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DECARBONISATION PATHWAYS AND HOW FINANCE CAN ACCELERATE THE BUSINESS TRANSITION TO A LOW-CARBON ECONOMY IN THE GUANGDONG–HONG KONG–MACAO GREATER BAY AREA

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EXECUTIVE SUMMARY

HIGHLIGHTS

- The Guangdong–Hong Kong–Macao Greater Bay Area (GBA) is expected to lead by example in peaking carbon emissions and achieving carbon neutrality, as well as in creating a regional benchmark for green and low-carbon development. This is achievable.

- Clean electricity will contribute to the largest emissions reductions in the long-term for the key energy-consumption sectors of manufacturing, road transport, and buildings. In the medium term, energy efficiency improvement and cleaner energies in manufacturing and buildings, as well as a mode shift in transport, will be the key to decarbonisation.

- Our analysis estimates that the GBA needs approximately US$1.84 trillion to achieve carbon neutrality by 2060, equivalent to around 1 percent of cumulative gross domestic product (GDP) during the 2020–60 period. We also estimate that $200 billion to $700 billion will be needed for road transport, with $150 billion to $300 billion required for the buildings sector.

- We recommend financial practices to accelerate the transition: establishing a cross-regional agency coordination mechanism in the GBA; facilitating interoperability of transition finance taxonomies and information disclosure standards on the Chinese mainland and in Hong Kong, as well as internationally; encouraging financial institutes and enterprises to set net-zero targets; facilitating development of regional carbon markets; developing a transition-related financial toolbox to scale up financing; and developing sector-specific financial solutions.

About this report

The need for action is urgent. Greenhouse gas (GHG) emissions rose over the past decade, reaching 59 gigatonnes of carbon dioxide equivalent ($GtCO_2e$) in 2019—roughly 12 percent higher than emissions in 2010 (IPCC 2022). In its 2023 synthesis report, the Intergovernmental Panel on Climate Change (IPCC) warned that 'rapid and deep' systemic changes are needed to limit global warming to the Paris Agreement's 1.5-degree Celsius (1.5°C) goal, and GHG emissions need to peak before 2025, at the latest, and then reach net-zero CO_2 emissions in the early 2050s (IPCC 2023). As the world's largest CO_2 emitter since 2005 (Climate Watch 2022), contributing 28 percent of the planet's CO_2 emissions, China is critical to carbon emissions reduction.

The GBA is expected to lead by example in peaking carbon emissions and achieving carbon neutrality earlier than the national '30-60' goals—China's national goal of peaking its carbon emissions by 2030 and achieving carbon neutrality by 2060, as well as in creating a regional benchmark for green and low-carbon development.

This report aims to connect decarbonisation solutions with the finance required to accelerate the net-zero transition in the GBA. It first applies a top-down approach to predict macro pathways for the whole GBA, then uses a bottom-up approach to analyse specific decarbonisation pathways and solutions for the key energy-consuming sectors—manufacturing, road transport and buildings—to highlight the actions most needed to achieve the 30-60 goal, as well as more ambitious goals to peak emissions and achieve carbon neutrality earlier. Based on the above decarbonisation pathways, this report estimates how much investment will be required and how challenges can be solved to ensure the finance needed to accelerate businesses' transition to carbon neutrality.

Overall and sectoral transition pathways

The GBA is one of the engines driving China's economic progress and a leader in the country's socioeconomic and green development. Can it lead by peaking its carbon emissions and achieving carbon neutrality earlier than the national 30-60 goals? This study estimates the GBA's carbon emissions from 2020 to 2060 using a top-down approach based on projected GDP and carbon intensity, and sets up three scenarios: the Baseline Scenario, the 30-60 Scenario and the 25-50 Scenario. Because the peak year and carbon

neutrality year vary from sector to sector, we use *Enhanced Policy Scenario* and *Zero-Emission Scenario* in the sectoral analysis as equivalents for the 30-60 Scenario and 25-50 Scenario in the overall GBA analysis.

Our analysis shows that ambitious actions are needed for the GBA's carbon emissions to peak earlier and achieve carbon neutrality. The Baseline Scenario answers the question of whether and when carbon emissions will peak and carbon neutrality will be achieved if no stronger measures are taken. The 30-60 Scenario and 25-50 Scenario predetermine the peaking year and carbon neutrality year as assumptions, and the analysis answers the question of how fast emissions will need to be reduced to be consistent with the national 30-60 goals, and how much more sharply they need to be cut to peak by 2025 and achieve carbon neutrality around 2050.

- As the 14th Five-Year Plan (FYP) includes no new national or subnational targets for carbon intensity, under the Baseline Scenario we assume that in future five-year periods the rate of each city's carbon-intensity reduction remains what it was in the 13th FYP. Under this scenario, our results show that the GBA will only reach its peak emissions in 2030, and a remaining 355 million tonnes of CO_2 emissions will need to be offset in 2060 (Figure ES-1), which seems beyond what is achievable.

- Under the 30-60 Scenario, to be consistent with the national 30-60 goals, carbon emissions in the GBA need to peak by 2030; carbon-intensity reductions equal to those of the Baseline Scenario can enable this. Emissions when peaking are 480 million tonnes of CO_2. But more ambitious actions need to start from 2030 to enable a sufficiently sharp emissions decline to achieve carbon neutrality by 2060. If carbon neutrality means a 90 percent emissions reduction and a 10 percent offset by forest sink and negative emissions technologies such as carbon capture, utilisation and storage (CCUS), as many other countries set their targets, an emissions cap goal will be needed beginning in 2030 and annual emissions reductions during the 2030–60 period will need to be around 7.5 percent.

- Under the 25-50 Scenario, if carbon intensity can be reduced by 24 percent in the 14th FYP, the GBA can peak its emissions by 2025. Emissions when peaking will be 467 million tonnes of CO_2. This will require much stricter

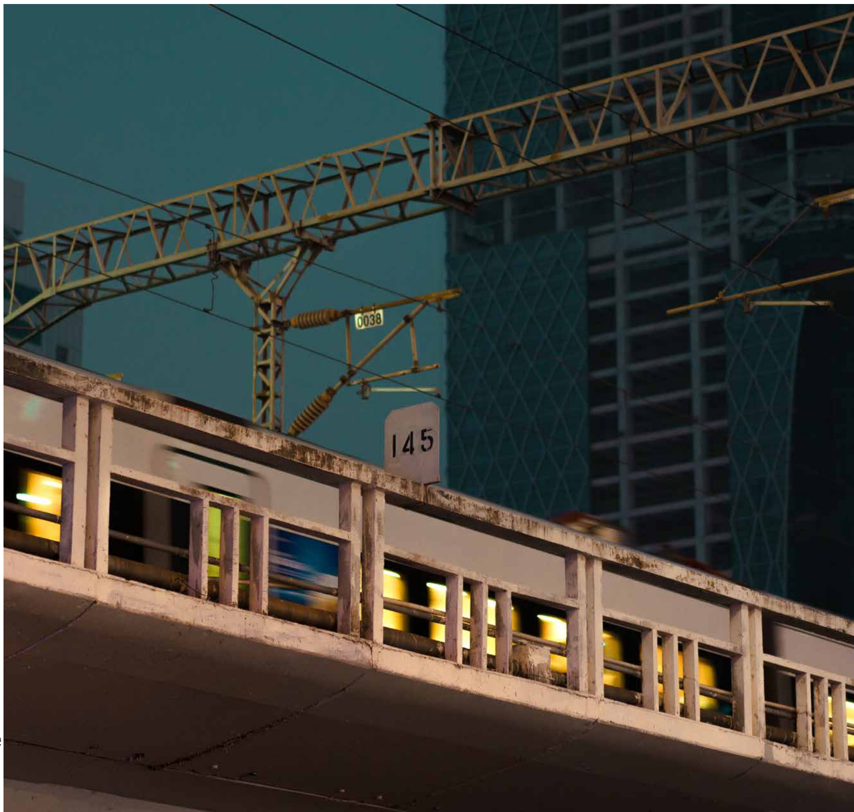
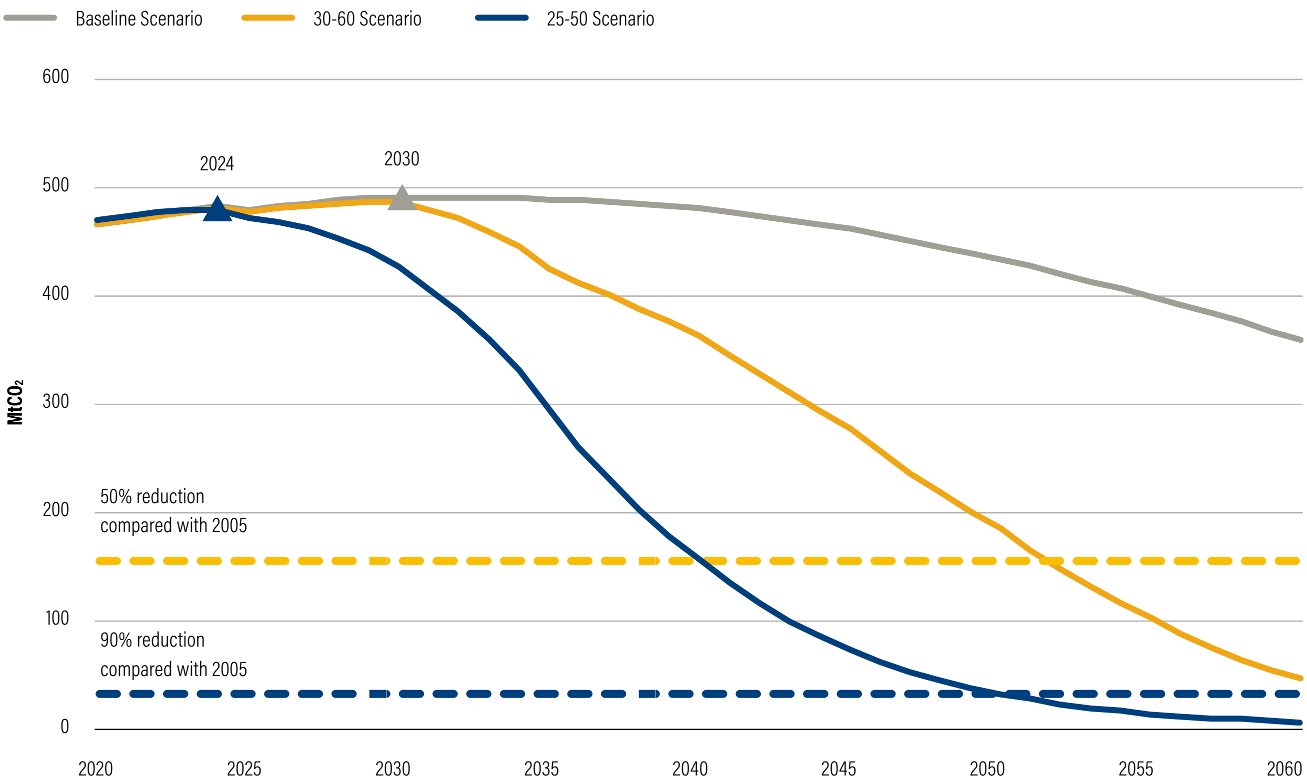


Figure ES-1 | **Scenario analysis of carbon emissions in the GBA towards 2060**



Note: $MtCO_2$ = million tonnes of carbon dioxide.
Source: Project team.

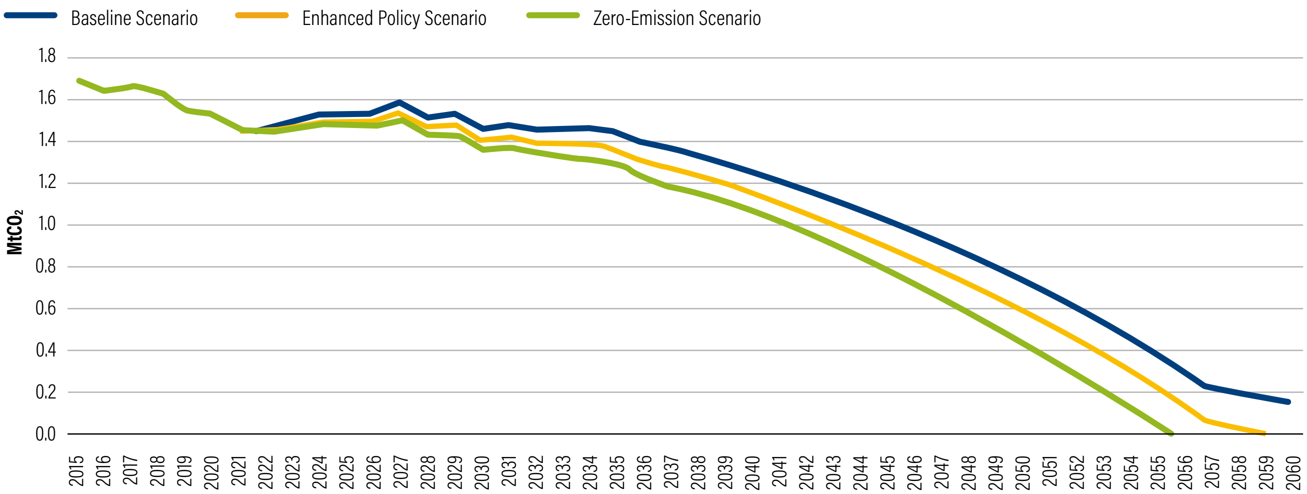
policies and measures because the target is higher than what was achieved in the 13th FYP in Guangdong—a 22.35 percent carbon intensity reduction, and emissions reductions from some measures such as energy efficiency will get harder. The annual rate of emissions reduction during the 2025–50 period should be around 16 percent if we want to achieve carbon neutrality around 2050. This scenario is consistent with advice in the newest IPCC report to ensure attainment of the Paris Agreement's 1.5°C goal.

How can the 30-60 or even the 25-50 Scenario pathway be achieved? The GBA's energy-related carbon emissions come mainly from three key sectors: manufacturing, building operations and road transport, which accounted for 32 percent, 31 percent and 20 percent of emissions, respectively, in 2020. This study provides in-depth analysis for the three sectors. A bottom-up approach was applied to model different scenarios for each sector.

Manufacturing

The GBA's manufacturing is expected to peak its carbon emissions during the 15th FYP (2025–30) and to achieve carbon neutrality around 2055–60. 'New Major Projects' (projects with energy consumption greater than 10,000 tonnes of coal equivalent and approved by the Energy Bureau of Guangdong Province before 2021) would lead to increased carbon emissions in the Pearl River Delta during the 2020–30 decade. But different interventions in energy intensity (energy consumption per unit of industrial value added), phasing down fossil fuels use, energy conservation technologies, and decarbonised power and heating systems will result in emissions reductions. Emissions peak values are 154.2 million tonnes for the Baseline Scenario, 150 million tonnes for the Enhanced Policy Scenario and 147.2 million tonnes for the Zero-Emission Scenario. However, the Baseline Scenario will not achieve carbon neutrality by 2060, with a residual 16 million tonnes of emissions, and the GBA's manufacturing

Figure ES-2 | **Scenario analysis for industrial carbon emissions**



Note: $MtCO_2$ = million tonnes of carbon dioxide.
Source: Project team.

industrial sector is expected to achieve carbon neutrality during the 2055–60 period under the Enhanced Policy and Zero-Emission Scenarios (Figure ES-2).

The largest emissions-reduction potential lies in the following areas:

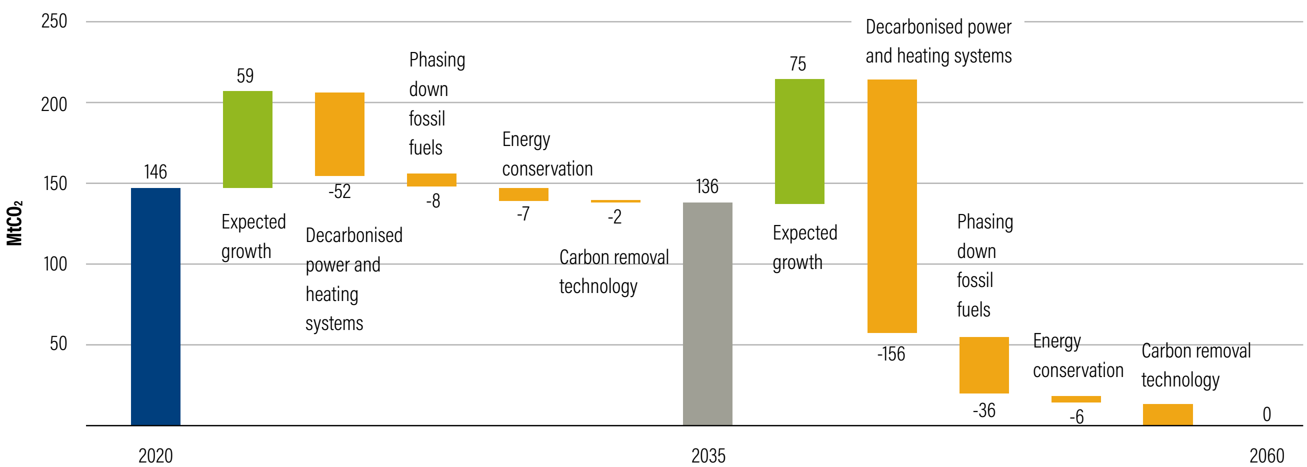
- **The most important contribution to carbon neutrality comes from decarbonised power generation and heating systems.** Decarbonised power and heating systems account for 74 percent of the total emissions-reduction potential from now to 2060. Phasing down fossil fuels in production accounts for 16 percent, energy conservation 5 percent and carbon removal technologies 5 percent (Figure ES-3). Power and heating generation can be decarbonised by leveraging advances in low-carbon electricity from the grid and switching to renewable energy to generate on-site electricity and heating. Decarbonised heating systems are also important to manufacturing, and the electrification of thermal processes should be one strategy to decarbonise heating systems and leverage decarbonised electricity sources.

- **Phasing down fossil fuels use, the second-largest contributor to emissions reduction,** can be achieved by substituting low- and no-carbon fuel and feedstocks to

reduce emissions for industrial processes. Technical improvements can lower emissions, including upgrading furnaces to phase down coal and consume waste heat. Coal used in ceramic kilns, papermaking and textile boilers can be replaced with natural gas in the short and medium term. Innovation in hydrogen production can also reduce the use of fossil fuels (such as coal-based hydrogen production). Hydrogen energy can be produced using industrial by-product hydrogen from propane dehydrogenation, from electrolysis of water via off-peak power and clean energy. Coal-related carbon emissions can be effectively reduced in the cement, steel and chemical industries over the long term. By 2060, low-emission fuels, including biodiesel, green hydrogen and methane produced from hydrogen, could replace approximately 50–60 percent of oil consumption in the petrochemical and chemical industries.

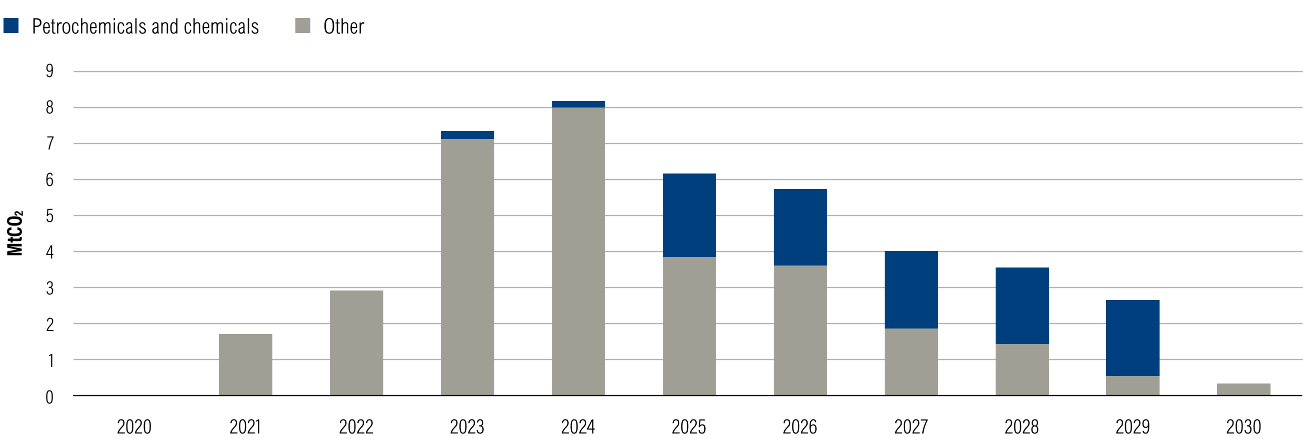
- **The petrochemical industry is a key sector for emissions peaking.** The petrochemical industry accounted for 18 percent of total energy use in Guangdong in 2020 and is the number one sector for energy use (Guangdong Provincial Bureau of Statistics 2021). There are five large

Figure ES-3 | **Contribution of decarbonisation pathways in industries in the GBA**



Note: $MtCO_2$ = million tonnes of carbon dioxide.
Source: Project team.

Figure ES-4 | **Manufacturing carbon emissions increase from the 'New Major Projects' during the 2020-30 period**



Note: $MtCO_2$ = million tonnes of carbon dioxide.
Source: Project team.

petrochemical bases in Guangdong and two in the GBA—Guangzhou and Huizhou. The Huizhou ExxonMobil Huizhou Ethylene Phase I Project will be completed and put into operation around 2025, leading to a large increase in emissions (Figure ES-4).

Road transport

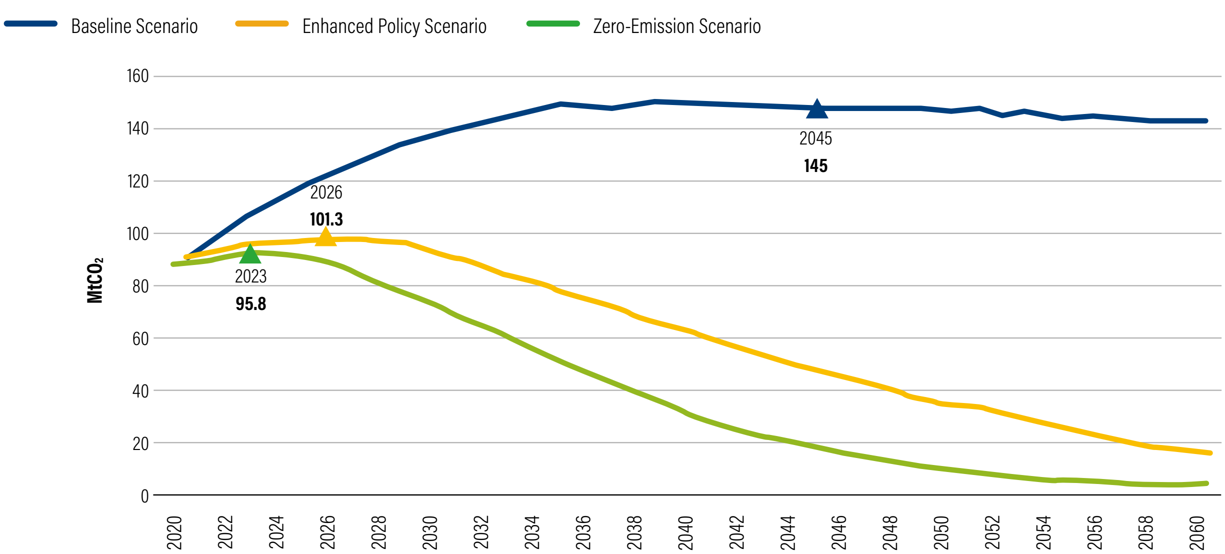
Stricter policies could allow the GBA's road transport sector to peak emissions by 2026 or even earlier. Carbon emissions from road transport in the GBA were 91.5 million tonnes in 2020. Private cars, light-duty vehicles and heavy-duty vehicles are the main sources of carbon emissions. Under the Enhanced Policy Scenario, road transport carbon emissions in the GBA would rise 31 percent above 2020 levels, peak around 2026, then fall to 20 million tonnes of CO_2—80 percent below the 2020 level—by 2060. In the Zero-Emission Scenario, road transport carbon emissions in the GBA would peak in 2023 and reach a near 100 percent reduction by 2060 (Figure ES-5). Carbon neutrality for road transport by 2060 is possible, but it will require greater determination and earlier actions, including more ambitious new-energy vehicle (NEV) promotion, fuel economy improvement, mode shift, reduced annual kilometres travelled, and clean electricity and green hydrogen.

The largest emissions-reduction potential lies in the following areas:

- **Outside of Guangzhou and Shenzhen (which is ahead of other cities in road transport decarbonisation), more aggressive emissions reduction measures have a dramatic impact on emissions.** We found that stricter measures would dramatically lower emissions peak in cities other than Guangzhou and Shenzhen in the Pearl River Delta and allow them to peak three years earlier than they otherwise would. This is because Guangzhou and Shenzhen have already adopted stricter policies, such as NEV promotion.

- **Gasoline and diesel will still be the main energy sources for a long time, but electricity and hydrogen will eventually become the main energy supply.** Under both the *Enhanced Policy Scenario and Zero-Emission Scenario*, the proportion of gasoline and diesel consumed drops rapidly after it peaks. However, by 2050 and 2041, respectively, under the two scenarios, the consumption of electricity and hydrogen can surpass gasoline and diesel and become the main energy supply (Figure

Figure ES-5 | **Road transport carbon emissions projections in the GBA under different scenarios**

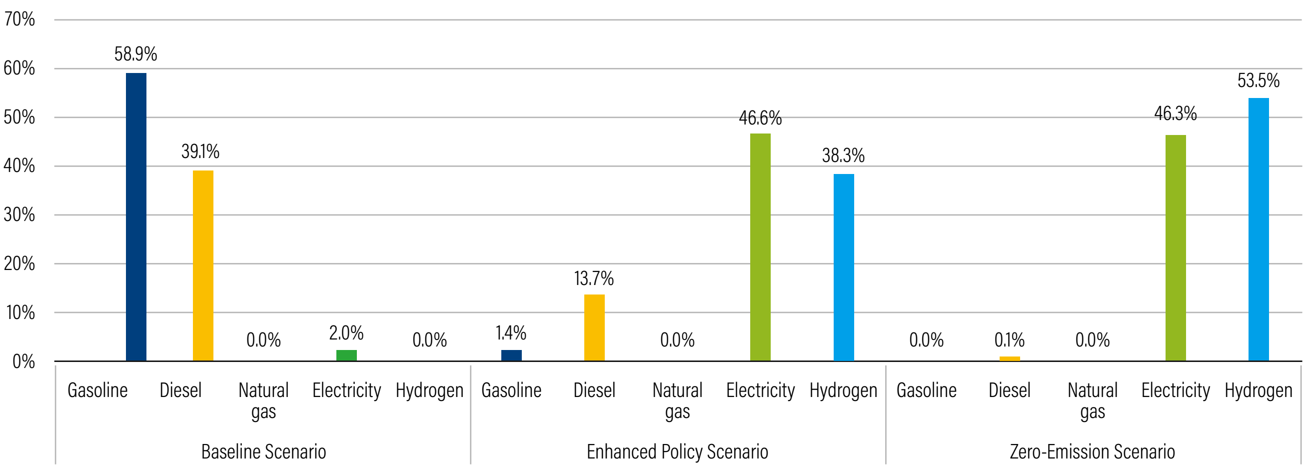


Note: $MtCO_2$ = million tonnes of carbon dioxide.
Source: Project team.

ES-6). This implies that intervention in internal combustion engine vehicles, such as improving fuel economy, shifting to public transport and the like, will still have significant impact. Meanwhile, the GBA's road transport infrastructure will need to be upgraded, especially in Guangzhou and Shenzhen, where NEVs are developing rapidly.

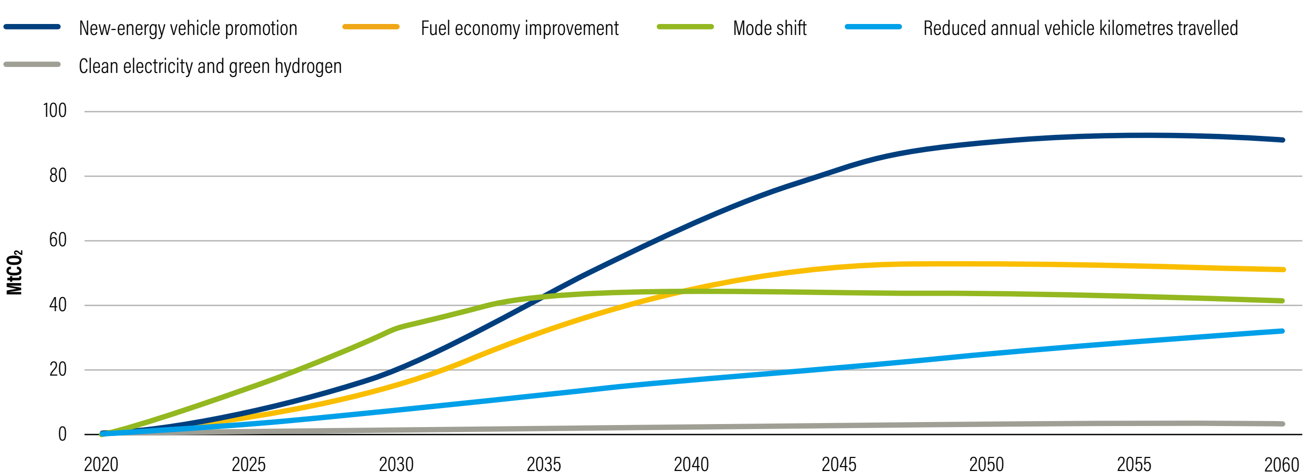
- **Among all policies and measures, promotion of NEVs together with upstream clean electricity and green hydrogen will contribute the largest emissions-reduction potential in the long term. In the medium term, mode shift will be the largest contributor to decarbonisation.** To compare the contributions of all measures, we analysed the emissions-reduction potential of five measures when any one of the measures is implemented alone. In the long run, a high proportion of NEVs has the greatest potential

Figure ES-6 | **Road transport carbon emissions projections in the GBA under different scenarios and proportion of different energies**



Source: Project team

Figure ES-7 | **Estimate of emission reduction potential of single measures under the Zero-Emission Scenario compared with the Baseline Scenario**



Note: $MtCO_2$ = million tonnes of carbon dioxide.
Source: Project team.

to reduce emissions, and its effect increases over time. Shifting passenger transport from private vehicles to public transit services and shifting road transport to railway and ships would bring larger emissions reductions than NEV promotion and fuel economy improvement before 2030 (Figure ES-7). This would require major investments in railway construction; more aggressive policies to expand public transit services and shift freight transportation from highways to railways and waterways; and multimodal transport, as well as green mobility in the Greater Bay Area.

Buildings

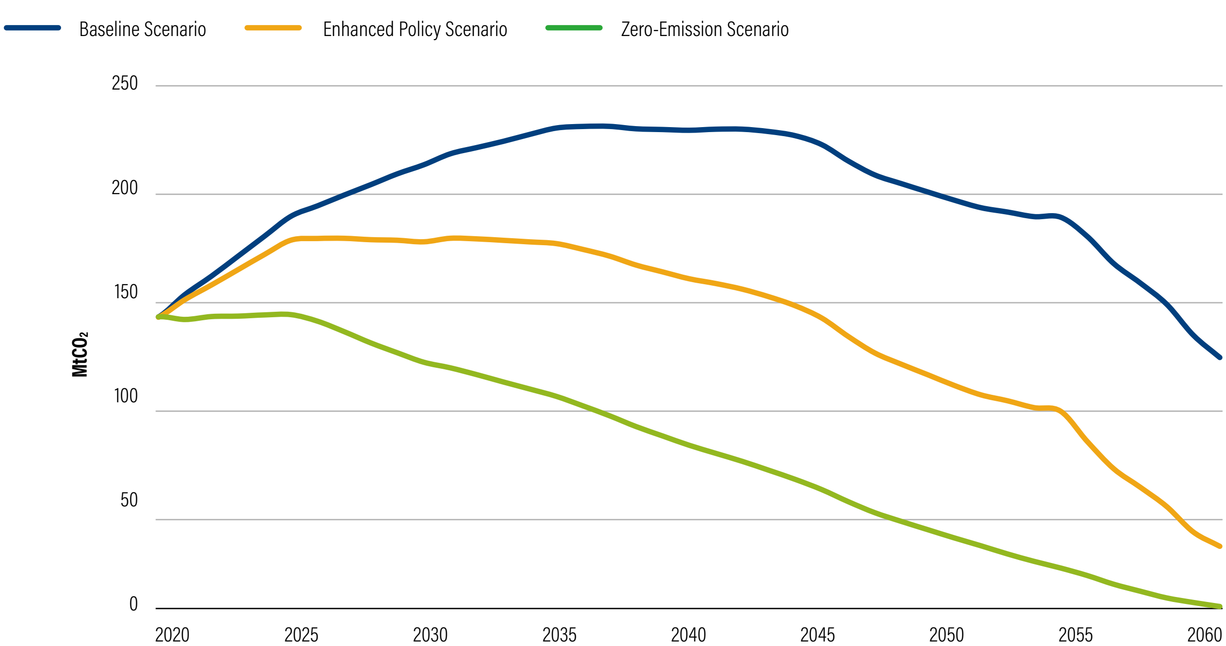
The GBA's buildings sector is projected to peak its carbon emissions in 2025 at the earliest and achieve carbon neutrality by 2058. Under the Enhanced Policy Scenario, carbon emissions from buildings in the GBA will reach their peak in 2030 at 180 million tonnes of CO_2. Under the Zero-Emission Scenario, the GBA buildings sector emissions will peak at a lower level of 144 million tonnes by 2025 and will fall to less than 10 million tonnes by 2058 (Figure ES-8).

The largest emissions-reduction potential lies in the following areas:

- **Both the stock and future increment of building emissions are mainly in public and commercial buildings.** Public and commercial buildings are responsible for 60 percent of emissions. Residential building area per capita in the GBA rivals that of the European Union and Japan, but public and commercial building area per capita is smaller and likely to grow. The GBA's residential area per capita was 35.7 square metres (m^2) in 2020, which is very close to the 36 m^2 for Europe and Japan. The GBA's public and commercial buildings area per capita is only 13 m^2, lower than the 14–16 m^2 for Europe and Japan, and is expected to catch up in the near future. This indicates that public and commercial buildings have further emissions-reduction potential.

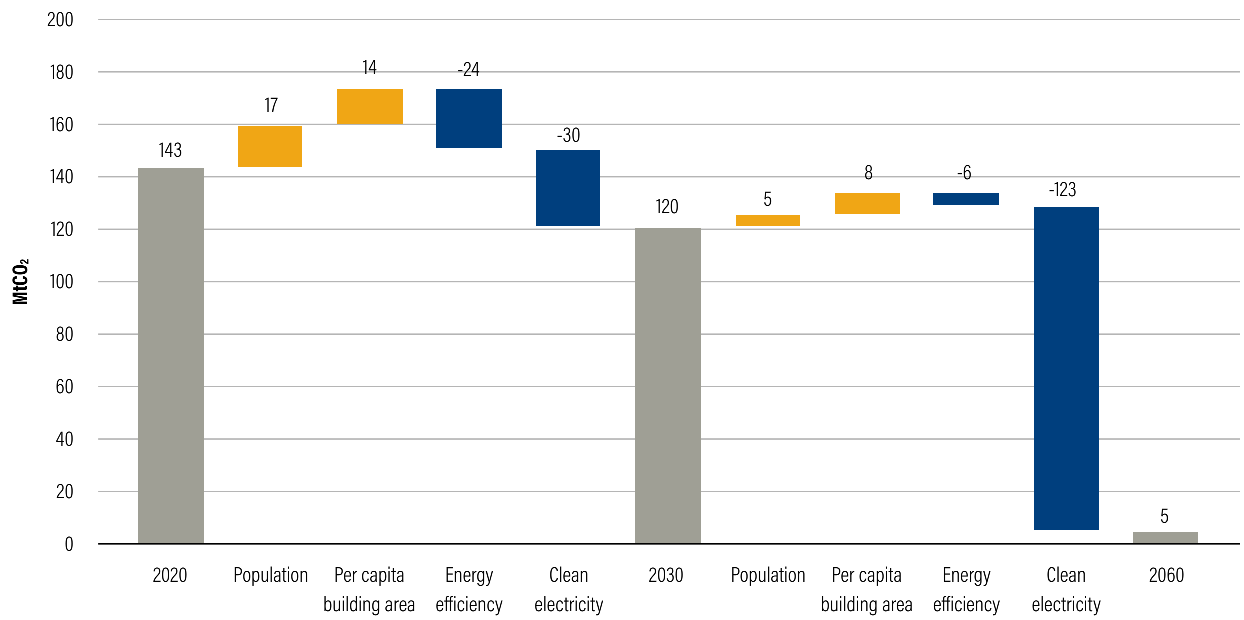
- **The three largest-emitting cities, Guangzhou, Shenzhen and Hong Kong, account for 60 percent of total emissions in buildings.** Buildings sector emissions across the GBA are varied. Usually, the higher the proportion of service industries,

Figure ES-8 | **Scenario projections of carbon emissions in the buildings sector**



Notes: $MtCO_2$ = million tonnes of carbon dioxide.
Source: Project team.

Figure ES-9 | **Contributions of decarbonisation pathways in the buildings sector under the Zero-Emission Scenario**



Note: $MtCO_2$ = million tonnes of carbon dioxide.
Source: Project team.

the greater the proportion of buildings emissions. Buildings emissions in Guangzhou and Shenzhen surpassed those of Hong Kong between 2017 and 2018.

- **Energy efficiency is important to decarbonise the buildings sector in the near future, while decarbonised electricity contributes the largest potential for emissions reduction.** In the Zero-Emission Scenario, between 2020 and 2030, improved energy efficiency and energy conservation will contribute 45 percent of emissions reductions, and the use of renewable energy in buildings and electricity generation will provide 55 percent of reductions. Between 2030 and 2060, the use of renewable energy will contribute the most emissions reductions (96 percent) (Figure ES-9). Efficiency improvement measures should be emphasised ahead of the design and construction stages and can be a potent tool for restricting energy consumption and enabling emissions to peak earlier. Electricity drove most of emissions increase in buildings and accounts for 89 percent of emissions, indicating a high electrification rate of the GBA's buildings sector. The GBA can focus on shifting to low-emission fuel for electricity generation and use renewable energy for cooking, water heating and space cooling. Electricity, and especially high-efficiency electric heat pumps, will become the primary source of energy use for space cooling. In addition to renewable energy now used to heat water in buildings, solar thermal technology can be used for cooking, and various forms of bioenergy can be tapped as well.

Funding needs to support the transition and key challenges in existing financial practices to accelerate the transition. Finance plays a pivotal role in helping the GBA's key sectors achieve the region's decarbonisation goals. This study estimates the investment needed to stay on track with the overall and sectoral decarbonisation pathways suggested above.

Our analysis estimates that the GBA needs approximately $1.84 trillion to achieve carbon neutrality by 2060, the equivalent of about 1 percent of cumulative GDP from now to 2060. We also estimate that $200 billion to $700 billion will be needed for road transport, and $150 billion to $300 billion for the buildings

Table ES-1 | **Estimates on the investment needed for the GBA**

PATHWAYS	INVESTMENT AREA	ESTIMATED AMOUNT UNDER ZERO-EMISSION SCENARIO (BILLION US$)
Road transport		696
Increase EV and Fuel Cell Vehicles	Promotion of new-energy vehicles	365
	New chargers and charge stations	34
	New hydrogen refilling stations	4
Mode shift	Road transport to railway and water transport	300
Buildings sector		314
Green buildings	New green buildings	78
Improved energy efficiency	Ultra-low and near-zero buildings	1
	Retrofitting existing buildings	209
Distributed renewable energy	Install solar thermal Install photovoltaics Install heat pumps	26
Manufacturing and other energy-intensive industries		830
Total Investment needs		1,840

Note: EV = electric vehicles.
Source: Authors.

sector. Of the estimated $1.84 trillion in financing required for the GBA's decarbonisation by 2060, 55 percent would be needed in energy-intensive industries, such as petrochemicals, road transport and buildings. Table ES-1 breaks down the investment needs.

The above investment estimates are not fully met. They can be partly supported by green finance, but the shortfall remains. Why does this shortfall exist and what challenges do we face in trying to fill it?

This study summarises five challenges of unlocking finance to accelerate business decarbonisation given the GBA's unique role in the 'dual markets':

- **More cross-regional policy coordination needed:** Government coordination at all levels across the GBA needs to be strengthened. The governments of key cities such as Guangzhou, Shenzhen, Hong Kong and Macao have not issued municipal-level planning guidelines that are drafted in tandem with each other. It is also not clear how the GBA will promote the coordinated cross-regional development of 'financing decarbonisation', especially the emerging transition finance, which is important to support decarbonising of carbon-intensive industries and is an efficient supplement to green finance.

- **Ambiguous definition for transition activities:** Financing decarbonisation of carbon-intensive sectors will be essential to facilitate the transition of the real economy in the GBA. A clear definition of transition activities is needed, allowing a broader range of stakeholders to understand and appreciate financing carbon-intensive sectors. However, there is a lack of common taxonomy-based approaches to identify specific transition activities, sectoral decarbonisation targets and information disclosure standards in the key sectors that support the net-zero transition and ensure an alignment approach across jurisdictions in the GBA. A great number of assets in these industries do not meet the requirements of the existing green finance taxonomy and thus cannot leverage green financial tools. Therefore, as a complement to green finance, China has started launching some tools for financing decarbonisation, including sustainability-linked bonds (SLBs), transition bonds and sustainability-linked loans (SLLs), to support the transition entities and activities. However, there is risk of greenwashing due to an ambiguous definition of transition activities. The People's Bank of China is leading on transition finance taxonomy, beginning with carbon-intensive sectors like coal-fired power generation, steel, building materials and agriculture (Ma 2022). Some leading international financial institutions are exploring transition finance frameworks to qualify and label financing that accelerates transition activities. For instance, in 2021 Standard Charted Bank released its transition finance framework, which is designed for asset-based financing and aligns with the International Energy Agency's 2050 net-zero scenario.

- **Insufficient scientific guidance for transition plans:** To transition to lower carbon emissions, enterprises will need unified standards, transition goals and pathways. Many high-carbon enterprises in China have the will to transition, but they often lack sector-specific guidance and expertise to set the transition goals, the ability to prepare transition plans and pathways, and the understanding of how to access the financial market with credible tools and products to support the transition.

- **Limited financial tools to accelerate transition:** A wide range of well-defined and well-understood financing tools are prerequisites for financing the decarbonisation of high-carbon enterprises and their transition activities. The acceptance and liquidity of transition-related financial tools are also an indication of the maturity of the transition market. At present, while SLLs and SLBs are being adopted for setting clear GHG reduction targets during the financing terms, transition finance tools, bonds and loans remain limited. Financial tools in the form of equity investment, insurance and asset-backed securities are relatively undefined or non existent.

- **Unaligned carbon market mechanisms:** There are now three carbon markets in the GBA, two pilot carbon markets on the Chinese mainland and one voluntary carbon market in Hong Kong. Due to differences in the allocation of carbon allowances and the regulation of the carbon market, the allowances in these three markets cannot be traded or mutually recognised, fragmenting the carbon markets in the GBA, which reduces the scale and liquidity of transactions and leads to the lack of comprehensive coverage of industries.

We offer six recommendations for finance to address the above challenges and fully exploit the supporting role of financing decarbonisation in the GBA:

1. Establish a cross-regional agency coordination mechanism for financing decarbonisation in the GBA. Given the fragmented nature of the GBA's finance market, it is imperative to establish a committee spanning regional agencies to coordinate transition finance. This committee, of which local policymakers and regulators should be key members, should aim to accelerate the GBA's sectoral transition by mobilising policy incentives and finance resources in support of transition activities and investment, drawing on the experience of green finance development in the region. This core coordination panel could be established based on the existing GBA Green Finance Alliance (GBA-GFA).

2. Facilitate interoperability of the Chinese mainland, international and/or Hong Kong transition finance taxonomies and information disclosure. To reduce transaction costs, improve market transparency and avoid transition washing in the region, it is necessary to promote interoperability of the transition taxonomies currently being developed on the Chinese mainland with international and Hong Kong standards whenever these taxonomies become available[1]. It is also essential to find consensus on mandatory information disclosure for transition activities among different regulators, promote mandatory information disclosure such as that advocated by the Task Force on Climate-Related Financial Disclosures, and facilitate market readiness for adopting international climate disclosure standards like those of the International Sustainability Standards Board in the region which will be served as a pioneer for China nationwide.

3. Encourage the GBA's financial institutions and enterprises to set net-zero targets. Setting net-zero targets is key to supporting businesses, including leading financial institutions and enterprises, to develop a credible technical roadmap and investment or financing plan for decarbonisation, with independent assessment for this progress. Existing green finance associations in the region, like GBA-GFA, Hong Kong GFA, and the Guangdong Green Finance Committee, can encourage financial institutions and enterprises to set net-zero targets, based on decarbonisation pathways from this study or other initiatives, such the Science Based Target initiative (SBTi) and the Hong Kong Exchange's *Practical Net-Zero Guide for Business*. The net-zero targets should be ambitious enough to achieve net-zero well before 2060. Some international banks that have joined SBTi, like Standard Chartered Bank, can play leading roles in target-setting, disclosure and engagement with corporate clients.

4. Develop a transition-related financial toolbox to scale up finance and accelerate the GBA's economy-wide transition.
The huge investment demand for the GBA's decarbonisation, $1.84 trillion, offers an enormous opportunity for financial institutions to mobilise private capital and scale up financial flows to transition activities and investments identified in the region and nationwide.

- **Debt:** Establish the GBA grant scheme to scale up the existing sustainability-linked and use-of-proceeds transition bonds in the identified sectors of manufacturing, buildings and transport. The scheme should adopt both policy supports on the Chinese mainland (e.g., subsidies for bond issuance and discount interest on green credit) and the Hong Kong Monetary Authority (HKMA) Green and Sustainable (GSF) grant scheme. In addition, carbon-related products can be innovated to link with carbon assets, such as Chinese Emissions Allowances (CEAs), China-Certified Emissions Reductions (CCERs) and carbon credits recognised in the international market. The carbon-related products are embedded carbon assets in the structure of SLLs and other carbon-trading products. They support energy-intensive enterprises in developing transition targets and technical roadmaps which follow the requirements of the Sustainability-Linked Loan Principles issued by the Asia-Pacific Loan Market Association, as well as those of China or GBA regional transition finance taxonomies.

- **Equity:** Consider setting up a tax concession private equity fund to invest in companies that are adopting new low-carbon technologies, upgrading high-carbon industries by using digital technologies or incubating innovative small and medium-sized enterprises in the key sectors; and utilise potential revenue from carbon allowance auctions to establish the industrial low-carbon fund, in collaboration with local governments for decarbonisation technology investment and projects in the GBA.

- **Insurance:** Innovate insurance products, such as green building insurance, mandatory liability insurance for environmental pollution, carbon-reduction loss insurance, carbon asset–related insurance and new low-carbon equipment insurance, to insure energy performance during the financing tenor.

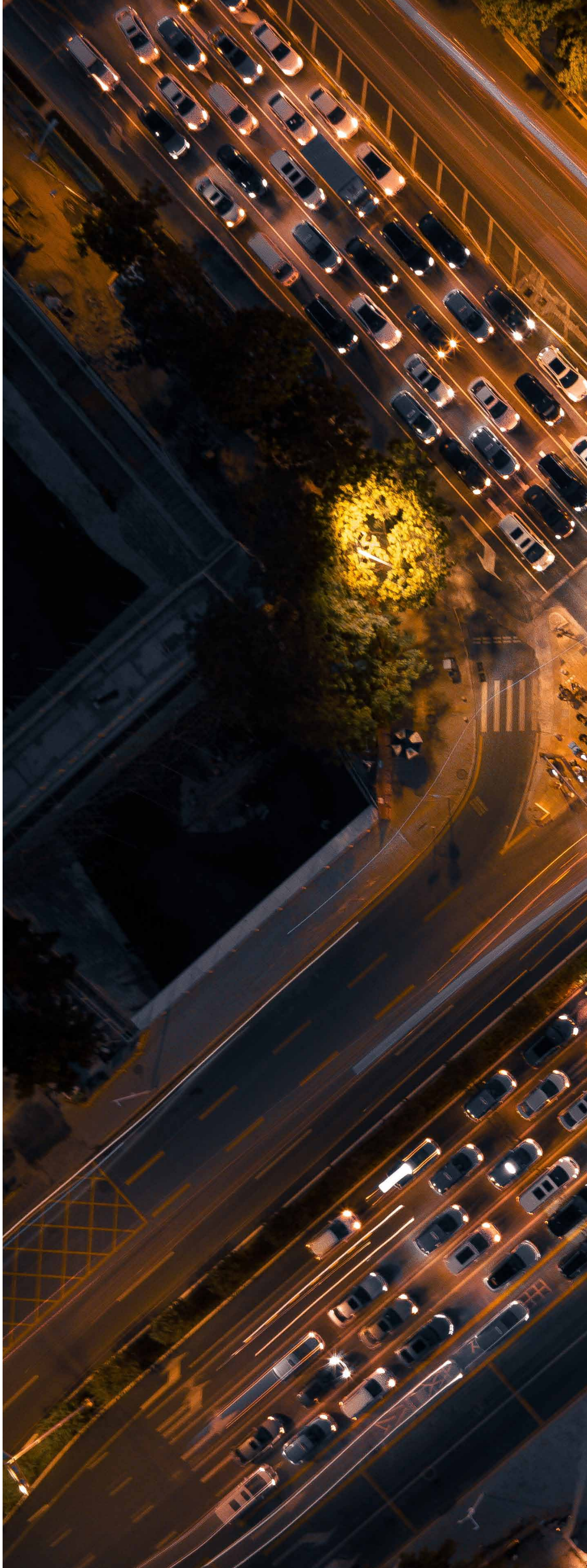
5. Develop industry-specific financial solutions for the key sectors in the GBA.

- **Manufacturing:** For the key energy-intensive industries identified by Chinese regulators, such as steel, petrochemicals, cement, ceramics and papermaking, financial institutions can partner with multinational corporations (MNCs) in those sectors to scale up sustainable supply chain finance (SSCF) along the value chain. Leveraging SSCF can assign value to MNCs' supply chain sustainability and provide tangible incentives to suppliers and their buyers.

- **Buildings:** Leveraging tools for financing decarbonisation to scale up green retrofitting via sustainability-linked loans, implement an effective energy performance contracting business model for green retrofitting, adopt a green insurance mechanism in the GBA to address term mismatch, expand recognition of international green building certifications (such as the Financial Corporation Excellence in Design for Greater Efficiencies [EDGE] certificate) to attract international funding and conduct operational assessment and disclosure of energy data.

- **Transport:** Through policy incentives for new energy–based freight fleet, electric and hydrogen fuel cell vehicles, mobilise private capital for construction in the region of new-energy vehicle infrastructure, such as charging piles and hydrogen refuelling stations. Encourage local governments to issue sustainable municipal bonds to invest in railways and leverage SLL and transition financing for shipping financing (beyond International Maritime Organization and duel-fuelled vessels).

6. Use local and regional carbon markets to accelerate the GBA's transition. The national carbon market, which is expected to expand the covered sectors and reboot the transaction of CCERs, presents an opportunity to connect with the Chinese mainland CCER market, the Hong Kong 'Core Climate' and international voluntary carbon markets linking capital with climate-related products worldwide. The existing Guangdong and Shenzhen carbon emissions trading systems can also help accelerate the GBA's transition by pioneering expansion of the scope of regional carbon markets to include the covered sectors not included in the national carbon market: ceramics, textiles, data centres, buildings and transport. The possibility could also be explored of establishing a GBA regional carbon market linking to the Hong Kong market to pilot financial tools and derivatives.




黃大仙站 Wong Tai Sin Station

INTRODUCTION

Climate change is an urgent challenge, and GHG emissions need to peak before 2025 and reach net-zero in the early 2050s to keep temperature rise within the 1.5-degree Celsius goal (IPCC 2023). China is playing a critical role in global climate governance and undertaking a comprehensive green transformation.

Background

Climate change is an urgent challenge. Global greenhouse gas (GHG) emissions rose over the past decade, reaching 59 gigatonnes of CO_2 equivalent ($GtCO_2e$) in 2019—roughly 12 percent higher than emissions in 2010 (IPCC 2022). In modelled pathways that keep temperature rise within the 1.5-degree Celsius (1.5°C) goal (with no or limited overshoot), GHG emissions will peak before 2025 and then reach net-zero in the early 2050s (IPCC 2023).

China has been the world's largest GHG emitter since 2005, contributing 28 percent of the world's CO_2 emissions in 2019, and is playing a critical role in global climate governance. China's new nationally determined contributions, submitted in 2021, and its commitment to carbon neutrality by 2060 show that it is taking this problem seriously. In 2021, China issued the *Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy* (hereafter 'The Guidance'), a major strategic policy stating that peaking carbon emissions, reaching carbon neutrality and undertaking a comprehensive green transformation should be guiding principles integral to economic and social development.

The Guangdong–Hong Kong–Macao Greater Bay Area (GBA) can play a leading role in the transition. The GBA's economy rests on emissions-intensive industries that consume fossil fuels, and this cannot change overnight. The needed comprehensive green transformation and low-carbon development of the GBA requires vigorously increasing the share of clean energy used and transforming emissions-intensive industries to improve energy efficiency and phase down fossil fuels.

Action now is imperative. This research provides the GBA with an effective, practical and feasible path forward by detailing objectives, policy measures and action plans and the roles that various public and private stakeholders and institutions will need to play.

About this report

As part of the 'Hong Kong 2050 Is Now' initiative, this report focuses on the GBA, including nine Pearl River Delta cities—Guangzhou, Shenzhen, Zhuhai, Foshan, Dongguan, Zhongshan, Jiangmen, Huizhou and Zhaoqing—in Guangdong Province, as well as the two special administrative regions of Hong Kong and Macao (State Council 2019).

This research uses publicly available statistical data from each city in the GBA to assess sectoral development and emissions status and models the carbon-reduction pathways based on scenario analysis. Because the share of the service industry in the Hong Kong and Macao Special Administrative Region of China (hereinafter referred as to as Hong Kong and Macao) is over 90 percent, with few industrial activities, our research into manufacturing mainly covers the nine Pearl River Delta cities in the GBA. Our analysis of the road transport and buildings sectors covers the nine Pearl River Delta cities and Hong Kong, due to limited publicly available data from Macao to support analysis.

This report estimates that about $1.84 trillion is required for the GBA's decarbonisation goal by 2060, of which $1.015 trillion would be needed in petrochemical manufacturing, road transport and the buildings sector. Based on the estimated investment needs for both economy-wide and sectoral decarbonisation, this report reviews available and potential tools for financing decarbonisation. It also summarizes the existing barriers and makes recommendations to use financial tools to accelerate the GBA's decarbonisation.

The report is organised as follows:

- Sections 1–4 review the status quo of energy consumption and carbon emissions in both the economy-wide and key emitting sectors—manufacturing, road transport and buildings. We build models to estimate energy consumption and carbon emissions from 2021 to 2060 under three scenarios for each GBA city.

- Section 5 and 6 estimate investment needs, both economy-wide and for three key sectors in the GBA. A top-down method estimates the GBA's total investment need based on a weighted number of the GBA's gross domestic product (GDP) to China and China's investment needs to carbon neutrality. We follow a bottom-up approach to calculate sectoral investment needs, using cost of carbon reduction and penetration of carbon-reduction technologies. These sections also review the development of transition finance and potential tools for financing decarbonisation, and summarise key challenges faced in adopting these tools to accelerate the GBA's decarbonisation.

- Section 7 provides policy recommendations on sectoral decarbonisation and financing practices to promote the GBA's transition.

- The appendices provide the scope of study, data sources, methodologies, key assumptions and scenario settings.

SECTION 1

THE EMISSIONS GAP FOR CARBON NEUTRALITY IN THE GBA

The GBA is a region of exceptional economic vitality with one of the highest levels of urbanisation in China. It is expected to lead in achieving peak carbon emissions and carbon neutrality as well as by creating a regional benchmark for green and low-carbon development (People's Government of Guangdong Province 2021).

The GBA is expected to lead green growth and decarbonisation

The GBA, shown in Figure 1, covers around 56,000 square kilometres (km^2) and had a population of more than 86 million and a GDP of US$1,668.8 billion in 2020 (Greater Bay Area 2022)[2]. This represents 0.6 percent of China's area, 6 percent of its population, and 11 percent of its GDP. The GBA's status as a main economic engine for China has led to a pronounced population siphon effect. The area's urbanisation rate was 87 percent as of 2020 (Guangdong Provincial Bureau of Statistics 2021), much higher than the 64 percent average for the nation as a whole (National Bureau of Statistics 2021).

The central government has singled out the GBA to play a key part in China's development. As one of the engines driving China's economic progress, it could spearhead the country's efforts to decarbonise. The GBA, the Yangtze River Delta (YRD) region and the Beijing-Tianjin-Hebei (BTH) region are the three national strategic areas in China. As shown in Table 1, of these three the GBA has the smallest land area and population, its aggregate economy is the second largest, and its per capita GDP is the highest ($22,585, compared with the YRD's $18,200 and BTH's $11,500) (National Bureau of Statistics 2021). The proportion of the service sector in the GBA has reached 62 percent (Guangdong Provincial Bureau of Statistics 2021), which is higher than that of the other two regions (National Bureau of Statistics 2021). Its modern service sector is characterised by lower emissions, which could help the GBA become a decarbonisation leader.

Figure 1 | **Location of GBA cities**

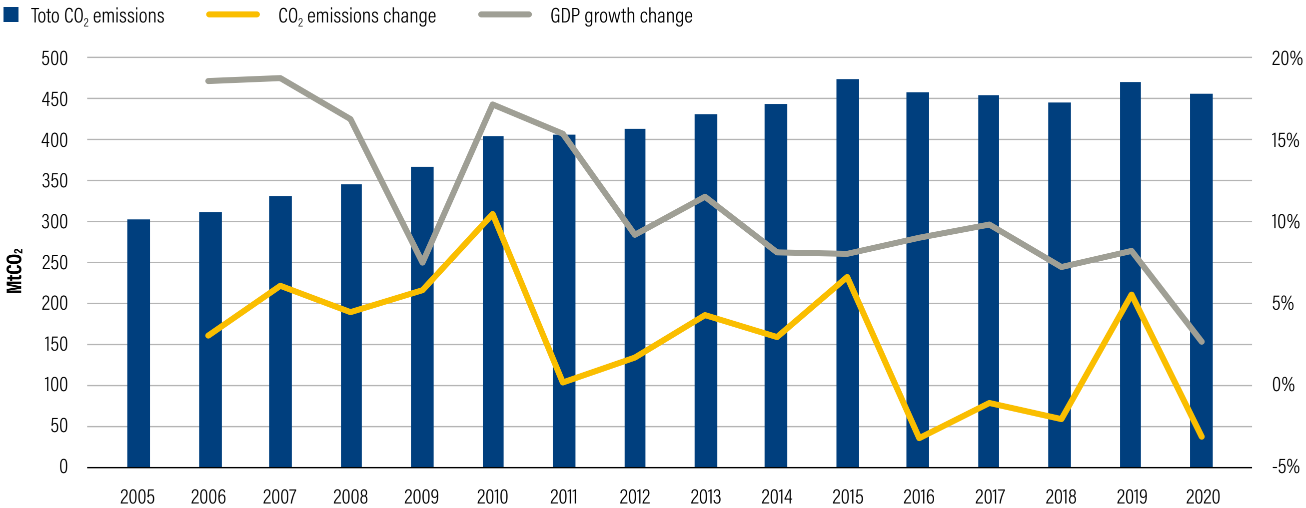
Source: Project team

Table 1 | **Comparison of the GBA with other city clusters in China**

	GUANGDONG-HONG KONG-MACAO GREATER BAY AREA	BEIJING-TIANJIN-HEBEI REGION	YANGTZE RIVER DELTA
Land area (km^2)	56,098	218,000	358,000
Population (million)	86.7	110.1	236.5
GDP (billion US$)	1,958	1,290	4,280
Per capita GDP (US$)	22,585	11,500	18,200
Proportion of the tertiary industry	62%		

Notes: Data year 2020. GDP = gross domestic product.
Sources: Statistical yearbooks of Guangdong, Beijing, Hebei, Tianjin, Jiangsu, Shanghai and Zhejiang in 2021.

Figure 2 | **Total CO_2 emissions and change in CO_2 emissions and GDP growth in the GBA**



Notes: CO_2 emissions do not include Macao as no public data are available. $MtCO_2$ = million tonnes of carbon dioxide; GBA = Guangdong–Hong Kong–Macao Greater Bay Area; GDP = gross domestic product.

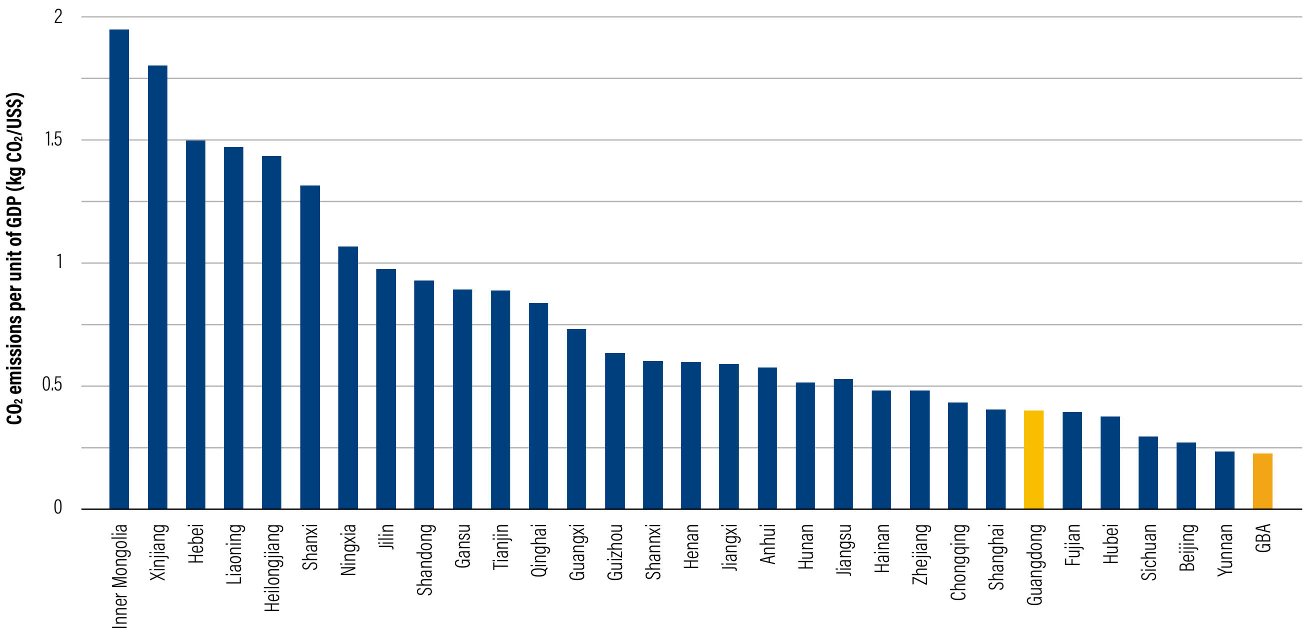
Sources: CO_2 emissions data for Hong Kong from Hong Kong Environment and Ecology Bureau (n.d.); CO_2 emissions data for Pearl River Delta cities from Institute of Public and Environmental Affairs (2022); GDP data from Guangdong Provincial Bureau of Statistics (2021).

The GBA's CO_2 emissions and GDP growth have begun to decouple. Since 2005, emissions have grown more slowly than the region's economy. Emissions have trended downwards since 2015, even as the economy continues to grow, but with higher energy efficiency and a wider use of clean energy. However, emissions rebounded in 2019, raising questions about when emissions will peak and revealing that much more needs to be done. The COVID-19 pandemic slowed emissions in 2020, when total CO_2 emissions in the GBA amounted to 457 million tonnes, about 4 percent of China's total CO_2 emissions (as shown in Figure 2) (Hong Kong Environment and Ecology Bureau n.d.; Institute of Public and Environmental Affairs 2022). Emissions will very likely rebound in 2023, however, as the economy recovers.

Ambitious actions are needed for the GBA's carbon emissions to peak earlier and achieve carbon neutrality

The GBA is a trailblazer in low-carbon development. Shenzhen, Guangzhou and Zhongshan were approved as the national low-carbon pilots in 2010, 2012 and 2017, respectively. After many years of pioneering trials, the pilot areas have developed policy frameworks and mechanisms to achieve three goals: encourage manufacturing that emits less carbon; increase the use of clean energy, low-carbon buildings and transportation; and incentivise institutional innovation. Guangdong Province and Shenzhen have further trialled a carbon emissions trading system (ETS). Implementing the ETS can improve the region's capacity for low-carbon development and lay a solid foundation for reducing regional emissions by managing high-emitting enterprises. At the same time, towns, communities and industrial parks are pioneering near-zero-emission demonstration projects to set a precedent for carbon neutrality. Hong Kong is the first Chinese city that has committed to carbon neutrality by 2050 and has launched a clear ban on fossil fuel–powered private cars, which will no longer be registered by 2035. Hong Kong decided not to build new coal-fired power plants in 1997 and has reduced the share of coal in power generation to 25 percent in 2020 (Wen et al. 2021). Technological innovation is a key ingredient in peaking carbon emissions and achieving carbon neutrality. The GBA has a cutting-edge scientific research environment which has laid the foundation for research and development (R&D). In 2021, Guangdong's R&D investment was $62 billion, ranking first among all the provinces (National Bureau of Statistics 2022).

Figure 3 | **Comparison of carbon intensity in 2020 by regions in China**



Notes: CO_2=carbon dioxide; GBA=Guangdong-Hong Kong-Macao Greater Bay Area; GDP=gross domestic product; kg = kilograms.
Source: Project team estimate based on Carbon Emission Accounts and Datasets database and statistical yearbook of each province.

Guangdong's considerable efforts at emissions reduction—such as improving energy efficiency and supporting low-carbon industries and clean energy sectors—have helped it become one of the provinces with the lowest carbon intensity (carbon emissions per unit of GDP) in 2020 (as shown in Figure 3). Moreover, the carbon intensity of the GBA was half of Guangdong's level.

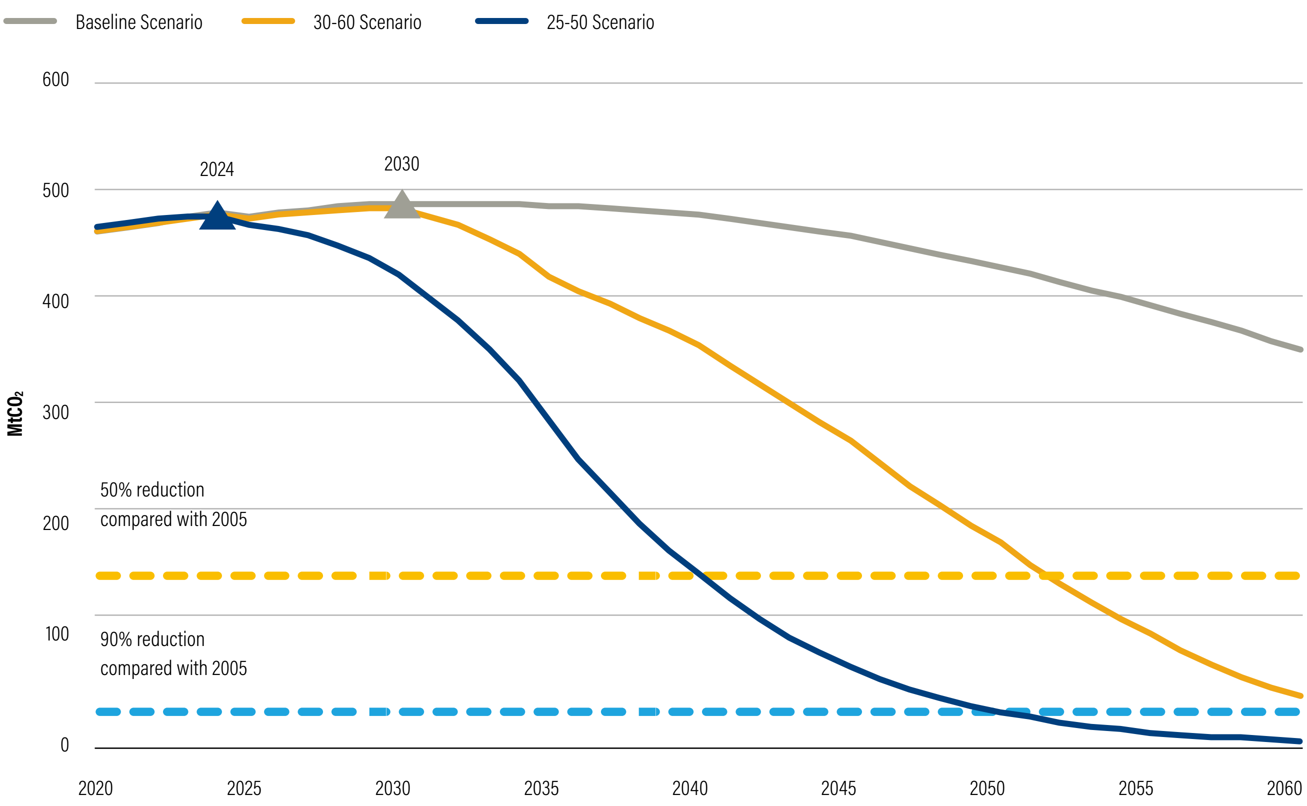
This study estimates the GBA's carbon emissions from 2020 to 2060 using a top-down approach based on projected GDP and carbon intensity (for a detailed methodology, see Appendix A). It sets up three scenarios: the Baseline Scenario, the '30-60' Scenario and the '25-50' Scenario. (Because the peak year and carbon neutrality year vary from sector to sector, we use *Enhanced Policy Scenario* and *Zero-Emission Scenario* in the sectoral analysis as equivalents for the 30-60 Scenario and 25-50 Scenario in the overall GBA analysis.) The Baseline Scenario answers the question of whether and when carbon emissions will peak and the carbon-neutrality goal be achieved if no stronger measures are taken. The 30-60 Scenario and 25-50 Scenario predetermine the peaking year and carbon neutrality year as assumptions, with the analysis answering the question of how fast emissions will need to be reduced to be consistent with the national 30-60 goals, and how much more sharply they need to be cut to peak by 2025 and achieve carbon neutrality around 2050.

- As the 14th Five-Year Plan (FYP) includes no new national or subnational targets for carbon intensity, under the Baseline Scenario we assume that in future five-year periods the rate of each city's carbon-intensity reduction remains what it was in the 13th FYP. Under this scenario, our results show that the GBA will only reach its peak emissions in 2030, and a remaining 355 million tonnes of CO_2 emissions will need to be offset in 2060 (Figure 4), which seems beyond what is achievable.

- Under the 30-60 Scenario, to be consistent with the national 30-60 goals, carbon emissions in the GBA need to peak by 2030; carbon intensity reductions equal to those of the Baseline Scenario can enable this. Emissions when peaking are 480 million tonnes of CO_2. But more ambitious actions need to start from 2030 to enable a sufficiently sharp emissions decline to achieve carbon neutrality by 2060. If carbon neutrality means a 90 percent emissions reduction and a 10 percent offset by forest sink and negative emissions technologies such as carbon capture, utilisation and storage (CCUS), as many other countries set their targets, an emissions cap goal will be needed beginning in 2030 and annual emissions reductions during the 2030–60 period will need to be around 7.5 percent.

- Under the 25-50 Scenario, if carbon intensity can be reduced by 24 percent in the 14th FYP, the GBA can peak its emissions by 2025. Emissions when peaking will be 467 million tonnes of CO_2. This will require much stricter policies and measures because the target is higher than what was achieved in the 13th FYP in Guangdong—a 22.35 percent carbon-intensity reduction, and emissions reductions from some measures, such as energy efficiency, will get harder. The annual rate of emissions reduction during the 2025–50 period should be around 16 percent if we want to achieve carbon neutrality around 2050. This scenario is consistent with advice in the newest IPCC report to ensure achievement of the Paris Agreement's 1.5°C goal.

Figure 4 | **Scenario analysis of carbon emissions in the GBA towards 2060**



Note: $MtCO_2$ = million tonnes of carbon dioxide.
Source: Project team.


SIX FEET DOWN
SINCERITY UNPARALLELED

SECTION 2

A CARBON NEUTRALITY ROADMAP FOR MANUFACTURING IN THE GBA

The GBA's industrial sector, which consists mainly of manufacturing, supports the region's economic and social development. Its production accounts for a 10^{th} of China's industrial value added (Guangdong Provincial Bureau of Statistics 2021; National Bureau of Statistics 2021) and its competitiveness will be essential to driving domestic high-quality economic development.

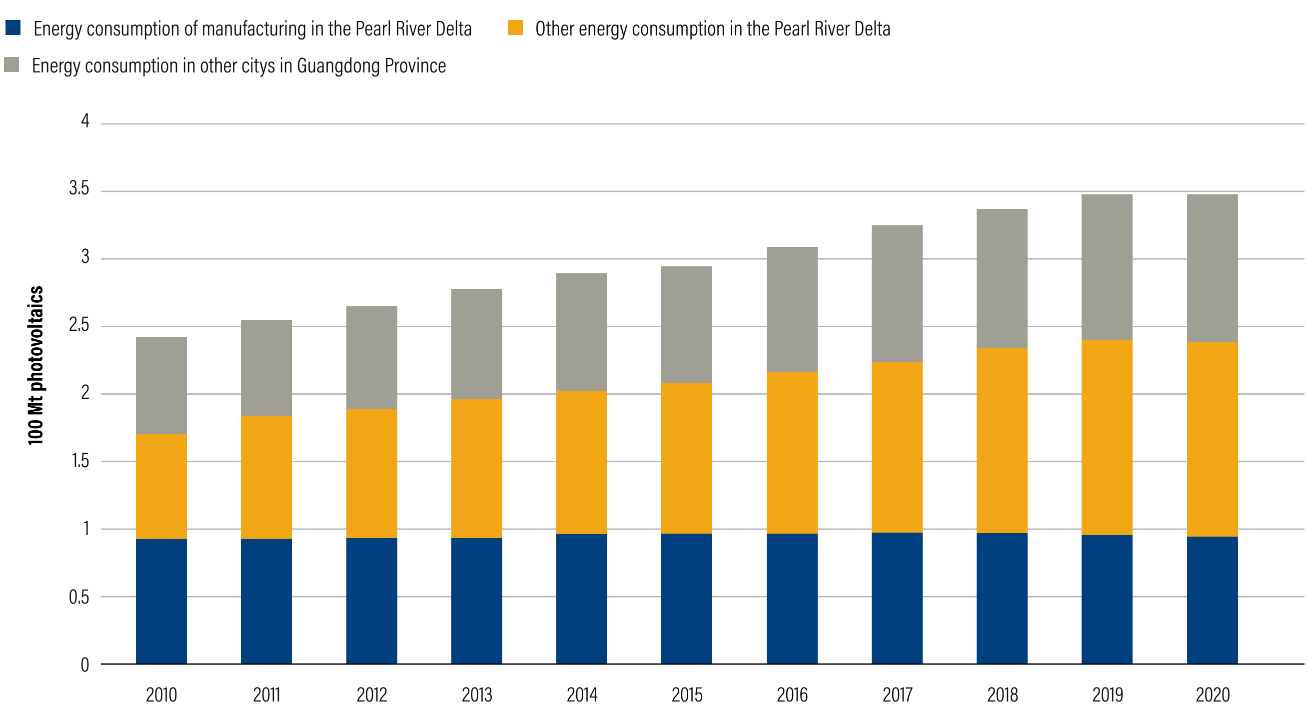
Current status of the manufacturing sector in the GBA

Manufacturing contributes about one-third of total carbon emissions in the GBA

Manufacturing was responsible for 32 percent of carbon emissions in 2020. Its industrial value-added output climbed from $262 billion in 2010 to $492 billion in 2020, while its share of the province's GDP declined from 37 percent to 29 percent over the same period (Guangdong Provincial Bureau of Statistics 2021). Carbon emissions stemming from manufacturing in the GBA have declined from 167 million tonnes in 2015 to 146 million tonnes in 2020, and energy consumption from manufacturing decreased from Blue bars in the Figure 5 are over 100 million tonnes and need to revise to 0.95 million tonnes of coal equivalent (Figure 5). This is because manufacturing's contribution to economic growth is gradually diminishing due to more rapid development of service industries. As Guangdong Province has deepened its socioeconomic transformation from an industry-led economy to a service-oriented one and upgraded from advanced to high-end manufacturing, the contribution of manufacturing output to GDP is decreasing, and the role of manufacturing in driving the regional economy is diminishing. The growth rate of manufacturing output dropped from its peak of 13.8 percent in 2010 to 4.9 percent in 2020.

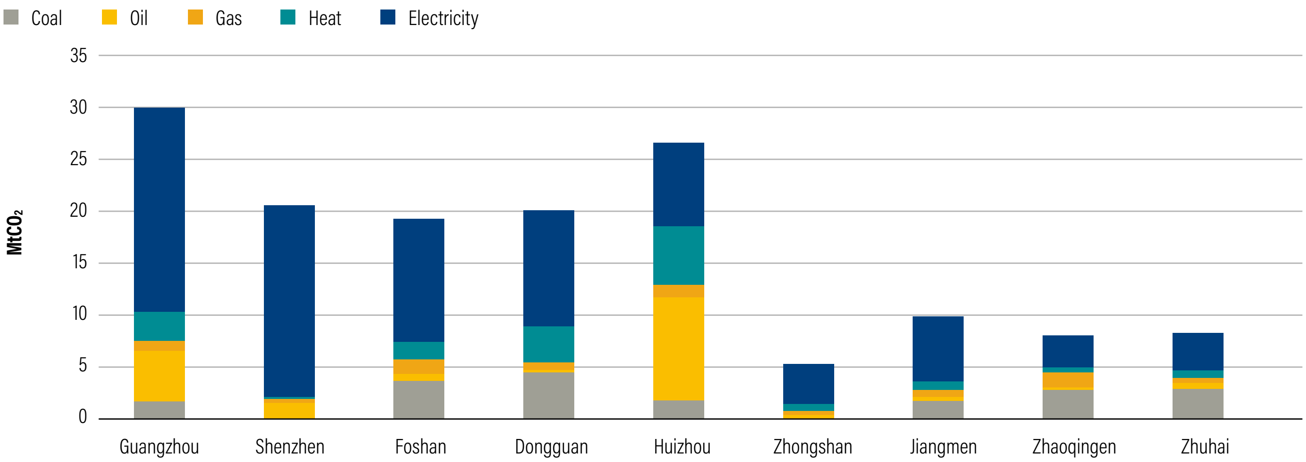
Analysis of the energy consumption elasticity coefficient (a term used to represent the ratio of the growth rate of energy consumption to the growth rate of GDP or industrial value added) shows that energy consumption for the GBA's manufacturing is growing more slowly than the sector's rate of production; the energy consumption elasticity coefficient is getting closer to zero, even becoming negative in 2019 and 2020 (Guangdong Provincial Bureau of Statistics 2021). This indicates that the development of manufacturing is decoupling from energy consumption and energy efficiency is improving.

Figure 5 | **Evolution of energy consumption in the Greater Bay Area (2010–20)**



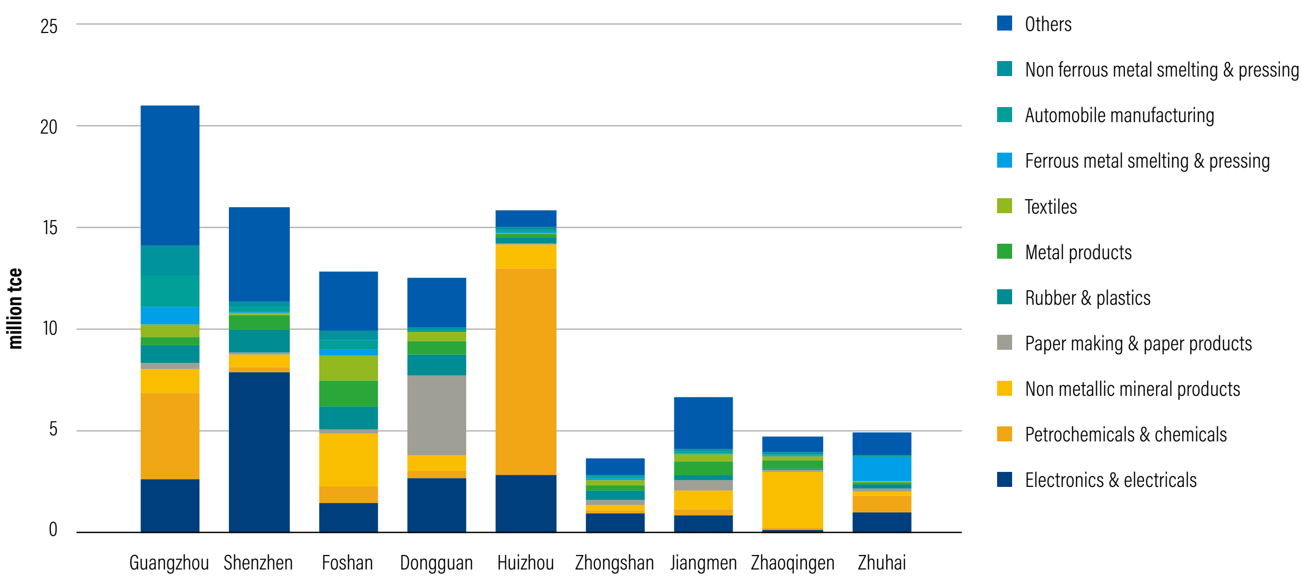
Note: Mt = million tonnes.
Source: Guangdong Statistical Yearbook, 2011–21.

Figure 6 | **Main sources of industrial carbon emissions in the GBA by city (2020)**



Note: $MtCO_2$ = million tonnes of carbon dioxide.
Source: Statistical yearbook of each city in 2021.

Figure 7 | **Sectoral composition of industrial energy consumption in the GBA by city (2020)**



Note: tce = tonnes of coal equivalent.
Source: Statistical yearbook of each city in 2021.

Each city's different prevalent industries require that municipal governments formulate tailored policies to promote carbon-peaking actions in key areas and industries

In 2020, the industrial value added of five cities in the GBA—Guangzhou, Shenzhen, Foshan, Dongguan and Huizhou—accounted for 79.5 percent of the region's total. Shenzhen's industrial value added took the lead with a contribution 1.5 times that of Guangzhou. Carbon emissions also had the same spatial distribution concentrated in these five cities (Figure 6), accounting for 79 percent of the GBA's industrial carbon emissions. Huizhou's industrial carbon emissions climbed rapidly between 2017 and 2019 due to the commissioning of new large-scale petrochemical projects since 2017. It lies upstream in the manufacturing chain of petrochemical and chemical products that serve as feedstock for other manufacturing industries.

When we compare sources of carbon emissions (Figure 6) and sectoral energy consumption (Figure 7) in each city, the industrial carbon emissions correlate closely with the industries prevalent in each city. Emissions from electricity are the major sources of industrial carbon emissions across the nine cities. Oil products are the largest contributor of emissions in Huizhou and the second-largest in Guangzhou, these being two of the five petrochemical-producing cities in Guangdong Province with intensive energy consumption. Coal is a major source of industrial carbon emissions in Foshan, Dongguan, Zhaoqing and Zhuhai because it is burned to manufacture ceramics in Foshan (non metallic mineral products), generate power and make paper in Dongguan, manufacture cement (non metallic mineral products) in Zhaoqing and produce iron and steel (ferrous metal smelting and pressing) in Zhuhai. In formulating tailored policies to promote implementation of carbon-peaking actions in its key areas and industries, the Huizhou government, for example, should focus on decarbonising the petrochemical and chemical industries and designing carbon-reduction targets.

Two industrial sub-sectors—petrochemicals and chemicals, and electronics and electricals—are key to decarbonising the GBA's manufacturing

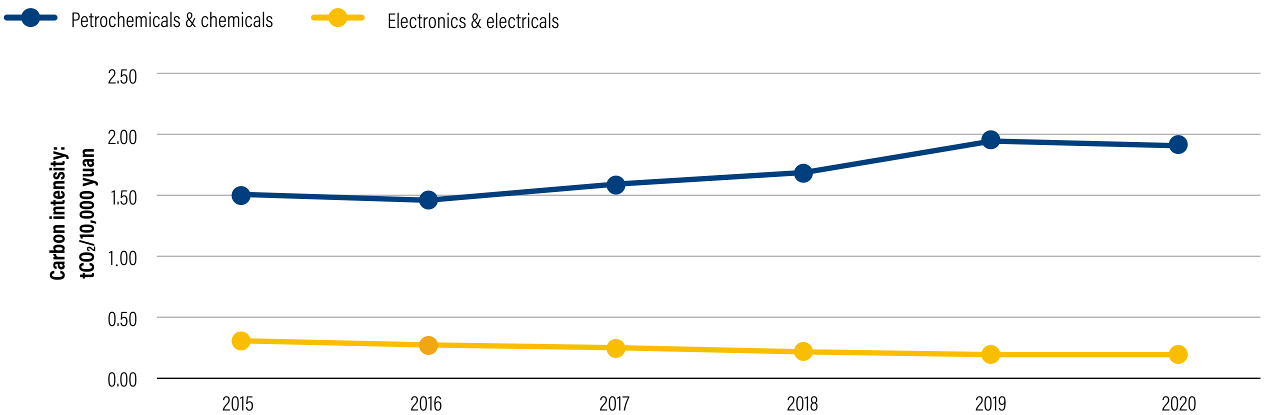
In 2020, the energy consumption of the GBA's energy-intensive industries, including textiles, papermaking and printing, non-metallic mineral products, and ferrous and non ferrous metal smelting and pressing industries, has declined 3 percent compared with the 2015 level (Guangdong Provincial Bureau of Statistics 2021). The energy consumption of the petrochemicals and chemicals sub-sector, however, has grown by 13 percent during the same period and is expected to further increase over the next decade because Guangdong Province plans to expand production capacity and construct two integrated refining and chemical bases in Guangzhou and Huizhou (Department of Industry and Information Technology of Guangdong Province 2020).

Another key industrial sub-sector with high energy consumption in the GBA is electronics and electricals manufacturing (computers, communications equipment and other electronics, and electrical machinery and equipment). The energy consumption of the electronics and electricals sub-sector increased 18.6 percent between 2015 and 2020, accounting for 19.8 percent of the GBA's manufacturing energy consumption in 2020, and its industrial value experienced a compound growth rate of 6 percent. Electronics and electricals are the engine driving industrial growth, and the GBA is planning to create an electronic information industrial cluster on the east bank of the Pearl River, with Shenzhen serving as an R&D centre (State Council 2019) and cities like Dongguan and Huizhou as production bases (*Nanfang Daily* 2021a; Bureau of Commerce of Dongguan City 2020).

Despite continued growth in energy consumption, these two industrial sub-sectors have not seen a notable increase in carbon emissions due to reduced fossil fuel usage in manufacturing and an increased share of clean energy in the electricity supply (this share rose 5 percent from 2018 to 2020) (Guangdong Power Exchange Centre 2022). The carbon emissions of the GBA's petrochemicals and chemicals sub-sector have fluctuated over the past six years, hitting a high of 30.89 million tonnes in 2018 and declining to 29.58 million tonnes in 2020, perhaps partly as a result of the COVID-19 pandemic in Guangdong Province. The carbon emissions of the GBA's electronics and electricals sub-sector have gradually decreased, from 27.65 million tonnes in 2017 to 25.7 million tonnes in 2020.

The carbon-intensity trajectories of the two major industrial sub-sectors between 2015 and 2020 are starkly different (see Figure 8). Petrochemicals and chemicals have seen a roughly 27 percent rise in carbon emissions per unit of output (from 0.975 tonnes to 1.242 tonnes of carbon dioxide per $1,000) because large-scale petrochemical projects were put into trial operation in Huizhou and consumed more energy between 2017 and 2018, but the industrial value added of the trial operation projects did not increase accordingly. In comparison, electronics and electricals have posted a decline of about 29 percent of carbon emissions per unit of output (from 0.176 tonnes to 0.124 tonnes of carbon dioxide per $1,000). Thus, it is important to explore carbon-neutrality pathways for the GBA's petrochemicals and chemicals manufacturing in depth. This underscores the challenges faced by the petrochemicals and chemicals sub-sector in attempting to peak its

Figure 8 | **Carbon intensity trajectories of major industrial sub-sectors in the Greater Bay Area (2015-20)**



Note: tCO_2 = tonnes of carbon dioxide.
Source: Guangdong Statistical Yearbook, 2016–21.

carbon emissions.

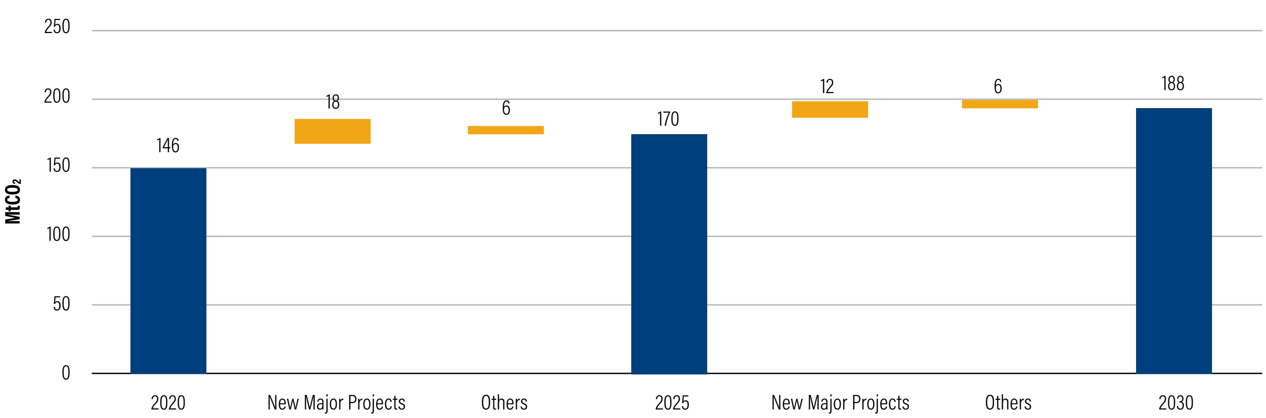
Scenario analysis and emissions-reduction potential

Manufacturing in the GBA is expected to peak its carbon emissions during the 15th Five-Year Period and to achieve carbon neutrality around 2055-60

This sub-section outlines the decarbonisation pathways of manufacturing in the GBA through scenario analysis, and then proposes specific pathways for decarbonisation. We outline three scenarios: Baseline, Enhanced Policy and Zero-Emission (for a detailed methodology of the scenario analysis, see Appendix B).

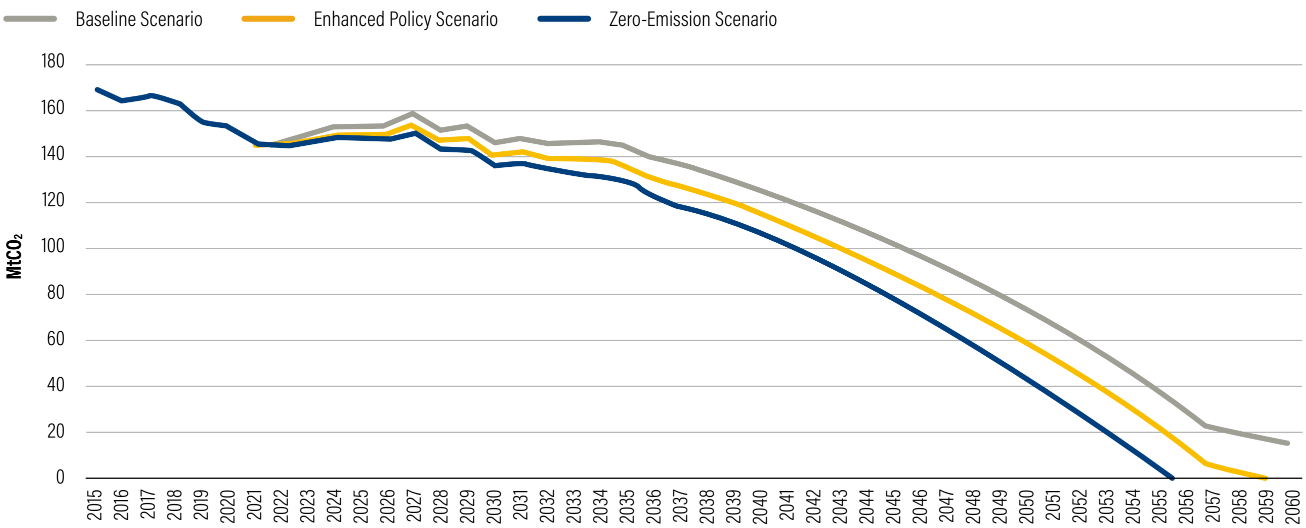
In the Baseline Scenario, the total energy consumption in the manufacturing industrial sector would reach 110.4 million tonnes of coal equivalent in 2025 and 123.5 million tonnes of coal equivalent in 2030. 'New Major Projects', ones with energy consumption greater than 10,000 tonnes of coal equivalent and approved by the Energy Bureau of Guangdong Province, would lead to an increase of 29.4 million tonnes of carbon emissions in the Pearl River Delta from 2021 to 2030, while carbon emissions from other projects would increase 12.8 million tonnes. The total carbon emissions in the manufacturing industrial sector would reach 170.10 million tonnes of carbon dioxide in 2025 and 188.30 million tonnes of carbon dioxide in

Figure 9 | **Incremental industrial carbon emissions under the Baseline Scenario without emissions-reduction intervention**



Notes: 'New Major Projects' are projects with energy consumption greater than 10,000 tonnes of coal equivalent and approved by Energy Bureau of Guangdong Province before 2021.
$MtCO_2$ = million tonnes of carbon dioxide.
Source: Project team.

Figure 10 | **Scenario analysis for industrial carbon emissions**



Note: $MtCO_2$ = million tonnes of carbon dioxide.
Source: Project team.

2030 (see Figure 9) under the Baseline Scenario.

The three scenarios will take different scenario settings in terms of energy intensity (energy consumption per unit of industrial value added), phasing down fossil fuel use, adoption of energy conservation technologies, and decarbonisation of power and heating systems. All three scenarios will peak carbon emissions by 2027. This is because the new Huizhou ExxonMobil Ethylene Phase I Project will be put into operation around 2025, with a huge impact on energy usage and the carbon emissions peak. Peak emissions values are 154.2 million tonnes for the Baseline Scenario, 150 million tonnes for the Enhanced Policy Scenario and 147.2 million tonnes for the Zero-Emission Scenario. However, the Baseline Scenario will not achieve carbon neutrality by 2060, with a residual 16 million tonnes of emissions. The GBA's manufacturing industrial sector is expected to achieve carbon neutrality between 2055 and 2060 under the Enhanced Policy and Zero-Emission Scenarios (see Figure 10).

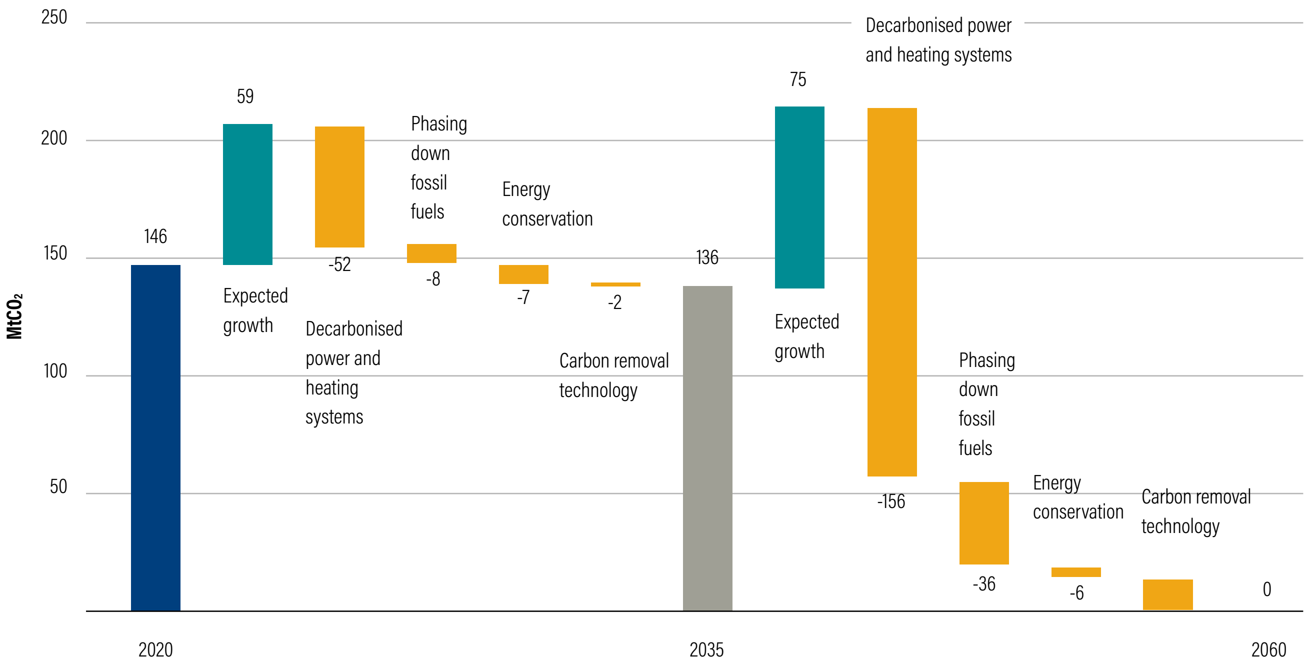
Decarbonised power and heating systems will contribute the largest emissions-reduction potential

Following the scenario settings of the Zero-Emission Scenario, we analysed the decarbonisation pathways of manufacturing (see Figure 11). In general, the largest contribution to carbon neutrality comes from decarbonised power generation and heating systems, accounting for 74 percent of carbon reductions, since electricity constitutes the majority of energy consumption in the GBA's manufacturing. Power and heating generation can be decarbonised by leveraging advancements in low-carbon electricity from the grid and switching to renewable energy to generate electricity and heating. Thermal processes should be decarbonised using decarbonised sources of electricity.

Phasing down fossil fuels is the second-largest contributor to emissions reduction

Although phasing down fossil fuel in production contributes less before 2035, it will contribute more in the medium and long term to reaching carbon neutrality, accounting for 16 percent of carbon reductions. This can be achieved by substituting low- and no-carbon fuel and feedstocks to reduce emissions for industrial processes. In the short and medium term, fossil fuel use will be phased down by shifting to less-carbon-intensive fuels, such as natural gas, which will require the development of fuel-flexible industrial processes. Technical improvements that

Figure 11 | **Contribution of decarbonisation pathways in GBA industries**



Notes: GBA = Guangdong–Hong Kong–Macao Greater Bay Area; $MtCO_2$ = million tonnes of carbon dioxide.
Source: Project team.

can lower emissions include upgrading furnaces to consume natural gas and use waste heat. In 2020, coal and oil consumption for manufacturing in the GBA produced 18.98 million tonnes and 17.93 million tonnes of carbon dioxide, respectively, calculated based on the statistical yearbook of each city in 2021 (see Figure 6). Natural gas, a less carbon-intensive fuel, can replace coal in ceramic kilns, papermaking and textile boilers in the short and medium term, but technological limitations make it hard to phase down coal and oil consumption in the cement, petrochemical and chemical industries.

In the long term, phasing down fossil fuel needs to lead to the phaseout of all fossil fuels, including coal, natural gas and oil. This requires technical improvements in manufacturing processes to eliminate coal and oil consumption in the cement and petrochemical and chemical industries. Innovation in raw materials production can also reduce the use of fossil fuels to produce hydrogen, methanol and ammonia. The petrochemical and chemical industries can integrate hydrogen fuels and feedstocks into production processes and use biomass to produce bio-based fuels, such as biodiesel.

Even so, fossil fuel consumption cannot be completely phased out in the GBA by 2060. Though this consumption cannot be reduced directly (McKinsey Greater China 2021), it can be offset through carbon dioxide removal technologies, such as carbon capture, utilisation and storage. Under the Zero-Emission Scenario, coal, oil and natural gas are estimated to emit 4.3 million tonnes, 7.7 million tonnes and 1.5 million tonnes of carbon dioxide, respectively, in the GBA by 2060.

SECTION 3

A CARBON NEUTRALITY ROADMAP FOR ROAD TRANSPORT IN THE GBA

In 2019, carbon emissions from transportation in Guangdong Province accounted for 18.7 percent of energy-related emissions (China Energy Statistical Yearbook Committee 2020). The numbers for the GBA cities are even bigger. In 2017, transport contributed 31 percent of the GBA's total energy consumption (Xie et al. 2020) and 36 percent of Shenzhen's total emissions. A future of sustained rapid development in the GBA will bring even greater demand for transportation, so developing low-carbon transportation and new-energy vehicles (NEVs) for the region will be urgent[3].

Current status of road transport in the GBA

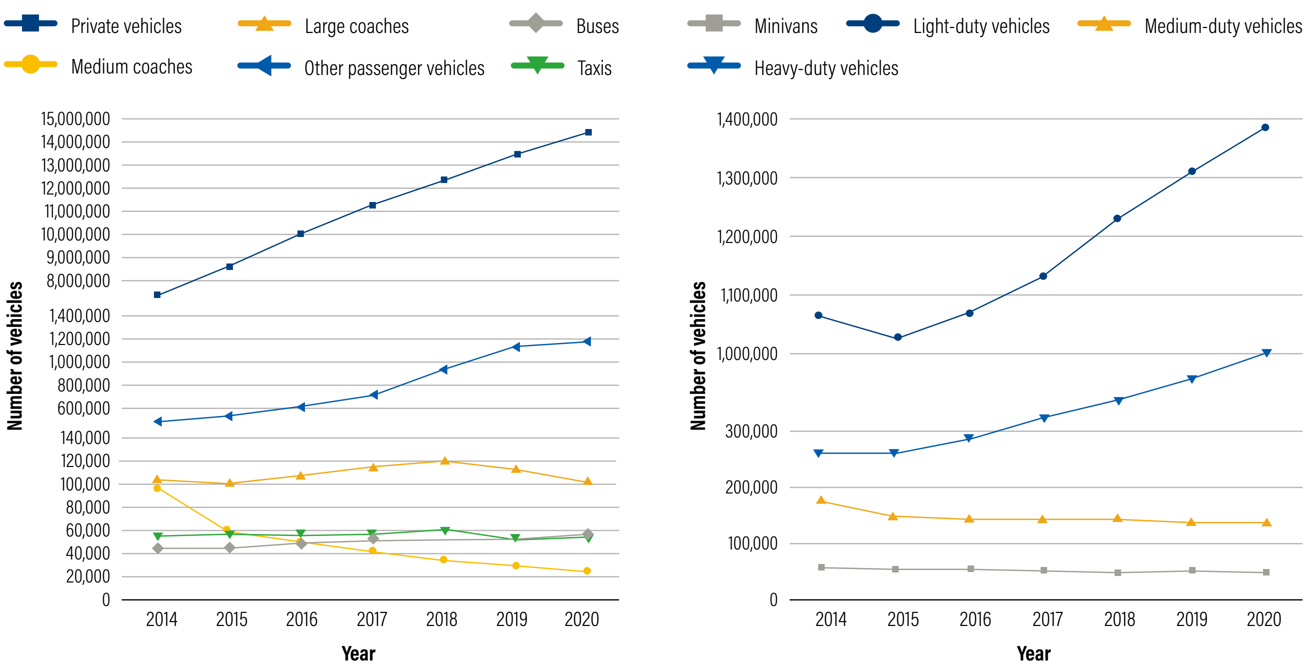
Private cars, light-duty trucks and heavy-duty trucks continue to proliferate and are the main sources of carbon emissions

Most vehicles in the GBA are now privately owned (Guangdong Provincial Bureau of Statistics 2021). Between 2015 and 2020, the number of passenger cars soared, with the number of private vehicles, ride-hailing vehicles[4], government-owned vehicles and corporate-owned vehicles trending sharply upward (see Figure 12). The number of private vehicles on the roads jumped 54 percent during that period, growing an average of 9 percent per year. Medium-sized coaches and taxis became slightly scarcer, while the number of buses grew under government policies that have prioritised public transport.

The number of freight vehicles climbed 48 percent between 2015 and 2020, 8.1 percent on average every year (Statistical Yearbook of Guangdong Province, 2015–21). Annual growth rates were higher for heavy-duty vehicles (12 percent) than for light-duty vehicles (8.1 percent), as shown in Figure 12.

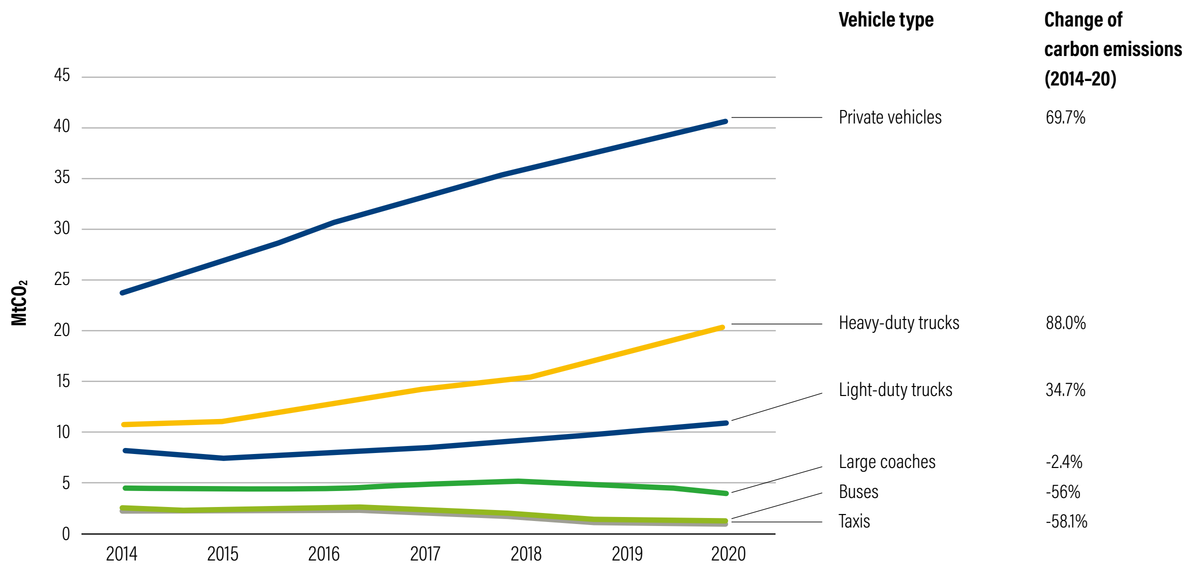
Figure 13 shows carbon emissions from taxis, buses, large coaches, private vehicles, light-duty trucks and heavy-duty trucks from 2014 to 2020. Emissions from taxis, buses and large coaches trended downward. Emissions from taxis and buses fell sharply, by more than 58 percent and 55 percent, respectively, because so many taxis and buses are now hybrids or electric vehicles (EVs). By 2020, thanks to the promotion and widespread adoption of new-energy vehicles (NEVs), every bus in the GBA and over half of all taxis in the region ran on electricity, and Shenzhen took the lead in reaching 100 percent penetration by 2020 (Guangdong Provincial Energy Bureau 2021). In contrast, the vast majority of privately owned passenger vehicles and freight are still powered by internal combustion engines. Private cars, light-duty trucks and heavy-duty trucks not only accounted for a high proportion of carbon emissions but also logged the fastest growth in emissions from 2014 to 2020, leaping by 70 percent, 35 percent and 88 percent, respectively. Curbing emissions from these three types of vehicles will be vital in addressing emissions from road transport.

Figure 12 | **Passenger vehicle and freight fleet by types in the GBA**



Notes: 'Other passenger vehicles' include ride-hailing vehicles, government vehicles and corporate vehicles. GBA = Guangdong–Hong Kong–Macao Greater Bay Area.
Source: Statistical Yearbook of Guangdong Province, 2015–21.

Figure 13 | **Carbon emissions of road transport in the GBA by vehicle type**



Notes: $MtCO_2$ = million tonnes of carbon dioxide; GBA = Guangdong–Hong Kong–Macao Greater Bay Area.
Source: Project team calculation based on vehicle fleet and annual mileage of vehicles.

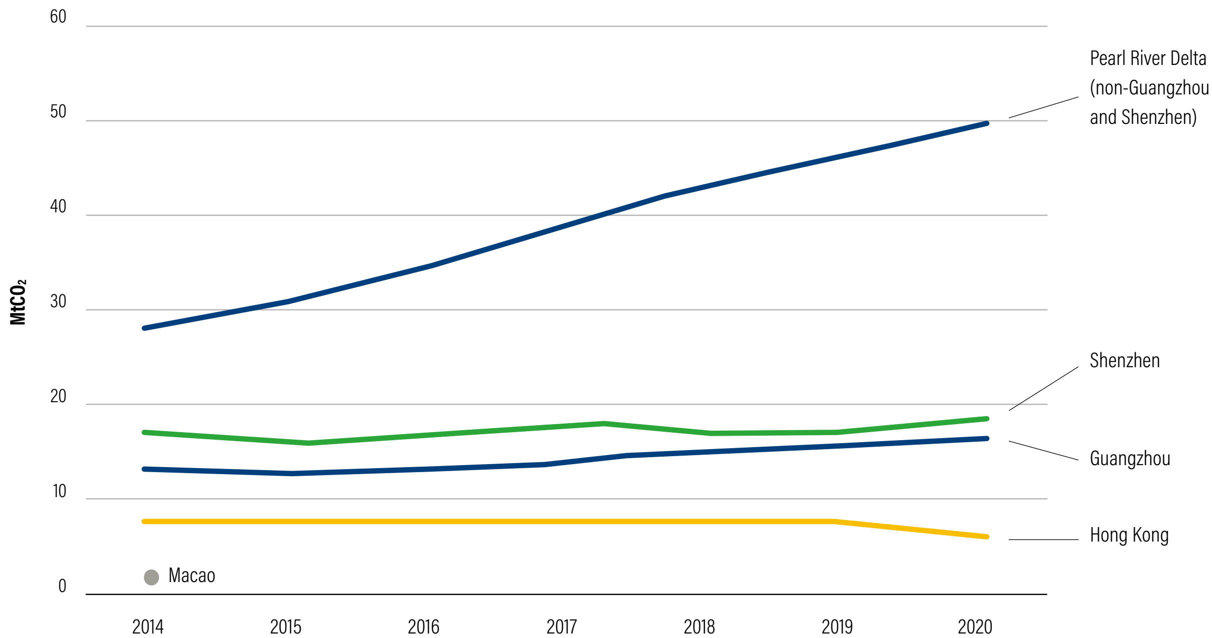
Surging emissions from GBA cities outside Guangzhou, Shenzhen and Hong Kong pose a major challenge to peaking emissions from road transport in the GBA

The cities of Guangzhou, Shenzhen and Hong Kong are attempting to slow emissions by encouraging people to switch to new-energy vehicles. Shenzhen and Guangzhou have enacted policies that restrict the number of traditional vehicles that can be sold but allow unlimited purchases of NEVs. Shenzhen allows only 80,000 and 100,000 new internal combustion engine cars to be sold per year, but people can buy as many hybrid and pure electric vehicles as they like (People's Government of Shenzhen 2019). This has constrained energy consumption in the transport sector from fossil fuels. Between 2015 and 2020, Shenzhen's consumption rose 11 percent.

Because of its integrated transit and land-use planning and the well-developed public transit system, as well as the heavy tax on private cars, the number of cars in Hong Kong's licensed vehicle fleet only increased 10.2 percent between 2014 and 2020, from 728,263 to 802,698 (Hong Kong Transport Department 2022). In addition, Hong Kong's overall transport emissions actually decreased 10 percent, from 7.4 million tonnes in 2015 to 6.6 million tonnes in 2020. This is mainly due to Hong Kong's promotion of vehicle electrification through technological readiness and ample incentives, while managing the ownership and use of private cars through travel demand management measures, including the vehicle First Registration Tax, annual licence fees, parking space purchase costs and road (tunnel) tolls (Xue et al. 2022).

These cities have done much more to slow energy consumption and emissions from transport than the GBA as a whole, which saw its energy consumption for transport jump 42 percent between 2015 and 2020. Figure 14 shows how most growth in carbon emissions has taken place in areas of the GBA outside the cities of Guangzhou, Shenzhen and Hong Kong. These other jurisdictions do not cap purchases of private cars. Their rail transit networks and green transportation infrastructure are less developed, and more and more private vehicles are crowding the roads. The share of transport with low-carbon emissions is low and shrinking as private internal combustion cars gain popularity. These other cities lack economic incentives, promotions and EV charging station infrastructure to encourage people to switch

Figure 14 | **Carbon emissions of road transport in the GBA by region**



Notes: GBA = Guangdong–Hong Kong–Macao Greater Bay Area; $MtCO_2$=million tonnes of carbon dioxide.
Sources: Project team calculated based on Guangdong Statistical Yearbook, 2015–21; Environment and Ecology Bureau (2022); and Ministry of Ecology and Environment of People's Republic of China (2018).

to NEVs. Their carbon emissions shot up 61 percent from 2015 to 2020, roughly twice as fast as emissions from Guangzhou (up 31 percent) and more than five and a half times faster than emissions from Shenzhen (up just 11 percent).

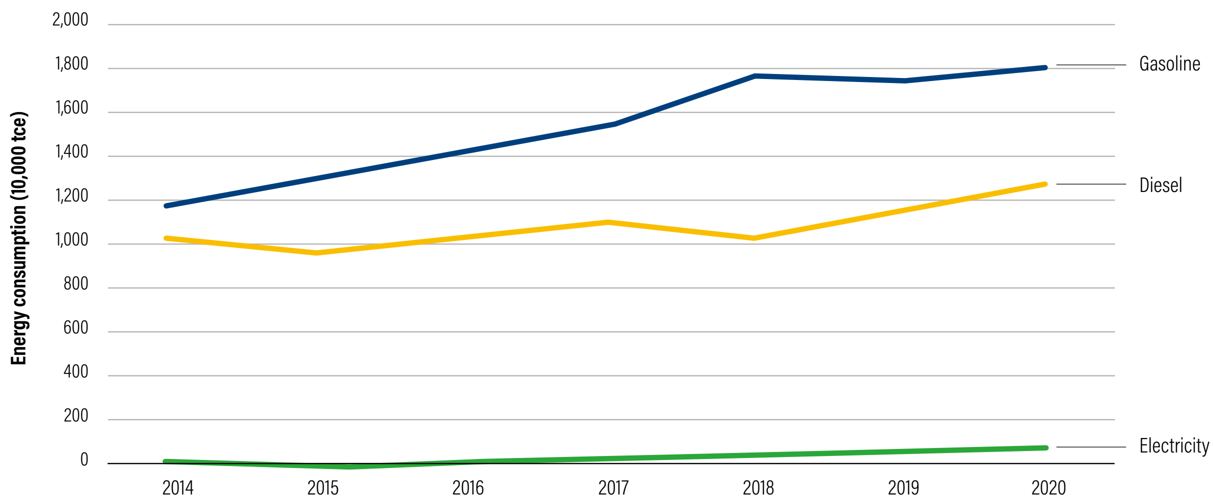
Passenger vehicles have begun to transition from traditional fuels to clean energy, but freight vehicles are still dominated by diesel

Gasoline-powered vehicles dominate the fleet, as shown in Figure 15. Between 2014 and 2020, gasoline consumption increased by more than 38 percent, and diesel consumption increased moderately over the same period, by about 23 percent (Guangdong Provincial Bureau of Statistics 2021). The method of calculation is included in Appendix C.

Among passenger vehicles, there has been a gradual transition from gasoline to cleaner fuels, from natural gas, to hybrid, to electric vehicles. More than 1 out of 10 private cars in Guangzhou and Shenzhen are NEVs, and the share of private cars registered in Hong Kong powered by electricity nearly tripled between 2017 and 2021, jumping from 8.8 percent to 24.4 percent. During the 13th Five-Year Plan, much of the efforts to develop greener, more sustainable transportation in the GBA focused on NEVs for public transit. Although public transit's share of electricity consumption in road transport remains small, it had doubled to 2 percent by 2020.

However, freight transport is still dominated by diesel vehicles, which account for more than 90 percent of medium-sized and heavy-duty trucks in the GBA. While electric heavy-duty trucks have been tested, their cost and limited range remain obstacles to widespread adoption. However, electric light-duty trucks are expected to gain popularity quickly thanks to recent improvements in electric vehicle technology. Hydrogen fuel cell vehicles are another development path for new-energy trucks. At present, some cities such as Foshan are carrying out small-scale demonstration projects, but there is still a long way to go before large-scale commercial operation.

Figure 15 | **Road transport energy consumption in the GBA by fuel**



Notes: GBA = Guangdong–Hong Kong–Macao Greater Bay Area; tce = tonnes of coal equivalent.
Source: Project team calculation based on Guangdong Statistical Yearbook, 2015–21.

Current road transport policies with gaps and deficiencies in six aspects

During the 13th FYP, the road transportation sector in the GBA has made progress in conserving energy and reducing emissions. However, surging demand for transportation is complicating efforts to peak emissions and reach carbon neutrality.

1. The proportion of non-fossil energy in the power sector is still low. In Guangdong Province, the share of fossil fuel in power generation remained at about 55 percent, and the share of non-fossil fuel (hydropower, nuclear, solar, wind and biomass) gradually increased to 23 percent from 2018 to 2020 (Guangdong Power Exchange Centre 2022).

2. Current hydrogen energy production is mainly based on coal-to-hydrogen (90 percent), industrial by-product hydrogen (7.4 percent) and only 0.03 percent from green hydrogen.

3. The penetration rate of NEVs in the GBA is uneven, with Guangzhou, Shenzhen and Hong Kong far ahead of other GBA cities. Progress in these other cities is hampered by low demand, scant infrastructure and the absence of policies to promote NEVs. In addition, transportation-related planning in the GBA's cities still lacks clear goals and measures for promoting zero-emission medium- and heavy-duty trucks, which are the key to reducing emissions in the medium to long term.

4. Inadequate infrastructure (such as EV charging stations) is hindering wider adoption of NEVs, particularly in smaller cities (Huang and Qian 2018). Cities outside of Guangzhou, Shenzhen and Hong Kong have used subsidies to make EVs more affordable. However, without adequate charging networks, promoting EVs has been difficult (Guangdong Provincial Energy Bureau 2021).

5. The share of public transit set in the 14th FYP is insufficient in some cities in the GBA. Hong Kong has achieved 90 percent of passenger transport made by public transit (Environment Bureau of Hong Kong 2017), and Guangzhou, Shenzhen and Foshan have set city-wide goals of making public transit over 50 percent of motorised travel by 2025 (Guangzhou Transportation Bureau 2021; Shenzhen Transportation Bureau 2022; Foshan Municipal People's Government Office 2021). However, for their central urban areas, Huizhou, Zhaoqing and Jiangmen have only set public transport targets of 35 percent to 50 percent by

2025. Dongguan and Zhongshan have not yet established a quantitative goal of prioritising green mobility through public transport.

6. The absence of a robust rail network for transporting freight in the GBA means a lot of cargo is shipped by truck. In the GBA, only 1.15 percent of freight moves by rail, far below the national average of 9.06 percent, and that share fell between 2015 and 2020. The GBA has several hub cities for freight transport, including Guangzhou, Shenzhen and Foshan, and they are expected to increase the volume of freight transport. However, these hub cities alone cannot effectively offset the GBA's heavy and growing reliance on carbon-intensive road transport for freight.

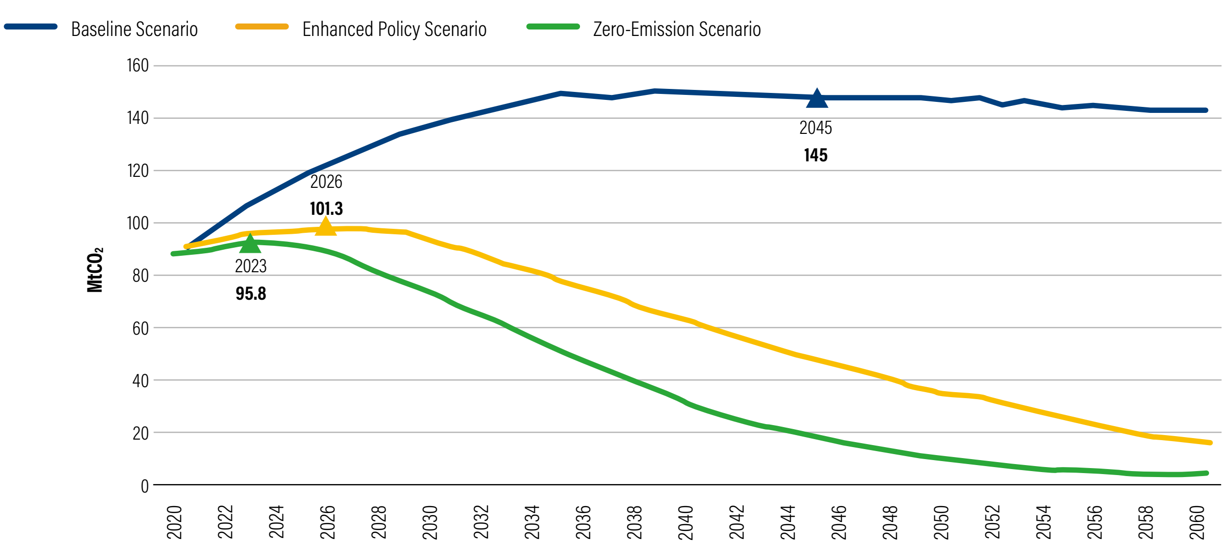
Scenario analysis and emissions-reduction potential

Stricter policies could allow the GBA's road transport sector to peak emissions as early as 2023

Based on analysis of existing policies and identified policy gaps, this study sets up three scenarios: the Baseline Scenario, the Enhanced Policy Scenario and the Zero-Emission Scenario, based on different assumptions for promotion of NEVs, fuel-economy improvement, mode shift, annual mileage and share of clean energy in upstream electricity and hydrogen production. Due to model limitations, this study does not consider other measures that may affect carbon emissions from road transport in the GBA, such as autonomous driving, shared mobility, transportation carbon pricing and zero-emission zones (for detailed methodologies, see Appendix C).

Figure 16 shows the results of the scenario analysis. Under the Baseline Scenario, carbon emissions from road transport in the GBA will continue to rise before peaking in 2045 at 145 million tonnes. In 2060, the GBA would still be emitting 140 million tonnes of CO_2 annually, 1.86 times as much as in 2020. Under the Enhanced Policy Scenario, road transport carbon emissions in the GBA would rise 31 percent above 2020 levels, peak around 2026 at 101.3 million tonnes, then fall to 20 million tonnes of CO_2—80 percent below the 2020 level—by 2060. In the Zero-Emission Scenario, road transport carbon emissions in the GBA would peak in 2023 at 95.8 million tonnes and reach a near 100 percent reduction by 2060. Our analysis shows that carbon neutrality by 2060 is possible, but it will require greater determination and earlier action. The peak emissions year and emissions change for different sub-regions in the GBA are shown in Table 2.

Figure 16 | **Road transport carbon emissions projections in the GBA under different scenarios**



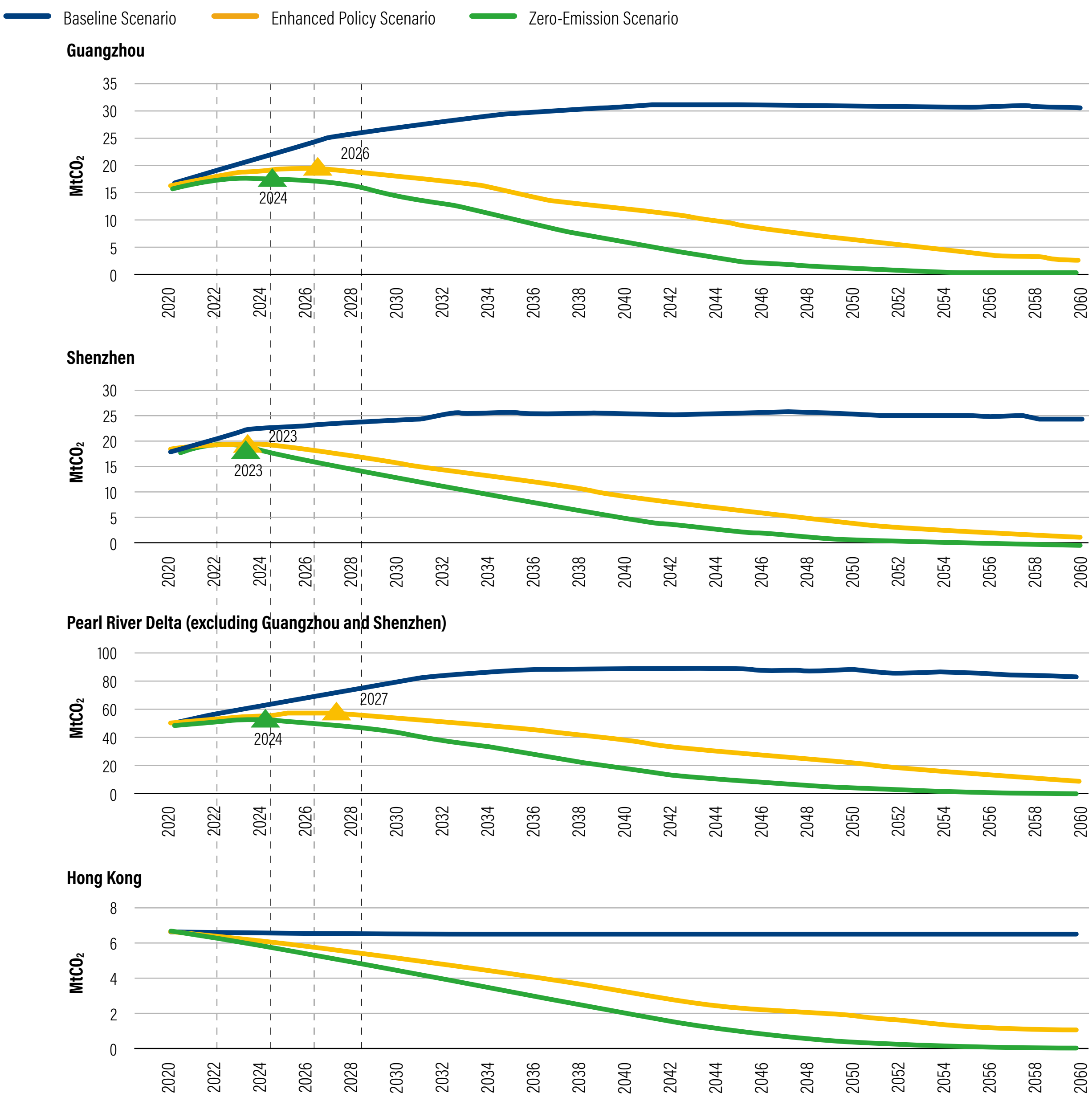
Note: $MtCO_2$ = million tonnes of carbon dioxide.
Source: Project team.

Outside of Shenzhen (which is ahead of other cities in road transport decarbonisation), more aggressive emissions-reduction measures have a dramatic impact on emissions

Because transport development varies among cities, this study categorises the GBA cities into three groups for analysis: Guangzhou, Shenzhen, and the other cities (excluding Guangzhou, Shenzhen and Hong Kong), as shown in Figure 17.

Guangzhou will peak its road transport emissions by 2026 under the Enhanced Policy Scenario and by 2024 under the Zero-Emission Scenario. Shenzhen could peak its emissions by 2023 under both scenarios. Other cities in the Pearl River Delta region will peak road transport emissions by 2024 or 2027, the earlier year being possible if stricter measures are adopted.

Figure 17 | **Road transport carbon emissions projections for Guangzhou, Shenzhen, Hong Kong and other Pearl River Delta cities**



Note: $MtCO_2$ = million tonnes of carbon dioxide.
Sources: Project team and Hong Kong Energy Policy Simulator (EPS) (https://hongkong.energypolicy.solutions).

Table 2 | **Peak year and emissions change when peaking for different regions in the GBA under the Enhanced Policy Scenario and the Zero-Emission Scenario**

REGION	PEAK YEAR		EMISSIONS CHANGE WHEN PEAKING COMPARED WITH 2020 LEVEL	
	ENHANCED POLICY SCENARIO	ZERO-EMISSION SCENARIO	ENHANCED POLICY SCENARIO	ZERO-EMISSION SCENARIO
Guangzhou	2026	2024	18.6%	8.6%
Shenzhen	2023	2023	8.5%	4.4%
Pearl River Delta (excluding Guangzhou and Shenzhen)	2027	2024	14.7%	5.3%
Hong Kong	Emissions peaked	Emissions peaked	N/A	N/A
GBA	2026	2023	10.7%	4.7%

Note: GBA = Guangdong–Hong Kong–Macao Greater Bay Area.
Source: Project team.

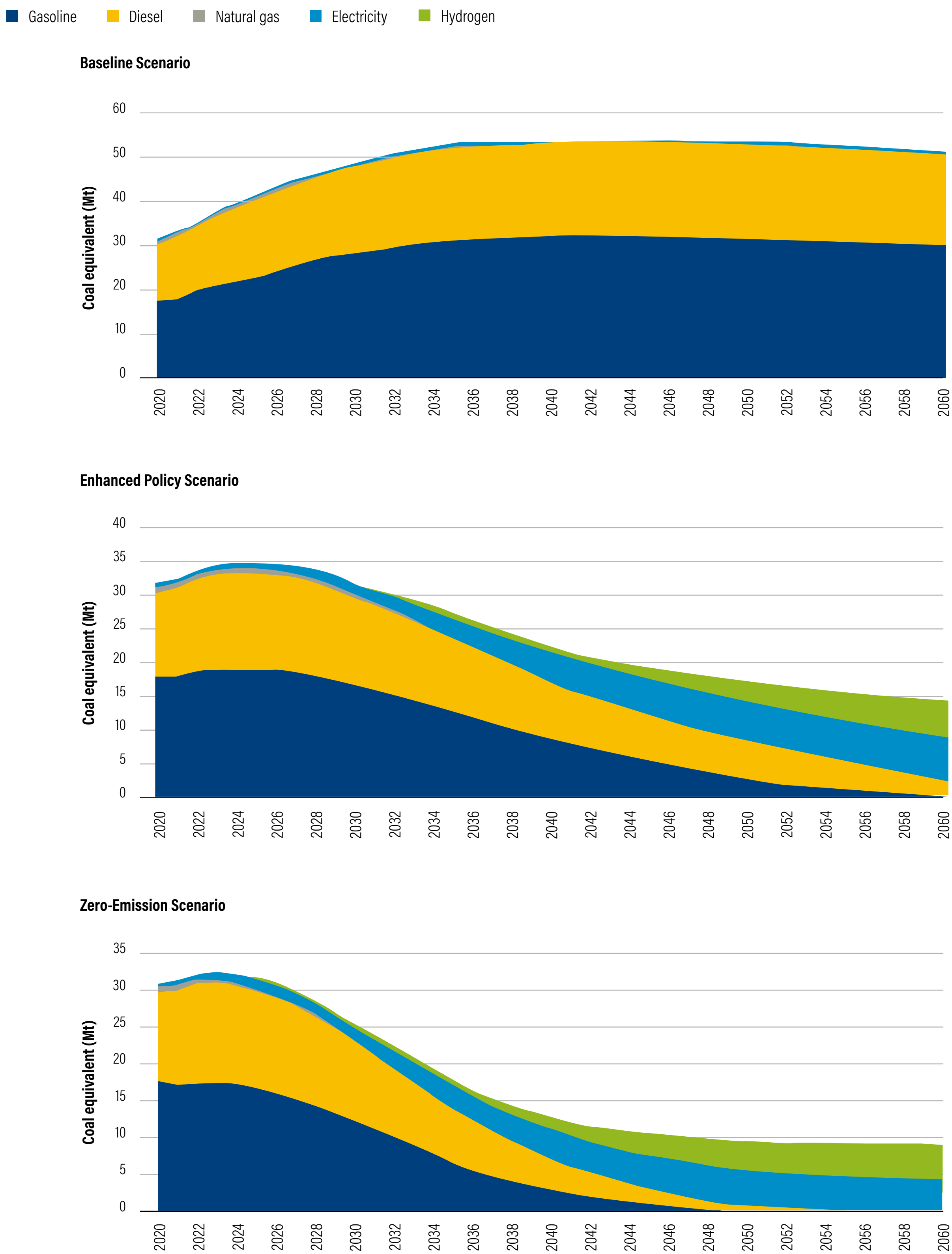
Stricter policies would also lower the emissions peak. For example, Guangzhou's emissions would peak in 2024 under the Zero-Emission Scenario after rising just 8.6 percent above the 2020 level. In contrast, the emissions peak in 2026 under the Enhanced Policy Scenario is 18.6 percent above the 2020 level. More data for the GBA cities are presented in Table 2.

If the level of mitigation ambition increases, the energy mix of road transport in the GBA will be much cleaner in the future

Under both the Enhanced Policy Scenario and the Zero-Emission Scenario, the proportion of gasoline and diesel consumed drops rapidly after it peaks, as shown in Figure 18. Consumption of electricity and hydrogen will surpass that of gasoline and diesel, making electricity and hydrogen the GBA transportation sector's main sources of energy by 2050 under the Enhanced Policy Scenario and by 2041 under the Zero-Emission Scenario. This underscores the importance of upgrading the GBA's road transport infrastructure (vehicle-charging and hydrogen-fuelling stations), especially in Guangzhou and Shenzhen, where NEVs are developing rapidly.

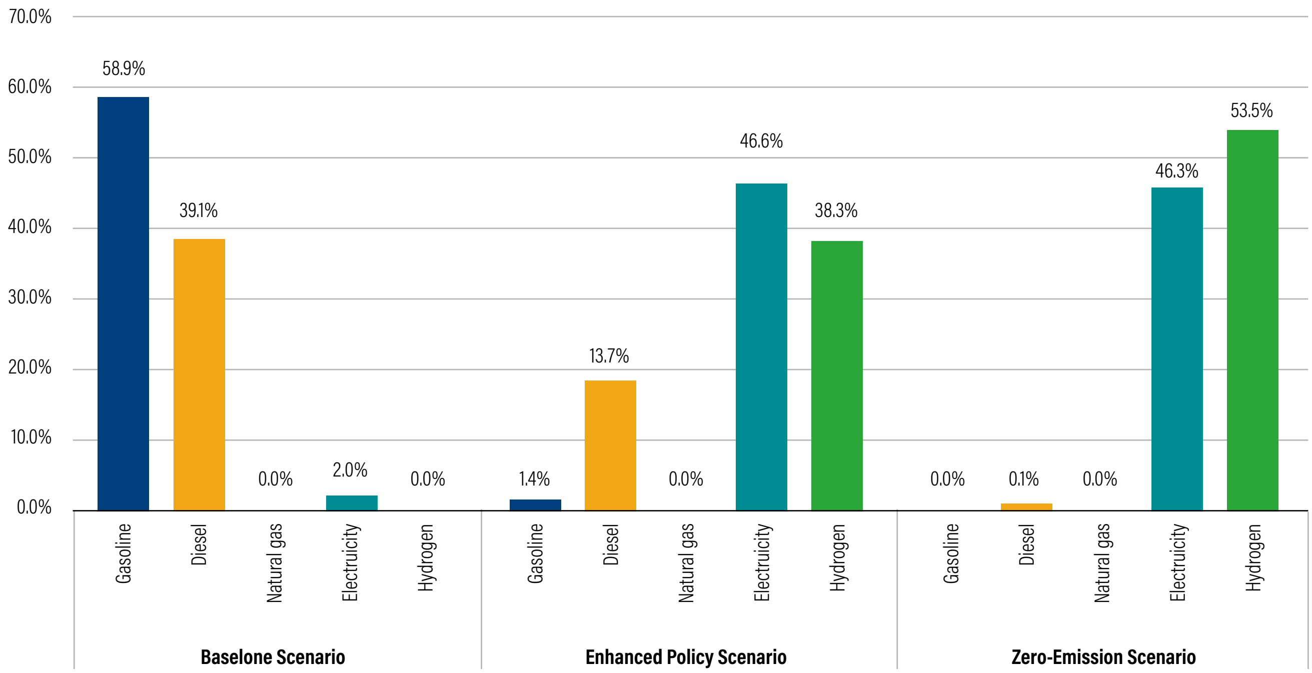
The main difference between the Enhanced Policy Scenario and the Zero-Emission Scenario is the choice of fuel for medium- and heavy-duty trucks, which is reflected in the share of diesel and hydrogen. Under the Enhanced Policy Scenario, some gasoline and diesel freight vehicles remain in use in 2060. Under the Zero-Emission Scenario, all medium- and heavy-duty trucks are electrical or fuel-cell vehicles by 2060. Due to the requirements of long-distance transportation, electric heavy-duty trucks have a higher life-cycle cost, insufficient charging infrastructure, and poor operation performance. Hydrogen fuel cell heavy-duty trucks will be the solution, so the share of hydrogen in the Zero-Emission Scenario will be higher than in the Enhanced Policy Scenario (see Figure 19). This requires that Guangdong Province overcome the challenges of an insufficient hydrogen supply and the high cost of hydrogen storage and transportation.

Figure 18 | **Energy structure of road transport in the GBA under the Baseline Scenario, Enhanced Policy Scenario and Zero-Emission Scenario**



Notes: GBA = Guangdong–Hong Kong–Macao Greater Bay Area; Mt = million tonnes.
Source: Project team.

Figure 19 | **Proportion of different energy sources for road vehicles in the GBA by 2060 under the Baseline Scenario, Enhanced Policy Scenario and Zero-Emission Scenario**



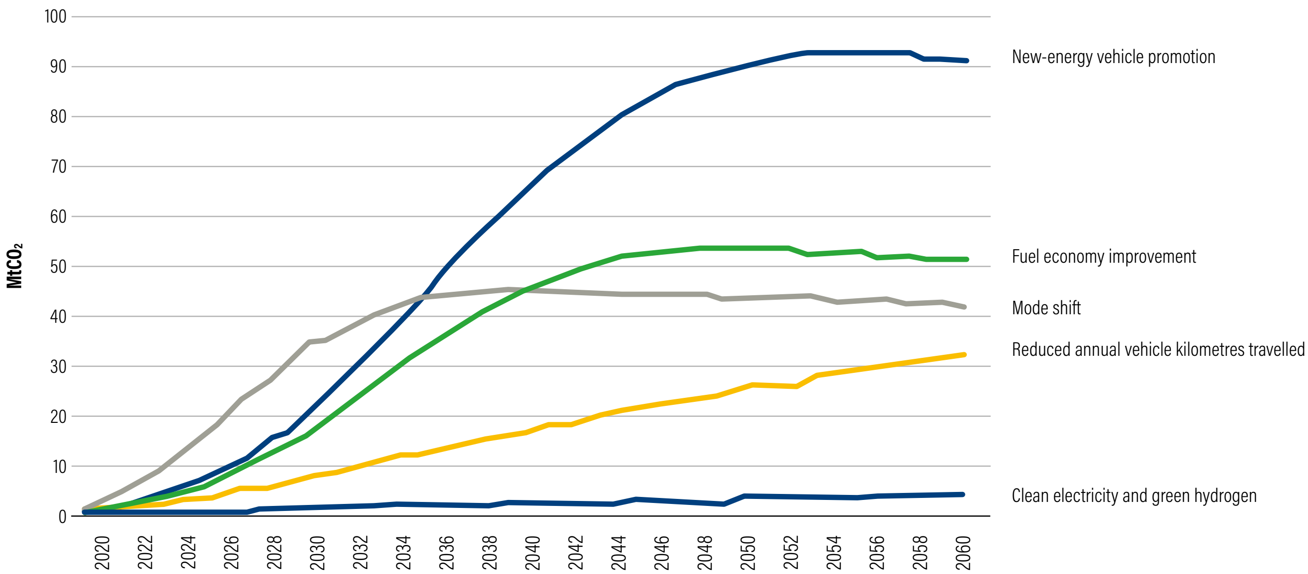
Notes: GBA = Guangdong–Hong Kong–Macao Greater Bay Area.
Source: Project team.

A mode shift can generate the largest emissions-reduction potential in the short term, while promotion of NEVs is the largest contributor in the medium and long term

This sub-section estimates the emissions-reduction potential of various mitigation measures under the Zero-Emission Scenario. We analysed emissions-reduction potential from five measures when any one of the measures is implemented alone. *Emissions-reduction potential* refers to the amount of carbon emissions reduction when implementing one measure alone in the Zero-Emission Scenario compared with the Baseline Scenario. Measuring the emissions-reduction potential can eliminate the correlation and mutual influence between various mitigation measures (see Figure 20).

- NEV promotion: In the long run, shifting the vehicle fleet to a high proportion of NEVs has the greatest potential to reduce carbon emissions to around 90 million tonnes, and this effect increases over time.
- Fuel economy improvement: The potential for fuel economy improvements to cut emissions will rise in the short and medium terms before decreasing, as technologies for increasing the efficiency of internal combustion engines and making vehicles lighter gradually reach their limits.
- Mode shifts: Shifting passenger transport from private vehicles to public transit and shifting road transport to railway and ships would bring larger emissions reductions than NEV promotion and fuel economy improvement before 2030. This would require major investments in railway construction; more aggressive policies (e.g., limiting the total number of private vehicles and increasing the vehicle purchase tax) to expand public transit services and shift freight transport from highways to railways and waterways; and multimodal transport, as well as green mobility in the Greater Bay Area.
- Clean electricity and green hydrogen: The effects of clean electricity and green hydrogen

Figure 20 | **Estimate of emissions-reduction potential of different measures under the Zero-Emission Scenario compared with the Baseline Scenario**



Notes: $MtCO_2$=million tonnes of carbon dioxide.
Source: Project team.

will be smallest without the promotion of NEVs. However, the combination of clean electricity and green hydrogen and promoting NEVs can dramatically lower emissions, because clean electricity and green hydrogen can make NEVs have lower carbon emissions in use.

Overall, promoting NEVs has the greatest potential to reduce emissions in the medium and long terms. Mode shifts will have the greatest impact in the short term, but their effects will plateau after 2035. In the short term, improving fuel economy will have less of an impact on emissions than mode shifts. Its effects will plateau later, however, and its overall emissions-reduction effect is slightly greater than that of mode shifts.

Since private cars are the key target for carbon neutrality, local governments should combine promoting NEVs and mode-shifting measures to reduce emissions

As discussed earlier in this section, the number of private cars in the GBA's cities outside Guangzhou, Shenzhen and Hong Kong has grown rapidly and the carbon emissions of private cars has also increased dramatically in the last five years (Figure 13). Emissions from private cars can be reduced by a combination of mode shifting and promoting NEVs; each city in the GBA should take different measures based on its situation.

Guangzhou, Shenzhen and Hong Kong have higher penetration rates of NEVs than other cities in the GBA, but the share of electric vehicles still accounts for only 10 percent of private cars (Guangdong Provincial Energy Bureau 2021). These cities still need to accelerate their promotion of NEVs to replace internal combustion vehicles and should further emphasise the construction of NEV infrastructure (i.e., charging stations and charging piles) to develop an advanced charging service network system. Other cities outside Guangzhou, Shenzhen and Hong Kong should prioritise mode shifting by improving public transit services, expanding rail transit and promoting green mobility. Local governments should regulate the total number of internal combustion cars, provide subsidies and tax concessions for purchasing NEVs, and promote 'mobility-as-a-service'[5]. In addition, governments in the GBA need to adopt preferential policies (i.e., land supply and tax incentives) to attract private investment in infrastructure construction.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SECTION 4

A CARBON NEUTRALITY ROADMAP FOR BUILDINGS IN THE GBA

The buildings sector accounted for 13 percent of energy consumption and 22 percent of carbon emissions in the GBA in 2020 (Xie et al. 2020). This section analyses how addressing the decarbonisation pathways of building operation can accelerate carbon peaking and carbon neutrality.

Current status of the buildings sector in the GBA

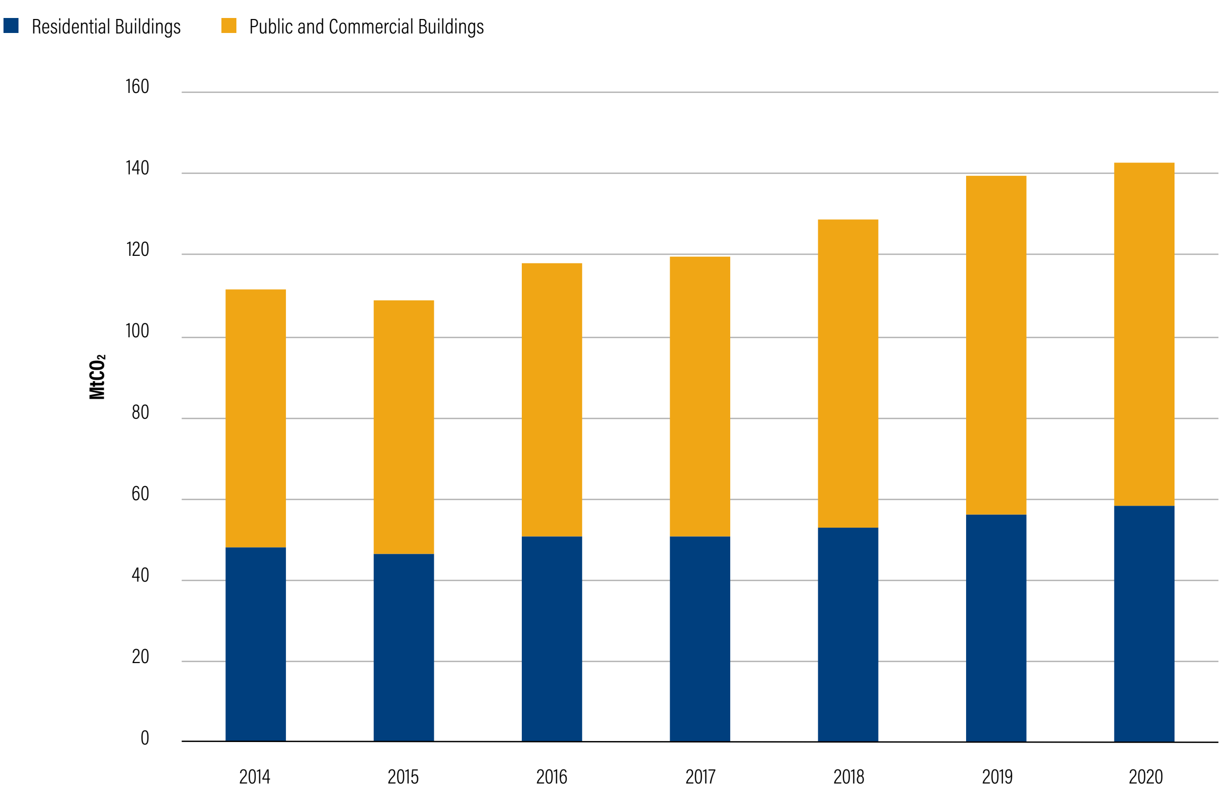
Carbon emissions from buildings in the GBA rose by 31 percent from 2015 to 2020

From 2015 to 2020, buildings' energy consumption in the GBA increased by 31.3 percent, from 28.2 to 37.0 million tonnes of coal equivalent. Buildings' energy consumption had the highest growth rate from 2019 to 2020. Although it declined following the outbreak of COVID-19, it is likely to rebound in the pandemic's aftermath. Similarly, buildings sector emissions in the GBA increased by 31.3 percent, from 108.9 to 142.9 million tonnes of CO_2, between 2015 and 2020, at an annual growth rate of 5.6 percent[6].

Public and commercial buildings were responsible for around 60 percent of total emissions in the buildings sector from 2014 to 2020, with residential buildings accounting for the remainder (Figure 21). Emissions from public and commercial buildings leapt from 62.1 to 84.4 million tonnes of CO_2, growing at an annual rate of 6.3 percent, faster than the rate of residential buildings, 4.6 percent.

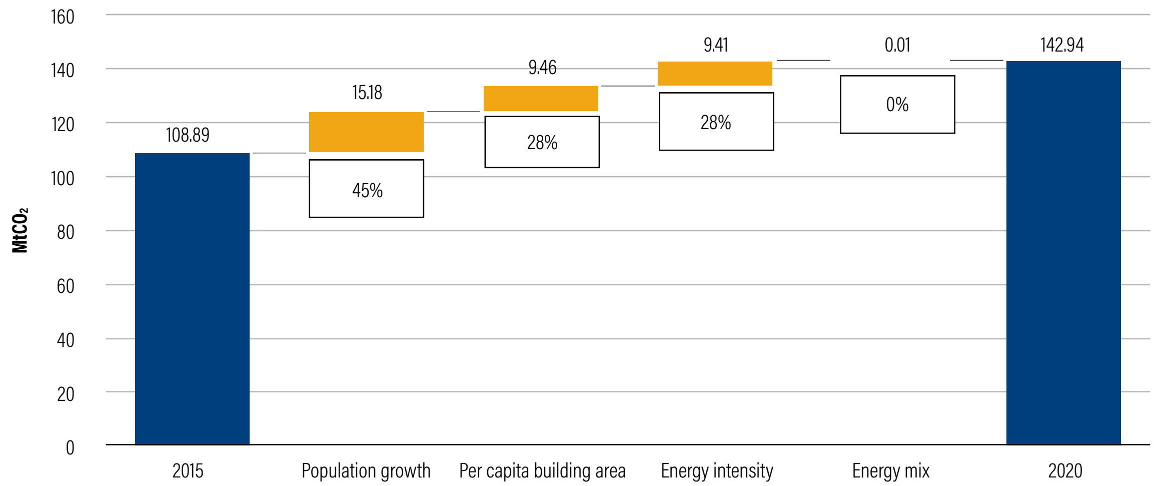
In the past five years, population growth has been the main driver for buildings sector emissions in the GBA (China Association of Building Energy Efficiency and Chongqing University 2022). Figure 22 shows that among the four factors driving carbon emissions, population growth is the most significant factor, responsible for 45 percent of emissions increase. Building area per capita and energy intensity per building area each contributed 28 percent to the increase.

Figure 21 | **Carbon emissions of buildings sector by building type in the GBA (2014–20)**



Notes: GBA = Guangdong–Hong Kong–Macao Greater Bay Area; $MtCO_2$=million tonnes of carbon dioxide.
Source: Project team calculation based on the statistical yearbook of each city, 2015–21.

Figure 22 | **Carbon emissions increase split by different drivers in the buildings sector (2015–20)**

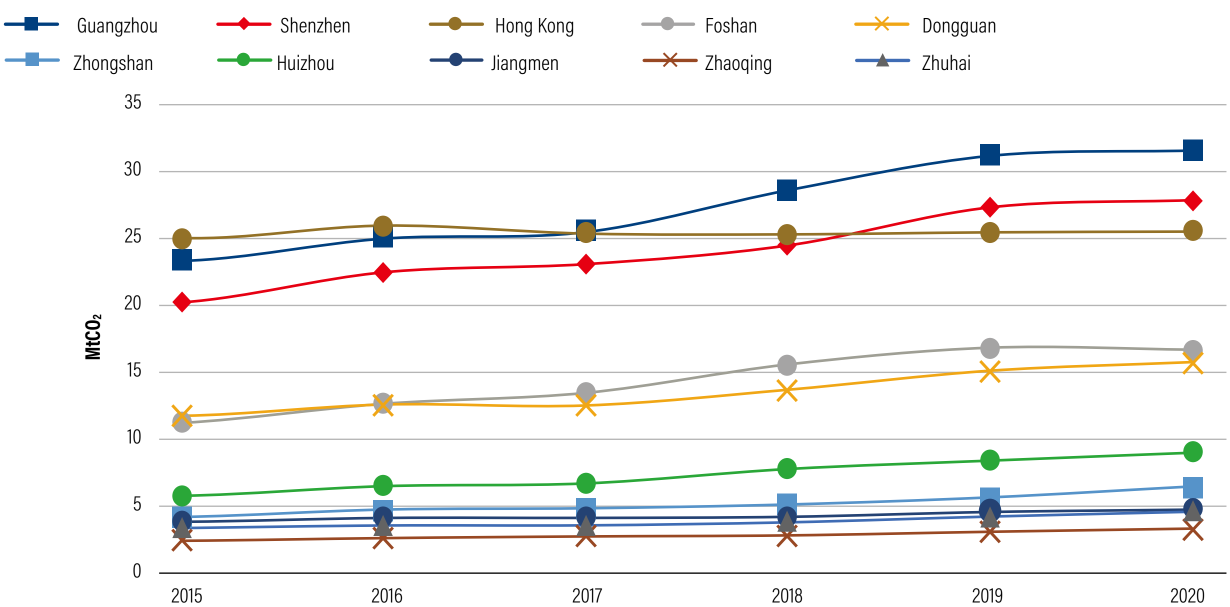


Notes: $MtCO_2$=million tonnes of carbon dioxide.
Source: Project team.

The three largest-emitting cities, Guangzhou, Shenzhen and Hong Kong, accounted for 60 percent of total GBA emissions from buildings in 2020

Buildings sector emissions across the GBA vary because of different levels of economic development status and structure in each city. The three largest emitters, Guangzhou, Shenzhen and Hong Kong, accounted for 60 percent of total emissions. Building emissions in Guangzhou and Shenzhen surpassed Hong Kong's between 2017 and 2018. From 2015 to 2020, the annual growth rates of Guangzhou and Shenzhen building carbon emissions were 6.2 percent and 6.6 percent, respectively, much higher than Hong Kong's, as shown in Figure 23.

Figure 23 | **Buildings sector carbon emissions by city (2015–20)**



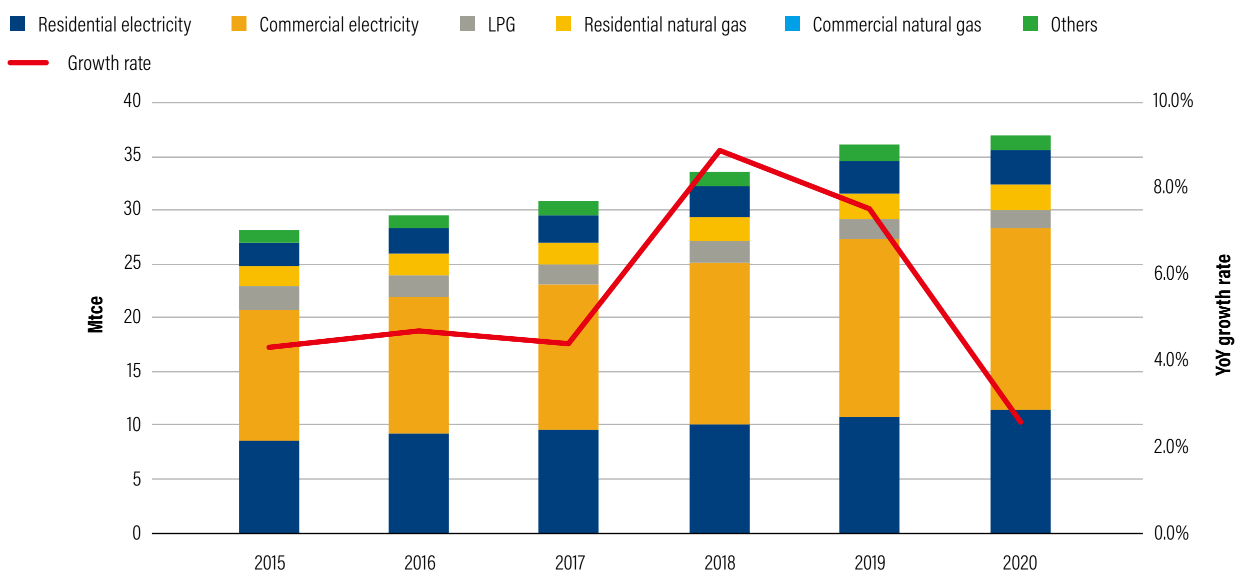
Note: $MtCO_2$=million tonnes of carbon dioxide.
Source: Project team calculation based on the statistical yearbook of each city, 2015–21.

Electricity is the major source of emissions

From 2015 through 2020, electricity accounted for more than 75 percent of total energy consumption, indicating a high electrification rate of the GBA's buildings sector, as shown in Figure 24 Box 1 provides a case study showing the electricity consumption of large public buildings in Shenzhen.

Electricity is also the leading source of carbon emissions, 89 percent of total carbon emissions for GBA buildings in 2020. Both residential and public and commercial buildings use natural gas for cooking and water heating, generating 6 percent of emissions. Some residential buildings use liquefied petroleum gas (LPG) for cooking, thus accounting for a small portion of emissions. The already high electrification rate implies that further electrification in the buildings sector would make limited contributions to carbon reduction and that more significant reductions will require shifting power generation sources from fossil fuels to clean renewable energy.

Figure 24 | **Energy consumption of buildings sector by fuel type in the GBA, 2015–20**



Notes: GBA = Guangdong-Hong Kong-Macao Greater Bay Area; LPG = liquified petroleum gas; Mtce = million tonnes of coal equivalent; YoY = year over year.
Source: Statistics yearbook of the 11 GBA cities.

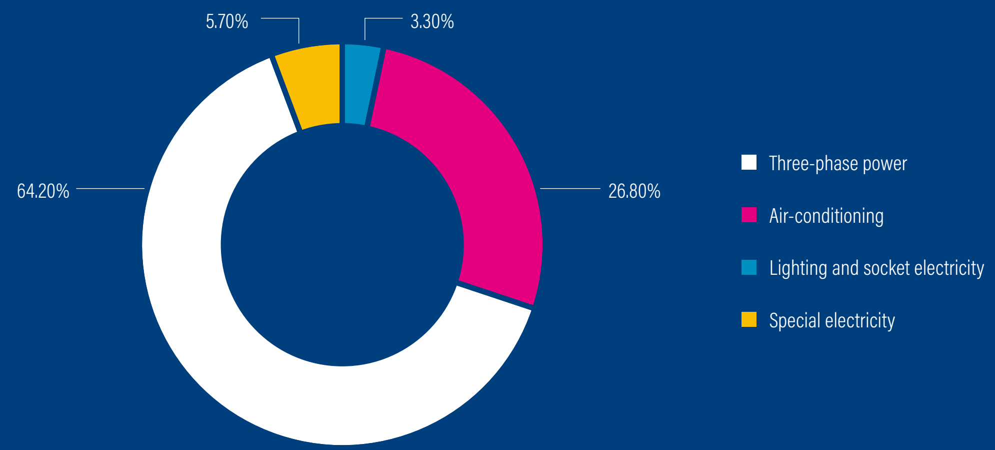
Box 1 | Energy consumption of large public and commercial buildings in Shenzhen[a]

The energy consumption of large public buildings is monitored by authorities to ensure their alignment with the National Regulations on Energy Conservation of Civil Buildings. In Shenzhen, the government has been monitoring the energy consumption of large public buildings since 2018. In 2020, 886 buildings were monitored, with a total area of 34.56 million square metres. The types of buildings monitored included government offices (8.4 percent), commercial offices (32.8 percent), shopping malls (12.8 percent), hotels and restaurants (6.8 percent), cultural and educational buildings (5.7 percent), general buildings (27.9 percent) and hospitals and sports buildings (5.6 percent).

This monitoring found public and commercial buildings in Shenzhen to be the leading consumers of energy, with their consumption dominated by electricity for lighting and air-conditioning (Figure B1).

Box 1 | Energy consumption of large public and commercial buildings in Shenzhen[a] (cont.)

Figure B1 | Electricity consumption, by end use, of large public buildings in Shenzhen in 2020



Source: Shenzhen Housing and Construction Bureau (2021a).

According to Shenzhen's statistical yearbook, public and commercial buildings accounted for about 28 percent of the city's electricity consumption in 2020. The average electricity consumption per unit area decreased 11.5 percent between 2019 and 2020, from 109 to 96.5 kilowatt hours (kWh), partially as a result of energy efficiency improvements. As of 2020, the public buildings with the highest energy intensity were shopping malls, at 168.9 kWh/m^2. In terms of end use, lighting and appliances use 64.2 percent of the total electricity, followed by air conditioners at 26.8 percent. The month seeing the highest electricity consumption was July, at 11.8kWh/m^2, and the lowest was February, at 2.8kWh/m^2.

Note: [a] According to the Shenzhen Housing and Construction Bureau (2021a), *large public building* refers to any single building with an area of over 20,000 m^2 that uses a central air-conditioning system.
Source: Shenzhen Housing and Construction Bureau (2021a).

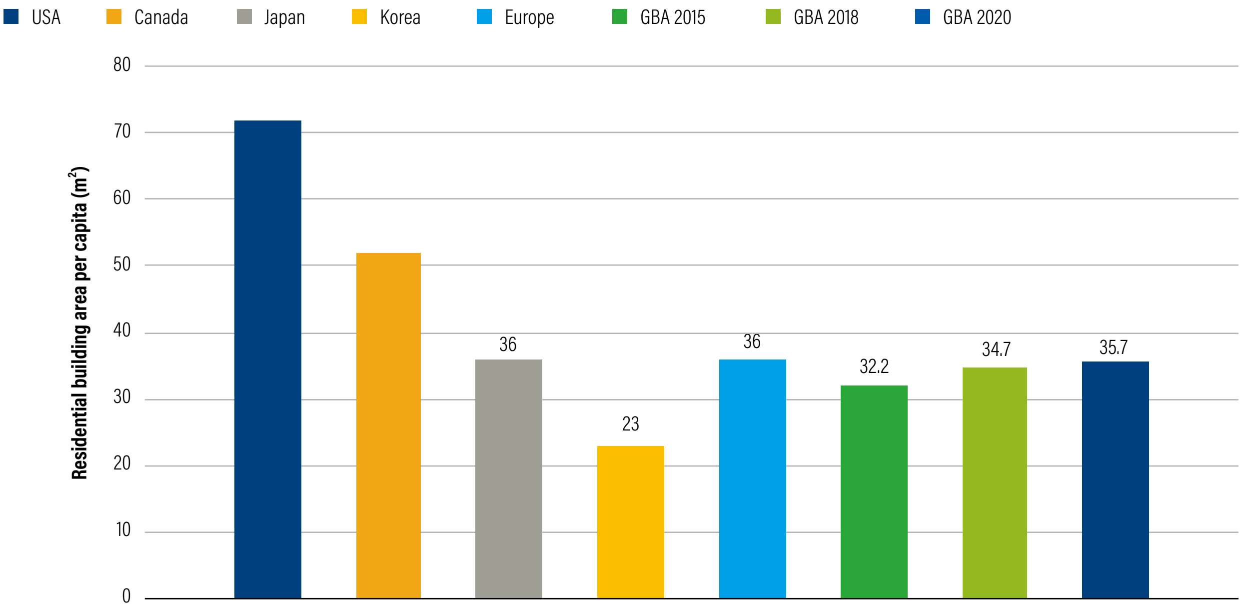
Residential building area per capita in the GBA rivals that of the European Union and Japan, but public and commercial building area per capita is smaller and likely to grow

The GBA's residential area per capita was 35.7 square metres (m^2) in 2020, which is very close to the 36 m^2 in Europe and Japan, as shown in Figure 25. The GBA's public and commercial buildings area per capita is only 13 m^2 (MoHURD 2022; Office of the Seventh National Population Census 2020), lower than the 14–16 m^2 for Europe and Japan (Institute of Standards of MoHURD 2019).

Guangzhou's built-up area covers 950 km^2, almost a quarter (24 percent) of the entire built-up area in the GBA, making it the geographically largest GBA city in 2020 (Guangdong Provincial Bureau of Statistics 2021). Guangzhou therefore has the largest area for expansion of public and commercial buildings (as shown in Table 3).

Shenzhen is likely to build more residential housing because of its rapidly growing population. Currently in the GBA, Shenzhen's population per square metre of residential space is second only to Hong Kong's. Shenzhen is a relatively new city and has a younger population, with 80 percent of residents between the

Figure 25 | **Comparison of residential building area per capita between the GBA and other large industrialised economies**



Notes: GBA=Guangdong-Hong Kong-Macao Greater Bay Area; m²=square metres.
Source: Institute of Standards of MoHURD (2019).

Table 3 | **Per capita building area and urban development land in 2020**

	PER CAPITA RESIDENTIAL BUILDING AREA (M²/PERSON)	URBAN RESIDENTIAL LAND (KM²)	PER CAPITA COMMERCIAL BUILDING AREA (M²/PERSON)	ADMINISTRATION AND PUBLIC SERVICES LAND (KM²)	COMMERCIAL AND BUSINESS FACILITIES LAND (KM²)
China	41.8	-	13 (2018)	-	-
GBA	35.7	-	13	-	-
Guangzhou	36.8	223.2	14	111.7	58.4
Shenzhen	22.5	227.5		37.7	60.6
Zhuhai	32.4	107.3		31.8	35.9
Foshan	45.2	52.5		12.5	16.5
Dongguan	58.3	312.1		66.7	77.8
Zhongshan	38.8	49.7		9.1	11.2
Huizhou	42.6	95.9		18.3	19.6
Jiangmen	35.6	31.0		9.0	6.9
Zhaoqing	35.4	37.6		12.2	7.3
Hong Kong	14.84	44	6.34	25	5

Notes: Guangdong-Hong Kong-Macao Greater Bay Area.
Source: Residential, public services, commercial and business facilities land from MoHURD (2022); Office of the Seventh National Population Census (2020).

ages of 15 and 59. Shenzhen's recent policy requires increasing per capita residential building area to 40 m^2 by 2035 (Shenzhen Municipal Bureau of Planning and Natural Resources 2021). The need for more residential and public buildings is expected to grow.

Hong Kong's energy consumption and carbon emissions from buildings were similar to Guangzhou's and Shenzhen's in 2020, even though its per capita residential, public and commercial building areas are the smallest in the GBA. Hong Kong's buildings consumed energy at several times the rate of buildings in Guangzhou and Shenzhen because Hong Kong has a much denser population and most of its buildings are high-energy-consuming commercial buildings. Due to Hong Kong's restricted geographic area and the slow growth of its population, the city will not experience the same kind of construction boom as other cities in the GBA.

Shifting focus on building priority

The newly published *Guangdong Guiding Opinions on Carbon Peaking and Carbon Neutrality* envisions a shift from green buildings to nearly zero-emission buildings (NZEBs)[7], with higher electrification rates and reliance on a high share of renewable energy use.

In the Urban-Rural Development Action Plan for Peaking Carbon Emissions (MoHURD and NDRC 2022), there is a shift of focus towards ultra-low-energy buildings and ultimately NZEB pilots. Ultra-low-energy buildings require an energy savings rate of 82.5 percent, using building energy consumption in the early 1980s as a benchmark. NZEBs require an energy savings rate of 91–95 percent and renewable energy to be the dominant form of energy.

The GBA's building efficiency is taking the next step with all newly constructed buildings to be green buildings by 2025. During the 13th FYP period, when green building was mainstreamed, Guangdong Province exceeded the FYP's target with 63 percent green buildings among all new urban buildings. More than 500 million m^2 of green buildings were constructed in Guangdong Province (*Nanfang Daily* 2021b). Since December 2021, Shenzhen, Zhongshan, Dongguan, Huizhou and Foshan successively issued follow-up city-level documents to stipulate the target area of ultra-low-energy-consumption buildings (Table 4). Shenzhen made the greatest effort in setting green building standards, targets and incentive plans (Shenzhen Housing and Construction

Table 4 | **Key policy documents on green buildings in the GBA**

YEARS	CITY	POLICY DOCUMENTS (AS CITED IN REFERENCES)	CORE GOALS AND OBJECTIVES
2022	Foshan City	Foshan Housing and Urban-Rural Development Bureau (2022)	From 2022 to 2025, the share of green buildings in new civil buildings reaches 80%, 85%, 95%, and 100%. By 2023, new buildings constructed with a one-star rating and above will account for 35% and reach 45% by 2025.
2022	Huizhou	Huizhou Housing and Urban-Rural Development Bureau (2022)	From 2022 to 2023, the share of green buildings in new civil buildings reaches 80% and 90%. By 2023, new buildings constructed with a one-star rating and above will account for 35%.
2021	Dongguan City	Dongguan Housing and Urban-Rural Development Bureau (2021)	From 2021 to 2023, the share of green buildings in new civil buildings reaches 75%, 80%, and 90%. By 2023, new buildings constructed with a one-star rating and above will account for 35%.
2021	Zhongshan City	Zhongshan Housing and Urban-Rural Development Bureau (2022)	From 2021 to 2023, the share of green buildings in new civil buildings reaches 75%, 80%, and 90%. By 2023, new buildings constructed with a one-star rating and above will account for 35%.
2021	Shenzhen	Shenzhen Housing and Construction Bureau (2021b)	By 2025, 100% of new civil buildings will implement green building standards; the area of new green buildings will be 80 million m^2, and the area of energy-saving renovation and green renovation of existing buildings will be 10 million m^2.

Note: GBA = Guangdong–Hong Kong–Macao Greater Bay Area; m^2=square metres.
Sources: Shenzhen Housing and Construction Bureau (2021b); Zhongshan Housing and Urban-Rural Development Bureau (2022); Dongguan Housing and Urban-Rural Development Bureau (2021); Huizhou Housing and Urban-Rural Development Bureau (2022); Foshan Housing and Urban-Rural Development Bureau (2022).

Bureau 2021b). Guangzhou has not yet issued an action plan exclusively for the buildings sector, but it is expected to lay out more detailed goals in the future.

Another important way to reduce buildings sector emissions is to use renewable energy. Guangdong's 14th FYP for Building Development (2021) lists targets for using renewable energy. The document states that by 2025, the installed capacity of solar photovoltaic buildings will be increased by 1,000 megawatts, and the area will reach 3 million m^2. It calls for promoting solar thermal systems, specifically in hotels, schools and other public buildings with stable hot water demand, and encourages the construction of solar photovoltaic systems on rooftops.

The current rate of building electrification in GBA cities exceeded the national average of 48 percent in 2021, with Shenzhen taking the lead. The Urban-Rural Development Action Plan for Peaking Carbon Emissions sets mandatory electrification targets in the buildings sector of 55 percent by 2025 and 65 percent by 2030, specifically calling for improvement of the electrification rate in buildings' heating systems, water heating and cooking. With the already-high electrification rate in the GBA, our analysis below shows that cleaner sources of electricity will be the driving factor in decarbonising buildings in the long term.

Scenario analysis for a decarbonised buildings sector

Under the Zero-Emission Scenario, the GBA buildings sector is projected to peak its carbon emissions in 2025 at 144 $MtCO_2$ and achieve carbon neutrality by 2058

This study adopts a scenario analysis for the decarbonisation of the GBA's buildings sector between 2020 and 2060 (see detailed methodologies in Appendix D).

Under the Baseline Scenario, CO_2 emissions in the GBA will peak in 2037 at 233.84 million tonnes, with nearly 1.6 times the emissions level in 2020, and there will still be 123 million tonnes of emissions remaining in 2060, far beyond the carbon neutrality goal.

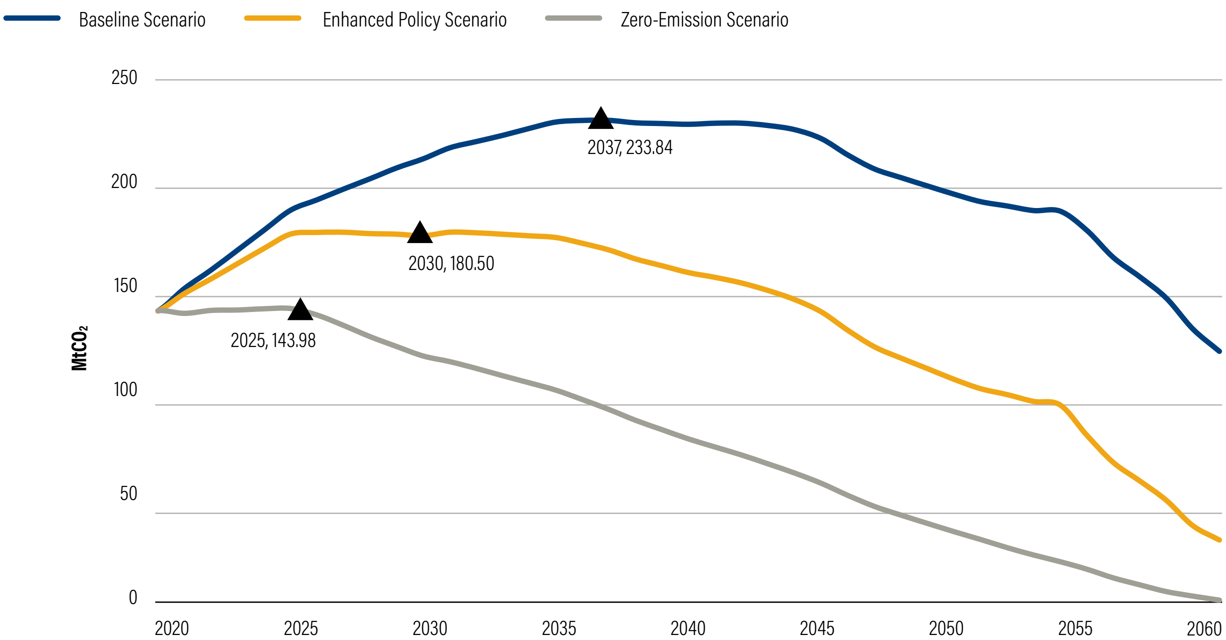
Under the Enhanced Policy Scenario, buildings sector emissions in the GBA will reach their peak in 2030, but with a higher peaking amount, at 180.50 million tonnes. The cumulative emissions reduction between 2020 and 2060 will reach 2.48 billion tonnes, 31 percent less than the Baseline Scenario. All cities will peak emissions earlier and with a lower emissions level. The peaking year for most cities would be before 2030, except for Shenzhen, Zhuhai and Dongguan, where population growth will drive emissions up until sometime between 2032 and 2035.

Under the Zero-Emission Scenario, GBA buildings sector emissions will peak at a much lower level of 143.98 million tonnes by 2025 and will fall to less than 10 million tonnes by 2058. Foshan, Zhongshan, Jiangmen and Guangzhou will peak the earliest, between 2021 and 2024, and Zhuhai will peak the latest, in 2035. Under this scenario, the buildings sector will reduce cumulative emissions by 4.91 billion tonnes from 2020 to 2060 compared with Baseline Scenario. As in the previous two scenarios, Guangzhou and Shenzhen will remain the largest emitters and have the highest potential to reduce emissions. Cumulatively, they could reduce emissions by 2.23 billion tonnes between 2020 and 2060. The results of the scenario analysis are shown in Figure 26.

Under the Zero-Emission Scenario, buildings sector emissions in all cities except Zhuhai are expected to peak between 2020 and 2025, and total emissions will start dropping quickly after 2025, as shown in Figure 27. Guangzhou and Shenzhen will contribute the largest cumulative carbon reductions, 1.17 billion tonnes and 1.06 billion tonnes, respectively, compared with the Baseline Scenario, while the cumulative reductions of Hong Kong and Dongguan will reach 700 million tonnes and 650 million tonnes, respectively.

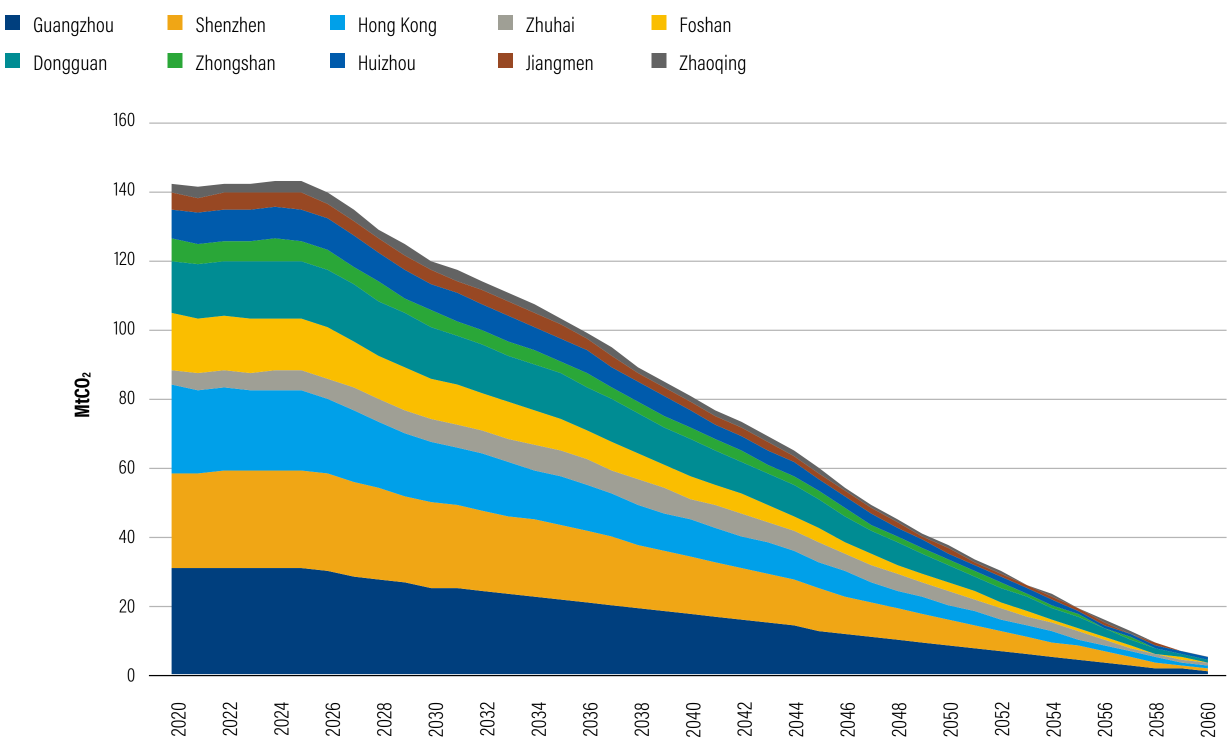
Energy efficiency is important to decarbonise

Figure 26 | **Scenario projections of carbon emissions in the GBA buildings sector**



Notes: GBA=Guangdong–Hong Kong–Macao Greater Bay Area; $MtCO_2$=million tonnes of carbon dioxide.
Source: Project team.

Figure 27 | **Carbon emissions of GBA cities under Zero-Emission Scenario, 2020–60**



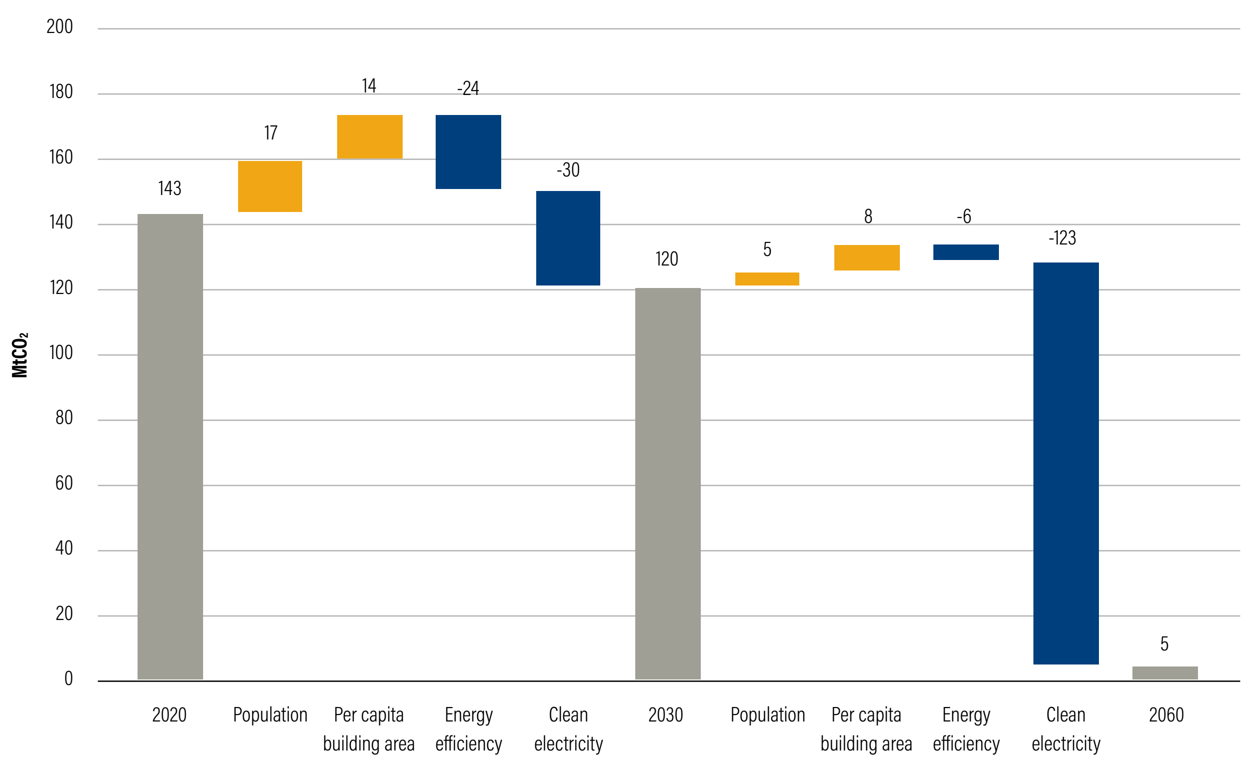
Notes: GBA=Guangdong–Hong Kong–Macao Greater Bay Area; $MtCO_2$=million tonnes of carbon dioxide.
Source: Project team.

the buildings sector in the near future, while decarbonised electricity contributes the sector's largest potential for emissions reduction

The project team examined building emissions and the carbon-reduction potential of buildings based on four factors: population, per capita building area, energy efficiency and share of clean electricity. As shown in Figure 28, emissions are driven up by the growth of population and per capita building area. The most effective way to bring emissions down is by powering buildings with renewable electricity. Shifting to decarbonised electricity alone can contribute 81 percent of potential emissions reduction in the GBA's buildings sector. However, energy efficiency continues to be important for lowering the energy intensity of buildings; in the near term there is still plenty of room for improvement and potential to have a great marginal effect on carbon reduction.

Under the Zero-Emission Scenario, energy efficiency is the pillar of transition, contributing 16 percent (24 million tonnes) of carbon reductions. Efficiency improvement measures should be emphasised ahead of the design and construction stages and can be a potent tool for restricting energy consumption and enabling emissions to peak earlier. Improving energy efficiency could push an energy intensity decrease of 20 percent below 2020 levels by 2030. Decarbonising electricity also requires electrification and switching to low-emission fuels. Already, there is no demand for heating in the GBA, and the electrification rate is high. The GBA can focus on shifting to low-emission fuel for electricity generation and use renewable energy for cooking, water heating and space cooling. Electricity, and especially high-efficiency electric heat pumps, will become the primary source of energy use for space cooling. In addition to renewable energy now used to heat water in buildings, solar thermal technology can be used for cooking, and various forms of bioenergy can be tapped as well.

Figure 28 | **Contributions of decarbonisation pathways in the buildings sector**



Note: $MtCO_2$=million tonnes of carbon dioxide.
Source: Project team.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SECTION 5

INVESTMENT NEEDED TO ACCELERATE THE TRANSITION

As discussed in Sections 2–4, green and low-carbon measures are key to sectoral decarbonisation and to achieving carbon neutrality by 2060. Our study in this section highlights the importance of the finance sector, both public and private, as a key actor and driver of emissions and a stakeholder in emissions reduction. We find that public finance falls short in adopting and implementing these new technologies and in providing the amounts needed to meet the net-zero goal. Green, transition and sustainable financing tools will all be needed.

In this section, we calculate investment need as the difference between the cost of green and low-carbon measures and government subsidies. For the cost, we focus on the additional cost of green measures rather than the total construction costs needed in the sector. This means a combination of the costs of traditional technologies in order to add green measures to them and the incremental costs of applying new green technologies. For example, in the buildings sector, green building costs comprise additional costs, such as strengthened exterior walls, lighting systems and air-conditioning, and the incremental costs of water-saving measures, air purification devices, business information modelling systems, and so on, that were not used for non-green buildings.

The GBA's transition to carbon neutrality will require an estimated investment of $1.84 trillion by 2060

Some of the major research forecasting investment need for China to reach its 30-60 goals is listed in Table 5. Although the results vary depending on the methods used, all research finds a huge need for green and low-carbon investments. The required amount is, in general, several trillion dollars to peak emissions by 2030, and tens of trillions to reach carbon neutrality by 2060.

We cross-checked the results found by the China International Capital Corporation (CICC)

Table 5 | **Estimates of green and low-carbon investment needs for China's 30-60 goals by different organisations**

ORGANISATION	METHODOLOGY	INVESTMENT NEEDED FOR CARBON EMISSIONS PEAK (2020-30)(US$)	INVESTMENT NEEDED FOR CARBON NEUTRALITY (2030-60)(US$)
People's Bank of China	-	3.4 trillion	18 trillion
China International Capital Corporation Limited	'Bottom-up'[a]	3.4 trillion	18 trillion
Institute of Climate Change and Sustainable Development, Tsinghua University	Combination of 'top-down' and 'bottom-up'[b]	26.8 trillion for 2020-50	
Green Finance Committee, China Society for Finance and Banking	Combination of 'top-down' and 'bottom-up'[c]	75 trillion for 2020-50	
National Climate Change Strategy Research and International Cooperation Centre	IAMC model[d]	21.4 trillion	
RMI and the Investment Association of China	-	10.8 trillion for 2020-50 on 7 key areas: renewable resources, energy efficiency, electrification in end use energy consumption, zero-emissions power generation technologies, energy storage, hydrogen, digitalization	
Standard Chartered Bank	-	20-30 trillion for 2020-50	
Goldman Sachs	-	16 trillion on clean energy infrastructure	

Notes: [a] Estimated investment needs of the seven industries with the highest carbon emissions in China: electricity, steel, transportation, cement, chemicals, agriculture and building.
[b] In order to achieve the 1.5°C target, China needs to invest in low-carbon energy supply, industry, construction and transportation.
[c] Drawing on the 211 fields in the Green Industry Catalogue, the research team used the Energy Policy Simulator model to estimate the investment demand of power, industry, transportation, buildings, and low-carbon energy systems and ecological environmental protection.
[d] The Integrated Assessment Modeling Consortium (IAMC) proposes a hybrid model composed of economic, energy, agricultural and land use, climate impact, and adaptation sub-models.
Sources: Chai (2021); Investment Association of China and RMI (2021); Standard Chartered Bank (2021); Goldman Sachs (2021).

and the National Centre for Climate Change Strategy and International Cooperation, the two most prestigious and trustworthy institutional estimates of investment need. These both showed a need of $21.4 trillion for 2060. Therefore, in this report, we estimated the GBA's overall investment need by scaling down the CICC's figure for the GDP ratio of the GBA to China, because sectors selected for our research are similar to those in the CICC's study[8]. We assume that the GDP share of the GBA to China and global economic growth and the GBA's returns to scale (what happens to long-run returns as the scale of production increases) will be constant from 2021 to 2060. From 2011 to 2020, the GDP of the Pearl River Delta accounted for an average of 8.95 percent of national GDP. During this period, Hong Kong and Macao's contributions to global economic growth averaged 0.32 percent and 0.10 percent, respectively (Trading Economics 2022). Our study shows that the estimated investment required for the GBA to peak by 2030 is approximately $226 billion. Another $1.61 trillion would be needed between 2031 and 2060 to reach carbon neutrality. Therefore, the total investment needs for the GBA's carbon neutrality will be around $1.84 trillion between 2021 and 2060. There is a methodology limitation to the GDP scale-down estimation since the assumptions are not all realistic and are subject to change with China's actual circumstances and the GBA's economic contributions over the next 40 years. However, this is the most-used method in this research field. These estimated results are thus a rough projection of the scale of financing shortfalls for the GBA's green transition, rather than a precise figure. We also cross-checked the estimated investment needs by using two different shares: first, the GBA's agriculture and manufacturing GDP in national agriculture and manufacturing GDP (8.4 percent) in 2020 and, second, the share of the GBA's manufacturing and service industry GDP in national manufacturing and service industry GDP (12.1 percent) in 2020. We found investment needs of $1.37 trillion and $1.97 trillion, respectively. Therefore, we believe that $1.84 trillion is a reasonable estimate. In the next sub-section, we detail sectoral investment opportunities.

An investment need of around $1.6 billion is estimated for the GBA's petrochemicals and chemicals sub-sector under the Enhanced Policy Scenario

Because the decarbonisation technologies are varied across sub-sectors of manufacturing, predicting decarbonisation investment in manufacturing requires a bottom-up calculation of the investment needs of each sub-sector; however, public data for sub-sectors were insufficient to support our study. In addition, as we saw in Section 2, decarbonised power and heating systems will contribute the largest emissions-reduction potential, but the greater investments needed in the power sector are beyond the scope of this study. Therefore, we take one of the key sub-sectors—petrochemicals and chemicals—as a case study to estimate its investment need for carbon neutrality, excepting investments for decarbonised power and heating systems.

One of the GBA's major energy-consuming and carbon-intensive industrial sub-sectors, petrochemicals and chemicals experienced a 30 percent increase in energy intensity and an 11 percent increase in carbon emissions from 2015 to 2020 (Guangdong Provincial Bureau of Statistics 2021). As noted in Section 2, this sub-sector is expected to develop rapidly between 2025 and 2030 and generate around 2.5 million tonnes of emissions annually under the Baseline Scenario. For these reasons, this sub-section aims to analyse the investment shortfall in the petrochemicals and chemicals sub-sector to illustrate the scale of the investment need to follow the Enhanced Policy Scenario. Section 2 provided three decarbonisation methods to reach the ultimate net-zero goals: energy structure-shifting (phasing down fossil fuels in production), energy conservation (decarbonising heating and power systems) and carbon removal technologies (CCUS) (NDRC 2017; IEA 2020, 2019; Chinese Academy of Environmental Planning 2021). The unit cost and technology maturity of potential solutions are indicated in Table 6.

Construction of new petrochemical and chemical manufacturing projects would drive carbon emissions to 14.1 million tonnes by 2035. Figure 29 shows the share of contributions of different decarbonisation pathways. The estimate is based

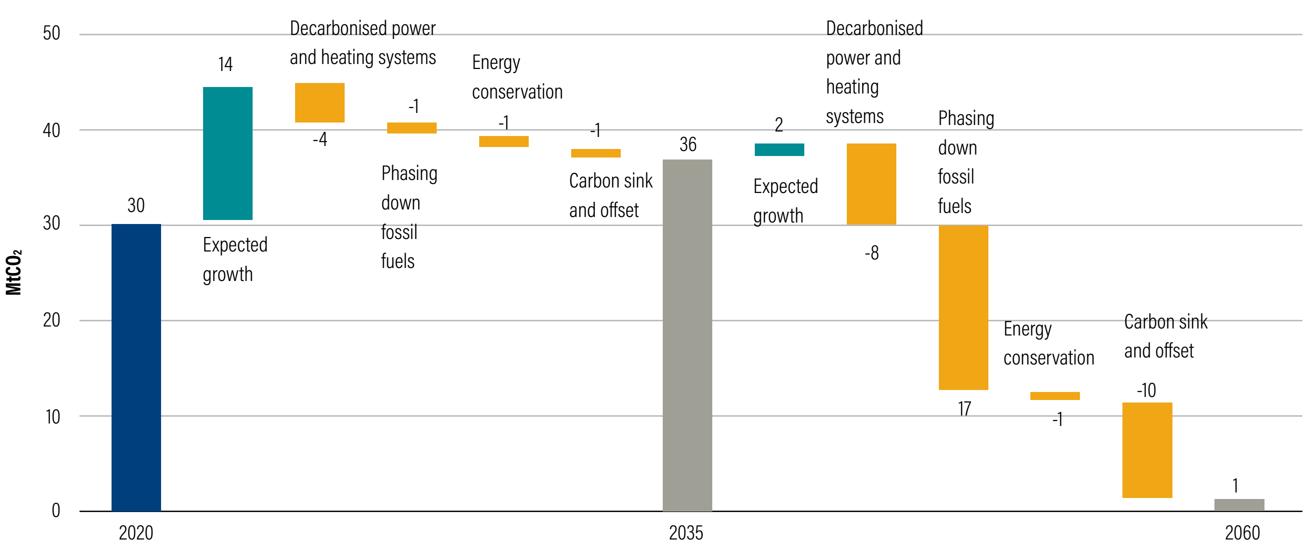
Table 6 | **Unit cost and technology maturity of emissions-reduction technology pathways in the petrochemicals and chemicals sub-sector**

CATEGORY	TECHNOLOGY ROUTE	UNIT COST (US$/TON)	TECHNOLOGY MATURITY
Energy conservation	Efficiency improvement technologies	270	2035: 68% 2060: 100%
	Heat conversion technologies	148	2035: 54% 2060: 100%
	Waste heat recovery	82	2035: 62% 2060: 100%
	System optimization	170	2035: 40% 2060: 100%
Energy structure	Fuel substitution: Replacing fossil fuels to produce hydrogen, ammonia and methanol with renewable energy	2035: 885 2060: 442	2035: 16% 2060: 95%
	Feedstock substitution: replacing coal to produce hydrogen, ammonia and methanol with water electrolysis and natural gas	2035: 511 2060: 255	2035: 20% 2060: 95%
Carbon dioxide removal	CCUS	2035: 500 2060: 200	2035: 2% 2060: 10%

Note: CCUS = carbon capture, utilisation and storage.
Sources: NDRC (2017); IEA (2020, 2019); Chinese Academy of Environmental Planning (2021).

on the Enhanced Policy Scenario in Section 2. Apart from upstream power and heating system decarbonisation, the other three pathways require investments totalling over $1.6 billion from 2021 to 2060. The majority of these investments, 65 percent, are dedicated to replacing fossil fuels in energy use and raw materials. The fuel substitution mainly involves replacing fossil fuels with renewable energy to produce hydrogen, ammonia and methanol. Raw materials, such as coal and oil, would be replaced with natural gas to produce hydrogen, ammonia and methanol in the short and medium term. In the long run, coal would be replaced with electrolysis of water to produce hydrogen.

Figure 29 | **Decarbonisation contributions of different pathways for the GBA's petrochemicals and chemicals sub-sector**



Note: GBA=Guangdong–Hong Kong–Macao Greater Bay Area; $MtCO_2$=million tonnes of carbon dioxide.
Sources: Project team.

An investment need of around $200 billion to $700 billion is estimated for the transition of road transport under the Enhanced Policy and Zero-Emission Scenarios

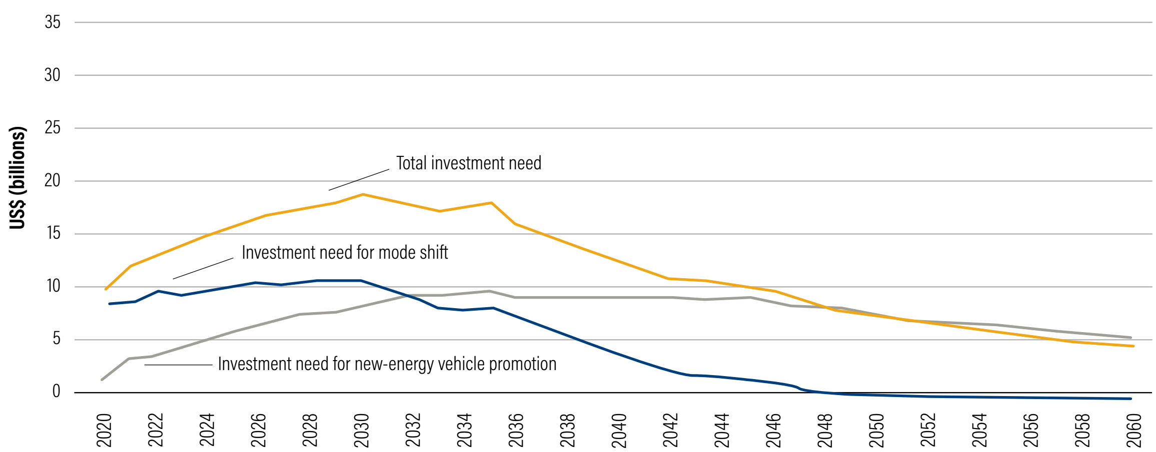
According to the scenario analysis in Section 2, investment in road transport should prioritise the two most effective decarbonisation pathways: promoting new-energy vehicles (including those powered by electricity and hydrogen) and shifting modes of transportation in order to reach the targets in the Zero-Emission Scenario. Under the Baseline Scenario, investment needed in road transport sector by 2060 will be roughly $200 billion, while about $700 billion will be needed under the Zero-Emission Scenario.

NEV promotion involves incentivising the purchase and use of electric vehicles and building supporting infrastructure such as charging stations and hydrogen refuelling stations. In the short term, the high marginal costs of emissions reductions through NEV promotion result in total costs for NEV promotion that continue to rise, while the emissions reductions are relatively low—about $700/tonne CO_2 and $760/tonne CO_2 under the Enhanced Policy Scenario and the Zero-Emission Scenario, respectively. However, as NEV manufacturing technology advances, and the industrial supply chain matures, the cost of manufacturing new-energy vehicles will gradually decrease between 2030 and 2060. NEV promotion has great potential to cut emissions in the medium and long term, with the marginal emissions-reduction costs dropping to about $133/tonne CO_2 and $127 /tonne CO_2 under the Enhanced Policy Scenario and the Zero-Emission Scenario, respectively.

Mode shifting involves constructing road, railway and water transport infrastructure. It requires major investment, and the rising curve of costs in the short term will be steeper than supporting the growth of NEVs. However, in the long run, mode shifting from road transport to railway and ships, and from private to public transit, will cut emissions significantly. Therefore, by 2045, the marginal cost of mode shifting will be close to zero, making this a more effective tool to reduce emissions. Under the Baseline Scenario and the Zero-Emission Scenario, the short-term marginal costs are $813/tonne CO2, and $812/tonne CO_2, respectively, but the mid- and long-term marginal cost of CO_2 emissions reduction drops to $60/tonne CO_2 and $22/tonne CO_2, respectively.

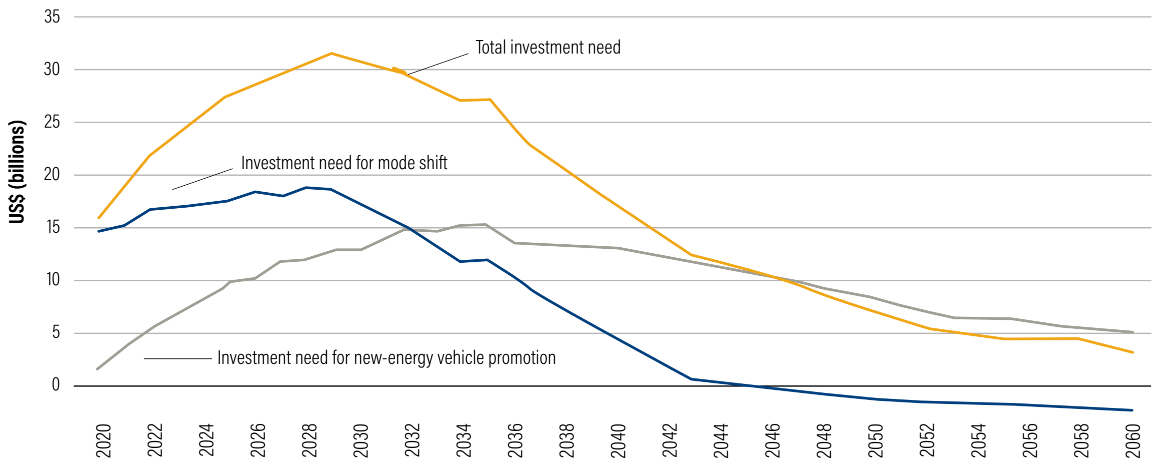
In general, although the current high cost of emissions-reduction strategies rises in decarbonisation measures, and the need to adopt more aggressive measures together pushes costs even higher, these approaches can bring greater emissions reductions than the Baseline Scenario. In the long run, the total abatement costs will gradually decline, as shown in Figures 30 and 31.

Figure 30 | **Estimate of investment need for GBA road transport under the Enhanced Policy Scenario**



Note: GBA=Guangdong–Hong Kong–Macao Greater Bay Area.
Sources: Project team.

Figure 31 | **Estimate of investment need for GBA road transport under the Zero-Emission Scenario**



Note: GBA=Guangdong–Hong Kong–Macao Greater Bay Area.
Sources: Project team.

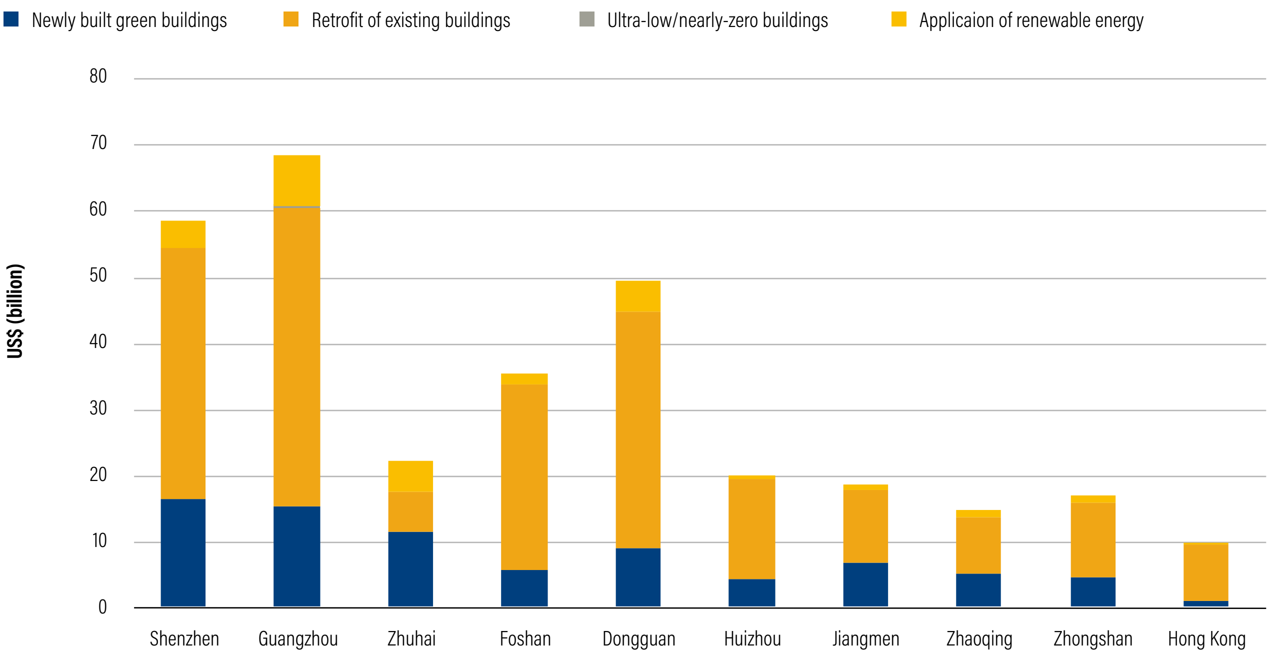
An investment shortfall of around $150 billion to $300 billion is estimated for the buildings sector under the Zero-Emission Scenario

As discussed in Section 4, in order to reach the targets of the Zero-Emission Scenario, increased energy efficiency will be crucial in the near term, whereas cleaner electrification contributes more in the long run. We therefore identified improving efficiency in existing buildings through retrofitting as a key pathway, while building new green buildings and NZEBs over the next several decades could contribute to both energy efficiency and clean electrification. Renewable energy usage is another important pathway to replace fossil fuels and encourage clean energy use. The four methods we outline are categorised based on the 14th FYP and policy classification for different areas of subsidies. This report will use a bottom-up approach to estimate investment needs through four building decarbonisation pathways[9]. The estimated results by each city are shown in Figure 32.

Financial subsidies are the most popular form of subsidies among subnational governments, accounting for 50 percent of green finance incentive plans, followed by plot ratio, land transfer and tax concession (Guangdong Architectural Design & Research Institute Co., Ltd. 2016). Subsidies are determined based on a combination of the China Green Building Label (CGBL) star level, building area, building type and subsidy ceiling. In 2012, China created an incentive for green buildings in which two-star and three-star CGBL buildings will be awarded $6.66 (45 yuan)/m^2 and $11.83 (80 yuan)/m^2, respectively (Ministry of Finance and MoHURD 2012). Following the national incentive plan, Guangdong set up provincial green building incentive mechanisms to provide higher levels of subsidies (People's Government of Guangdong Province 2013). Funding is allocated to green building research, certification, star-level building construction and special projects with demonstration value.

We estimate that subsidies will account for less than 5 percent of total investment need in buildings sector decarbonisation. The total investment shortfall for GBA cities is estimated at around $150 billion under the Enhanced Policy Scenario and $300 billion under the Zero-Emission Scenario. Although incentive plans are increasing in number and precision, public statistics on the number of successful applicants and disbursement are limited, making policy effectiveness hard to analyse. Moreover, many of the subsidies are limited to 'demonstration projects', so the subsidy program's impact is also likely to be limited due to the narrow scope.

Figure 32 | **Estimated investment shortfall for different pathways in GBA cities**



Note: GBA=Guangdong–Hong Kong–Macao Greater Bay Area.
Sources: Building Energy Efficiency Plan and Renewable Energy Development Plan of Guangdong Province and nine municipalities in the 14th Five-Year Plan; WRI forecast.

Retrofitting of existing buildings has an estimated shortfall of over $200 billion, accounting for over 60 percent of the total investment shortfall in the buildings sector. The slow progress in retrofitting is caused by a mix of challenges, including the lack of building energy monitoring and an assessment platform to track historical energy performance, the lack of willingness by homeowners to renovate (most retrofitting work is for residential buildings), a long and complicated application and review process, and the lack of financing sources and market mechanisms (Ma 2018). Existing building stock in the GBA is significantly larger than projected new green building area. With city renovation becoming a national strategy starting in 2022, we assume that all existing buildings will need to conduct at least basic retrofitting in the next 40 years. Our research team therefore uses existing building areas in 2020 minus the building area we expect to be demolished to get the needed retrofitting areas. We assume that the unit cost of retrofitting existing buildings is related to the energy savings level, in which the unit cost of green retrofitting is twice the cost of achieving energy savings of 30–50 percent. Overall, the retrofitting market is huge, and the need is the most urgent for GBA building decarbonisation.

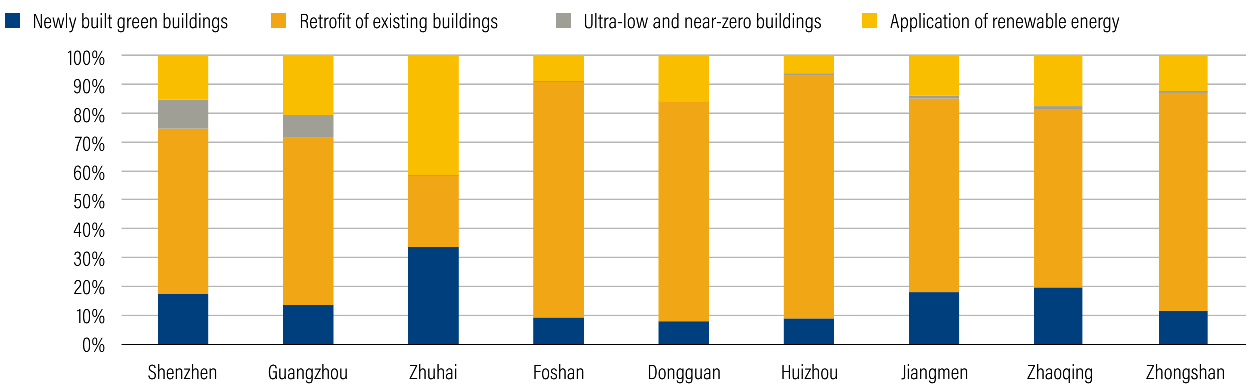
Newly built green buildings have the second-largest investment shortfall, at nearly $80 billion. Based on targets set between the 12th and 14th FYPs, there is a clear upward trend in green building areas. The research team thus assumes a linear projection for green building areas until 2060, but the cost will decline linearly with technical maturity in the process; for example, the two-star level will decrease to the one-star cost in 2060. Costs of green building measures (MoHURD 2019a) and local subsidies are referred to in official publications or standards, and further calculated based on our assumptions.

Ultra-low- or near-zero-energy buildings are even more decarbonised than green buildings. The estimated investment shortfall for this pathway, an add-on to green buildings, is around $400 million. Once all new buildings become green buildings, the extra cost for near-zero buildings will be significantly reduced. While ultra-low buildings require a substitution rate of at least 10 percent of renewable energy (RE) for both commercial and residential buildings (MoHURD 2019b), 20–40 percent of the incremental cost is caused by RE application; namely of solar photovoltaic, solar water heating and air-source heat pumps (China Academy, of Building Research 2020). Our research team estimates the investment shortfall of NZEBs based on the cost of low-carbon measures and the building areas of approved demonstration projects (China Association of Building Energy Efficiency 2022; Shenzhen Green Building Association 2022).

The estimated investment shortfall for utilising renewable energy in buildings will be about $25 billion. This estimate is based on relevant policies and cases of renewable energy deployment (Guosheng Securities 2022). To help attract the needed investment, policies and incentives conducive to renewable energy development will be important in the GBA, and governments should issue special funds for wider application of building-integrated photovoltaics, building-applied photovoltaics, air-source heat pumps and relevant technologies. To avoid double counting from RE application in the other three pathways, we only calculate RE usage and maintenance fees until 2060 rather than including installation fees. Compared with NZEBs and ultra-low-energy buildings, which require a mandatory percentage of RE applications, retrofitting and green buildings have a much lower RE application and usage cost.

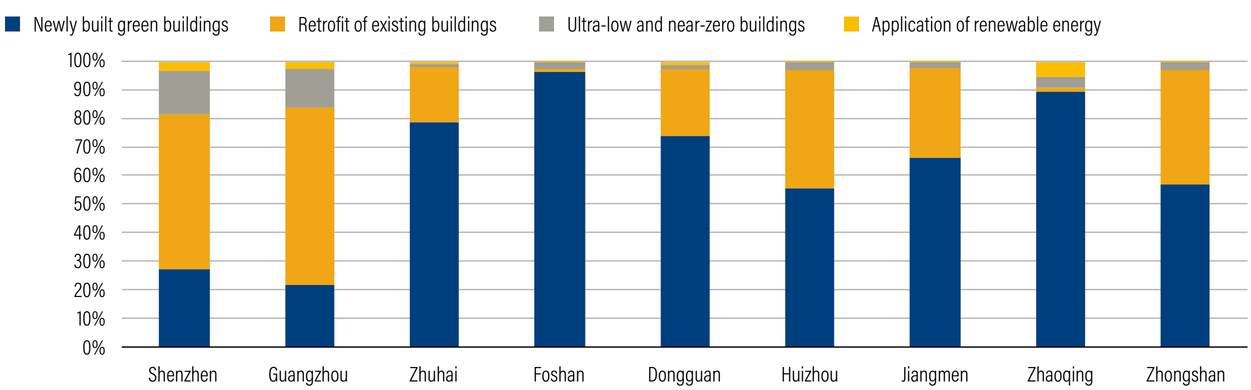
Overall, as shown in Figure 33, for all the cities in the GBA except Zhuhai, retrofitting existing buildings takes up the biggest proportion of decarbonisation costs, over 50 percent in general. Green building construction and the use of RE require roughly the same share of cost for each city. However, as shown in Figure 34, since most subsidies are given to green building development, there is a distinct discrepancy between governments' priority of

Figure 33 | **Share of total cost of buildings sector decarbonisation**



Sources: Project team.

Figure 34 | **Share of total subsidies for buildings sector decarbonisation**



Sources: Project team.

incentivising building decarbonisation and actual decarbonisation potential.

Transition finance will be needed to fill these investment shortfalls

The estimated cumulative investment needed to decarbonise the above three sectors in the GBA—road transport, petrochemical and chemical manufacturing, and buildings—will reach over $1 trillion by 2060. This is over half (55 percent) of the total investment needed for the entire GBA.

Table 7 | **Potential investment area, needs and instruments in the GBA, 2020–60**

PATHWAYS	INVESTMENT AREA	ESTIMATED AMOUNT UNDER ZERO-EMISSION SCENARIO (US$)	FINANCIAL TOOLS AVAILABLE[a]
ROAD TRANSPORT			
Increase EVs and FCEVs	Increase EV private cars, buses, taxis, logistic vehicles and freight vehicles	over 350 billion	☒ Green finance ☐ Transition finance
	Increase hydrogen private cars, buses, taxis, logistic vehicles and freight vehicles		☒ Green finance ☐ Transition finance
	New chargers and charging stations	over 30 billion	☒ Green finance ☐ Transition finance
	New hydrogen refilling stations	near 5 billion	☒ Green finance ☐ Transition finance
Mode shift	Road-transport to railway and shipping	near 300 billion	☒ Green finance ☐ Transition finance
Sub-total		**over 300 billion**	
BUILDING SECTOR			
Green Building	New green buildings: 1.61 billion m^2	near 80 billion	☒ Green finance ☐ Transition finance
Energy efficiency improved	Ultra-low and near-zero buildings: 76.9 million m^2	over 400 million	☒ Green finance ☐ Transition finance
	Retrofitting existing buildings: 2.53 billion m^2	Over 200 billion	☒ Green finance ☐ Transition finance
Distributed renewable energy	Install solar thermal: 1.2 million m^2 Install photovoltaic: 8GW Install heat pump: 543.38 million m^2	near 30 billion	☒ Green finance ☐ Transition finance
Sub-total		**over 300 billion**	
PETROCHEMICAL AND CHEMICAL INDUSTRY			
Mode shift	Efficiency improvement	over 50 million	☒ Green finance ☐ Transition finance
	Heat conversion	near 10 million	☒ Green finance ☐ Transition finance
	Waste heat recovery	over 10 million	☒ Green finance ☐ Transition finance
	System optimization	near 1 million	☒ Green finance ☐ Transition finance
Replacing the fossil fuel	Fuel substitution	over 600 million	☒ Green finance ☐ Transition finance
	Feedstock substitution	over 400 million	☒ Green finance ☐ Transition finance
NET	CCUS	near 500 million	☒ Green finance ☐ Transition finance
Sub-total		**over 1 billion**	

Notes: CCUS=carbon capture, utilisation and storage; EV=electric vehicle; FCEV=fuel cell electric vehicle; GBA=Guangdong–Hong Kong–Macao Greater Bay Area; GW=gigawatts; m^2 =square metres.
[a] Green finance tools include green loans, green bonds, green funds, green trusts and green insurance. Transition finance instruments include transition bonds, sustainability-linked bonds, sustainability-linked loans, transition insurance and private equity funds.
Source: Project team.

Table 7 breaks down these investment needs, with investment areas and their suitability for green and/or transition finance tools.
In this report we will focus on finance tools that are directly linked to greenhouse gas (GHG) emissions reduction, including green bonds or loans, sustainability-linked bonds (SLBs), sustainability-linked loans (SLLs) and transition bonds or loans. These are labelled in our report as tools for 'financing decarbonisation'.

Although the current finance system in China is relatively well developed, it pays more attention to financially supporting 'green' projects that meet the criteria of the *Guidance Catalogue of Green Industry* and the *Green Bonds Endorsed Projects Catalogue* (2021 edition). By the end of September 2022, the balance of green loans in China was $3.2 trillion, an increase of 41.4 percent year-on-year, and the stock of green bonds exceeded $194 billion (Guangdong Financial Supervisory Authority 2023). The Guangdong Branch of the Bank of China continues to make efforts in green finance, supplying 38.8 billion yuan in 2020, an increase of over 19 percent compared with the previous year (China News 2020).

However, some key sectors still lack financing tools to fund the transition to low-carbon and net-zero emissions. Cutting emissions from the petrochemicals and chemicals sub-sector would require steps to increase energy efficiency in production and phase down the use of coal as a fuel. These activities are not covered by green finance yet and would cost an estimated $486 million. The investment shortfall for shifting transportation modes from roads to railways and ships will reach an estimated $293 billion, which is also not eligible for green finance. As for the buildings sector, 30–40 percent of the GBA's existing buildings were constructed before 2000 and based on outdated energy efficiency standards. Retrofitting them can hardly qualify them for the current design standards of building energy conservation or the green building star-rating that is supported by green bonds. Such projects and activities not supported by the green finance system would require an estimated investment of $43 billion to $62 billion. Altogether, over $300 billion in investments needed for decarbonisation in the GBA are estimated to be uncoverable by green finance.

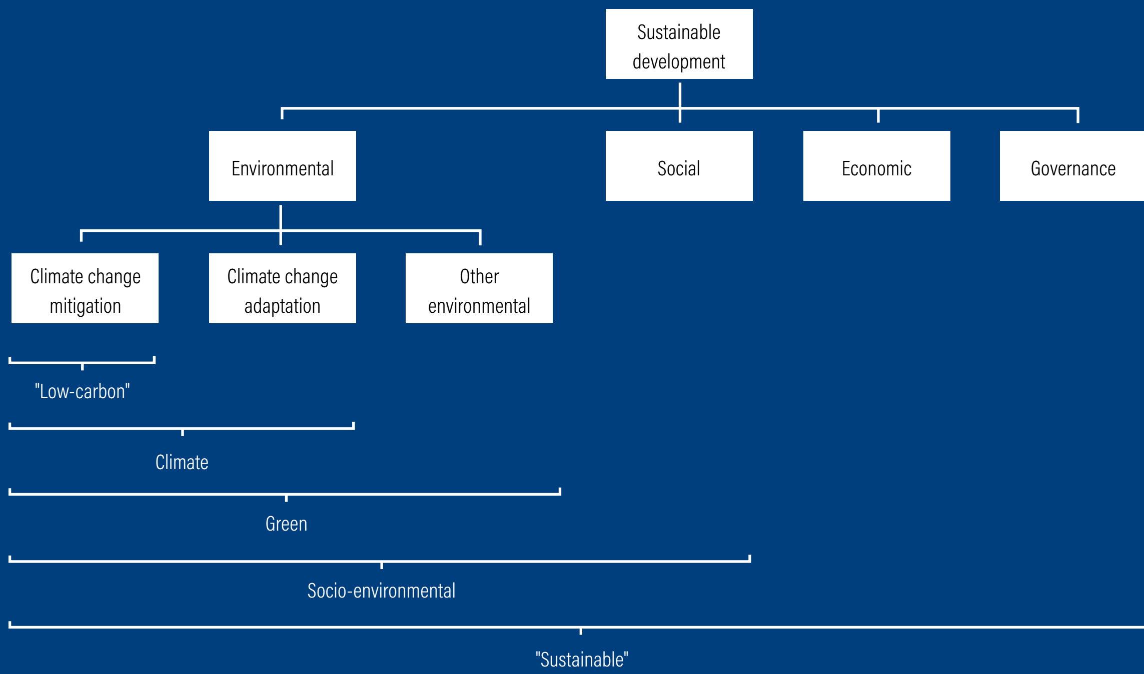
Therefore, within the sustainable finance system of the UN Environment Programme, the emerging tool of 'transition finance' should

Box 2 | Climate finance, green finance, sustainable finance and transition finance

The scope and definitions of sustainable finance tools are shown in Figure B2. Climate finance provides funds for addressing climate change adaptation and mitigation; green finance functions under a use-of-proceeds framework and has a broader scope as it also covers other environmental goals (e.g., biodiversity protection and restoration); sustainable finance also covers environmental, social and governance factors. Green finance should be seen as a subset of sustainable finance; alternatively, sustainable finance can be considered as an evolution of green finance. A commonly agreed definition of transition finance has been developed in the G20's framework to also pursue the net-zero objectives in the Paris Agreement (Zhu et al. 2022). Covering the journey towards the goal rather than the goal itself, it is a supplement to green finance to finance non-green activities, especially those transitioning in carbon-intensive sectors. The Net-Zero Banking Alliance developed four key financing strategies to help banking consider transition finance: financing or enabling entities and activities that develop and scale climate solutions; financing already aligned with the 1.5°C pathway; financing committed to transitioning in line with the 1.5°C pathway; and the accelerated, managed phaseout of high-emitting physical assets (Net-Zero Banking Alliance 2022).

Box 2 | Climate finance, green finance, sustainable finance and transition finance (cont.)

Figure B2 | Definitions and scope of finance tools used in this report



Sources: Spinaci (2021); UNEP (2016).

be viewed as an effective solution to bridge the investment needs of carbon-intensive sectors (UNEP 2016) (see Box 2).

The *G20 Sustainable Finance Report* gives a clear definition of transition finance and allows for some flexibility in the formulation of specific policies and norms (G20 Sustainable Finance Working Group 2022). Following the G20's framework, the core mission of transition finance is to financially support transition activities leading to lower and net-zero emissions. Although there are different carbon neutrality targets within the GBA, such as the Chinese mainland's commitment to achieve carbon neutrality by 2060 and Hong Kong's commitment to achieve carbon neutrality by 2050, transition finance support for carbon-intensive sectors and enterprises focuses on the credibility of their strategic targets, the consistency with relevant carbon neutrality targets and the feasibility of transition pathways.

Transition finance is just getting started in China and the GBA

There are two main types of criteria for defining transition activities: the taxonomy-based approach and the principles-based approach. The former is a taxonomy or list of eligible transitional activities, including requirements for transition pathways and effects. The latter requires the subjects of transition activities to use a scientific approach to identify transition plans that meet the requirements of the Paris Agreement, without specifying which activities are recognised as transition activities.

Box 3 | Development of China's transition finance

- **The People's Bank of China** is taking the lead in developing transition finance standards and taxonomy, starting with sectors that include iron and steel, coal-fired power generation, building materials and agriculture. The transition finance standards and taxonomy was regarded as one of the priorities for China's green finance policy framework in 2022.
- **The National Association of Financial Market Institutional Investors** rolled out a transition bond pilot program in June 2022. It defines transition bonds in eight energy-intensive industrial sectors—power generation, building materials, iron and steel, nonferrous metals, petrochemicals, chemicals, papermaking and civil aviation—and supports two types of projects and economic activities: projects that have been included in the *Guidance Catalogue of Green Industry and the Green Bonds Endorsed Projects Catalogue* but have not met the technical indicators; and projects and other related economic activities that are compatible with the 30-60 goals and play a significant role in reducing carbon and improving energy efficiency.
- **The Shanghai Stock Exchange (SSE)** added a new specific type of corporate bond, called the Low-Carbon Transition Corporate Bond, in June 2022. The exchange identified five types of low-carbon transition areas and four types of uses for the raised funds.
- **The Huzhou municipal government** in Zhejiang Province released China's first subnational transition finance taxonomy in January 2022. It defines transition activities in nine energy-intensive industries by defining a transition baseline, a target range and a roadmap.

In China, the net-zero transition of energy-intensive industries is the top priority for achieving China's carbon neutrality goal (Lin and Tan 2017). Finance regulators, financial associations and financial institutions are taking steps to define transition finance and identify transitional activities (see Box 3). Transition bonds were widely issued across China's financial institutions from 2020 to 2022 to support the low-carbon transition of power generation and manufacturing.

In November 2020, the Hong Kong Green Finance Association released the report *Navigating Climate Transition Finance*, which proposes a principles-based framework for climate transition finance and lays out pathways and technological solutions to achieve climate transitions in three hard-to-abate sectors: steel, cement and energy.

The transitioning of high-carbon sectors to lower emissions is receiving increasing attention, including from governments and markets, which is accelerating its development. The GBA's transition requires large investments, especially in Pearl River Delta cities with emissions-intensive industries. Therefore, the GBA could play a key role in adopting China's transition finance standards and launching pilot or demonstration projects. Hong Kong can bridge the gaps between the GBA and international markets and strengthen international cooperation by integrating transition finance standards with international practices, helping to attract international capital.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SECTION 6

FINANCE PRACTICES TO ACCELERATE THE TRANSITION AND ADDRESS CHALLENGES IN THE GBA

In China and the GBA, a variety of tools for financing decarbonisation are being used to accelerate industries as they transition to a low-carbon economy. We have seen various green and sustainability-linked finance tools being applied, but transition finance remains nascent and faces many challenges. Transition finance is particularly important to accelerate the transition to net-zero of high-carbon-emitting industries.

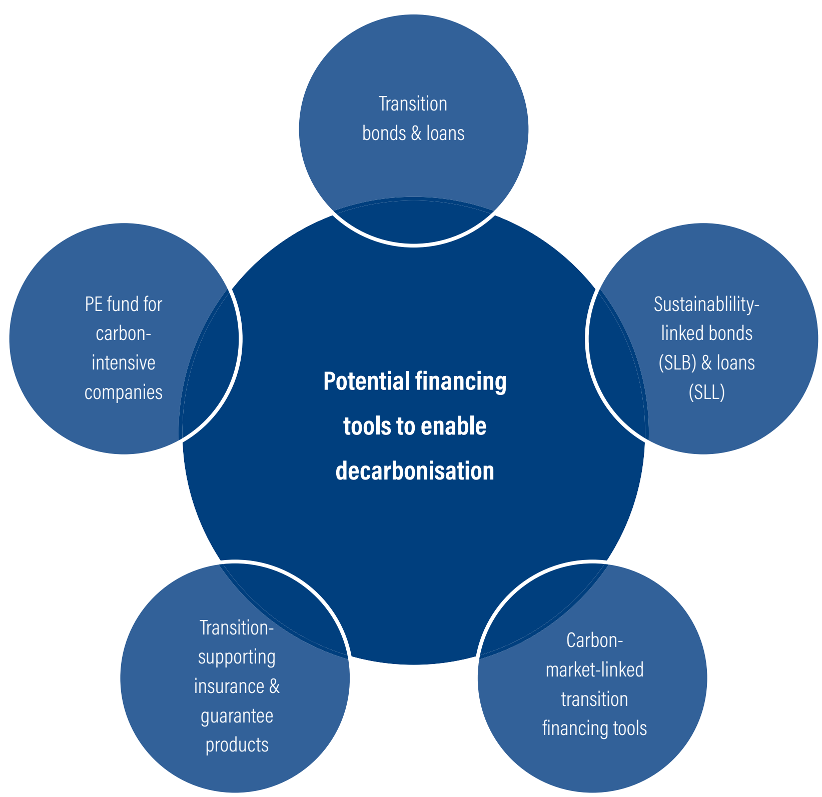
Available and potential financial tools, shortfalls and case studies

Around the globe in recent years, there has been steady and increasing growth in 'financing decarbonisation' issuances and borrowing. The market is also growing increasingly sophisticated, as evidenced by the growing volumes of issuances and lending in formats other than green bonds and green loans. According to Bloomberg (2022), more than $1.6 trillion in sustainable debt instruments were issued in 2021, and sustainability-linked loans and bonds showed the strongest growth, reaching $530 billion, four times the volume offered in 2020.

Over the past seven years, China's green finance market has developed a well-stocked toolbox, including various types of loans, bonds, private equity (PE) funds and insurance products. In contrast, transition finance is in its infancy, although it is gaining traction. Despite the lack of a universally accepted transition finance taxonomy or standard when they first emerged, tools of transition finance picked up momentum after China proposed its climate goals in 2020 and after the launch of the G20 Transition Finance Framework. Currently, the major financial tools that can be directly linked to sustainability and transition finance include sustainability-linked bonds, sustainability-linked loans, transition bonds and transition loans. Figure 35 summarises existing and potential financial tools to support decarbonisation.

China's green and sustainable finance market is policy-driven and was highlighted in the 2022 priorities of the People's Bank of China (PBoC), which include deepening transition finance research and aiming to achieve a convergence of green finance and transition finance (Luo 2022). With financial markets' burgeoning interest in transition finance, the types and volume of transition finance tools will multiply.

Figure 35 | **Available and potential financing tools to accelerate the transition**



Notes: PE=private equity.
Source: Project team.

Transition bonds and loans

The National Association of Financial Market Institutional Investors (NAFMII), China's interbank bond market regulator, is the main regulating authority for transition bonds in China. According to the 'Notice on the Piloting of Innovation Related to Transition Bonds', a transition bond is defined as a financing tool that raises funds specifically for low-carbon transition (NAFMII 2022). The pilot covers eight industries: power, building materials, steel, nonferrous metal, petrochemicals, chemicals, papermaking and civil aviation. Transition bonds could be issued by corporates and undertaken by commercial banks.

Two types of project and economic activities are supported by the NAFMII's pilot program of transition bonds: projects that fit into the types listed in the *Green Bond Endorsed Project Catalogue* (2021 edition) but have not met the criteria for labelling as a green bond; and projects and other related economic activities that could contribute to China's carbon-peaking and carbon-neutral targets. The issuance of transition bonds is expected to facilitate projects, economic activities and pilot programs for the low-carbon transition. These include

- cleaner coal production and efficient utilisation;
- clean use of natural gas;
- phaseout or upgrade of production capacity in the eight most energy-intensive manufacturing industries; and
- application of green equipment and technology.

In June 2022, the first five transition bonds were issued, all from traditional carbon-intensive industries and all in line with the high-level standards of the International Capital Market Association (ICMA) in four core elements: the use of raised funds, the disclosure of transition information, third-party assessment and certification, and fund management (cases are shown in Box 4). By the end of 2022, China had issued 10 transition bonds totalling $4.93 billion to support the low-carbon transition in the steel, power, chemical and civil aviation sectors. However, the short maturity of the transition bonds issued, mainly two and three years, is not in line with the NAFMII's objective of encouraging companies to issue medium- and long-term transition bonds to facilitate the long-term development of their low-carbon transition.

Globally, the transition finance market is still hampered by the absence of clear and agreed-upon definitions, making it difficult for a high-emitting sector to access financial markets. Early examples of transition bonds were frequently criticised for lacking clarity and ambition, and making commitments that represented little more than 'business-as-usual' practices. The difficulty of defining and standardising the transition products has been a major reason for the relatively slow growth of use-of-proceeds transition bonds compared with key performance indicator (KPI)–linked products such as SLBs. Within the GBA, the Hong Kong Green Finance Association's report *Navigating Climate Transition Finance*, released in November 2020, proposes important principles that market authorities and market participants should consider when defining the operational framework for climate transition financing; this work will likely continue in 2023 with an emphasis on robust transition planning.

In the Chinese market, the use-of-proceeds transition bonds, currently regulated by the NAFMII, can enhance their robustness by learning from international experience, including the attention to the company-level transition plan, the setting of KPIs, and the technical criteria specific to each sector. The GBA offers a perfect testing ground for further alignment and interoperability of transition finance standards and tools. Early examples of transition transactions, including transition bonds issued by the Bank of China and the energy transition bond issued by the Hong Kong–based CLP Group, can further demonstrate credibility to investors by articulating short-, medium-, and long-term transition trajectories and explaining the plan to avoid carbon 'lock-in'.

Box 4 | Examples of transition bonds or loans

Case 1: Shandong Iron and Steel Group Co., Ltd.

- Led by China CITIC Bank and CITIC Securities, with an amount of $153.9 million and a term of 2+N (2) years.
- Issuer's transition plan: Shandong Iron and Steel Group will use clean production technology and equipment to improve energy efficiency. It plans to peak emissions before 2030 and reduce total carbon emissions from the peak by 30 percent by 2035, then to reduce emissions by 80 percent from the peak by 2050, and finally to achieve carbon neutrality by 2060.
- Project highlights: This is a major construction project in Shandong Province. It will replace the original high-energy-consuming production line. It is expected to save 325,200 tonnes of coal equivalent annually and reduce carbon dioxide emissions to 784,900 tonnes (Shandong Iron and Steel Group 2022).

Case 2: Yinson Holdings Berhad FPSO Maria Quitéria Project (Brazil)

- Standard Chartered bank has led in 'structuring, underwriting, and arranging' a $720 million syndicated loan facility for a floating production storage and offloading project, catering to oil and gas investors' increasing appetite for energy transition agendas.
- The transition finance facility incorporates technologies that aim to help reduce flaring from the field. This meets the parameters for Standard Chartered Bank's transition finance framework to achieve the corresponding labelling.

Sustainability-linked bonds

Sustainability-linked bonds (SLBs) are forward-looking, performance-based debt instruments that link the terms of the bond to the issuer's achievement of a predefined sustainability performance target (SPT). SLBs are primarily structured to encourage issuers to make actual contributions to sustainable development goals at an institutional level. Coupon rate adjustments (with increases now widely used as a disincentive but which in the future could include decreases as an incentive), early maturity and additional one-off payments are designed to be linked to the achievement of sustainability targets. One key feature and concern for issuers is SLBs' punishment mechanism. Their punitive fees when the issuer fails to meet SPTs is a coupon step-up, mostly a flat rate of 25 basis points regardless of coupon size, credit quality, scale of business or consistency across the institutions (Reznick et al. 2022).

SLBs are designed to expand the role that bond markets can play in funding and encourage companies to pursue sustainability goals. Unlike transition bonds, proceeds from SLBs can be used for general purposes, needing only to comply with five core components for SLBs. As climate mitigation is among the 17 Sustainable Development Goals, we take SLBs as one of the possible choices for transition finance.

The SLB market is growing rapidly around the world. Since the ICMA released the Sustainability-Linked Bond Principles in 2020, SLBs have attracted more attention because of their diverse bond issuers and flexible uses of funds to achieve performance indicators in reducing carbon emissions. They now make up about 7 percent of the world's bond market. However, investors still view SLBs as polarised in the market compared with SLLs. Their progress in the Asian market has been comparatively much slower, only increasing from $0.22 billion in 2018 to $16.29 billion in 2021. China has issued a total of $6.1 billion (CNY 39.6 billion) in the SLB market as of January 2022, with 23 entities issuing 27 products (Qiu and Zhang 2022).

Box 5 | Guangdong Huizhou Pinghai Power Plant Company Limited Phase I medium-term notes for 2021 (sustainably linked)

Issue amount: CNY 300 million

Issue term: Three years

Preset KPI and SPT profile: Two SPTs under two KPIs

KPI 1: Reduce coal consumption for electricity supply and improve coal combustion efficiency to reduce greenhouse gas emissions.

SPT 1: Reduce the average coal consumption per unit of thermal power supply to 290.33 grams per kilowatt-hour by 31 December 2023.

KPI 2: Achieve carbon compliance through carbon market compliance.

SPT 2: By 31 December 2023, complete compliance with the national carbon-trading market or Guangdong carbon-trading market in accordance with the relevant national and Guangdong policy requirements, corresponding to the respective compliance years.

Bond structure: The coupon rate is linked to the sustainability performance target. If the target is met, normal capital repayment will be made in the last interest-bearing year; if the target is not met, the coupon rate will be increased by 10 basis points (Guangdong Huizhou Pinghai Power Plant Co., Ltd. 2021).

There are five core components for SLBs:

- Selection of key performance indicators (KPIs)
- Calibration of sustainability performance targets
- Bond characteristics
- Reporting
- Verification

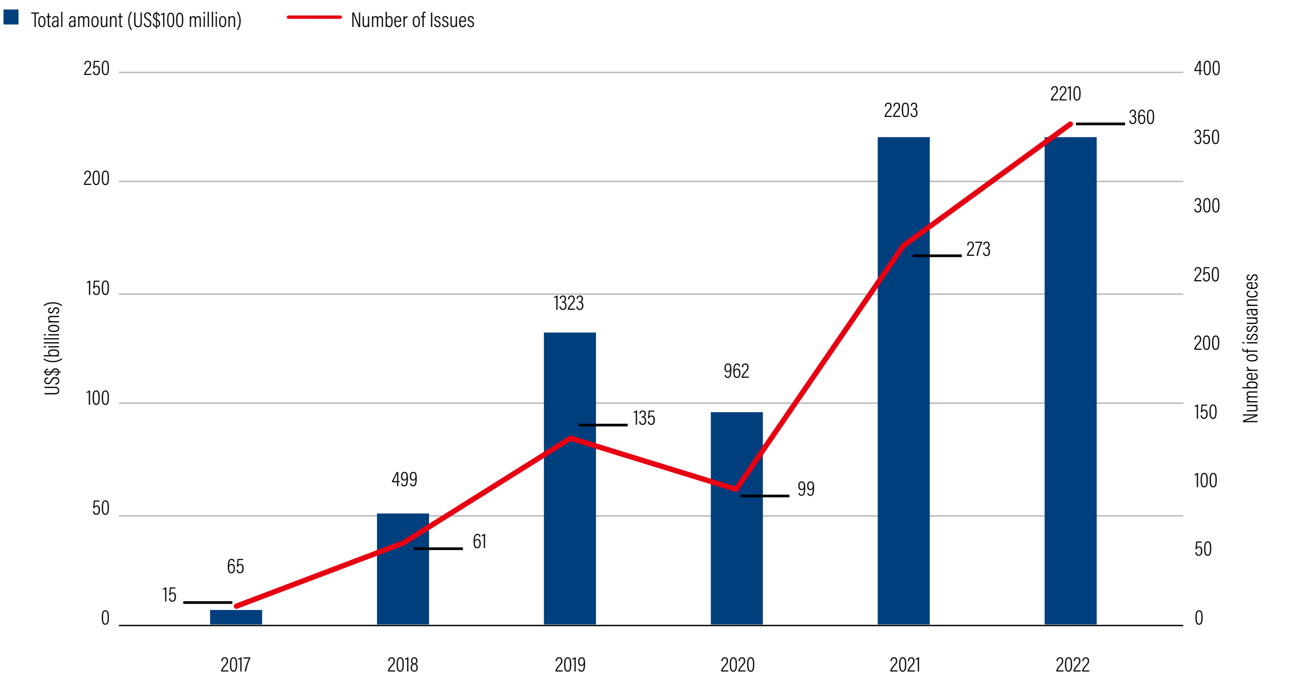
In China, the NAFMII launched SLBs in April 2021 based on the ICMA's Sustainability-Linked Bond Principles to increase financial support for the low-carbon transition of traditional sectors to achieve the country's decarbonisation target. By the end of 2022, a total of 58 SLBs had been issued in China's domestic market, with a total issuance scale of CNY 74.2 billion (China Chengxin Green Fund 2023). In terms of bond types, the vast majority are medium-term notes. Bond maturity terms range from two to five years, with three-year bonds being the most popular type. SLBs cover all eight emissions-intensive industries. Indicators for evaluating a corporation's performance for SLBs mainly include recycling of coal-mining resources and improvement in energy efficiency. One case is shown in Box 5.

SLBs face some limitations. Short maturity terms may make corporates hesitate to choose SLBs for transition finance. Insufficient penalties on return rates for not being able to achieve the SPT will make SLBs less effective in stimulating the low-carbon transition.

Sustainability-linked loans

In addition to the bond space, transition-related loans are increasingly being embraced by the market, with a similar set of rules. Compared to SLBs, sustainability-linked loans apply more rigorous metrics to judge companies' sustainability performance. These loan instruments give companies the incentive to achieve ambitious, predetermined sustainability performance targets, as measured by key performance indicators, which make it possible to quantify and assess improvements in a company's sustainability profile.

Figure 36 | **Global sustainability-linked loan amount**



Source: Ministry of Environment of Japan, based on the Environmental Finance Database (data as of December 1, 2022).

The SLL market is well-developed and one of the fastest-growing segments thanks to the flexibility in the way proceeds can be used on working capital, margin pricing tied to performance of predefined KPIs (both incentive and penalty pricing structure) and its applicability for various industries. According to data from Environmental Finance, across sustainable-labelled bonds and loans in 2021 (Figure 36), SLLs took the second-largest share (27.5 percent) at $453 billion. Asia issued $58 billion in SLLs, accounting for 13 percent of the world total. SLLs on the Chinese mainland are just getting started but have made substantial progress. In 2021, companies on the Chinese mainland received a total of $6.7 billion in SLLs. Hong Kong's SLLs started earlier than the Chinese mainland's, and its financial institutions are more familiar with SLLs (see one case in Box 6). SLLs accounted for 9 percent of Hong Kong's corporate loans in 2022 (Sina 2022). That year witnessed a first-time decline in sustainability-linked products globally, but China's market continues to grow fast; Chinese and Hong Kong firms signed an unprecedented $13.1 billion in sustainability-linked loans in 2022 (Chen and Huang 2022). Shanghai's first sustainability-linked international syndicated loan landed in the Lingang New Area, which adopted 'Offshore wind + international financing institutes + domestic banks' as a model to link domestic and international financing sources. As its sustainable performance targets, Lingang New Area selected building new green buildings, starting up scientific and innovative enterprises, and introducing manufacturing for clean energy equipment (Wenhui 2022). In June 2022, Shui On Centre Co., Ltd., raised $732.45 million in its first asset-backed syndicated sustainability-linked loan. Through the SLL, Shui On Centre will apply for the Excellence in Design for Greater Efficiencies (EDGE) green building certification programme and seek to improve energy efficiency beyond the EDGE certification level of 20 percent during the loan tenor of five years, to reduce carbon emissions from building operations (The Asset 2022).

Box 6 | CSSC (Hong Kong) Shipping Company sustainable development ship financing project

Sector: Transportation

Financial tool: Sustainability-linked loan

In June 2021, Standard Chartered Bank provided a 10-year ship mortgage term loan to CSSC (Hong Kong) Shipping Co., Ltd., in a total amount of US$96 million, for the mortgage financing of four container ships.

In contrast to traditional ship financing loans, this loan adopts a structure linked to the Sustainable Development Goals (SDGs). Throughout the duration of the loan, the average energy efficiency of the financed ships and other SDGs are continuously evaluated.

Standard Chartered Bank requires borrowers to follow the requirements of the Sustainability-Linked Loan Principles issued by the Asia-Pacific Loan Market Association, including the establishment of and compliance with the core elements of the borrower's sustainable strategy, such as relationship, target-setting, reporting and review.

Carbon-market-linked transition financing tools

The national carbon emissions trading scheme (ETS) in China will play an important role in peaking carbon and achieving carbon neutrality. Since it launched in July 2021, the ETS has grown to include more than 2,100 power generation plants and corporates producing 4.5 billion tonnes of CO_2, more than any other carbon market in the world (Ecology China 2022). Research from Tsinghua University (Zhang et al. 2021) shows that when China's national ETS scales up, it will cover eight carbon-intensive industries, including about 8,500 large carbon-emitting enterprises. The emissions eligible to be traded will account for 70 percent of the country's total energy-related carbon emissions.

The carbon market is one of the main tools for determining effective carbon prices and climate information disclosures. Transparent carbon prices and high-quality information disclosures help financial institutions quantify climate transition risks and incorporate them into their daily investment decisions. At present, the trading price of the first compliance period in the national carbon market is $7.7–$9.2 per tonne of carbon dioxide (Ecology China 2022). As an important tool to mobilise capital for decarbonisation, the national ETS will promote innovation and investment in China's low-carbon, zero-carbon and carbon offset technologies, and help promote China's low-carbon economic transformation.

Box 7 | Case studies of carbon-market-linked transition financing tools

Case 1: In 2021, the Bank of Nanjing launched Xin Carbon Reduction, the country's first loan product whose loan interest rate is linked to the carbon performance of emission-controlled enterprises. It issued a US$4.62 million loan to Huaneng Nanjing Thermal Power Co., Ltd. Xin Carbon Reduction is a loan issued by the Bank of Nanjing to emission-controlled enterprises that hold emissions allowances in the national carbon market. The loan interest rate is linked to a business's carbon performance in production and operations, and will decrease as the enterprise's carbon performance improves (Hexun 202).

Case 2: In October 2021, Standard Chartered Bank helped Baring Private Equity Asia establish a sustainability-linked loan (SLL) worth up to $3.2 billion, in which the margin is tied to both an incentive and a penalty requiring the purchase of carbon credits. The first of its kind for a private equity firm in the region, the SLL is subject to sustainability performance targets around gender diversity and climate change that could reduce a loan's interest rate if achieved (Standard Chartered Bank 2021).

The current ETS cannot meet the requirements of China's low-carbon transition, because only one energy-intensive sector was covered by the national carbon market between 2021 and 2022. The market needs to use basic assets, such as China Emissions Allowances (CEAs) and China-Certified Emissions Reductions (CCERs), to develop innovative carbon financing products to attract more entities and funds to enter the low-carbon market and enhance market liquidity (case studies in Box 7). Insufficient liquidity will affect the accuracy of carbon prices, and once prices drop excessively, carbon prices cannot truly reflect marginal costs of emissions reductions, causing carbon trading to lose its value in promoting enterprises' emissions reductions. The release of China's Standard for Carbon Financing Products in April 2022 significantly boosts the development of carbon-financing products (CSRC 2022).

The GBA is a pioneer in the development of China's carbon market, and a testing ground for attracting foreign investors and developing new carbon financial tools. In the GBA, much work to build the carbon market has already been done (see Box 8). The GBA also has two pilot carbon exchanges, a carbon futures exchange and two stock exchanges, which will allow

Box 8 | Carbon financing innovation and regional carbon-trading development in the GBA

In 2020, the State Council's 'Opinions on Financial Support for the Construction of the Guangdong-Hong Kong-Macao Greater Bay Area' was officially released. It proposed to carry out the pilot project of foreign exchange for carbon emissions trading, allowing foreign investors (overseas institutions and individuals) who have passed the qualification examination of local emissions exchanges to participate in carbon emissions trading in the Greater Bay Area (GBA) in foreign currency or Chinese yuan (PBoC 2020).

In April 2021, the Guangzhou Futures Exchange was officially established. It is the fifth futures exchange on the Chinese mainland. Its objective is to foster innovation, marketisation and internationalisation, serving the real economy and green development (Guangdong Provincial Local Financial Supervision and Administration Bureau 2021).

In March 2022, the Hong Kong Stock Exchange (HKEX) signed an agreement with the Guangzhou Emissions Exchange to explore cooperation opportunities in the field of carbon finance, jointly explore the deepening development of the regional carbon market and create a voluntary emissions-reduction mechanism suitable for the GBA. They will actively study the rules, standards and paths of the international carbon market to support the internationalisation of China's carbon market (HKEX 2022a).

In March 2022, the CICC Carbon Futures Exchange-Traded Fund (ETF), the first carbon futures ETF on the HKEX, was listed, further expanding the scope of commodity ETFs listed in Hong Kong as carbon credit products. The newly listed ETF is managed by CICC Hong Kong Asset Management (HKEX 2022b).

In March 2022, the carbon market task force under the Green and Sustainable Finance Cross-Agency Steering Group, led by the HKEX and the Hong Kong Securities Regulatory Commission, conducted a preliminary assessment of development opportunities for Hong Kong's carbon market. It suggested promoting the development of a unified carbon market in the GBA, exploring opportunities to connect international investors with this unified carbon market and China's national carbon market, strengthening cooperation with the Guangzhou Futures Exchange in carbon market development, and making Hong Kong an offshore risk management centre for the Chinese mainland (Green and Sustainable Finance Cross-Agency Steering Group 2022).

In July 2022, the HKEX announced the establishment of the Hong Kong International Carbon Market Committee. The panel's first members include a number of leading companies and financial institutions. They will work with the HKEX to explore the development opportunities of regional carbon markets and help Hong Kong build an efficient and effective international carbon market, providing superior market infrastructure, products and services. In October 2022, the HKEX announced the launch of Core Climate, through which participants can access product information, hold, trade, settle and retire voluntary carbon credit products (HKEX 2022c).

Core Climate recorded over 40 transactions involving approximately 400,000 tonnes of carbon credits in just under a month between its launch on 28 October and 24 November 2022. Core Climate has attracted over 20 participants from Hong Kong, Chinese mainland and international organisations representing different industries, including the China Carbon-Neutral Development Group, China Energy Conservation and Environmental Protection Group, State Power Investment Group, Carbon Asset Management Company Limited, Standard Chartered Bank (Hong Kong), Carbon Growth Partners and others (HKEX 2022d).

more room for development of the GBA carbon market. The GBA also has the potential to bridge the domestic voluntary carbon market (VCM) with the international VCM via Hong Kong's Core Climate, an international carbon market platform designed to connect capital and climate-related products, but the GBA's carbon market currently lacks a multilateral cooperation mechanism with international carbon markets. In addition, because the subnational GBA carbon market is affected by the national policy of a 'unified national market' when building the carbon market and VCM (State Council 2022), prospects for a local carbon market remain uncertain.

Insurance and guarantee products supporting transition

As a financial tool involving risk identification, risk quantification and management, and risk investment, insurance can support the green and low-carbon development of various industries in a multidimensional and holistic manner. On the asset side, insurance funds offer the advantages of large volume and long cycle, providing a long-term and stable source of funds through investment in the low-carbon transition of traditional industries. On the liability side, the insurance industry can provide risk management and risk compensation and protection for the economy and reduce carbon emissions from the three insurable areas of low-carbon transition, energy conservation and emissions reduction, and climate risk and environmental governance.

However, in China, insurance products for green and low-carbon transition are mostly limited to environmental pollution liability insurance. Insurance's potential to provide mechanisms for decarbonising the national economy has not yet been tapped. This status quo began to change with the introduction of the 30-60 goals. The best examples of this are the *Green Finance Guidelines for the Banking and Insurance Industry* and the *Green Insurance Business Statistics System*, issued by the China Banking and Insurance Regulatory Commission (CBIRC) in June and November 2022, respectively (one case shown in Box 9).

Insurance support for the GBA's green and low-carbon development has borne some fruit, such as the Shenzhen Green Finance Regulation, which establishes a green insurance system in the form of legislation. Guangzhou is vigorously promoting environmental pollution liability insurance, innovations and pilot varieties of 'Green Farmers Insurance+'. Under the guidance of the CBIRC, the Guangdong Bureau of Banking and Insurance promotes the establishment of an insurance service centre in the GBA. According to statistics from the Guangdong Bureau of Banking and Insurance, if a platform built for 'insurance capital to enter into Guangdong', the accumulated investment balance of insurance funds in the GBA would exceed CNY 1.52 trillion (*Financial Times* 2022).

However, in general, three institutional issues remain in the GBA. First, the implementation of green finance relies on mandatory regulations and lacks an effective incentive mechanism to attract the participation of insurance institutions and enterprises. Second, green insurance mechanisms need to be strengthened, such as by completing mechanisms for insurance application, underwriting and premium rates. Only Shenzhen has established a mandatory liability insurance system for environmental pollution. The differences between

Box 9 | Case study of a carbon-reduction insurance product and an insurance product under conception

If the insured's suffering from natural disasters and accidents results in excessive carbon emissions, this insurance will provide compensation for the additional costs of emission allowances trading. The insured amount is determined by the amount of emission allowances for normal production and operation and the average price of emission allowances trading. In November 2021, the China Banking and Insurance Regulatory Commission provided this insurance product to emissions-reduction equipment of China Grain and Logistics Group Beiliang Co., Ltd., as the first carbon-reduction loss insurance in China.

Figure 37 | **Key challenges in using financial tools to accelerate the transition in the GBA**

Note: GBA = Guangdong–Hong Kong–Macao Greater Bay Area.
Source: Project team.

the management systems of Guangdong, Hong Kong and Macao have hampered the integration of a green insurance system, including inconsistencies between insurance product systems and rules, inconvenient cross-border green insurance services and the lack of a coordination mechanism for cross-border insurance supervision (Li and Lin 2022).

Private equity funds

In order to achieve a low-carbon transition, some carbon-intensive and high-polluting companies may need to adopt innovative green and low-carbon technologies, especially for manufacturing. However, such adoption often requires large investments for R&D and the application of new technologies. Currently, many transition projects and activities cannot meet the risk appetite of financial institutions, despite having great potential for profits in the long term. Equity funds have become an increasingly popular vehicle for institutional investors to participate in transition financial activities. While consensus is emerging in the debt-capital market on how to define a credible transition, clear guidelines and tools are still needed for private equity funds to screen and assess transition projects with demonstrable climate impacts. Academia has a large role to play in defining technological maturity and feasibility to help direct capital to technologically feasible solutions. Box 10 provides a case study.

Box 10 | Private equity helps to accelerate transitions by using a sustainability-linked loan structure at the fund or platform level

PAG, an investment firm focused on the Asia Pacific region, established a sustainability-linked loan in September 2022, with BNP Paribas, Société Générale and Standard Chartered Bank acting as joint sustainability coordinators. The three-year subscription facility is backed by unfunded capital commitments from a diversified group of blue-chip investors and integrates environmental, social and governance principles throughout the investment process. Proceeds from the transaction will be used to support PAG's private equity (PAGPE) strategy. The size of the facility will scale with the scope of PAGPE investments.

Source: PAG (2022).

Key challenges faced in using financial tools to accelerate the transition

Introducing various decarbonisation financing tools could accelerate decarbonisation in China and the GBA, but the GBA still suffers from a lack of finance standards (such as a transition finance taxonomy) and insufficient regional synergies in the finance market, which hinder the ability of Guangdong, Hong Kong and Macao to produce joint effects (see Figure 37).

More cross-regional policy coordination needed in the GBA

Government cooperation at all levels across the GBA needs to be strengthened. The top-level documents for the development of green finance in the GBA, the 'Outline of the Development Plan for the Guangdong–Hong Kong–Macao Greater Bay Area' and the 'Opinions on Financial Support for the Construction of the Guangdong–Hong Kong–Macao Greater Bay Area', urge the strengthening of green finance cooperation in the GBA. However, the governments of key cities–namely, Guangzhou, Shenzhen, Hong Kong and Macao–have not issued municipal-level planning guidelines drafted in tandem with each other. It is also not clear how the GBA will promote the coordinated cross-regional development of 'financing decarbonisation', especially the emerging transition finance.

In September 2020, the Guangdong–Hong Kong–Macao Greater Bay Area Green Finance Alliance was established under the guidance of the Green Finance Committee of the China Society for Finance and Banking. The key members of the alliance, including the Hong Kong Green Finance Association, Guangdong Green Finance Committee, Shenzhen Green Finance Association and a number of regulatory and market bodies, have been coordinating the development of an aligned approach towards the green and transition finance market.

Ambiguous definition for transition activities

Since 2015, China's green finance standards have seen a few rounds of update and consolidation across ministries. The green finance regulatory regime has been consistently improving in sophistication and is now able to provide clarity to the market and reduce greenwashing.

In comparison, transition finance has just gotten started on the Chinese mainland, and neither widely recognised transition finance standards nor a clear taxonomy of high-carbon industries have yet been developed. There are strict definitions of green finance in China, and these exclude many hard-to-abate sectors, even though transforming these sectors will be vital for China to reach its 30-60 goals. The transition label requires a rigorous taxonomy and definition, especially given that transition activities vary significantly from one manufacturing industry to the next. Transition pathways research has been carried out in some industries (construction, road transport and rail) but not in others (e.g., aviation, shipping and heavy industry). Currently, international consensus is lacking about what should be considered transitional and eligible for financing. Even if financial institutions have issued proprietary transition finance frameworks to guide their activities, uncertainty remains about which standards and regulations should apply and how adherence to these should be monitored and enforced.

The lack of common principles hinders deeper cooperation across the GBA. For example, the NAMFII issued the guidance for piloting transition bonds, and the Shanghai Stock Exchange also identifies the scope of corporate transition bonds, where differences in rules and procedures are obvious. For transition loans, no national-level guidance or rules yet exist. Financial institutions and business practitioners will wonder whether there is a common rule for transition loans.

The integration and mutual recognition of third-party verification could still be strengthened. Issuance management, evaluation and certification processes are inconsistent, which will increase the transaction cost of green capital assets. For example, corporates align with the *Green Bond Endorsed Project Catalogue* (2021 edition) on the Chinese mainland, while corporates in Hong Kong align with the ICMA's Green Bond Principles, which more closely follow international standards.

The inconsistency of environmental information disclosure standards will affect the process of financial integration and regional cooperation in the GBA. Eight cities on the Chinese mainland (not including Shenzhen) were covered by a pilot program of environmental information disclosure in 2021. Hong Kong has issued its own ESG Reporting Guidelines, while Macao has no disclosure requirements.

Insufficient scientific guidance for transition plans

The transition to lower carbon-emissions enterprises will require unified standards, transition goals and pathways. A large number of high-carbon enterprises in China have the will to transition, as the State-Owned Assets Supervision and Administration Commission of the State Council requires all state-owned companies to establish a carbon emissions peak action plan (Xinhua News Agency 2022). However, they typically lack the expertise to set the transition goals and paths, the ability to prepare transition plans, and an understanding of how to access the financial market with credible tools and products to support the transition. This, coupled with the fact that many financial institutions wait for high-carbon enterprises to come up with their own transition plans to apply for transition financing, will lead to missed opportunities and wrong signals that stall businesses' low-carbon transition. It is also likely to raise transition costs.

Most of the existing transition pathway initiatives, such as the Science Based Targets initiative, the Transition Pathways Initiative, and Assessing Low-Carbon Transition, address a subset of the total range of economic activities, assets and projects that need to be decarbonised rapidly. Though most initiatives agree that the ultimate goal of transition is alignment with the Paris Agreement's 1.5°C pathway to net zero by 2050, and the carbon-neutrality pledges of Chinese cities and organisations also largely stick to the 2050 timeline (instead of 2060), there is little consensus on how this can be achieved and the time it would take. These initiatives are also global and not calibrated at the country level.

Clear criteria relating to heavy industry are only mentioned in four frameworks: the EU Taxonomy, China's *Green Bond Support Project Catalogue*, the Transition Pathways Initiative and the Corporate Knights and Clean Capitalism Commission Classification. However, the first two classification schemes only relate to current performance and do not establish a transition pathway to achieving long-term goals.

Limited financial tools to accelerate transition

Having a wide range of well-defined and well-understood financing tools is a prerequisite for financing the decarbonisation of high-carbon enterprises and their transition activities. The acceptance and liquidity of transition-related financial tools are also an indication of the maturity of the transition market. At present, while SLLs and SLBs are being adopted to set clear GHG reduction targets during the financing terms, transition finance tools, bonds and loans are still limited. Financial tools in the form of equity investment, insurance and asset-backed securities are relatively undefined or non-existent. Currently, the Chinese mainland's sustainability-linked products tend to be short term and/or medium term (3–5 years) compared with global and Hong Kong markets, which have maturities of 5–10 years or even longer, creating a funding maturity mismatch. Tools for financing decarbonisation thus need to be further diversified to match the demand for transition funding of different maturities. Additional products are needed to address risk-sharing in the transition activities through the capital markets. In addition, the HKEX has already launched the carbon futures ETF, and the Guangzhou Futures Exchange is also studying the launch of a carbon futures product. With the gradual development of the carbon market, more carbon finance–related financial tools will become available to meet the needs of various entities in carbon asset management.

Unaligned carbon market mechanisms

Currently, there are two pilot carbon markets in the GBA, one in Guangdong and the other in Shenzhen. Due to differences in the initial allocation of carbon allowances and the regulation of the carbon market, the allowances in the two markets cannot be traded or mutually recognised, thus fragmenting the GBA's carbon markets, which reduces the scale and liquidity of transactions and leads to a lack of comprehensive coverage of industries. In addition, the national carbon market and local pilot carbon markets currently exist in parallel. Local pilot carbon markets would have more opportunities to develop in the short to medium term in a unified national market, but they would face greater challenges in the long term. For example, they may be polarised or even eliminated if a national carbon market is gradually formed.

SECTION 7

RECOMMENDATIONS FOR FINANCING PRACTICES TO ACCELERATE THE TRANSITION

The GBA is China's economic powerhouse. It can spearhead growth, innovation and China's national 30-60 goals for carbon peaking and carbon neutrality. This section provides recommendations on how to accelerate the transition through sectoral actions and finance practices.

The GBA is uniquely positioned to initiate strong and lasting collaboration among various regional and international stakeholders to incentivise investments in transition and to level the playing field for all transitioning entities. As discussed in Section 6, tools for financing decarbonisation are directly related to GHG emissions reductions and should be given higher priority in the GBA. In order to fully exploit the supporting role of financing the GBA's decarbonisation, we propose the implementation of the following key measures.

Establish a cross-regional agency coordination mechanism for financing decarbonisation in the GBA

The Outline Development Plan for the Guangdong–Hong Kong–Macao Greater Bay Area calls for further deepening cooperation and integration between Guangdong, Hong Kong and Macao, fully leveraging their various advantages and promoting coordinated regional economic development to create an internationally first-class Greater Bay Area ideal for living, working and travelling.

The development of financing decarbonisation requires joint efforts by multiple stakeholders to promote cooperation between municipalities and policy and market stakeholders, especially when there are two systems in the GBA. It is imperative to establish a committee spanning regional agencies to coordinate the decarbonisation financing mechanism and strengthen communication and cooperation in the GBA.

The core coordination agency could be based on the existing GBA-GFA, with a steering committee including local policymakers and regulators, such as the PBoC Guangzhou Branch, the PBoC Shenzhen Central Subbranch, the Guangdong Provincial Development and Reform Commission, the Guangdong Financial Supervisory Bureau Authority, the Hong Kong Monetary Authority and the Monetary Authority of Macao. The coordination mechanism would seek to mobilise policy incentives and finance resources in support of transition activities and investment by drawing on experiences of green finance development in the region.

Facilitate interoperability of Chinese mainland, international and/or Hong Kong transition finance taxonomies and information disclosure

Rapid decarbonisation of the hard-to-abate sectors through the lever of finance is an increasingly mainstream concept among China's policy and market actors. The PBoC, NAFMII and other government-affiliated bodies have already started developing a transition finance policy framework and transition finance products for China. The PBoC is preparing the transition finance standard for four industries—thermal power, steel, construction and building materials, and agriculture—and will cover petrochemicals, chemicals, buildings, civil aviation and non-ferrous sectors in the next few years. Subnational government bodies, such as Huzhou in Zhejiang Province, have released local, region-specific taxonomies to accelerate the low-carbon transition.

To reduce transaction costs, improve market transparency and avoid transition washing in the region, it is necessary to promote interoperability of the transition taxonomies currently being developed on the Chinese mainland with international and Hong Kong standards whenever these taxonomies become available. A transition finance taxonomy is a practical tool that guides high-carbon-emission entities and sectors in their transition. Its key benefit is that it outlines a clear and time-based pathway to achieve alignment with the Paris Agreement and China's 30-60 goals. The scope of the taxonomy can be based on the key manufacturing industries in the GBA, such as the six major industries included in the Guangdong Carbon Market, or a selection of industries not covered by the PBoC's Transition Finance Standard.

Information disclosure is also important to the transparency and credibility of transition activities. It is also essential to find consensus on mandatory information disclosure for transition activities among different regulators, and to facilitate market readiness for adopting international climate disclosure standards like those of the International Sustainability Standards Board in a region that will become a pioneer for China nationwide.

Encourage the GBA's financial institutions and enterprises to set scientific net-zero targets

The development of clear and scientific transition frameworks and standards is a prerequisite for financial markets to facilitate a low-carbon transition in high-carbon sectors. As the coordination mechanism and the taxonomy gradually move forward, the market is paying particular attention to the setting of scientific transition plans for enterprises. The guidance to date is not clear for many high-carbon-emitting sectors and does not always have sufficient granularity for it to be used to put forward strategies and capital expenditure plans that are in line with the climate targets set by domestic and international government stakeholders. Meanwhile, the transition path developed based on the goal should be feasible, acceptable and recognised by the market. Based on this principle, from a policy-oriented point of view, the Chinese mainland has no relevant guidelines to clarify the transition path of enterprises.

The HKEX issued the '*Practical Net-Zero Guide for Business*' in December 2021. These guidelines, based on a set of SBTi's scientific carbon-target-setting guidelines, are tailored to the major industry categories of Hong Kong–listed companies and seek to be more focused and practical. Enterprises in the GBA can use the HKEX or SBTi guidelines to develop their transition plans. To date, SBTi has released guidance for the apparel and footwear, cement, financial, forest, land and agriculture, information and communication technology, maritime and power sectors. The market also needs to develop more sustainability advisory talent to support companies along the pathway to decarbonisation. Some international banks that have joined SBTi, like Standard Chartered, can be showcases and play leading roles in target-setting, disclosure and engagement with corporate clients for their decarbonisation goals and pathways.

Develop a transition-related financial toolbox to scale up finance

The huge investment demand for the GBA's decarbonisation, $1.84 trillion, offers an enormous opportunity for financial institutions to mobilise private capital and scale up financial flows to transition activities and investments identified in the region and nationwide. Currently, SLLs and labelled debt instruments such as SLBs and transition bonds have begun to be created in China. The GBA can establish a grant scheme to scale up sustainability-linked and transition financial products in its manufacturing, buildings and transport sectors. The scheme should adopt both policy supports on the Chinese mainland, such as subsidies for bond issuance and discount interest on green credit, and Hong Kong Monetary Authority (HKMA) Green and Sustainable (GSF) grants, to help eligible bond issuers and loan borrowers cover their expenses on bond issuance and external review services.

In addition, carbon-related products can be innovated to link with carbon assets, such as Chinese Emissions Allowances (CEAs), China-Certified Emissions Reductions (CCERs) and carbon credits recognised in the international market. For example, the International Finance Corporation (IFC) Forest Bond offers economic incentives to reduce deforestation and invest in low-carbon growth. Investors in the IFC Forest Bond choose between a cash or carbon credit coupon which can be redeemed to offset corporate greenhouse gas emissions or sold on the carbon market. The carbon-related products are carbon assets embedded into the structure of SLLs and other carbon-trading products. They support energy-intensive enterprises in developing transition targets and technical roadmaps which follow the requirements of the Sustainability-Linked Loan Principles issued by the Asia-Pacific Loan Market Association, as well as those of Chinese national or GBA regional transition finance taxonomies.

Financial tools with a higher risk appetite, including transition-focused equity investment and mergers and acquisitions funds, can be employed to address additional financing shortfalls and promote the transition at the entity level. They also offer an opportunity to explore setting up a tax concession private equity fund to invest in companies adopting new low-carbon technologies, upgrading high-carbon industries by using digital technologies or incubating innovative small and medium-sized enterprises in the key sectors. Financial institutions can collaborate with local governments to use revenue from carbon allowance auctions to establish the industrial low-carbon fund for decarbonisation technology investment and projects in the GBA.

Insurance and blended finance tools such as credit guarantees, concessional capital, local currency hedging and first-loss position can also be explored to better allocate the risks associated with transition activities. Like developmental finance and climate finance, the transition activities of the hard-to-abate sectors face a matrix of transition, off-taker, policy, currency, liquidity, scale and other risks. Risk-mitigation instruments can thus play a critical role in insuring the energy performance of transition activities during financing tenor.

Develop industry-specific financial solutions for the key sectors in the GBA

Manufacturing: For the key energy-intensive industries identified by Chinese regulators, such as steel, petrochemicals, cement, ceramics and papermaking, financial institutions can partner with multinational corporations (MNCs) to scale up sustainable supply chain finance (SSCF) along the value chain. Leveraging SSCF can assign value to MNCs' supply chain sustainability and provide tangible incentives to suppliers and their buyers.

Building: Leveraging tools for financing decarbonisation to scale up green retrofitting via sustainability-linked loans, implement an effective energy performance contracting business model for green retrofitting, adopt a green insurance mechanism in the GBA to address term mismatch, expand recognition of international green building certifications (such as the International Financial Corporation Excellence in Design for Greater Efficiencies [EDGE] certificate) to attract international funding, and conduct operational assessment and disclosure of energy data.

Transport: Through policy incentives for new energy–based freight fleet, electric and hydrogen fuel cell vehicles, mobilise private capital for construction in the region of new-energy vehicle infrastructure, such as charging piles and hydrogen refuelling stations. Encourage local governments to issue sustainable municipal bonds to invest in railways and leverage SLL and transition financing for shipping financing (beyond International Maritime Organization and duel-fuelled vessels).

Use local and regional carbon markets to accelerate the GBA's transition

As a key economically advanced region, the GBA should adopt and model stringent and ambitious targets for controlling carbon emissions. As no authority oversees the GBA as a whole, it is more realistic to implement an emissions cap through a regional carbon market. The GBA carbon market can play a role in the following strategies to accelerate the GBA's transition:

- The first step is to build more regional cooperation. This should include establishing a mechanism for data exchange and sharing between different carbon markets, thereby improving the transparency and effectiveness of carbon emissions data.

- The existing Guangdong and Shenzhen carbon emissions trading systems can also help accelerate the GBA's transition by pioneering expansion of the scope of regional carbon markets to include the covered sectors not in the national carbon market: ceramics, textiles, data centres, buildings and transport. A GBA regional carbon market linked to the Hong Kong market could be developed to pilot financial tools and derivatives.

- The national carbon market, which is expected to expand the covered sectors and reboot the transaction of CCERs, presents an opportunity to connect with the Chinese mainland CCER market, the Hong Kong 'Core Climate' and international voluntary carbon markets. In promoting and implementing Article 6 of the Paris Agreement, the Integrity Council for the Voluntary Carbon Market has been established to formulate a global unified standard for tradable and high-quality carbon credits. In this context, many countries and regions are building international voluntary carbon markets. Hong Kong has launched the 'Core Climate' voluntary carbon market, serving domestic and global VCMs, connecting capital with climate-related products and opportunities in Hong Kong, the Chinese mainland and the world. Follow-up research can be carried out in terms of mutually recognised domestic and international standards, market infrastructure, trading products and international cooperation.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APPENDICES

APPENDIX A. METHODOLOGY OF CARBON EMISSIONS GAP ANALYSIS IN THE GBA

Scope and carbon emissions accounting methodology

In Section 1, the project team forecast the future emissions based on GDP and carbon intensity for the Pearl River Delta region cities. We incorporated previous study results for Hong Kong from the Hong Kong Energy Policy Simulator ("Hong Kong EPS" 2020). Macao is not included in this analysis due to lack of available data.

The equation for emissions calculation is as follows:

Equation 1

$$CO_2 = GDP \times Carbon\ Intensity$$

The above two indicators were chosen instead of four indicators—population, GDP per capita, energy consumption per unit of GDP, carbon emissions per unit of energy consumption—because there are official expectations for GDP growth in the 14th FYP as a reference, and there are both provincial and city-level carbon intensity targets as a reference. In contrast, the GBA has no relevant planning document providing a reference for the indicator on carbon emissions per unit of energy consumption.

Data sources, key assumptions and scenario settings

The year 2020 was chosen as the base year in this study. The data source for carbon emissions in 2020 is from the 'Zero Carbon Map' of the Institute of Public and Environmental Affairs (2022). The data sources for GDP in 2020 are the statistical yearbooks of each city in the GBA and the Guangdong Provincial Statistical Yearbook. The predicted GDP growth from 2020 to 2025 is derived from each city's 14th FYP for National Economic and Social Development and Outline of Long-Term Goals for 2035. Separately, Hong Kong's current and projected carbon emissions are directly cited from WRI's Hong Kong study (Jiang et al. 2020).

GDP for each year is calculated based on the GDP of the previous year and the growth rate, so assumptions must be made about the GDP growth rate from 2021 to 2060. Considering that the GBA's economic development is transitioning from high speed to high quality (State Council 2019), one of the key assumptions is that the average GDP growth rate for every five years will reduce by 0.5 percentage points from 2025 to 2060, as shown in Table A-1.

We created three scenarios: the Baseline Scenario, the 30-60 Scenario and the 25-50 Scenario:

Baseline Scenario: Carbon intensity reduction rates for every five years in the 2020–60 period will remain the same as those in the 13th FYP period (2015–20), as shown in Table A-2. This is because there is no national carbon emissions intensity target for the 14th FYP; we therefore offer a

Table A-1 | **Average annual growth rate of GDP (%) for every five years, 2020-60**

	2021-2025	2025-2030	2030-2035	2035-2040	2040-2045	2045-2050	2051-2055	2056-2060
Guangzhou	6	5.5	5.0	4.5	4.0	3.5	3.0	2.5
Shenzhen	6	5.5	5.0	4.5	4.0	3.5	3.0	2.5
Zhuhai	7	6.5	6.0	5.5	5.0	4.5	4.0	3.5
Foshan	6	5.5	5.0	4.5	4.0	3.5	3.0	2.5
Dongguan	6	5.5	5.0	4.5	4.0	3.5	3.0	2.5
Zhongshan	6.5	6	5.5	5.0	4.5	4.0	3.5	3.0
Jiangmen	6	5.5	5.0	4.5	4.0	3.5	3.0	2.5
Huizhou	7.5	7.0	6.5	6.0	5.5	5.0	4.5	4.0
Zhaoqing	5.35	4.9	4.4	3.9	3.4	2.9	2.4	1.9

Source: Data for 2021–25 from each city's 14th FYP for National Economic and Social Development and Outline of Long-Term Goals for 2035. Data for 2025–60 are assumptions by the project team.

Table A-2 | **Carbon intensity reduction assumption every five years under the Baseline Scenario**

	CARBON INTENSITY REDUCTION EVERY FIVE YEARS (2020–60)
Guangzhou	23
Shenzhen	23
Zhuhai	20.5
Foshan	23
Dongguan	23
Zhongshan	23
Jiangmen	20.5
Huizhou	20.5
Zhaoqing	20.5

Source: Guangdong Provincial People's Government, 2017, 'Guangdong Province's Implementation Plan for Controlling Greenhouse Gas Emissions for the 13th Five-Year Period,' http://www.gd.gov.cn/gkmlpt/content/0/146/post_146048.html#7.

conservative estimate by using the target for the 13th FYP.

30-60 Scenario and 25-50 Scenario: The 30-60 Scenario is assumed to peak emissions by 2030 and achieve carbon neutrality by 2060, while the 25-50 Scenario is assumed to peak emissions by 2025 and achieve carbon neutrality by 2050. Our analysis will answer the question of how much carbon intensity reduction is needed for carbon emissions to peak by 2030 and 2025, respectively, and how we should set an emissions cap target after the peak year towards carbon neutrality by 2060 or even by 2050.

Carbon intensity reduction assumptions under the 30-60 Scenario and the 25-50 Scenario are as follows:

- In the 30-60 Scenario, to just peak emissions in 2030, Guangdong Province needs to reduce 81 percent of carbon intensity by 2035 compared with 2005. These data are from the WRI China paper 'Some Thinking on Carbon Emissions Peak Target Allocation at the Sub-national Level' (Jiang 2021). Based on the relationship between the provincial target and city-level target during the 13th FYP, we calculated carbon intensity in 2035 for each city in the

GBA. Carbon intensity between 2020 and 2035 is calculated by linear difference. Each city's achieving carbon neutrality in 2060 will entail reducing carbon emissions by 90 percent compared with 2020 level, and the carbon intensity in 2060 is calculated based on this condition. Carbon intensity between 2035 and 2060 is also calculated by linear difference.

- According to the requirements of the latest IPCC report, we assume that emissions will peak in 2025, that they will be halved in 2040, and that carbon neutrality will be achieved around 2050 (assuming a 90 percent reduction compared to 2020, with the remaining emissions offset). Based on the 30-60 Scenario assumptions, carbon intensity reduction is enhanced to achieve the above assumptions.

It should be noted that in the analysis of the 30-60 and 25-50 Scenarios, only the assumption of a 24 percent reduction in carbon emissions intensity during the 14th Five-Year Plan under the 20-50 Scenario has reference significance for policy formulation. Considering that China will implement total carbon emissions control in the future, and that the total reduction target is more meaningful than the intensity reduction target in order to achieve the goal of carbon neutrality, this research's assumptions for the reduction rate of carbon emissions intensity every five years after 2025 are not referenced for policymaking; instead we suggest a total reduction target after 2025—an average annual decline of 7.5 percent under the 30-60 Scenario, and an average annual decline of 16 percent under the 25-50 Scenario.

APPENDIX B. METHODOLOGY OF CARBON EMISSIONS ANALYSIS AND PROJECTION IN MANUFACTURING

This study adopts the 'bottom-up' approach to analysing carbon dioxide emissions across manufacturing industries in GBA cities based on the consumption and emissions factors of each energy source. This study takes carbon emissions from enterprises and projects in 2020 as the baseline and estimates increased carbon emissions from new projects after 2020. Meanwhile, this study uses scenario analysis to estimate the reduction in carbon emissions led by decarbonisation measures, such as phasing down fossil fuels and using renewable energy to produce raw materials or feedstock, applying clean energy in power and heating supplies, improving energy efficiency and deploying carbon dioxide–removal measures.

Data sources and scope

The project team carried out the carbon emissions accounting for the manufacturing sector according to the 'Guidelines for Compiling Greenhouse Gas Inventories at City and County (District) Levels in Guangdong Province' (hereafter the 'Guidelines') (Guangdong Provincial Department of Ecology and Environment 2020).

According to the 'Guidelines', the scope of manufacturing carbon emissions includes the direct and indirect emissions generated by the final consumption of the energy mix (coal, oil, natural gas, electricity and heat) within the jurisdiction of each city and indirect emissions from consumed electricity and heating. Carbon emissions in this study refers to carbon dioxide emissions, excluding other greenhouse gas and carbon emissions from industrial processes.

The nine GBA cities in Guangdong Province dominate the GBA's manufacturing, while service industries are concentrated in Hong Kong and Macao. Within the GBA, the nine cities of Guangdong Province consistently contribute more than 98 percent of the industrial added value, while Hong Kong's and Macao's industrial added values only account for 2.12 percent and 0.14 percent, respectively (Yan and Liu 2020). Thus, our analysis here of GBA manufacturing focuses only on the nine GBA cities in Guangdong Province.

The data sources come from public data such as the China Energy Yearbook, the statistical yearbooks of Guangdong Province and each city in the GBA, and Hong Kong Energy End-Use Data. The energy consumption data are categorised by city or municipality from 2015 to 2020 and broken down by fuel types. 'New Major Projects' is a list of information collected by the project team from the energy conservation reports of the Guangdong Energy Bureau as of May 2021 (http://drc.gd.gov.cn/snyj/tzgg/). The list includes projects whose energy consumption is greater than 10,000 tonnes of coal equivalent and provides project information in terms of name, location, sector, annual energy consumption and energy type. This study adopts the emissions factors for coal, oil and natural gas combustion and the electricity emissions factors of cities' power grids from 2015 to 2018 in the 'Guidelines'.

Carbon emissions accounting methodology

Direct (carbon) emissions of fossil fuel consumption is the sum of the carbon dioxide emissions from the consumption of coal, oil and natural gas as shown in Equation 2.

Equation 2

$$E_{Direct}=AD_c \times EF_c+AD_o \times EF_o+AD_g \times EF_g$$

where,

E_{Direct}=Direct emissions of fossil fuel consumption

AD_c=Coal consumption

AD_o=Oil consumption

AD_g=Natural gas consumption

EF_c, EF_o, EF_g=carbon dioxide emissions factors of coal, oil and natural gas, respectively

The indirect carbon emissions of electricity and heating are calculated as Equation 3

Equation 3

$$E_{Indirect}=AD_e \times EF_e+AD_h \times EF_h$$

where,

$E_{Indirect}$=Indirect carbon emissions from electricity and heat

AD_e=Electricity consumption

EF_e=Emissions factor of electricity

AD_h=Heating consumption

EF_h=Emissions factor of heating

Analytical methods

This study takes the year 2020 as the baseline and regards existing carbon emissions in the manufacturing sector as the 'Stock'. Carbon emissions after 2020 from new projects (that were constructed but not in operation, that were under construction or that were approved to be constructed) and increased emissions from existing projects in manufacturing are regarded as 'Incremental'. The carbon emissions reduced from phasing down fossil fuels, switching to renewable energy in power and heating generation, and improving energy efficiency are regarded as 'Reduction'. Through different scenarios for 'Incremental' and 'Reduction', the research team will outline the decarbonisation pathways of manufacturing in the GBA and then propose the implementation of specific decarbonisation measures.

The estimation of 'Incremental' emissions between 2020 and 2030 is derived from the energy consumption of 'New Major Projects', from other new projects whose annual energy consumption is less than 10,000 tonnes of coal equivalent and from the growth of energy consumption in existing projects.

For the long-term estimation, based on the Guangdong Province 14th Five-Year Plan, GDP growth will be 5.0 percent between 2030 and 2035, and GDP after 2035 will be reduced by 0.5 percent every five years. The ratio of industrial value added to GDP will be assumed to be reduced from 82 percent in 2020 to 75 percent by 2060. For the carbon emissions to peak by 2030, no new fossil-fuel consuming projects in energy-intensive industries may be approved. The autoregressive integrated moving average (ARIMA) model is used to estimate the increased electricity consumption in the GBA by using electricity consumption data of manufacturing in each city from 2015 to 2020. Assuming that no more energy-intensive projects are approved after 2030 (the peak emissions year), the ARIMA model uses the energy consumption and carbon emissions data in each city by sector from 2015 to 2030 as a baseline to predict the energy consumption of manufacturing from 2030 to 2060. Results of the regression could be provided by using the Augmented Dickey Fuller stationary test after applying a first order of differencing and a white noise test. The model results of electricity emissions factors and heating emissions factors are verified with significance, and industrial electricity consumption and energy consumption adopt the prediction results at significance levels of 0.24 and 0.15.

Based on our analysis of Guangdong's 14th Five-Year Plan, manufacturing energy consumption and industrial value added, we assume that GDP growth from 2020 to 2025 follows the 14th Five-Year Plan and will reduce 0.5 percent every five years from 2025 to 2035. The industrial value added is estimated based on the ratio of the growth rate of industrial value added to GDP growth. The industrial value added is used to estimate carbon emissions under different carbon intensities. The emissions reductions are estimated based on mitigation measures under scenario settings. This study designed three scenarios:

- Baseline Scenario: a scenario that calculates based on historical data and projections of energy consumption of 'New Major Projects' and relies on existing plans and foreseeable measures to reduce energy consumption and carbon emissions.
- Enhanced Policy Scenario: a scenario that prescribes policy tools for a more ambitious emissions-reduction target. Manufacturing accelerates the current low-carbon transition to implement energy-saving and carbon-reduction actions aiming to peak carbon emissions before 2030.
- Zero-Emission Scenario: involves additional and acute energy-saving and carbon-reduction policy measures. Under this scenario, the energy consumption cap should be restricted so that carbon emissions can peak at a lower value, paving the way for carbon neutrality before 2060.

Scenario parameter settings

For the three scenarios, we designed and assumed some settings for key parameters, including GDP, manufacturing added value, incremental emissions from key major projects, replacement of fossil fuels and energy intensity of products. We present these parameter settings in Table B-1.

Table B-1 | **Key parameter settings for the three scenarios**

GDP	BASED ON GUANGDONG 14TH FYP PLANNING: 5%
Baseline Scenario	• 14th FYP: 6.0% • 15th FYP: 5.5% • 16th FYP: 5.0% • Reduce 0.5% every 5 years
Enhanced Policy Scenario	• 14th FYP: 5.5% • 15th FYP: 5.0% • 16th FYP: 4.5% • Reduce 0.5% every 5 years
Zero-Emission Scenario	• 14th FYP: 5.0% • 15th FYP: 4.5% • 16th FYP: 4.0% • Reduce 0.5% every 5 years

MANUFACTURING ADDED VALUE/ GDP	BASED ON RATIO OF 'INDUSTRIAL ADDED VALUE/GDP', 82% IN 13TH FYP
Baseline Scenario	• 82% before 2035 • 75% between 2035 and 2060
Enhanced Policy Scenario	• 82% before 2035 • 75% between 2035 and 2060
Zero-Emission Scenario	• 82% before 2035 • 75% between 2035 and 2060

INCREMENTAL FROM MAJOR PROJECTS		
	SHORT AND MEDIUM TERM	**LONG TERM**
Baseline Scenario	Same as Enhanced Policy Scenario	Same as Enhanced Policy Scenario
Enhanced Policy Scenario	According to the audit opinion of the public energy-saving report	It is assumed that no new projects will be built in energy-intensive industries consuming fossil energy
Zero-Emission Scenario	Same as Enhanced Policy Scenario	Same as Enhanced Policy Scenario

OTHER INCREMENTAL		
	SHORT AND MEDIUM TERM	**LONG TERM**
Baseline Scenario	The upper bound of the ARIMA forecast	The upper bound of the ARIMA forecast
Enhanced Policy Scenario	Using ARIMA to estimate the trend of electricity and heating consumption	Using ARIMA to estimate the trend of electricity and heating consumption
Zero-Emission Scenario	The lower bound of the ARIMA forecast	The lower bound of the ARIMA forecast

REPLACEMENT OF COAL	
Baseline Scenario	· Textile: 2025 reduce 8%, 2035 reduce 24%, 2060 reduce 80% · Papermaking: 2025 reduce 20%, 2035 reduce 40%, 2060 reduce 80% · Ceramic kiln: 2025 reduce 8%, 2035 reduce 16%, 2060 reduce 18% · Ceramic spray tower: 2025 reduce 0%, 2035 reduce 4%, 2060 reduce 9% · Cement: 2035 reduce 4%, 2060 reduce 6% · Petrochemicals: 2035 reduce 8%, 2060 reduce 80% · Steel: 2035 reduce 8%, 2060 reduce 80%
Enhanced Policy Scenario	· Textile: 2025 reduce 10%, 2035 reduce 30%, 2060 reduce 100% · Papermaking: 2025 reduce 25%, 2035 reduce 50%, 2060 reduce 100% · Ceramic kiln: 2025 reduce 10%, 2035 reduce 20%, 2060 reduce 23% · Ceramic spray tower: 2025 reduce 0%, 2035 reduce 5%, 2060 reduce 12% · Cement: 2035 reduce 5%, 2060 reduce 7% · Petrochemicals: 2035 reduce 10%, 2060 reduce 100% · Steel: 2035 reduce 10%, 2060 reduce 100%
Zero-Emission Scenario	· Textile: 2025 reduce 12%, 2035 reduce 36%, 2060 reduce 100% · Papermaking: 2025 reduce 30%, 2035 reduce 60%, 2060 reduce 100% · Ceramic kiln: 2025 reduce 12%, 2035 reduce 21%, 2060 reduce 23% · Ceramic spray tower: 2025 reduce 0%, 2035 reduce 10%, 2060 reduce 12% · Cement: 2035 reduce 5%, 2060 reduce 7% · Petrochemicals: 2035 reduce 15%, 2060 reduce 100% · Steel: 2035 reduce 15%, 2060 reduce 100%

REPLACEMENT OF OIL	
Baseline Scenario	· Petrochemicals: 2025 reduce 0%, 2030 reduce 8%, 2060 reduce 40% · Other industries: 2025 reduce 4%, 2035 reduce 12%, 2060 reduce 36% · Oil carbon emissions: 2025 remain 80%, 2035 remain 72%, 2060 remain 35%
Enhanced Policy Scenario	· Petrochemicals: 2025 reduce 0%, 2030 reduce 10%, 2060 reduce 50% · Other industries: 2025 reduce 5%, 2035 reduce 15%, 2060 reduce 45% · Oil carbon emissions: 2025 remain 99%, 2035 remain 89%, 2060 remain 43%
Zero-Emission Scenario	· Petrochemicals: 2025 reduce 0%, 2030 reduce 12%, 2060 reduce 60% · Other industries: 2025 reduce 6%, 2035 reduce 18%, 2060 reduce 54% · Oil carbon emissions: 2025 remain 98%, 2035 remain 85%, 2060 remain 39%

REPLACEMENT OF NATURAL GAS	
Baseline Scenario	• Reduce 75% by 2060, linear change 2020–60
Enhanced Policy Scenario	• Reduce 88% by 2060, linear change 2020–60
Zero-Emission Scenario	• Reduce 95% by 2060, linear change 2020–60

NEW PROJECTS' FOSSIL ENERGY REPLACEMENT	
Baseline Scenario	• 90% reduction of coal use by 2060 • Oil for petrochemicals expected to reduce 55% by 2060 • Natural gas for heating and power supply expected to reduce 80% by 2060
Enhanced Policy Scenario	• 100% reduction of coal use by 2060 • Oil for petrochemicals expected to be reduced 60% by 2060 • Natural gas for heating and power supply expected to reduce 90% by 2060
Zero-Emission Scenario	• 100% reduction of coal use by 2060 • Oil for petrochemicals expected to reduce 65% by 2060 • Natural gas for heating and power supply expected to reduce 95% by 2060

ENERGY INTENSITY OF PRODUCTS		
	SHORT AND MEDIUM TERM	LONG TERM
Baseline Scenario	• 14th FYP: reduce 4% • 15th FYP: reduce 2%	• 2035: reduce 1% • 2060: reduce 5%
Enhanced Policy Scenario	• 14th FYP: reduce 5% • 15th FYP: reduce 3%	• 2035: reduce 2% • 2060: reduce 6%
Zero-Emission Scenario	• 14th FYP: reduce 6% • 15th FYP: reduce 4%	• 2035: reduce 3% • 2060: reduce 7%

CARBON DIOXIDE REMOVAL TECHNOLOGY		
	SHORT AND MEDIUM TERM	LONG TERM
Baseline Scenario	• 2035: removal of 1 $MtCO_2$	• 2060: removal of 14 $MtCO_2$
Enhanced Policy Scenario	• 2035: removal of 2 $MtCO_2$	• 2060: removal of 15 $MtCO_2$
Zero-Emission Scenario	• 2035: removal of 2.5 $MtCO_2$	• 2060: removal of 18 $MtCO_2$

Notes: ARIMA = autoregressive integrated moving average; $MtCO_2$ = million tonnes of carbon dioxide; FYP = five-year plan.

APPENDIX C. METHODOLOGY OF CARBON EMISSIONS ANALYSIS AND ESTIMATION IN ROAD TRANSPORT

Data sources and scope

The scope of this appendix is the energy consumption and carbon emissions of road transport by different types of vehicles in the GBA. The variables used include fleet structure, vehicle parc (all registered vehicles), annual mileage, fuel consumption and emissions factors of fuels and electricity (Table C-1).

Carbon emissions accounting methodology

The 'bottom-up' approach of vehicle parc is more consistent with our objective of calculating the status quo of road transport carbon emissions in the GBA, and estimating its emissions and the emissions-reduction potential of various measures. Transport energy consumption accounting is obtained by multiplying vehicle parc, activity level (average annual mileage) and fuel economy level, as shown in the following formula:

Equation 4

$$F_k=\sum P_{ijk}\times VKT_{ijk}\times U_{ijk}$$

where,
i, j, k=respectively, the vehicle model, registration time and energy type
F=energy consumption of the vehicle
P=vehicle parc
VKT=average annual mileage of the vehicle
U=vehicle fuel economy

The carbon emissions of vehicles on the road are divided into life-cycle carbon emissions and upstream fuel carbon emissions. Emissions throughout the life cycle are obtained by multiplying the transportation end-use energy consumption and the emissions factor of fuel combustion.

Equation 5

$$E_k=F_k\times EF^1{}_k$$

where,
k=type of fuel
E=carbon dioxide emitted by different energy consumption
F=energy consumption of vehicles
EF^1=carbon emissions factor when different fuel types are burned

Emissions from upstream electricity generation and hydrogen production are obtained by multiplying the transportation energy consumption at the end and the upstream carbon emissions factor at the time of fuel production.

Table C-1 | **Data structure for road transport analysis**

VARIABLES	DATA SOURCE	TIME COVERAGE
Fleet structure	Guangdong Statistical Yearbook, statistical yearbook of each GBA city, Hong Kong Transport Department	2015–20
Vehicle parc		2015–20
Annual mileage	Xue et al. (2019)	2015–50
Fuel consumption	China Automotive Energy Consumption Database, Ministry of Industry and Information Technology	N/A
Emissions factor of fuels	Guidelines for the Compiling of Greenhouse Gas Inventories (Trial)	N/A
Emissions factor of electricity	Guidelines for Compiling of Greenhouse Gas Inventories at City and County (District) Levels in Guangdong Province	2015–18

Equation 6

$$E_k=F_k \times EF^2{}_k$$

where,
k=type of fuel
E=carbon dioxide emitted by different energy consumption
F=energy consumption of vehicles
EF_2=upstream carbon emissions factors to produce electricity and hydrogen

Abatement cost model

In this study, the marginal abatement costs are calculated separately for different emissions-reduction technologies and measures. *Marginal abatement cost* refers to the abatement cost corresponding to each unit of emissions reduction in a given year. The formula is as follows:

Equation 7

$$Marginal\ abatement\ cost=\frac{Abatement\ cost}{Reduction\ volume}$$

Abatement cost is the difference between the cost input required for abatement measures and the future cost savings, expressed as a net present value. Considering the impact of the dynamic adjustment of subsidies and tax policies on cost calculation, these two items are not included in the cost in this study. The formula for calculating abatement costs is as follows:

Equation 8

$$Abatement\ cost=\frac{Total\ cost\text{-}Cost\ savings}{(1+discount\ rate)^{year}}$$

Scenario settings

We design scenarios on the basis of the forecast of vehicle parc, road transport in the GBA, policy analysis of emissions reduction during the 14th FYP, and existing literature to predict the technological progress. We selected several key parameters to set scenarios, including the promotion of NEVs, transportation mode shift, improved fuel economy, annual mileage and share of clean energy in upstream electricity and hydrogen production.

Three scenarios are established as follows:

- Baseline Scenario: This scenario is defined as a continuation of the historical trend and does not reflect policy intervention. The forecast of vehicle fleet uses the Gompertz curve (Wu et al. 2014) and the elasticity coefficient method (Lin et al. 2019) by the type of vehicle, and it is assumed that the vehicle parc will maintain natural growth under the Baseline Scenario. With the adoption of NEVs, the fuel economy and annual mileage of vehicles stay at their current levels.

- Enhanced Policy Scenario: This scenario takes into account existing policies and predicted urban development and technology development. Recently released policies provide reliable references for defining parameters. For example, the State Council proposes that non-fossil energy will increase to 20 percent, 25 percent and 80 percent of total energy consumption by 2025, 2030, and 2060, respectively (Xinhua News Agency 2021), and NEVs will make up about 20 percent of total new vehicle sales by 2025 (State Council 2020).

- Zero-Emission Scenario: This scenario comprises strict policy controls and significant technological progress to ensure carbon neutrality by 2060. For example, under this scenario, the wide adoption of NEVs would occur 10–15 years earlier than under the Baseline Scenario, particularly for medium- and heavy-duty trucks, and 100 percent non-fossil electricity and green hydrogen would be achieved by 2050, 10 years earlier than under the Baseline Scenario.

It is worth noting that different emissions-reduction measures are subject to different implementation policies, and the authority may not necessarily be at the provincial level. For example, the improvement in the fuel economy of new cars is mainly driven by national-level vehicle fuel consumption standards and 'dual-credit' policy (MIIT 2020). The influencing variables and implementing entities of various emissions-reduction measures are shown in Table C-2.

Table C-2 | **Influencing variables and implementing entities of emissions-reduction measures**

	INFLUENCING VARIABLES	IMPLEMENTING ENTITIES
Promotion of NEV	Fleet structure	Joint national and local policies
Transport structure	Vehicle parc, annual mileage	Local policy
Improved fuel economy for new vehicle	fuel consumption of new vehicles	National policy
Reduced activity level	Annual mileage	Local policy
Upstream power and hydrogen generation	Emission factor of power and hydrogen	Local policy

In Guangdong Province, only Guangzhou and Shenzhen have imposed restrictions on car purchases, and these mainly target traditional fossil-fuel cars. In addition to the level of economic development, the projection for the vehicle parc takes into account other major factors like urban population and geographical size. It adopts two models to various vehicle types, using the Gompertz curve method (Wu et al. 2014) to predict the number of private cars and the elasticity coefficient method to predict commercial vehicles (Lin et al. 2019). The predicted number of private vehicles per thousand people and the growth rate of heavy-duty trucks by 2060 are similar to the national level in existing literature and reports (Xue et al. 2019; Lu et al. 2018).

NEV adoption is the most important factor affecting traffic emissions. Vehicle electrification varies vastly among cities, due to widely different levels of economic development. The study offers projections for NEV adoption in Guangzhou, Shenzhen and other cities in Pearl River Delta, respectively.

Traffic structural changes primarily include fleet of passenger transportation shifts from private vehicles to public transit services and the mode of freight transportation shifts from highways to railways and waterways, and multimodal transport (State Council 2021). These changes mainly reflect a lower share of road transport. A study conducted by World Resources Institute (Xue et al. 2019) argues that in a radical scenario, the proportion of road freight could decline from 48 percent by 2015 to 35 percent by 2050 in China. A study for Tsinghua University–Zhang Jiagang Joint Institute for Hydrogen Energy and Lithium-Ion Battery Technology (Yuan et al. 2021) argues that the ratio of rail freight in China will grow from 23 percent in 2030 to 45 percent in 2050, replacing waterway and road freight. The decrease in the percentage of road freight is mainly attributed to lower ownership of medium- and heavy-duty trucks in comparison with the Baseline Scenario.

There are many studies on vehicle fuel economy for 2021–35. According to the *Energy-Saving and New-Energy Vehicle Technology Roadmap 2.0* (Society of Automotive Engineers of China 2021), the average fuel consumption of traditional fossil-fuel passenger vehicles may reach 5.6 litres (L) / 100 kilometres (km), 4.8 L / 100 km and 4.0 L / 100 km, respectively, by 2025, 2030 and 2035. By 2035, fuel consumption of commercial freight vehicles may decrease by 15–20 percent compared with the 2019 level. Passenger vehicle fuel consumption may decline by 20–25 percent compared with the 2019 level. The Innovation Centre for Energy and Transportation provides a more detailed summary and forecast of the fuel economy of various commercial vehicles and the trends towards 2060 (Qin et al. 2021). Many studies have shown that fuel economy under actual road conditions is 20–30 percent less efficient than under test conditions.

Annual mileage is mainly based on data provided by the *Inventory Guidebook on Air Pollutant Emissions from On-Road Motor Vehicles* (Zhang 2015). However, the figures for private cars and heavy trucks were revised as 12,000 km and 50,000 km (Xue et al. 2019) because many studies indicate that the *Guidebook*'s average annual mileages for these vehicles are relatively high.

The share of clean energy in upstream electricity and hydrogen production is based on WRI's previous study of China's road transport (Xue and Liu 2022). Clean energy will account for 92 percent of electricity generation by 2050 and will reach 100 percent by 2060; by 2050, the share of grey hydrogen in the hydrogen supply will drop to 15 percent, and grey hydrogen will be completely out of the market by 2060.

The key parameter settings for scenario analysis of the road transport sector are shown in Table C-3.

Table C-3 | **Key parameter settings for the three scenarios**

	BASELINE SCENARIO	ENHANCED POLICY SCENARIO	ZERO-EMISSION SCENARIO
Vehicle fleet	Private vehicles: 2020: Guangzhou 2,150,000; Shenzhen 2,710,000; other cities 9,620,000 2060: Guangzhou 5,030,000; Shenzhen 3,750,000; other cities 17,000,000 Heavy-duty vehicles: 2020: Guangzhou 90,000; Shenzhen 110,000; other cities 170,000 2060: Guangzhou 190,000; Shenzhen 160,000; other cities 370,000		
NEV adoption	Remain as 2020	**Shenzhen:** 100% NEV from 2035 to 2050 **Guangdong:** 100% NEV from 2035 to 2055 Other cities: 100% NEV by 2060 **HDV:** 70% hydrogen fuelled, 30% NEV adoption	**Shenzhen:** 100% NEV from 2030 to 2040 **Guangdong:** 100% NEV from 2030 to 2040 Other cities: 100% NEV from 2025 to 2045 **HDV:** 70% hydrogen fuelled, 30% NEV adoption
Traffic structural changes	Remain as 2020	**2020–25:** Fleet of passenger vehicles reduced by 8% and freight vehicles by 10% **2025–30:** Fleet of passenger vehicles reduced by 15% and freight vehicles by 15%	**2020–25:** Fleet of freight vehicles reduced by 14% **2025–30:** Fleet of passenger vehicles reduced by 25% and freight vehicles by 25% **2030–35:** Fleet of passenger vehicles reduced by 30% and freight vehicles by 30%
Vehicle fuel economy	Remain as 2020	**2020–35:** Passenger vehicles improve 37.5%, commercial vehicles improve 20%, freight vehicles improve 15% **2035–60:** Remain as 2035	**2020–35:** Passenger vehicles improve 45%, commercial vehicles improve 30%, freight vehicles improve 25% **2035–60:** Remain as 2035
Annual mileage	Remain as 2020	Private vehicle: 12,000 km HDV: 50,000 km Other vehicles: Refer to *Technical Guide for Road Vehicle Emissions Inventory* By 2060, private vehicle reduce 20%	Private vehicle: 12,000 km HDV: 50,000 km Other vehicles: Refer to *Technical Guide for Road Vehicle Emissions Inventory* By 2060, private vehicles reduce 40%
Share of clean energy in electricity and hydrogen production	Remain as 2020	2050: 92% non-fossil fuel-electricity; green hydrogen 85% 2060: 100% non-fossil-fuel electricity; green hydrogen 100%	2050: 100% non-fossil-fuel electricity; green hydrogen 100%

APPENDIX D. METHODOLOGY OF CARBON EMISSIONS ANALYSIS AND PROJECTION IN THE BUILDINGS SECTOR

Data sources and scope

This appendix covers the building operational emissions only and establishes a 'bottom-up' carbon emissions model. The variables used include population, building area per capita, energy consumption by fuels, emissions factor of fuels and electricity (Table D-1). The data variables are from the statistical yearbook of each city in Guangdong Province (Guangdong Provincial Bureau of Statistics 2021), the *Urban and Rural Construction Statistical Yearbook* of the Ministry of Housing and Urban-Rural Development (MoHURD 2022) and the Hong Kong Energy End-Use Data Set (Electrical and Mechanical Services Department 2022).

China's Energy Policy Simulator model is used to estimate the emissions factor of electricity with assumptions for the share of clean energy and deployment of carbon capture, utilisation and storage (CCUS) in the GBA. In addition, energy consumption per unit of building area is a basic indicator to measure the energy of buildings and has been widely used in building energy-saving policies and standards (Huo et al. 2019; Zhao et al. 2016).

Carbon emissions accounting methodology

The energy consumption and carbon emissions of the buildings sector are calculated based on energy consumption and emissions factors. The study considers three major fuel types—electricity, liquefied petroleum gas (LPG) and natural gas—which together accounted for over 90 percent of the total energy consumption from 2000 to 2018 in Guangdong Province. The carbon emissions calculation method is as follows:

Equation 9

$$CE(operation)=\sum(Q_e \times EF_e)=\sum((Q_{r,e}+Q_{p,e}) \times EF_e)$$

where,

$Q_{r,e}$=consumption of energy e in residential buildings

$Q_{p,e}$=consumption of energy e in public and commercial buildings (electricity: kWh; LPG: kg; natural gas: m^3)

EF_e=emissions factor representing energy e (electricity: $kgCO_2e/kWh$; LPG: $kgCO_2e/kg$; natural gas: $kgCO_2e/m^3$)

The energy consumption of residential buildings ($Q_{r,e}$) and public and commercial buildings ($Q_{p,e}$), can be calculated from indicators such as

Table D-1 | **Date structure for building sector analysis**

VARIABLES	DATA SOURCE	TIME COVERAGE
Population	*Guangdong Statistical Yearbook*, statistical yearbook of each GBA city, Hong Kong Population Census	2015–20
Building area per capita	*Guangdong Statistical Yearbook*, statistical yearbook of each GBA city	2015–20
Energy consumption by fuels	Statistical yearbook of each GBA city, MoHURD *Urban and Rural Construction Statistical Yearbook*, Hong Kong Energy End-Use Data Set	2015–50
Emissions factor of fuels	Guidelines for Compiling Greenhouse Gas Inventories (Trial)	N/A
Emissions factor of electricity	Guidelines for Compiling Greenhouse Gas Inventories at City and County (District) Levels in Guangdong Province	2015–18

Notes: GBA = Guangdong–Hong Kong–Macao Greater Bay Area; MoHURD = Ministry of Housing and Urban-Rural Development.

population, per capita building area and energy consumption per unit area:

Equation 10

$$Q_{r,e}=\sum P\times A_{r,pp}\times EI_r\times R_e$$
$$Q_{p,e}=\sum P\times A_{p,pp}\times EI_p\times R_e$$

where,
P=population (10,000 people)
$A_{r,pp}$ and $A_{p,pp}$=per capita residential area and per capita public and commercial building area (m^2/person), respectively
EI_r and EI_p=energy intensity (energy consumption per unit building area) of residential and public commercial buildings
R_e=proportion of energy e in energy consumption

Scenario settings

The basic principle for the carbon emissions simulation for the buildings sector is the scenario analysis method. The scenario setting mainly considers the impact on energy consumption intensity, energy consumption structure, clean energy penetration rate and other driving factors, such as economic development and population growth of the buildings sector. Carbon emissions are calculated based on energy consumption structures and share of clean energy in electricity generation (Table D-2).

Based on our literature review of provincial and municipal policy requirements for green buildings and energy-saving retrofitting of existing buildings, this study designs the Baseline (business-as-usual) Scenario, *Enhanced Policy Scenario* and *Zero-Emission Scenario*. All three scenarios share the same assumptions regarding building area increase, which is based on the territorial and spatial planning of each city and key findings of Reinventing Fire China (Energy Research Institute et al. 2018). Three scenarios are set up reflecting different levels of intervention on energy intensity (energy consumption per unit of building area), electrification rate and electricity decarbonisation (share of electricity generated from renewable sources).

Baseline Scenario: This scenario is defined as a continuation of the historical trend, maintaining current policy measures, and does not reflect policy intervention. Under this scenario, building energy intensity will increase by 30 percent from 2020 to 2030 and increase an additional 30 percent from 2030 to 2060 (Liang et al. 2020). Energy mix would shift to 95 percent electricity among all energy sources by 2060, and the share of clean electricity would reach 67 percent by 2060.

Enhanced Policy Scenario: Policy tools for a more ambitious emissions-reduction target would be considered. By 2030, all new buildings would follow the standard of GB 55015-2021,

Table D-2 | **Model framework for estimation of carbon emissions in buildings sector**

SUB-SECTOR	ENERGY STRUCTURE	INPUT PARAMETERS
Residential building	· Electricity · LPG · Natural gas	· Permanent population · Per capita residential area · Residential energy consumption intensity · Electrification rate · Share of clean energy in electricity generation · Emissions factor of fuels and electricity
Public and commercial building	· Electricity · Natural gas · Other energy (including LPG)	· Permanent population · Public building area per capita · Energy intensity of public and commercial buildings · Electrification rate · Share of clean energy in electricity generation · Emissions factor of fuels and electricity

Notes: LPG = liquified petroleum gas.

which calls for reducing energy intensity by 30 percent. Existing buildings would increase energy intensity by 30 percent by 2030 and an additional 30 percent by 2060. By 2060, new buildings would show a 30 percent decrease in energy intensity. Electricity share of total end-use energy consumption would account for at least 85 percent of the energy mix by 2030 and reach 95 percent by 2050. The share of clean electricity would be up 77 percent by 2060. CCUS would not be applied.

Zero-Emission Scenario: Even more ambitious emissions targets would be considered. By 2030, the energy intensity of new buildings would be the same as in the Enhanced Policy Scenario. In addition, 60 percent of existing buildings would reduce energy intensity by 50 percent below the Baseline Scenario. All buildings would decrease their energy intensity by 20 percent from 2030 to 2060. Electricity would account for at least 85 percent of the energy mix by 2030 and reach 100 percent by 2060. The share of clean electricity would reach 88 percent by 2060. CCUS would be introduced in power plants.

The key parameter settings for scenario analysis of the buildings sector are shown in Table D-3.

Table D-3 | **Key parameter settings for the three scenarios**

POLICY MEASURES	BASELINE SCENARIO	ENHANCED POLICY SCENARIO	ZERO-EMISSION SCENARIO
Reduced energy intensity	• Increase 30% by 2030 compared to 2020 • Increase 30% by 2060 compared to 2030	Compared to Baseline Scenario • Existing buildings: reduce 30% by 2030 compared to 2020, and reduce 30% by 2060 compared to 2030 • New buildings: reduce 30% by 2030 compared to 2020, and reduce 30% by 2060 compared to 2030	Compared to Baseline Scenario • Existing buildings: reduce 50% by 2030 compared to 2020, and reduce 20% by 2060 compared to 2030 • New buildings: reduce 30% by 2030 compared to 2020, and reduce 20% by 2060 compared to 2030
Improved electrification rate	• Up to 95% by 2050	• Up to 85% by 2030 • Up to 95% by 2050	• Up to 85% by 2030 • Up to 100% by 2060
Increased clean electricity	• Share of clean electricity will reach 67% by 2060	• Share of clean electricity will reach 77%, and no CCUS is deployed	• Share of clean electricity will reach 88%, with CCUS equipment installed for electricity generated from fossil fuel

Notes: CCUS = carbon capture, utilisation and storage.

ABBREVIATIONS

BTH	Beijing-Tianjin-Hebei
CBIRC	China Banking and Insurance Regulatory Commission
CCERs	China-Certified Emissions Reductions
CCUS	carbon capture, utilisation and storage
CEAs	China Emissions Allowances
CGBL	China Green Building Label
CICC	China International Capital Corporation Limited
EDGE	Excellence in Design for Greater Efficiencies
ESG	environmental, social and governance
ETF	exchange-traded fund
ETS	emissions trading system
EU	European Union
EV	electric vehicle
FYP	five-year plan
GBA	Guangdong–Hong Kong–Macao Greater Bay Area (including Guangzhou, Shenzhen, Foshan, Dongguan, Zhuhai, Zhaoqing, Huizhou, Zhongshan, Jiangmen, Hong Kong, Macao)
GHG	greenhouse gas
HKEX	Hong Kong Stock Exchange
ICMA	International Capital Market Association
IFC	International Finance Corporation
KPI	key performance indicator
LNG	liquified natural gas
MNC	multinational corporation
NAFMII	National Association of Financial Market Institutional Investors
NDC	nationally determined contribution
NZEB	near-zero-energy building
PBoC	People's Bank of China
PE	private equity
RE	renewable energy
SBTi	Science Based Targets initiative
SLB	sustainability-linked bond
SLL	sustainability-linked loan
SME	small and medium-sized enterprise
SPT	sustainability performance target
SSCF	sustainable supply chain finance
30-60 goals	China's national goals of peaking carbon emissions by 2030 and achieving carbon neutrality by 2060
VCM	voluntary carbon market
YRD	Yangtze River Delta

ENDNOTES

1. For a discussion of "transition washing", see Quinson (2021).
2. The currency equivalents used throughout this report are US$1 = CNY 6.5; and CNY 1 = US$0.1538.
3. NEVs are zero- or low-emission vehicles, including battery-operated electric vehicles, plug-in hybrid vehicles, hybrid vehicles and fuel cell vehicles.
4. Ride-hailing's overarching idea is that a customer hires a driver to take them exactly where they need to go. Customers do this by hailing a taxi on the street, calling a car service on the phone or virtually hailing a car and driver from an app.
5. Mobility-as-a-service is a new concept that integrates various forms of transport services into a single platform, accessible on demand, which can provide the most cost-effective solutions to users' needs and reduce mobility difficulties.
6. The energy consumption data are from the statistical yearbook of each GBA city. Emissions are calculated based on energy consumption and emissions factors for different energy types.
7. An NZEB is a building that has few carbon emissions, usually due to large-scale use of renewable energy.
8. CICC's research covers building, agriculture, power, petrochemical, iron and steel, transportation and cement.
9. The incremental costs of green buildings, NZEBs and retrofitting also include the use of renewable energy. Using renewable energy is singled out from new and existing building costs because they have a separate government subsidy system. However, we don't take building construction expenses into consideration. Using projections of floor area from Section 4, we calculate the investment demand based on total building area and the costs of low-carbon measures per unit of area. Based on the current incentive policies for low-carbon measures, we also estimated the amount of subsidies expected to be issued by the government. The difference between the cost of low-carbon measures and the subsidies is the investment shortfall for the GBA's buildings sector.

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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.

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