPS) (https://hongkong.energypolicy.solutions/).

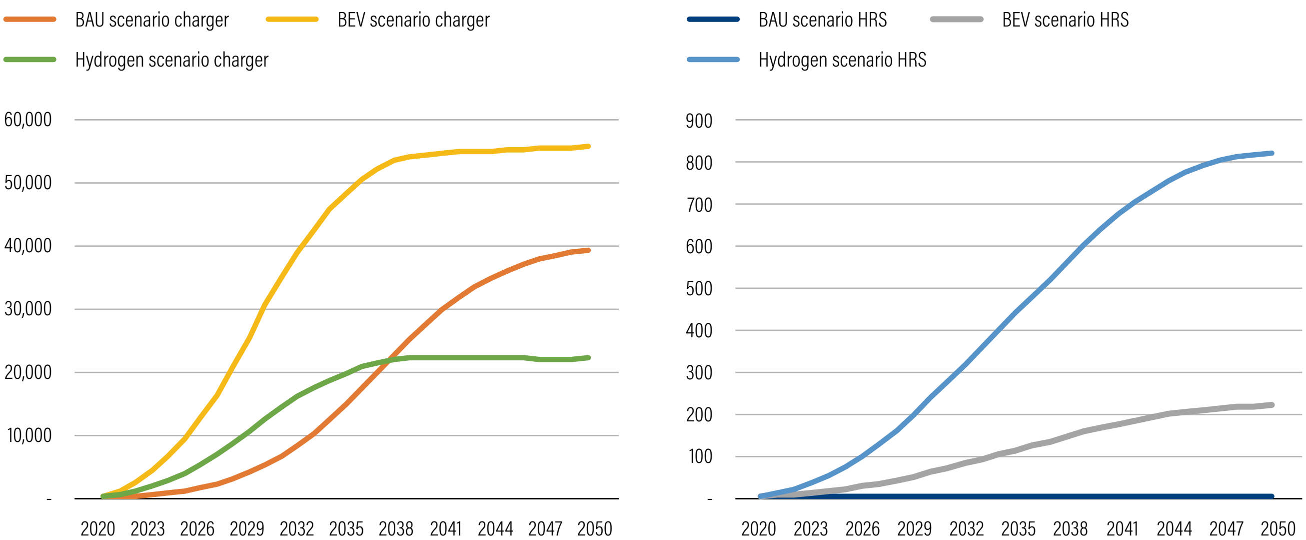
we assumed half of the HGV fleet will use hydrogen vehicles, since hydrogen technology seems more promising for heavy-goods vehicles. While BEVs are commonly accepted to be the most promising technology for decarbonising LGVs, the most cost-effective route to decarbonise HGVs is less clear. It is expected that battery electric or hydrogen HGVs could be available in the 2020s, and once they reach TCO parity with diesel, uptake of zero-emission options could accelerate rapidly (Ricardo Energy and Environment 2019).

Based on the simulation, the total fleet will be about 103,900 trucks in Hong Kong in 2050 (Figure 44), with 85,665 electric trucks and 18,252 hydrogen trucks if Hong Kong chooses the BEV Scenario pathway, and with 33,699 electric trucks and 70,221 hydrogen trucks if it chooses the Hydrogen Scenario pathway. It is worth noting that even under the BAU Scenario, without further policy incentives on ZEVs, there will still be 60,297 BEVs (mainly LGVs) in the market in 2050, mainly because of rapid market uptake due to cost and technology advantages of light electric vehicles. However, without policy incentives and ICE restrictions, there will still be 32,679 diesel trucks and other ICT trucks in the market in 2050.

Infrastructure

As of March 2022, there were 4,852 EV charging stations for public use (Hong Kong Environmental Protection Department 2022b), mainly for cars. However, the number of depot chargers for trucks is unclear, and there is no hydrogen-refuelling station in Hong Kong. To meet the charging and refuelling demand of all zero-emission trucks, significant growth in infrastructure will be required in all scenarios. This will include a large number of depot chargers, especially in the BEV Scenario, with a requirement for about 56,000 chargers in 2050. This is due to the low number of vehicles that can use a charger at any given time. We assumed that about 0.3–1.0 depot chargers are needed per vehicle and 0.003–0.020 hydrogen-refuelling stations (three dispensers per station) are needed per vehicle, based on the existing literature (ICCT 2019; Ricardo Energy

Figure 45 | **Number of Depot Chargers for Trucks and Hydrogen-Refuelling Station Infrastructure for Each Scenario**



Notes: The figure represents the medium value from the calculation.
BEV = Battery electric vehicle; BAU = Business as usual; HRS = Hydrogen-refuelling station.
Source: Authors, based on the Hong Kong Energy Policy Simulator (EPS) (https://hongkong.energypolicy.solutions/).

and Environment 2019). Figure 45 shows the estimated number of depot chargers for trucks and hydrogen-refuelling station infrastructure for each scenario.

In this study, we assumed the CAPEX per hydrogen-refuelling station to be between US$2 million and US$5 million (400kg–1,200kg/day) (U.S. Department of Energy 2021; Ricardo Energy and Environment 2019; ICCT 2019), while the cost will be much higher if the construction of on-site hydrogen generation is included (about US$16 million). The lifetime of a hydrogen-refuelling station can be considered to be the same as for a conventional site in that they are refreshed every 10 years. OPEX per hydrogen-refuelling station will be 5 percent of CAPEX per year; installation cost will be US$240,000; and the network-associated cost will be US$130,000 per hydrogen-refuelling station, approximately, based on the Hydrogen for Transport Programme (HTP) in the United Kingdom (Ricardo Energy and Environment 2019).

Cost-benefit analysis for net-zero scenarios

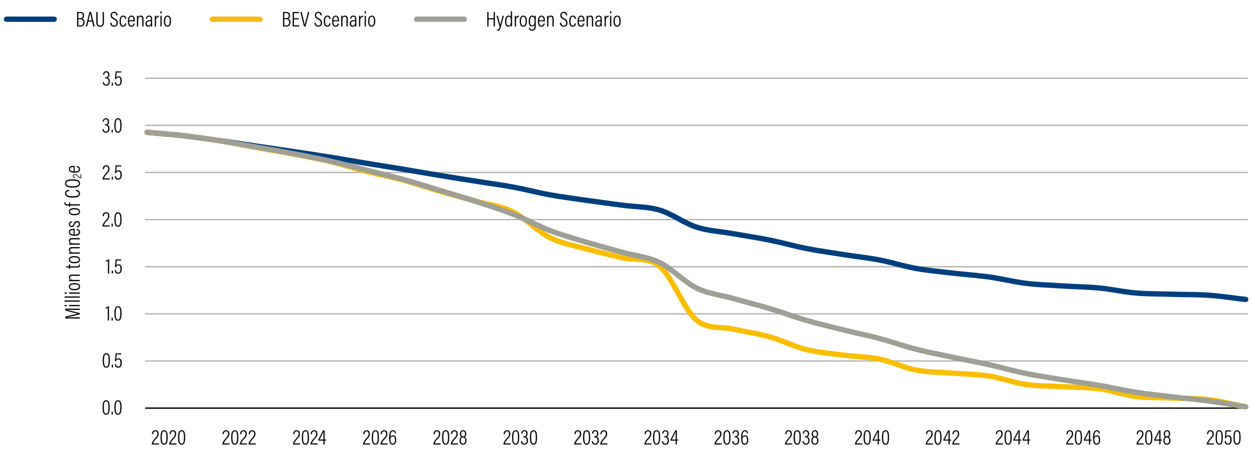
In this part, we examine both external (public/society) and internal (private) benefits and costs from the scenarios under different ZEV technology roadmaps. In terms of public impact, we estimate the amount of GHGs (carbon dioxide [CO_2], methane [CH_4], and nitrous oxide [N_2O]) avoided and the corresponding cost saving from climate change mitigation. We also estimated the amount of air pollutants (fine particulate matter [$PM_{2.5}$] and nitrogen oxides [NO_X]) avoided and the economic value of local public health improvement. In terms of private impact, we estimate the benefit and/or cost for the private sector–for example, trucking companies that follow different ZEV technology pathways. We also estimated the costs of the hydrogen-refuelling station and charging infrastructures that will be built and operated through a PPP or by the public or private sector.

Climate impact

GHGs avoided

Both the BEV and Hydrogen Scenarios will reach the net-zero emissions target by 2050, meeting the target set by the Hong Kong government. With a more rapid and ambitious battery electric powertrain uptake, Hong Kong will reduce more cumulative GHG emissions from 2021 to 2050, if it follows the deeper net-zero pathway described

Table 46 | **Annual GHGs Emission for Each Scenario: Well-to-Wheel**



Notes: CO_2-e = Carbon dioxide-equivalent; BAU = Business as usual; BEV = Battery electric vehicle.
Source: Authors.

Table 26 | **Cumulative GHG Emissions and Climate Benefits for Each Scenario (2020–2050)**

SCENARIO	CUMULATIVE GHGs, INSTEAD OF GHGs (million tCO_2e)	CUMULATIVE GHGs SAVING (million tCO_2e)	SOCIAL BENEFITS FROM GHGs SAVING (@3.0% discount rate) (billion HK$ 2020)
BAU	61.6	0	0
BEV	41.4	20.2	11.8
Hydrogen	44.2	17.4	10.3

Notes: GHGs = Greenhouse gases; tCO_2e = Tonnes of carbon dioxide equivalent; BAU = Business as usual; BEV = Battery electric vehicle.
Source: Authors.

in the BEV Scenario. There will be about 61.6 million tonnes of cumulative GHG emissions under the BAU Scenario if Hong Kong takes no action on existing truck fleet decarbonisation. The cumulative GHG saving from the BEV and Hydrogen Scenarios would be 20.2 million tonnes and 17.4 million tonnes, respectively (Figure 46).

Climate benefit

We assumed the social cost of carbon (SCC) for Hong Kong as calculated in the EPS. We also used 3.0 percent as the social discount rate for Hong Kong, which was consistent with the EPS assumption and similar to the one in the United Kingdom (Ricardo Energy and Environment 2019). The present value of the social benefits from cumulative GHG savings for each scenario was then calculated (Table 26). On average, the net-zero scenarios (BEV and Hydrogen) could have around HK$10–12 billion in benefits from GHG savings in the Hong Kong road freight transport sector from 2020 to 2050 (at 2020 value).

Health impact

Road freight is the primary source of transport-related air pollutants in China, in terms of $PM_{2.5}$ and NO_X (Ministry of Ecology and Environment 2021), though the maritime sector is the largest contributor to both air pollutants (Hong Kong

Environmental Protection Department 2021). Therefore, the economic value of health benefits from air pollutant reduction, as co-benefits of net-zero scenarios, could largely outweigh the climate benefit, especially in the short term and on a local scale.

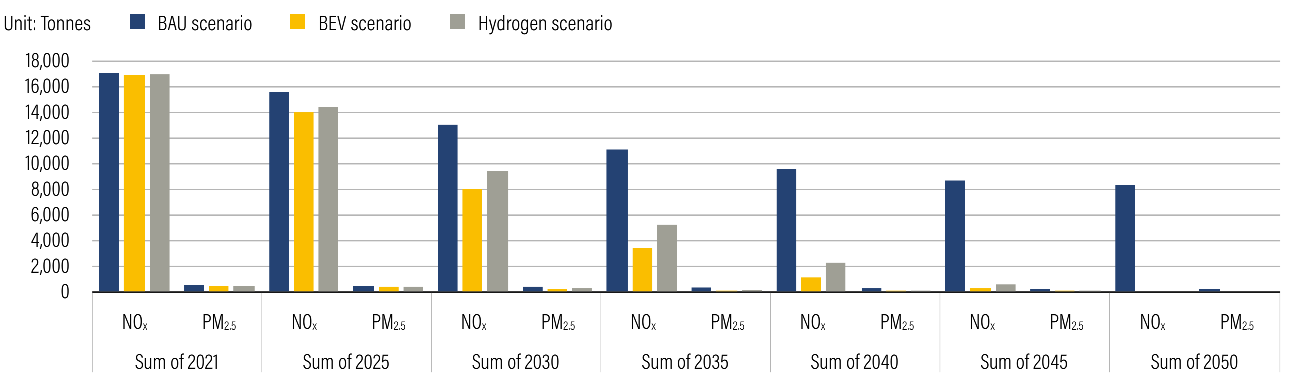
Air pollutants avoided

We chose $PM_{2.5}$ as the key indicator for air pollution in the study since it causes a large public health burden (GBD 2017 Risk Factor Collaborators 2018) and is a main pollutant from trucks. We also presented NO_X in this study, for it is also a main pollutant from trucks and the precursor of ozone (O_3) and $PM_{2.5}$. Figure 47 shows the annual $PM_{2.5}$ and NO_X emissions for the BAU, BEV, and Hydrogen Scenarios. Air pollutants have similar reduction patterns to GHG emissions have. We did not calculate decadal cumulative air pollutants because local air pollutants have a relatively short-term impact compared to CO_2 emissions.

Health benefit

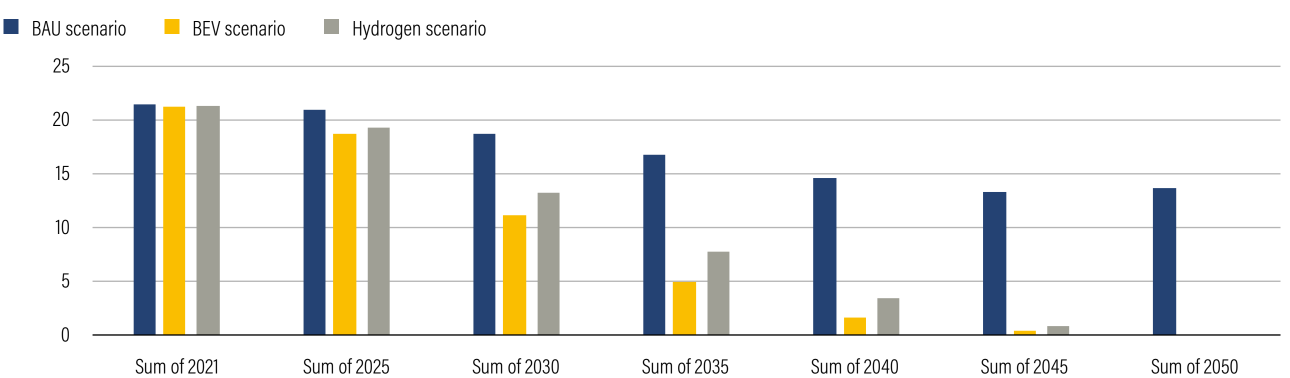
We used premature deaths, in terms of expected changes in all-cause mortality (ACM), to represent the health impact of $PM_{2.5}$. ACM was used as the health outcome since strong evidence shows its association with $PM_{2.5}$ exposure (Héroux et al. 2015). We then calculated premature deaths avoided (lives saved) in the BEV and Hydrogen Scenarios (Figure 48). And finally, we estimated associated economic values for premature deaths avoided by using the localised value of statistical life (VSL) for Hong Kong (Brajer et al. 2006) (Table 27).[25]

Figure 47 | **Annual Air Pollutant Emissions for Each Scenario (Tonnes)**



Notes: BAU = Business as usual; BEV = Battery electric vehicle; NO_x = Nitrogen oxides; $PM_{2.5}$ = Fine particulate matter.
Source: Authors.

Figure 48 | **Number of Annual Premature Deaths for Each Scenario**



Notes: BAU = Business as usual; BEV = Battery electric vehicle.
Source: Authors.

Table 27 | **Cumulative Premature Deaths and Health Benefits for Each Scenario (2020–2050)**

SCENARIO	NUMBER OF CUMULATIVE PREMATURE DEATHS	NUMBER OF CUMULATIVE LIVES SAVED	SOCIAL BENEFITS FROM LIVES SAVED (@ BILLION HK$ 2020)
BAU	526	0	0
BEV	249	277	6.6
Hydrogen	287	239	5.7

Notes: BAU = Business as usual; BEV = Battery electric vehicle.
Source: Authors.

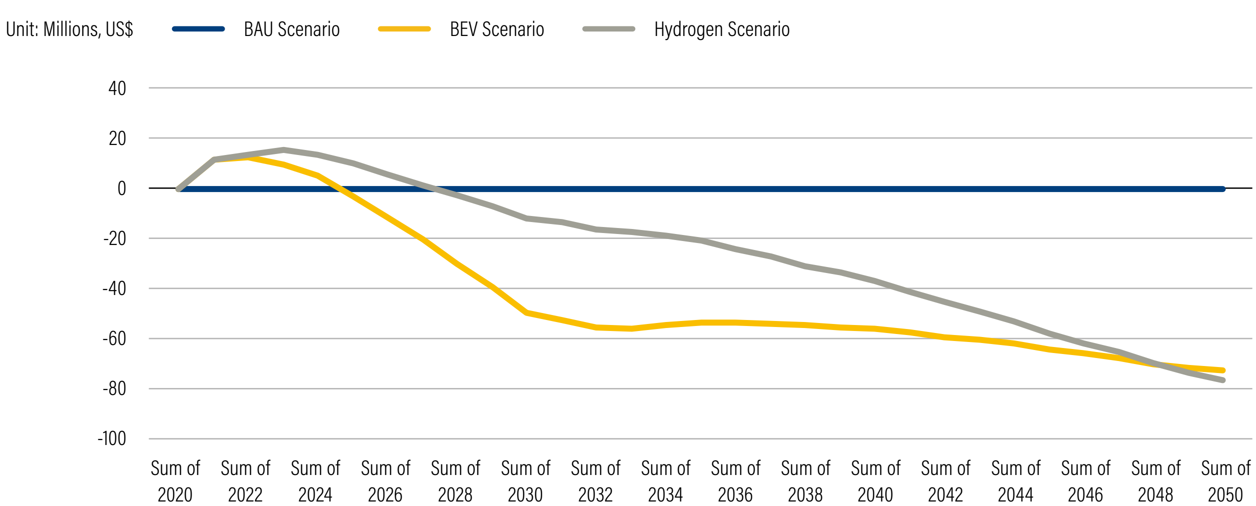
Financial impact

Trucking industry

For a long-term point of view until 2050, introducing ZEVs (either battery electric or hydrogen fuel cell electric vehicles) will bring cost savings from energy and vehicle purchases to the trucking industry. The savings do not depend only on potential electricity and hydrogen price reductions or from ZEVs' price reduction due to the higher learning rate of new technologies, but also on fleet restructuring progress with a radical replacement of ICE vehicles, especially diesel ICEs, as well as the higher energy efficiency of ZEVs.

In terms of the CAPEX (mainly the capital costs of vehicle purchases), the industry will face significant financial pressure for rapid diesel ICE replacements within the next 10 years. The trucking industry will reach a breakeven point around 2025 for the BEV Scenario and around 2028 for the Hydrogen Scenario, in terms of the capital cost of its entire fleet portfolio. In terms of the OPEX (mainly the energy costs), costs are highly relevant to the future price of hydrogen and electricity. And fuel prices depend on the energy and technology roadmap that is selected by the Hong Kong government and energy industry as discussed above (WRI and Civic Exchange 2021). In general, in the Hydrogen Scenario we assumed the trucking industry will reach the fuel cost breakeven point before 2045; however, the BEV Scenario could be much cheaper since the price reduction of hydrogen is difficult to forecast (Figure 49).

Figure 49 | **Cash Flow Difference from BAU Scenario for Vehicles Purchases**



Notes: BAU = Business as usual; BEV = Battery electric vehicle.
Source: Authors.

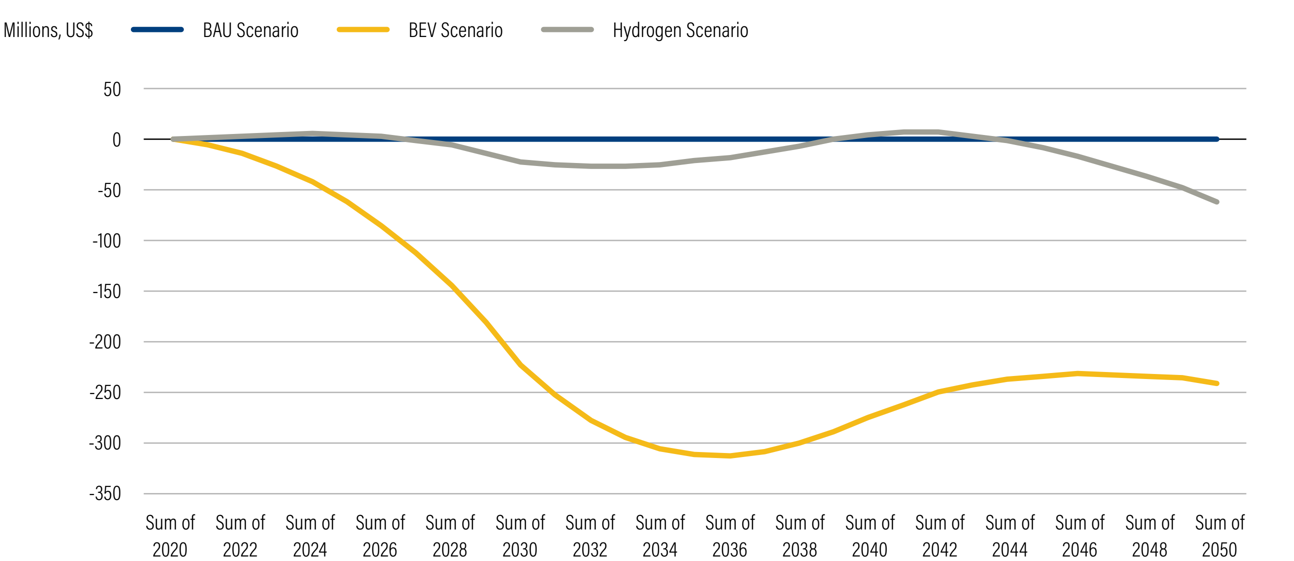
The findings also suggest strong public and private efforts before 2030 or earlier to push the trucking industry towards the pathway of ZEV fleets. For Hong Kong's trucking industry, there would be a roughly US$8–9 million (HK$60–70 million) additional cost burden per year for truck purchases before 2025 or 2028, following a pathway under the BEV Scenario or Hydrogen Scenario, respectively. That will require around US$40–72 million (HK$311–HK$560 million) either leveraged from the NET Fund or from other financial incentives allocated to the trucking industry. There would also be a roughly US$4 million (HK$31 million) additional burden of fuel cost annually under the Hydrogen Scenario, compared with the BEV Scenario, with large fuel savings throughout the decades. Under the BEV Scenario pathway, the trucking industry will enjoy more cost savings and reach an earlier breakeven point (Figure 50). However, it is important to note that the cash flow assessment in this study could have greater uncertainty due to market prices of energy, the technology roadmap, policy, willingness to pay, and many other factors. The cash flows here are just rough estimates and provide decision-makers a general understanding of the financial impacts of different net-zero scenarios.

Infrastructure

Although the requirement for depot chargers is much larger than for hydrogen-refuelling stations, the cash flow for the total infrastructure cost (including CAPEX and OPEX) of depot chargers is lower than for hydrogen-refuelling stations. This is driven by much higher up-front capital expenditure as well as the operation and maintenance costs of hydrogen-refuelling stations compared with depot chargers. Cash flows of the infrastructure CAPEX and OPEX will peak in early 2040s for both net-zero scenarios, with the maximum annual investment of US$100 million (HK$788 million) and US$287 million (HK$2,234 million) in the BEV Scenario and Hydrogen Scenario, respectively (Figure 51).

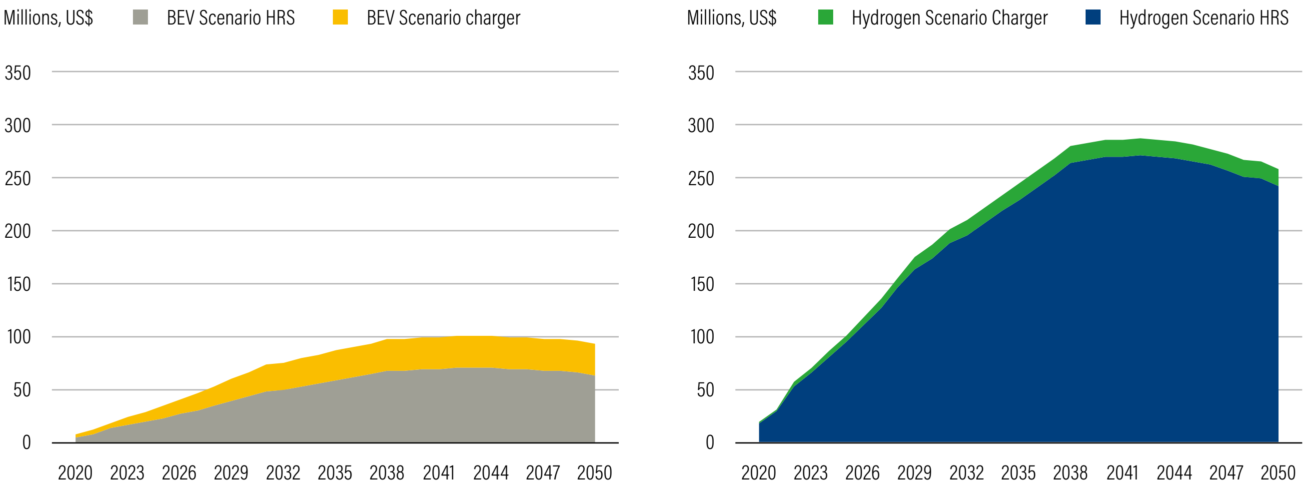
Based on our estimate, NPV for infrastructure costs (CAPEX+OPEX) for the BEV Scenario will be around US$1.3 billion (HK$10 billion), and around US$3.8 billion (HK$30 billion) for the Hydrogen Scenario. However, total infrastructure costs in both net-zero scenarios cannot be internalised by the trucking industry (or infrastructure operator) nor covered solely by subsidies from the government, especially for the hydrogen-refuelling station investment.

Figure 50 | **Cash Flow Difference from BAU Scenario for Energy Costs (Millions, US$)**



Notes: BAU = Business as usual; BEV = Battery electric vehicle.
Source: Authors.

Figure 51 | **Cash Flow of Electricity Charging and Hydrogen-Refuelling Station Infrastructure Costs for Both Net-Zero Scenarios**



Notes: BAU = Business as usual; HRS = Hydrogen-refuelling station; BEV = Battery electric vehicle.
Source: Authors.

Recommendations

- ***ICE restriction roadmap:*** Hong Kong should stop new registrations of ICE light-goods trucks, including plug-in hybrids, by 2030 or earlier and stop new registrations of ICE medium- and heavy-goods trucks, by 2039 or earlier (e.g., trucking manufacturers in the European Union [EU] have agreed on 2040) (ACEA 2020a, 2020b). We encourage the government to upgrade the "Hong Kong Roadmap on Popularisation of Electric Vehicles," and include restriction targets for fuel-propelled ICE trucks based on our recommendations (see analysis from Sections 4.1 and 4.2.1).

- ***Prioritisation of electric trucks:*** Hong Kong should prioritise electric trucks in all sizes, especially LGVs and a certain share of hydrogen fuel cell HGVs. Under the BEV Scenario pathway, the trucking industry will enjoy more cost savings and reach an earlier breakeven point (based on the analysis from Section 4.2.3). It is also important to provide the industry some certainty with respect to the choice of technology (Ricardo Energy and Environment 2019).

- ***Money to boost net-zero trucking industry:*** Hong Kong's government needs to allocate up to HK$311–HK$560 million from the NET Fund or through other financial incentives to help the trucking industry move towards ZEV fleets and amend the negative cash flow in the next decade. That will require about HK$60 million annually before 2025 in the BEV Scenario, and about HK$70 million annually before 2028 in the Hydrogen Scenario. If the trucking industry chooses the Hydrogen Scenario pathway, there will be roughly an annual cost burden of HK$31 million for energy costs, compared with the BEV Scenario, where there would be large fuel savings across the decades (based on analysis from Section 4.2.3).

- ***Financial innovations:*** EV charging infrastructure and hydrogen-refuelling stations need continuous financial support through public-private partnerships. The Hong Kong government should use the NET Fund (and other budgets) to leverage capital from the private sector to co-finance infrastructure for ZEVs. Government and the private sector should build hydrogen-refuelling stations as soon as possible with the help of commercial green loans (zero-carbon loans) (based on analysis from Section 4.2.3).

APPENDIX A. METHODOLOGY TO FORECAST BEV PRICES

The capital cost of BEVs is anticipated to decline rapidly, due to the continuous reduction in battery pack costs, research and development (R&D) expenses, warranty costs (i.e., cost of failure), and improvement in energy efficiency. Further, the study assumes that the capital cost of ICE vehicles will experience a 0.3 percent annual increase, due to tightened fuel economy and exhaust emission standards (Lutsey et al. 2021). The rest of the costs are assumed to be constant.

- **The reduction in battery pack costs** is attributed to two factors—lower unit cost of battery packs and smaller battery capacities due to improved energy intensities of electric vehicles. The decline in unit cost of battery packs is captured by the "learning curve," which describes the reduction in unit production costs of battery packs as a function of accumulated production volumes, approximated by electric vehicles' sales volumes in this study. Using mainland China's battery pack prices and production volumes to perform the regression, the learning coefficient of unit production costs of battery packs is estimated to be -0.26 (learning rate = 17 percent, learning curve no. 2). The projection of future energy intensity improvements is based on the literature.

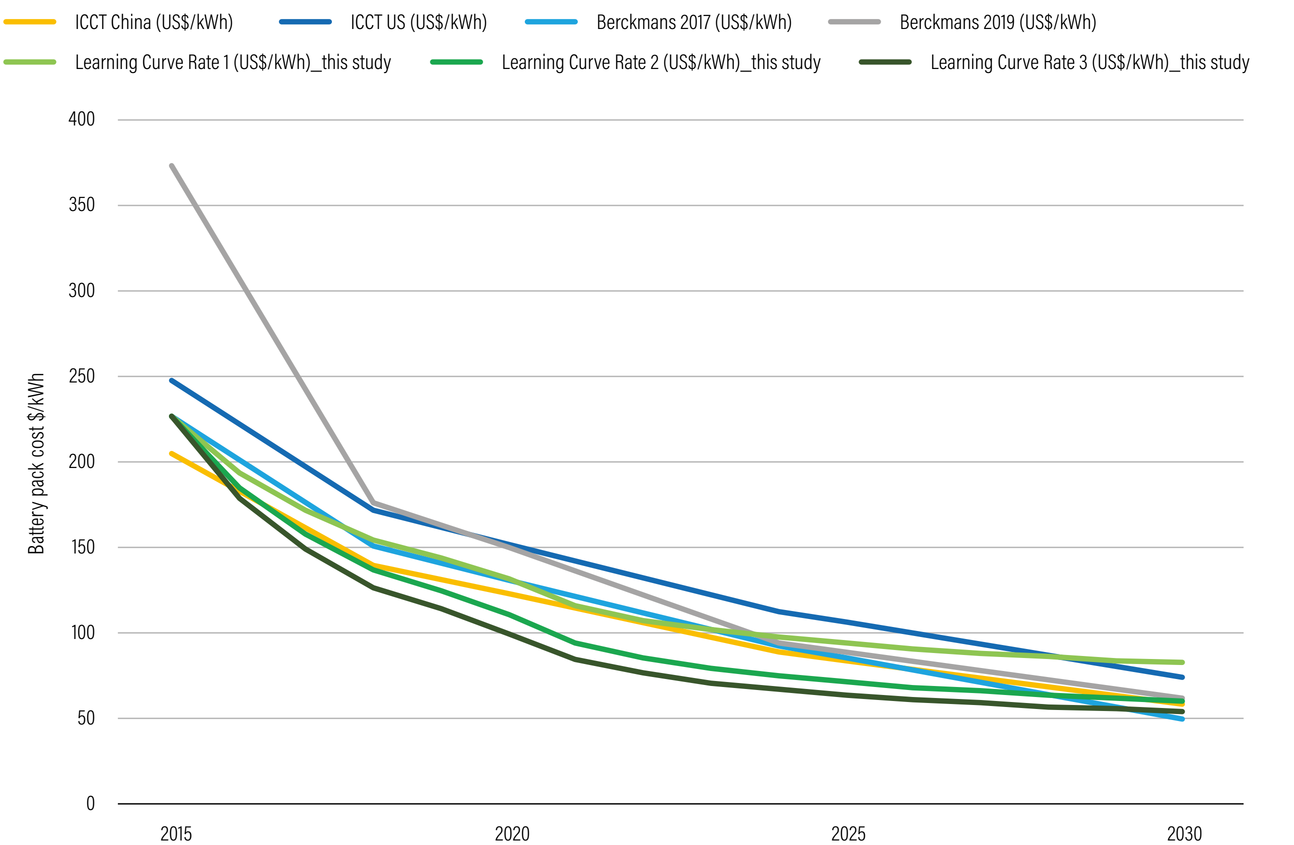
$$Unit\_Cost_{battery\ pack,t} = Unit\_Cost_{battery\ pack,0} \times (V_t/V_0)^b$$

$$Battery\ size_t = Energy\ intensity_t \times Range$$

$$Cost_{battery\ pack,t} = Unit\_Cost_{battery\ pack,t} \times Battery\ size_t$$

where:
b is the learning coefficient.
V_t is the production volume of Year t.
V_0 is the production volume of Year 0 (the base year of the study).

Figure A1 | **Comparisons of the Projected Unit Cost of Battery Packs**



- **Reductions in the indirect costs of R&D expenses and warranty costs.** The reduction in indirect costs such as R&D expenses and warranty costs is reflected by the falling values of indirect cost multipliers over time. Specifically, the indirect costs are inferred based on the linear extrapolation between the short-term and the long-term indirect cost multipliers used by the U.S. Environment Protection Agency (U.S. EPA) (Table 5).

$$Cost_{DMC,t} = Cost_{battery\ pack,t} + Cost_{others}$$

$$Cost_{retail,t} = Cost_{DMC,t} \times ICM_t$$

Table A1 | **Indirect Cost Multiplier for High Technology Complexity**

	SHORT-TERM INDIRECT COST MULTIPLIER	LONG-TERM INDIRECT COST MULTIPLIER
Direct manufacturing cost (DMC), including battery packs	1	1
Production overhead		
Warranty	0.12	0.03
R&D	0.2	0.02
Others (depreciation)	0.1	0.1
Corporate overhead	0.04	0.04
Selling & dealer	0.15	0.07
ICM sum	1.45	1.27

Notes: ICM = Indirect cost multiplier; R&D = Research and development.
Source: U.S. EPA. 2009. Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers.

ABBREVIATIONS

ALF	Annual Licence Fee
BAU	Business as Usual
BEV	Battery Electric Vehicle
CAPEX	Capital Expenditure
DDs	Double-Deckers
EPS	Energy Policy Simulator
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
FRT	First Registration Tax
GHG	Greenhouse Gas
ICE	Internal Combustion Engine
LGV	Light-Goods Vehicle
LPG	Liquefied Petroleum Gas
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
PC	Private Car
PHEV	Plug-in Hybrid Electric Vehicle
PLB	Public Light Bus
PPP	Public-Private Partnership
R&D	Research and Development
SDs	Single-Deckers
SUVs	Sport Utility Vehicles
TCO	Total Cost of Ownership
TDM	Travel Demand Management
TOD	Transit-Oriented Development
WTT	Well-to-Tank
WTW	Well-to-Wheel
ZEV	Zero-Emission Vehicle

ENDNOTES

1. The superlarge double-deckers are designed specifically for meeting Hong Kong's trunk bus services and accommodating the exceptionally high transit demands. The data were from a consultation workshop with bus companies.

2. There are direct and indirect emissions in a city. Direct emissions refer to emissions that occur within the city's geographic boundaries, such as emissions from fossil fuels burned in a power station. Indirect emissions refer to emissions that occur outside the city's geographic boundaries but are caused by activities within the city's geographic boundaries, such as emissions from electricity imported from other cities.

3. The ASI (avoid-shift-improve) framework categorises mitigation policies into three groups: avoiding unnecessary travel demand, shifting trips from high-emission modes to low-emission modes, and improving vehicle technologies.

4. This also includes 2,163 special-purpose vehicles and 6,688 government vehicles, which are not presented here because the GHG emission data do not include these two types.

5. The Hong Kong population was 7,413,070 at the end of June 2021 (which are the latest official statistics). There were 823,518 cars in 2021 (see Table 2). The source of population: https://www.info.gov.hk/gia/general/202202/28/P2022022800462.htm.

6. Calculated by WRI (excluding motorcycles). Raw data are from official statistics.

7. But it is promising to see that some leading franchised bus companies have indicated that their fuel cells are capable of operating for over 30,000 hours (Ballard 2022).

8. As a global port hub, 91 percent of the freight movements in Hong Kong rely on maritime (and coastal) shipping (55 percent) and riverways (36 percent). In comparison, only a small fraction (7 percent) of freight movement relies on roadways.

9. The VSL data are retrieved from "Valuing the Health Impacts of Air Pollution in Hong Kong" (Brajer et al. 2006). The calculation applies to the mid-range VSL and does a currency year adjustment, which is 23.7 million HK$ (at 2020 constant prices).

10. The superlarge double-deckers are designed specifically for meeting Hong Kong's trunk bus services and accommodating the exceptionally high transit demands. https://documents1.worldbank.org/curated/en/572491468764379405/pdf/multi-page.pdf.

11. The superlarge double-deckers are designed specifically for meeting Hong Kong's trunk bus services and accommodating the exceptionally high transit demands.

12. The range of 240–280 km is the labelled range; given e-buses' intensive energy consumptions in Hong Kong, the real-world range could be lower.

13. Increased battery capacities will lead to larger vehicle gross weights that would possibly affect e-buses' fuel efficiency and passenger load losses.

14. Rapid charging speeds would possibly require larger investments on grid capacity expansion and lead to rapid battery degradation.

15. The underlying assumption is that the ranges and refuelling time of hydrogen DDs can meet Hong Kong's bus operational needs without additional hydrogen DDs as backup vehicles.

16. Although the prices of charging equipment will drop over time, for simplicity, the research assumes the capital cost of charging equipment will remain the same.

17. Same as Endnote No.5.

18. Eligibility criteria of "old ICE cars" include: (1) the "old PC" must first have been registered in Hong Kong for at least six years; (2) the vehicle owner participating in the "One-for-One Replacement" Scheme must have been the registered owner of the "old PC" for 18 months or more, without interruption; (3) the "old PC," with or without interruption, must have been licenced for at least 10 months, within the 12 months immediately before its deregistration. https://www.td.gov.hk/en/public_services/licences_and_permits/vehicle_first_registration/new_frt_concessions_for_electric_vehicles_2018/index.html.

19. Although shared home chargers are viable solutions, the study considers private home chargers.

20. This is because (1) residential utility rates are lower, and (2) no charging service surcharges are imposed.

21. For a comparison on global fuel prices, see https://www.bloomberg.com/graphics/gas-prices/#20202:Hong-Kong:USD:g.

22. All the parking spaces should be wired with electrical conduits linked to the building's electrical panels.

23. See the net-zero scenarios in Section 4.1.1.

24. For example, some ICE trucks (especially most LGVs that will be replaced by e-LGVs) could disappear much earlier than 2035 (naturally "banned" by market), even without policy incentives, due to cheaper costs. The Hong Kong government tends to consider hydrogen regardless of its higher cost; it is less realistic to ban all trucks by 2035, especially HGVs. It is also less realistic to set the target for 2045 (e.g., for HGVs), thus causing unfairness in the industry and market.

25. About US$3 million in 2019.

REFERENCES

ACEA (European Automobile Manufacturers' Association). 2020a. "All New Trucks Sold Must Be Fossil Free by 2040, Agree Truck Makers and Climate Researchers." https://www.acea.auto/press-release/all-new-trucks-sold-must-be-fossil-free-by-2040-agree-truck-makers-and-climate-researchers/.

ACEA. 2020b. "The Transportation to Zero-Emission Road Freight Transport." https://www.acea.auto/files/acea-pik-joint-statement-the-transition-to-zero-emission-road-freight-trans.pdf.

Anenberg S., J. Miller, D. Henze, and R. Minjares. 2019. "A Global Snapshot of the Air Pollution–Related Health Impacts of Transportation Sector Emissions in 2010 and 2015." The International Council on Clean Transportation. https://theicct.org/publications/health-impacts-transport-emissions-2010-2015.

ANL (Argonne National Laboratory). 2014. "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model." Lemont, IL: Argonne National Laboratory.

Ballard. 2022. FCmove. https://www.ballard.com/about-ballard/publication_library/product-specification-sheets/fcmovetm-spec-sheet.

Brajer, Victor, Robert W. Mead, and Feng Xiao. 2006. "Valuing the Health Impacts of Air Pollution in Hong Kong." *Journal of Asian Economics* 17 (1): 85–102. doi:10.1016/j.asieco.2005.12.002.

California Air Resources Board. 2019. "Advanced Clean Trucks Total Cost of Ownership Discussion Document Preliminary Draft for Comment." https://ww2.arb.ca.gov/sites/default/files/2020-06/190225tco_ADA.pdf.

China National Energy Administration. 2018. 年度全国电力价格情况监管通报. http://www.nea.gov.cn/2019-11/05/c_138530255.htm.

CLP. 2020. CLP Information Kit. https://www.clp.com.hk/content/dam/clphk/documents/about-clp-site/media-site/resources-site/publications-site/CLP-Information-Kit-English.pdf.

Competition Commission. 2017. "Report on Study into Hong Kong's Auto-Fuel Market." https://www.compcomm.hk/en/media/press/files/Full_Report_Auto_fuel_Market_Study_Report_Eng.pdf.

C40 Knowledge Hub. 2020. "How to Shift Your Bus Fleet to Zero Emission by Procuring Only Electric Buses." C40 Cities Climate Leadership Group, Financing Sustainable Cities Initiative. https://www.c40knowledgehub.org/s/article/How-to-shift-your-bus-fleet-to-zero-emission-by-procuring-only-electric-buses?language=en_US.

de Blas, I., M. Mediavilla, I. Capellán-Pérez, and C. Duce. 2020. "The Limits of Transport Decarbonisation under the Current Growth Paradigm." *Energy Strategy Reviews* 32: 100543.

Deloitte. 2020. 未来移动出行的动力源泉 氢能源及燃料电池交通解决方案. https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/finance/deloitte-cn-fueling-the-future-of-mobility-zh-200101.pdf.

Deliali, A., D. Chhan, J. Oliver, R. Sayess, K. J. Godri Pollitt, and E. Christofa, 2021. "Transitioning to Zero-Emission Bus Fleets: State of Practice of Implementations in the United States." *Transport Reviews* 41 (2): 164–191.

Doyle, D., A. Harris, S. Chege, L. Douglas, J. Early, and R. Best. 2020. "Hydrogen Fuel Cell Buses: Modelling and Analysing Suitability from an Operational and Environmental Perspective," SAE Technical Paper 2020-01-1172. https://doi.org/10.4271/2020-01-1172.

El-Taweel, N. 2020. "Design and Operation Mechanisms of Battery and Hydrogen Based Transport Systems Integrated with Power Grids." PhD diss., York University.

Environmental Protection Department. 2021a. "Greenhouse Gas Emissions in Hong Kong by Sector." https://www.climateready.gov.hk/page.php?id=23&lang=1.

Environmental Protection Department. 2021b. "2019 Hong Kong Emission Inventory Report." https://www.epd.gov.hk/epd/sites/default/files/epd/data/2019%20Emission%20Inventory%20Report_Eng.pdf.

Environmental Protection Department. 2021c. "Problems and Solutions." https://www.epd.gov.hk/epd/english/environmentinhk/air/prob_solutions/new-energy-transport-fund.html.

Eudy, Leslie, and Matthew Post. 2018. "Fuel Cell Buses in U.S. Transit Fleets: Current Status 2018." https://www.nrel.gov/docs/fy19osti/72208.pdf.

European Commission. 2019. Quarterly reports on European gas and electricity markets 2019 Q4. https://ec.europa.eu/energy/data-analysis/market-analysis_en.

EV Power Group. n.d. "Professional EV Charging Services in Residential Buildings." https://www.hkelectric.com/zh/ElectricLiving/ElectricVehicles/Documents/%E6%96%BC%E5%B1%8B%E8%8B%91%E5%A4%A7%E5%BB%88%E5%85%A7%E6%8F%90%E4%BE%9B%E5%B0%88%E6%A5%AD%E7%9A%84%E9%9B%BB%E5%8B%95%E8%BB%8A%E5%85%85%E9%9B%BB%E6%9C%8D%E5%8B%99.pdf.

EV-Volumes. 2021. "Global EV Sales for 2021 H1." https://www.ev-volumes.com/.

Fraunhofer. 2020. "Opportunities and Challenges When Importing Green Hydrogen and Synthesis Products." https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cce/2020/policy_brief_hydrogen.pdf.

Fridstrøm, L. 2021. "The Norwegian Vehicle Electrification Policy and Its Implicit Price of Carbon." *Sustainability* 13 (3): 1346.

Gallet, M., T. Massier, and T. Hamacher. 2018. "Estimation of the Energy Demand of Electric Buses Based on Real-World Data for Large-Scale Public Transport Networks." *Applied Energy* 230: 344–56.

GBD 2017 Risk Factor Collaborators. 2018. "Global, Regional, and National Comparative Risk Assessment of 84 Behavioural, Environmental and Occupational, and Metabolic Risks or Clusters of Risks for 195 Countries and Territories, 1990–2017: A Systematic Analysis for the Global Burden of Disease Study 2017." *Lancet* (London) 392 (10159): 1923–94. https://doi.org/10.1016/S0140-6736(18)32225-6.

Government of Hong Kong. 2019. "LCQ12: Promoting Use of Biodiesel." https://www.info.gov.hk/gia/general/201906/05/P2019060500435.htm?fontSizefontSise=2.

Government of Hong Kong. 2021. "Hong Kong's Climate Action Plan 2050." https://www.climateready.gov.hk/files/pdf/CAP2050_booklet_en.pdf.

Government of Hong Kong. 2022. "The 2022–2023 Budget." https://www.budget.gov.hk/2022/eng/budget71.html.

Government of the Hong Kong Special Administrative Region. 2019. "LCQ21: Parking Spaces for Private Cars." https://www.info.gov.hk/gia/general/201911/27/P2019112700349.htm. Accessed December 7, 2021.

Government of the Hong Kong Special Administrative Region. 2021. "LCQ5: Promoting Use of Electric Public Light Buses." https://www.info.gov.hk/gia/general/202105/26/P2021052600589.htm. Accessed December 7, 2021.

GovHK. 2021. "Air Quality in Hong Kong." https://www.gov.hk/en/residents/environment/air/airquality.htm.

Hardman, Scott, Alan Jenn, Gil Tal, and John Axsen. 2018. "A Review of Consumer Preferences of and Interactions with Electric Vehicle Charging Infrastructure." https://phev.ucdavis.edu/wp-content/uploads/a-review-of-consumer-preferences-and-interactions-with-electric-vehicle-charging-infrastructure.pdf.

Héroux, Marie Eve, H. Ross Anderson, Richard Atkinson, Bert Brunekreef, Aaron Cohen, Francesco Forastiere, Fintan Hurley, et al. 2015. "Quantifying the Health Impacts of Ambient Air Pollutants: Recommendations of a WHO/Europe Project." *International Journal of Public Health* 60 (5): 619–27. https://doi.org/10.1007/s00038-015-0690-y.

HK01. 2019. "Electric Vehicle Charging Has a Market Fork Power Ratio of About 20 Percent of the Monthly Oil Input." https://www.hk01.com/%E7%A4%BE%E5%8D%80%E5%B0%88%E9%A1%8C/305684/%E9%9B%BB%E5%8B%95%E8%BB%8A-%E6%94%B6%E8%B2%BB%E5%85%85%E9%9B%BB%E6%9C%89%E5%B8%82%E5%A0%B4-%E5%8F%89%E9%9B%BB%E6%AF%94%E5%85%A5%E6%B2%B9%E6%9C%88%E8%A8%88%E7%B4%84%E5%B9%B3%E5%85%A9%E6%88%90.

Hong Kong e-Legislation. 2012. "Dangerous Goods (Application and Exemption) Regulation 2012." https://www.elegislation.gov.hk/hk/cap295E.

Hong Kong Environment Bureau. 2021. "Hong Kong Roadmap on Popularisation of Electric Vehicles." https://www.enb.gov.hk/sites/default/files/pdf/EV_roadmap_eng.pdf.

Hong Kong Environmental Protection Department. 2020. New Energy Transport Fund. https://www.epd.gov.hk/epd/english/environmentinhk/air/prob_solutions/new-energy-transport-fund.html.

Hong Kong Environmental Protection Department. 2021." 2019 Hong Kong Emission Inventory Report." https://www.epd.gov.hk/epd/sites/default/files/epd/data/2019%20Emission%20Inventory%20Report_Eng.pdf.

Hong Kong Environmental Protection Department. 2022a. "Phasing Out Euro IV Diesel Commercial Vehicles—Ex-Gratia Payment Scheme." https://www.epd.gov.hk/epd/english/environmentinhk/air/prob_solutions/Phasing_out_euro_iv_comm_veh.html.

Hong Kong Environmental Protection Department. 2022b. "Promotion of Electric Vehicles in Hong Kong." https://www.epd.gov.hk/epd/english/environmentinhk/air/prob_solutions/promotion_ev.html.

Hong Kong Extras. n.d. "Bus Services in Hong Kong." https://www.hongkongextras.com/busservices.html.

Hong Kong Legislative Council. 2019. "Promoting the Use of Electric Vehicles." https://www.legco.gov.hk/yr18-19/english/panels/ea/papers/ea20190128cb1-487-3-e.pdf.

Hong Kong Legislative Council. 2020. "Transportation Demand Management Strategies in Seoul." https://www.legco.gov.hk/research-publications/english/essentials-2021ise09-transportation-demand-management-strategies-in-seoul.htm.

Hong Kong Legislative Council. 2021. "Promoting the Use of Electric Public Light Buses." https://www.info.gov.hk/gia/general/202105/26/P2021052600589.htm.

Hong Kong Transport Advisory Committee. 2014. "Report on Study of Road Traffic Congestion in Hong Kong." https://www.tlb.gov.hk/eng/boards/transport/land/Full_Eng_C_cover.pdf.

Hope-Morley, A., B. Madden, and E. Boyd. 2019, "New Bus ReFuelling for European Hydrogen Bus Depots." http://newbusfuel.eu/wp-content/uploads/2019/03/NewBusFuel_D3.8_Business-cases-to-support-FC-bus-commercialisation.pdf.

ICCT (The International Council on Clean Transportation). 2019. "Estimating the Infrastructure Needs and Costs for the Launch of Zero-Emission Trucks." https://theicct.org/sites/default/files/publications/ICCT_EV_HDVs_Infrastructure_20190809.pdf.

ICCT. 2020a. "Electric Vehicle Capitals: Cities Aim for All-Electric Mobility." https://theicct.org/sites/default/files/publications/ev-capitals-update-sept2020.pdf.

ICCT. 2020b. "Growing Momentum: Global Overview of Government Targets for Phasing Out Sales of New Internal Combustion Engine Vehicles." https://theicct.org/blog/staff/global-ice-phaseout-nov2020.

ICCT. 2021. "Total Cost of Ownership for Heavy Trucks in China: Battery-Electric, Fuel Cell Electric, and Diesel Trucks." https://theicct.org/sites/default/files/publications/ze-hdvs-china-tco-EN-nov21.pdf.

Interagency Working Group on Social Cost of Carbon, U.S. Government. 2015. "The Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis." https://www.epa.gov/sites/default/files/2016-12/documents/sc_co2_tsd_august_2016.pdf.

IPA (Interpretative Phenomenological Analysis). 2015. "Review of Electricity Price Setting Mechanisms" (final report). https://www.enb.gov.hk/sites/default/files/en/node2213/IPA_Review_of_Electricity_Price_Setting_Mechanisms.pdf.

Isenstadt, Aaron, and Nic Lutsey. 2017. "Developing Hydrogen Fueling Infrastructure for Fuel Cell Vehicles: A Status Update." https://theicct.org/publication/developing-hydrogen-fueling-infrastructure-for-fuel-cell-vehicles-a-status-update/.

Jin, Lingzhi, and Peter Slowik. 2017. "Literature Review of Electric Vehicle Consumer Awareness and Outreach Activities." https://theicct.org/sites/default/files/publications/Consumer-EV-Awareness_ICCT_Working-Paper_23032017_vF.pdf.

Kao, Ernest. 2016. "Hong Kong's Hybrid Electric Buses Found to Use More Fuel than Normal Ones." *South China Morning Post*, March 30. https://www.scmp.com/news/hong-kong/health-environment/article/1932126/hong-kongs-hybrid-electric-buses-found-use-more.

Kwiksure. 2021. "Electric Car Chargers in Hong Kong: Types, Locations, and Installation Costs." https://kwiksure.com/blog/ev-charging-installation-hk/.

Lo Ka Wah, Joe, Elvin Ng Cheuk Yin, Chan Ka Chun, and R. Chong Ka Ho. 2020. "Final Report on Trial of Hybrid Light Bus for Green Public Light Bus Service." https://www.epd.gov.hk/epd/sites/default/files/epd/english/environmentinhk/air/prob_solutions/files/178NamKee_ES_FR_Eng.pdf.

Lustey, Nic, and Michael Nicholas. 2019. "Update on Electric Vehicles Costs in the United States through 2030." https://theicct.org/publication/update-on-electric-vehicle-costs-in-the-united-states-through-2030/.

Lutsey, N., H. Cui, and R. Yu. 2021. "Evaluating Electric Vehicle Costs and Benefits in China in the 2020–2035 Time Frame." https://theicct.org/publication/evaluating-electric-vehicle-costs-and-benefits-in-china-in-the-2020-2035-time-frame/.

Marcinkoski, J., R. Vijayagopal, J. Adams, B. James, J. Kopasz, and R. Ahluwalia. 2019. "Hydrogen Class 8 Long Haul Truck Targets." Washington, DC: U.S. Department of Energy. https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf.

Mao, S., H. Basma, P.-L. Ragon, Y. Zhou, and F. Rodríguez. 2021. "Total Cost of Ownership for Heavy Trucks in China: Battery Electric, Fuel Cell Electric and Diesel Trucks." White Paper. Beijing: International Council on Clean Transportation (ICCT).

Ministry of Ecology and Environment of the People's Republic of China. 2021. "China Mobile Source Environmental Management Annual Report." https://www.mee.gov.cn/hjzl/sthjzk/ydyhjgl/202109/W020210910400449015882.pdf.

MIIT (Ministry of Industry and Information Technology of the People's Republic of China). 2021. "MIIT Notice: New Energy Vehicle Models Entitled to Vehicle Purchase Tax Exemption."

NREL (National Renewable Energy Laboratory). 2021. "Fuel Cell Buses in U.S. Transit Fleets: Current Status 2020." https://www.nrel.gov/docs/fy21osti/75583.pdf.

Ockenden, James. 2020. "Hybrid Minibus Emits 10 Times the Pollution of Old Bus, Costs Double to Run." *Transit Jam*, August 18. https://transitjam.com/2020/08/18/hybrid-minibus-emits-10-times-the-pollution-of-old-bus-costs-double-to-run/.

Phadke A., A. Khandekar, N. Abhyankar, D. Wooley, and D. Rajagopal. 2021. "Why Regional and Long-Haul Trucks Are Primed for Electrification Now." Berkeley, CA: Lawrence Berkeley National Laboratory Report.

Quarles, N., K. M. Kockelman, and M. Mohamed. 2020. "Costs and Benefits of Electrifying and Automating Bus Transit Fleets." *Sustainability* 12 (10): 3977.

Ricardo Energy and Environment. 2019. "Zero Emission HGV Infrastructure Requirements." Final report for Committee on Climate Change. ED12387. https://www.theccc.org.uk/wp-content/uploads/2019/05/Zero-Emission-HGV-Infrastructure-Requirements-Ricardo-Energy-and-Environment.pdf.

Royal Academy of Engineering. 2017. "Sustainability of Liquid Biofuels." https://www.raeng.org.uk/publications/reports/biofuels.

SAE International. 2020. "Hydrogen Fuel Cell Buses: Modelling and Analysing Suitability from an Operational and Environmental Perspective." https://saemobilus.sae.org/content/2020-01-1172/#authors.

Suzuki, H., J. Murakami, Y.-H. Hong, and B. Tamayose. 2015. *Financing Transit-Oriented Development with Land Values: Adapting Land Value Capture in Developing Countries.* Washington, DC: World Bank. documents.worldbank.org/en/publication/documents-reports/documentdetail/468551468165570019/financing-transit-oriented-development-with-land-values-adapting-land-value-capture-in-developing-countires.

TIC (Truck Industry Council). 2019. "Modernising the Australian Truck Fleet: Budget Submission 2019/20." https://treasury.gov.au/sites/default/files/2019-03/360985-Truck-Industry-Council.pdf.

TradingEconomics. 2019. "Gasoline Prices in 2019." https://tradingeconomics.com/country-list/gasoline-prices.

TradingEconomics. 2021. "Hong Kong Gasoline Prices in 2021." https://tradingeconomics.com/hong-kong/gasoline-prices.

Transport Department. 2014. "Travel Characteristics Survey 2011." Final report. https://www.td.gov.hk/filemanager/en/content_4652/tcs2011_eng.pdf.

Transport Department. 2016–2021. "Monthly Traffic and Transport Digest," Table 4.4. https://www.td.gov.hk/filemanager/en/content_5052/table44.pdf.

Transport Department. 2019. "Monthly Traffic and Transport Digest," Table 4.1. https://www.td.gov.hk/filemanager/en/content_4883/table41a.pdf.

Transport Department. 2020. "Annual Transport Digest 2020." Section 5: Public Transport. https://www.td.gov.hk/mini_site/atd/2020/en/section5_5.html.

Transport Department. 2021a. "Fact sheet on Transport." https://www.td.gov.hk/en/publications_and_press_releases/publications/free_publications/fact_sheet_on_transport/index.html.

Transport Department. 2021b. "Fees of Vehicle and Driving Licence Services—Vehicle Licence." https://www.td.gov.hk/filemanager/common/td341_02_2021.pdf.

Transport Department. 2021c. "First Registration Tax Concessions for Electric Vehicles." https://www.td.gov.hk/en/public_services/licences_and_permits/vehicle_first_registration/new_frt_concessions_for_electric_vehicles_2018/index.html.

Transport Department. n.d. (a). "ERP in Hong Kong." https://www.td.gov.hk/mini_site/erpgovhk/erp_in_hk.html#year_anchor_25.

Transport Department. n.d. (b). "Promotion of Electric Vehicle—EV Models in Hong Kong." https://www.epd.gov.hk/epd/english/environmentinhk/air/prob_solutions/promotion_ev.html#Model.

Transport Department. n.d. (c). "Vehicles Registration and Licensing." https://www.td.gov.hk/en/transport_in_hong_kong/transport_figures/vehicle_registration_and_licensing/index.html.

T&E (Transport & Environment). 2020. "Recharge EU: How Many Charge Points Will Europe and Its Member States Need in the 2020s." electrive.com, September 1.

Transport and Housing Bureau. 2017. "Public Transport Strategy Study." https://www.td.gov.hk/filemanager/en/publication/ptss_final_report_eng.pdf.

Ueckerdt, Falko, Christian Bauer, Alois Dirnaichner, Jordan Everall, Romain Sacchi, and Gunnar Luderer. 2021. "Potential and Risks of Hydrogen-Based E-Fuels in Climate Change Mitigation." https://www.nature.com/articles/s41558-021-01032-7. Accessed December 7, 2021.

UC (University of California), Berkeley. 2021. "Plummeting Costs and Dramatic Improvements in Batteries Can Accelerate Our Clean Transportation Future." https://www.2035report.com/transportation/transportation-new/wp-content/uploads/2020/05/2035_Transportation_Report.pdf?hsCtaTracking=544e8e73-752a-40ee-b3a5-90e28d5f2e18%7C81c0077a-d01d-45b9-a338-fcaef78a20e7.

U.S. Department of Energy. 2020. "Compressed Gas Storage for Medium and Heavy Duty Transportation Workshop." https://www.energy.gov/sites/prod/files/2020/02/f71/fcto-compressed-gas-storage-workshop-2020-adams.pdf.

U.S. Department of Energy. 2021. "DOE Hydrogen Program Record." https://www.hydrogen.energy.gov/pdfs/21002-hydrogen-fueling-station-cost.pdf.

U.S. EIA (U.S. Energy Information Administration). 2019. *Electric Power Annual 2019*. Table 2.10: Average Price of Electricity to Ultimate Customers by End-Use Sector, by State." https://www.eia.gov/electricity/annual/.

U.S. Government, Interagency Working Group on Social Cost of Carbon. 2015. "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis." Washington, DC. https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf.

Wager, Guido, Jonathan Whale, and Thomas Braunl. 2016. "Driving Electric Vehicles at Highway Speeds: The Effect of Higher Driving Speeds on Energy Consumption and Driving Range for Electric Vehicles in Australia." *Renewable and Sustainable Energy Reviews* 63. https://www.sciencedirect.com/science/article/abs/pii/S1364032116301721.

WikiRoutes. 2017. "Bus Route 962X on the Map of Hong Kong." https://wikiroutes.info/en/hong-kong?routes=39934.

World Bank. 2020. "Lessons from Chile's Experience with E-mobility: The Integration of E-buses in Santiago." Washington, DC.

World Bank. 2021. "Electrification of Public Transport: A Case Study of the Shenzhen Bus Group. Mobility and Transport Connectivity." Washington, DC. https://openknowledge.worldbank.org/handle/10986/35935 Licence: CC BY 3.0 IGO.

WRI (World Resources Institute) and Civic Exchange. 2019. "Hong Kong Energy Policy Simulator: Methods, Data, and Scenario Results for 2050." Washington, DC.

WRI and Civic Exchange. 2020. "Towards a Better Hong Kong: Pathways to Net Zero Carbon Emissions by 2050." WRI: Beijing.

WRI, Civic Exchange, and Energy Innovation. 2020. "Hong Kong Energy Policy Simulator: Methods, Data, and Scenario Results for 2050." Beijing: WRI. https://hongkong.energypolicy.solutions/.

WRI and Civic Exchange. 2021. "Powering a Carbon-Free Hong Kong: Pathways towards a Net-Zero Emissions Power System for Hong Kong." Beijing: WRI.

Ziegler, M., and J. Trancik. 2021. "Re-examining Rates of Lithium-Ion Battery Technology Improvement and Cost Decline." *Energy and Environmental Science* 4. https://pubs.rsc.org/en/content/articlelanding/2021/EE/D0EE02681F.

21st Century Business Herald. 2021. 新能源车销量四大城市占比1/4：哑铃型市场结构亟需转型 https://m.21jingji.com/article/20211101/herald/054a081616beba06087355886938d21f_zaker.html. Accessed December 7.

ABOUT THE AUTHORS

Lulu Xue is a research associate with WRI. Contact: lxue@wri.org

Su Song is a research associate with WRI. Contact: ssong@wri.org

Wenyi Xi is a research associate with WRI. Contact: wenyi.xi@wri.org

Xiaoqian Jiang is a research associate with WRI.
Contact: xqjiang@wri.org

Lawrence Iu is Executive Director of Civic Exchange.
Contact: liu@civic-exchange.org

Simran Sawhney is a former research analyst with Civic Exchange.

ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our Challenge
Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision
We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach
COUNT IT
We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT
We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure that our outcomes will be bold and enduring.

SCALE IT
We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

ABOUT CIVIC EXCHANGE

Civic Exchange is an independent Hong Kong public-policy think tank established in 2000 with a vision to shape a livable and sustainable Hong Kong. Its mission is to engage society and influence public policy through in-depth research, dialogue, and the development of practical solutions. With research covering four areas—environmental, economic, social, and governance—Civic Exchange has been ranked among the top 50 environmental think tanks in the world by the Lauder Institute at the University of Pennsylvania since 2011.

ABOUT HONG KONG 2050 IS NOW

"Hong Kong 2050 Is Now" galvanises collective action in science, media, business and policy towards a carbon-neutral Hong Kong by 2050. This initiative of Civic Exchange, World Resources Institute, and the ADM Capital Foundation aims to build a broad-based collective platform for driving action in Hong Kong in response to the 2018 Intergovernmental Panel on Climate Change (IPCC) report on Global Warming of 1.5°C. According to that report, without urgent, large-scale action, global warming is likely to reach 1.5°C above pre-industrial levels, with potentially significant and dangerous consequences for the world. We believe that a decarbonised city is people-centric, more livable, healthier and successful. That's what we want for Hong Kong.

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世界资源研究所
WORLD RESOURCES INSTITUTE

WRI CHINA
RM K-M, 7/F, TOWER A, THE EAST GATE PLAZA,
#9 DONGZHONG STREET, BEIJING, CHINA, 100027
PHONE: 86 10 6416 5697
FAX:86 10 6416 7567
WWW.WRI.ORG.CN