Regional Roadmap for Buildings and Construction in China's Greater Bay Area

Towards a zero-emission, efficient, and resilient buildings and construction sector

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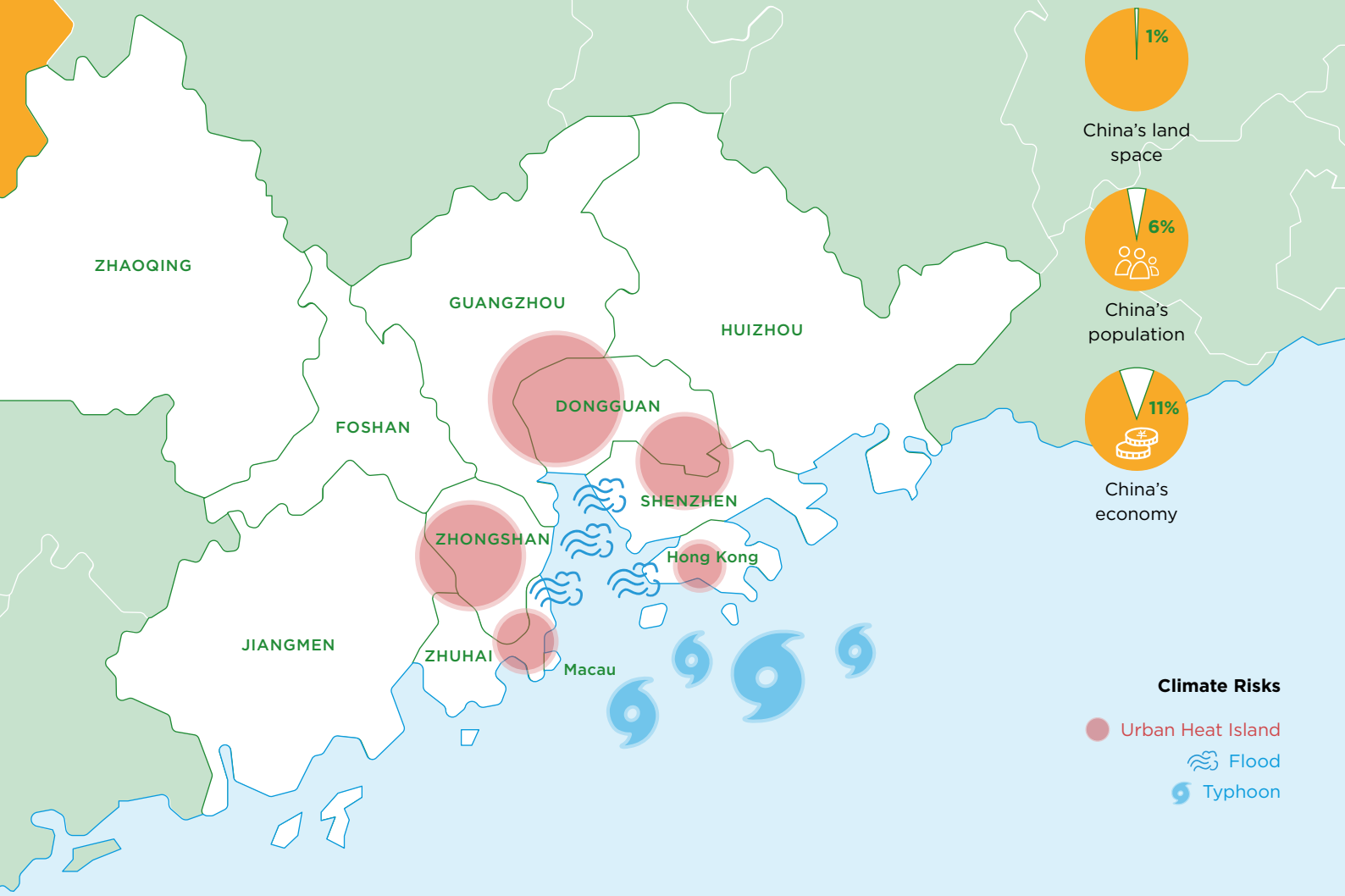
Charting the Roadmap

At a Glance: Regional Roadmap For Buildings and Construction in China's Greater Bay Area

Towards a zero-emission, efficient, and resilient sector for achieving carbon neutrality targets

Regional Context



Climate Risks

- Urban Heat Island
- Flood
- Typhoon

Climate Policy Outline

2015
Paris Agreement, international treaty on climate change

2020
China's 30–60 strategy announced

2030
China's target to peak carbon emissions

2050
international target to limit global temperature increase to 2°C

2060
China's target for carbon neutrality

The Global Alliance for Buildings and Construction (GlobalABC) has launched a Roadmap process to facilitate a shared language and vision for achieving the complete decarbonisation of the sector.

The project team applied this approach to the region, starting in 2022, with the aim of engaging multiple stakeholders. This highly dynamic megalopolis has the potential to play a pioneering role in supporting China's carbon neutrality journey.

Intersted in learning more?

We invite you to take a deeper look into the complete study.

Key Findings

New Buildings

Scalability: significantly increase ambition target and building codes in all project phases. Mitigate the risk of stranded long-term investments.

Existing Buildings

Create awareness for the decarbonisation of the building stock. Prioritize public buildings to lead by example. Accelerate scalable modularized retrofit measures.

Appliances & Systems

Increase supply and demand for high energetic performance in appliances.

Building Operations

Implement energy management obligations and processes to drive an energy efficient building operation through information and behaviour change.

Materials

Integrate life cycle perspectives through low carbon materials and recycling programmes.

Urban Planning

Promote integrated sustainable urban planning between core GBA zones, including smart city solutions.

Resilience

Implement forward-looking planning approaches and accelerate dynamic response speed and flexibility to climate emergencies.

Clean Energy

Scale up local renewable energy and regional grid supply, implement smart city solutions.

Enablers

Key to achieve the complex transition is establishing an effective stakeholder engagement network, including public, private, academic and financial sectors, and fostering of system innovation.

Global Alliance for Buildings and Construction
dena German Energy Agency
ICLEI Local Governments for Sustainability EAST ASIA
中国建筑科学研究院有限公司 China Academy of Building Research

Setting the Scene: Remarks from the GlobalABC

Decarbonising the buildings and construction sector is critical to achieving the emission cuts required by the Paris Agreement and addressing the triple planetary crisis of climate change, biodiversity loss, and pollution. Despite this, the sector remains off track to achieve decarbonisation by 2050, and the gap between its actual climate performance and the necessary decarbonisation pathway is widening. Decarbonising buildings across their entire life cycle is possible, but it requires a transformation of the sector and deep collaboration between all stakeholders in its highly fragmented value chain.

Three years ago, the Global Alliance for Buildings and Construction (GlobalABC) launched Regional Buildings and Construction Roadmaps for Africa, Asia, and Latin America, hoping to inspire and support countries and local authorities worldwide in finding their own pathway and setting their own targets for building decarbonisation and resilience. These roadmaps align stakeholders behind a common vision and set the path for implementing the systemic changes needed to achieve zero-emission, efficient, and resilient buildings and construction.

The Chinese government has demonstrated a strong commitment to decarbonising its economy, including buildings and construction. The country aims to peak its emissions by 2030 and achieve carbon neutrality by 2060. The Guangdong-Hong Kong-Macao Greater Bay Area (GBA), one of the fastest-growing urban areas in the world and a major economic hub, is a key starting point and strategic region for advancing China's climate targets and implementing low-carbon solutions for the buildings and construction sector. By implementing the strategy provided in this roadmap, the GBA can serve as a model for other regions in China and other countries to follow.

We are delighted and proud to see the GlobalABC roadmap model continuing to be cascaded at the subnational, national, and subregional levels. We commend the German Energy Agency (dena), the China Academy of Building Research (CABR), and the ICLEI – Local Governments for Sustainability and all the experts involved for the countless hours they have devoted to this important work. This roadmap provides clear and ambitious policy signals to drive the range of measures needed for GBA to become a climate-neutral and integrated economic and innovation hub.

We firmly believe that the widespread adoption of these roadmaps is the first step toward the success of the Buildings Breakthrough, spearheaded by the governments of France and the Kingdom of Morocco with the GlobalABC. This new stepping stone toward the decarbonisation of the buildings and construction sector is part of the Breakthrough Agenda, a set of global goals to make clean technologies and sustainable solutions the most affordable, accessible, and attractive option in emitting sectors before 2030. The Buildings Breakthroughs statement 'near-zero emission and resilient buildings are the new normal by 2030' serves as a joint vision and rallying point for all countries, and we warmly invite them to join us on our common journey toward achieving this objective.

We hope that the roadmap will inspire policymakers with specific and time-bound actions, and we look forward to seeing them implemented in the years to come.

Jonathan Duwyn

GlobalABC Secretariat

The Journey Ahead: What to Expect

The Greater Bay Area (GBA) in China, a rapidly developing mega-region spanning 11 cities in Guangdong province including the Special Administrative Regions (SAR) of Hong Kong and Macao, is working to become a climate-neutral and integrated economic and innovation hub by 2060, leveraging the strengths of its various cities and serving as a best practice example for China (State Council of the People's Republic of China, 2021). While the GBA has made considerable progress in promoting energy efficiency in buildings through the development of green building standards and demonstration projects, challenges remain that require further policy measures and investments to accelerate the transition to a zero-emission, efficient, and resilient built environment.

Decarbonising buildings across their entire life cycle is key to achieving carbon neutrality, according to the International Energy Agency (IEA), and requires transforming the buildings and construction sector through measures such as passive building design, material efficiency, low-carbon materials, efficient building envelope measures, and highly efficient lighting and appliances (United Nations Evironment Programme (UNEP), 2021). Achieving these outcomes at scale and pace necessitates greater collaboration between policy makers, urban planners, architects, developers, investors, construction companies, and utility companies. The transition to a low-carbon built environment also presents a compelling opportunity for businesses to capitalise on green finance, with the potential to unlock an estimated 14.5 trillion RMB (approximately 1.9 trillion EUR) in value by 2030 (International Finance Corporation (IFC), 2013).

Following the framework of the Global Alliance for Buildings and Construction (GlobalABC), the German Energy Agency (dena), in partnership with the China Academy of Building Research (CABR) and the ICLEI – Local Governments for Sustainability, is working with a multi-stakeholder group to create a roadmap for the decarbonisation of the building and construction sector in China's Guangdong-Hong Kong-Macao GBA. The roadmap outlines a plan for a zero-emission, efficient, and resilient buildings and construction sector in the GBA, targeting national and GBA Chinese policymakers, government officials, and international organisations and professionals in the sustainable building sector who seek to improve the region's sustainability and resiliency.

Involving a wide range of stakeholders, including government agencies at the national, provincial, and local levels, businesses in the buildings and construction sector, and local communities, is critical to the roadmap's success and promoting sustainable development in the GBA. The roadmap addresses the challenges facing the GBA in promoting sustainable buildings and construction practices, including high energy consumption, high emissions, and a lack of awareness and capacity among stakeholders.

The GBA has a unique opportunity to become a model for sustainable urban development in China and globally, contributing significantly to achieving China's

climate goals (European Chamber of Commerce in China, 2021). The roadmap is expected to have a number of positive outcomes and benefits, including reduced energy consumption and emissions due to high consumption and the dominance of carbon-based energy sources, improved air quality, and increased awareness and capacity among stakeholders. By working together and implementing the actions outlined in the roadmap, all stakeholders in the GBA can promote sustainable development and help achieve its carbon neutrality goal.

Getting to Zero-Emission, Efficient and Resilient Buildings by 2060

In 2021, China submitted an updated Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC) that included ambitious targets such as peaking carbon dioxide emissions before 2030 and achieving carbon neutrality by 2060, as well as increasing the share of non-fossil fuels in primary energy consumption to 25% by 2030 (UNFCCC, 2021). These updates demonstrate China's continued commitment to addressing climate change and transitioning towards a low-carbon economy. To achieve these targets, the Chinese government has implemented a policy infrastructure that includes Five-Year Plans, guidance documents, and regulations issued by relevant ministries, as well as financial support provided through diverse channels. In addition, the government has set a number of intermediate or secondary goals related to climate change, and provinces and localities have committed to their own climate goals. For example, at least 23 provinces and cities have committed to peaking CO_2 emissions before 2030 as part of China's Alliance of Pioneer Peaking Cities. In the GBA, the Outline Development Plan (ODP) for the Guangdong-Hong Kong-Macao GBA was released outlining, among other things, a range of objectives and targets related to urban development, environmental protection, and economic integration in the region such as promoting the use of renewable energy sources and green building materials, and improving the design and construction of buildings to enhance their durability and safety. The National Development and Reform Commission (NDRC) and the National Bureau of Statistics report annually on progress toward these goals and related indicators. These developments set the context for efforts to achieve zero-emission, efficient, and resilient buildings by 2060 in China's GBA.

The Global Alliance for Buildings and Construction Roadmap for China's Greater Bay Area

The GBA has set even more ambitious goals to achieve peak carbon emissions by 2025 and carbon neutrality by 2060.

In 2019, the GBA announced its ODP, which prioritises sustainable and low-carbon development through the implementation of its INDC. This plan is considered crucial for China's overall economic and development strategy by the Chinese government, business leaders, and industry experts. However, implementing the ODP also presents various challenges, such as coordination across cities, balancing economic growth with environmental protection, addressing socio-economic

disparities, managing cross-border regulations and institutions, ensuring stakeholder engagement, and overcoming technological and infrastructural barriers.

To address these challenges, the GBA needs a comprehensive and well-coordinated approach that involves close collaboration between the cities and stakeholders.

The GlobalABC roadmap approach offers a valuable framework for the GBA to achieve its vision and is specifically designed to help regions and cities transition to a low-carbon and climate-resilient economy, construct necessary infrastructure and institutions, and secure progress over time. It aligns with the United Nations' Sustainability Development Goals (SDGs) and the Paris Agreement, and supports China in fulfilling its commitments to addressing global climate change as stated in its INDC and 30–60 goals[1], which are part of China's national climate policies aimed at reducing carbon emissions and promoting sustainability through the promotion of sustainable buildings and infrastructure.

The GlobalABC approach lays out a roadmap for the systematic and effective implementation of the GBA's ODP, with the goal of maximising benefits and minimising risks. This approach places emphasis on stakeholder engagement and robust monitoring and evaluation systems, ensuring the INDC are executed in a transparent and accountable manner. The focus on a diverse multidisciplinary stakeholder network is crucial for achieving the GBA's ambitious targets and aligning with the United Nations' SDGs and the Paris Agreement.

The GlobalABC covers eight 'activity areas', as shown in the table below, and for each proposes key actions as well as targets for policies and technologies, and enabling measures with the aim of reaching net-zero carbon emission buildings by 2060. Below is an overview with key actions for each of the activity areas and enablers:

1 China's 30–60 climate goals refer to its commitment to peak carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060. The formal name of this pledge is the 'Enhanced Actions on Climate Change: China's Intended Nationally Determined Contributions', which was announced by President Xi Jinping at the United Nations General Assembly in September 2020.

2 According to the International Atomic Energy Agency (IAEA), nuclear power is a low-carbon energy source that can help reduce greenhouse gas emissions and meet growing energy demands, but radioactive waste and safety risks must be carefully managed (International Atomic Energy Agency, 2020). The classification of nuclear power as clean energy remains a contentious issue among scholars. While nuclear power has the potential to reduce carbon emissions, it must be used alongside other low-carbon technologies and subject to strict safety and waste management measures.

3 In this context, the term 'performative' refers to the ability of a building component or system to deliver a specific level of performance or functionality. Performative appliances can be understood as building appliances or systems that are designed to deliver high levels of performance, energy efficiency, or sustainability.

Table 1 GlobalABC GBA roadmap summary timelines

Activity area	Current status (2022)	Key recommended actions
Urban planning 	As urban growth and densification continue to accelerate, it is increasingly evident that a GBA integrated planning is necessary to ensure sustainable development	Prioritise sustainable urban planning and development that is integrated regionally Implement smart city solutions to enhance urban development Build stakeholder and enabler networks to facilitate sustainable urban planning and development
New buildings 	Different authorities in the GBA have set goals of implementing ongoing gradual improvement plans for new buildings, aimed at enhancing their sustainability and efficiency	Building codes, norms, and standards must be prioritised for execution and maintenance control in all project phases It is essential to increase the ambition target for the implementation of building codes and standards to enhance sustainability and energy efficiency
Existing buildings 	The current status of sustainable development for existing buildings in the GBA is at a primary phase due to the absence of a corresponding product chain	Accelerating scalable retrofit measures is essential in the current status Prioritising integrated methodologies can help achieve sustainable retrofit goals effectively Facilitating goal visualisation can help stakeholders understand the retrofit objectives better Offering investment options can make retrofitting more financially feasible and attractive for investors
Building operations 	Despite the availability of some tools, the currently planned measures show a significant dependence on the Internet of Things (IoT) technology	Develop operation and maintenance standards Train personnel on these standards Adopt the standards in daily operations Integrate these standards throughout the sector chain for increased efficiency and reliability
Appliances and systems 	Low performance appliances and systems are still widely used in households and industries, leading to decreased efficiency	Stimulate accelerated development and demand for performative[2] appliances Facilitate user access to performative appliances Promote scalability of IoT technologies
Materials 	At present, the development of performative construction materials is still in its early stages, and Life Cycle Assessment (LCA) and Life Cycle Costs (LCC) approaches are not yet widely used	Increase ambition targets for performative materials by integrating planning strategies such as life cycle costing and circular economy principles Facilitate goal visualisation to help individuals envision and work towards their desired outcomes Implement and/or further develop a construction material recycling and reuse programme
Resilience 	Currently, urban resilience is in its primary phase and there are minimal emergency planning measures in place	Develop collaborative sub-regional efforts to help increase the ambition of climate targets Accelerate the dynamic response speed and flexibility needed to effectively address climate emergencies
Clean energy 	There is still a heavy reliance on fossil fuels and on plans to increase the GBA's nuclear power[3] capacity due to the lack of adequate Renewable Energy (RE) infrastructure	Increase targets for RE scalability of regional grid supply Improve RE implementation methodology for regional grid supply Increase RE targets for demand and feedback balance Improve RE implementation methodology for demand and feedback balance
Enablers 	Currently, there are existing formalised networks that facilitate stakeholder involvement and enabling conditions in place	Reinforce networks is needed with emphasis on multi-stakeholder engagement An adaptive methodology should be established for capacity building, including financing and regional leadership transitions

Although it is necessary to address the recommendations of each activity individually, there is a notable overlap between different disciplines. Additionally, it is important to note that the GBA is a mega-region composed of highly diverse sub-regions. A holistic approach to sustainability takes into account the interconnectedness of these different factors and systems, instead of treating them as isolated, an approach that can also be used here.

Development of Regional Frameworks in China's Greater Bay Area

The GBA has a pressing need to develop ambitious and comprehensive strategies and roadmaps to decarbonise its building and construction sector. To accelerate action, strategic collaboration and greater integration between the sub-regions is key to addressing the challenges in meeting their climate goals and improving the sustainability of their building and construction sectors.

Below is an overview of the key recommended integrated actions and strategies that cross over multiple activity areas and sub-regions.

Identifying Stakeholders and Baseline Collaboration Networks
National ministries and city agencies in the GBA should collaborate with a range of stakeholders which are unique to the different cities and regions of the GBA, including urban planning, building design and construction, materials, resilience, and clean energy experts. Through consultation and engagement, these stakeholders should develop early action plans that prioritise decarbonisation, energy savings, and efficiency planning. Collaboration and coordination between sub-regions can help identify and engage a broader range of stakeholders.

Establishing Data Collection Systems and Methodologies
To support the development of decarbonisation and efficiency planning, governments and industry coalitions should work toward closing information gaps on building performance in the GBA. This can be achieved by establishing data collection systems and methodologies that cover the entire GBA, providing essential evidence to inform sustainability interventions and to quantify the benefits of efficiency planning.

Advancement of Integrated Urban Planning Policies and Climate Resilience Frameworks
In addition, city-level actors in the GBA should collaborate across sectors and government levels to develop integrated urban planning policies and climate resilience frameworks. These should prioritise equitable and sustainable land use, transit-oriented design, accessible greenspace, climate resilience, and clean energy district planning.

Improvement of Regulatory and Cross-Regional Incentive Frameworks
To promote the adoption of energy-efficient and low-carbon-driven construction in the GBA, regulatory agencies should establish clear regulatory and incentive frameworks. Collaboration and coordination between sub-regions can help in the

development of such frameworks, prioritising investment in energy efficiency improvements, and reducing carbon emissions from major building materials. The resulting regulatory and incentive frameworks should promote the use of on-site and building-integrated renewable energy.

Development of a Living Roadmap and Iterative Implementation Plan (LRIP)

To successfully achieve the goal of zero-emission, efficient, and resilient buildings, national governments and city agencies in the GBA must create a living roadmap for the building and construction sector, which should be viewed as an iterative and dynamic process. The roadmap must address the current high construction rates in the area and be comprehensive, forward-thinking, and be developed through a consultative process that includes input from a wide range of experts in urban planning, building design and construction, materials, resilience, and clean energy. A living roadmap is a dynamic and continuously evolving plan that is regularly updated based on new information, insights, and changing circumstances. It is designed to be flexible and adaptable, allowing for adjustments to be made as new opportunities arise or challenges arise. By taking an iterative approach, stakeholders can test different strategies and identify potential roadblocks, leading to a more efficient and effective implementation process. It is essential that the roadmap be continuously updated and adjusted to reflect changes in the industry and technological advancements, ensuring its relevance and effectiveness over time. The strategies should be developed through consultation and engagement that brings in a range of disciplines of urban planning, building design and construction, materials, resilience, and clean energy.

Leveraging of Circular Economy and Resource Efficiency

Adopting circular economy principles and resource efficiency measures in the building and construction sector is a promising opportunity for the GBA to reduce waste and increase sustainability. Prioritising the use of recycled materials and promoting circular design practices can create a more sustainable and resilient built environment. Building Information Modelling (BIM) can facilitate this by allowing for collaboration and coordination among stakeholders and efficient tracking of materials. Serialised dry construction approaches can further promote circularity and resource efficiency by reducing waste and improving construction speed and quality. By taking a holistic approach to building and construction, the GBA can create a more sustainable and liveable built environment for its residents, while also reinforcing multi-stakeholder participation and achieving roadmap longevity.

The Landscape: A Regional Overview

The Greater Bay Area (GBA) of China is a cluster of megacities in southern China which includes Hong Kong and Macao as Special Administrative Regions (SARs), the Pearl River Delta (PRD) in the South of the Guangdong Province, and other sub-regions like Western Guangdong, Eastern Guangdong, and Northern Guangdong.

The GBA first began as a strategic initiative launched by the Chinese government in 2017 aimed at promoting economic integration and development across the region. The goal was to build a world-class city cluster by leveraging the strengths of cities in the region, including their infrastructure, human capital, and technology. The GBA boasts advantages such as a strategic location, strong economy, high concentration of innovative elements, and high degree of internationalisation, making it a hub of global technological innovation and a source of emerging industries, as well as a major centre for transportation and logistics and a hub for cultural exchange.

However, the GBA also faces several challenges. Within the GBA, this can occur due to disparities in development, distinct social and legal systems, and different customs territories among its three sub-regions. These factors create imbalances in resource distribution and usage, and lead to regions competing for the same resources, such as energy and land. Additionally, differences in regulations and policies can make it difficult to coordinate resource management and create barriers to collaboration. This can lead to inefficient use of resources as regions may overuse them in order to gain a competitive advantage. As a result, the pressure on resources and the environment increases, as well as the risk of urban development instability. Additionally, the GBA, which is located in a geographically complex region[4], is prone to severe weather, which has already caused major urban disruptions and urban development instability.

To address this, the Chinese government has implemented several policies aimed at meeting the challenges in the GBA. The 14th Five-Year Plan for National Economic and Social Development[5], commonly referred to as the 14th Five-Year Plan, lays out the government's strategic vision and goals for the country's economic, social, and environmental progress over the period from 2021 to 2025. Meanwhile, the 'Guangdong-Hong Kong-Macao Greater Bay Area Development Plan' serves as the main policy for integrating the infrastructure and resources of the three re-

4 A geographically complex region is described here considering the interplay between various interdependent features such as physical geography (topography, hydrology, and geology), relief (elevation changes, mountains, valleys, and plateaus), drainage (flow of water including rivers, lakes, and wetlands), climate (prevailing weather patterns and temperature ranges), and land use (urban areas, agricultural lands, and natural habitats).

5 The 14th Five-Year Plan, covering the period from 2021 to 2025 (National Development and Reform Commission, 2021), includes a range of policies and measures aimed at addressing the challenges of economic, social, and environmental sustainability, including mitigating the impacts of climate change and reducing greenhouse gas emissions.

gions in the GBA. The 'Outline Development Plan for the Guangdong-Hong Kong-Macao Greater Bay Area' (ODP) provides guidelines for regional cooperation in areas such as finance, innovation, and environment protection and is closely connected to China's Intended Nationally Determined Contribution (INDC) in promoting sustainable development and mitigating the impact of climate change as well as for meeting China's global obligations under the Paris Agreement. These policies are interdependent, as the 14th Five-Year Plan and the GBA Development Plan support the implementation of the ODP and China's INDCs, while the ODP and INDCs provide the framework for realising the goals set forth in the 14th Five-Year Plan and GBA Development Plan. Although it is widely recognised that the GBA has already made significant progress in terms of economic integration and development since the implementation of those plans, the transition towards a zero-emission, energy-efficient, and resilient building and construction sector in the GBA still faces several challenges. These include, for example, a lack of standardisation in building codes and sustainable construction practices across the three sub-regions, limited incentives for adoption of energy-efficient and sustainable building practices, limited capacity building and awareness, financing and investment constraints, the need for integration of smart and green technologies, and the requirement for ongoing government support.

Given the challenges facing the GBA's efforts to achieve a zero-emission, energy efficient, and resilient buildings and construction sector, there is a need for a comprehensive and coordinated approach that considers the interdependence of various policies and factors. Such an approach could potentially involve collaboration with international organisations and the sharing of best practices and solutions from other regions. Last but not least, it is important to note that the development of a sustainable and low-carbon built environment requires a holistic and multi-stakeholder approach, as well as continuous monitoring and evaluation to ensure the effectiveness of measures and the achievement of goals.

Regional Context

Towards a megacity cluster: The GBA has a long history of urban development, dating back to the early days of Chinese civilisation when Guangzhou was a major trading port and cultural centre.

Over the centuries, the cities in the GBA have experienced periods of growth and decline, with some cities becoming more prominent than others. For example, Hong Kong became a major centre of trade and commerce in the 19th and 20th centuries, while Shenzhen developed into a major manufacturing hub in the late 20th century.

In 2014, the Shenzhen Municipal Government Work Report first proposed the idea of building a 'Bay Area Economy', which envisioned the Guangdong-Hong Kong-Macao urban agglomeration as a connected and integrated entity. In 2017, the concept of the Guangdong-Hong Kong-Macao GBA was officially written into the work reports of the State Council and Guangdong Provincial Government and progressed towards implementation. On February 18, 2019, the Chinese government released the ODP for the Guangdong-Hong Kong-Macao GBA to support and guide its development. The Chinese government has assumed sovereignty over both Hong Kong and Macao since 1997 and 1999, respectively.

In more recent years, the Chinese government has implemented various policies to promote the development of the GBA as a whole. This has included investing in infrastructure projects such as transportation and communication networks, as well as offering tax incentives to companies that establish operations in the area. With a total area of 56,000 km^2 and a total population of about 86 million by the end of 2020, the GBA has become one of the most open and economically dynamic regions in China. It plays an important role in the overall development of China (The State Council, PRC, 2019).

The geography of the GBA is also a factor in its development, as its location on the coast provides access to major shipping lanes and the potential for further development as a hub for trade and commerce. The nine cities in the PRD are the most outward-oriented economic region in the mainland. They are an essential window for international cooperation and exchanges and promote the construction of a new open economic system at the national level. The region's proximity to Hong Kong and Macao also makes it an attractive location for businesses looking to take advantage of the unique opportunities and resources offered by these two special administrative regions.

The goal of the GBA is to develop it into an urban agglomeration that serves as a driving force for the global economy. The GBA aims to become one of the largest bay areas in the world with a projected population of 140 million by 2050. The government is promoting the development of smart cities through pilot projects and cooperation between Guangdong, Hong Kong, and Macao. The GBA intends to become an example in smart city construction and a benchmark for smart city clusters. Furthermore, the GBA plans to implement carbon emission trading, following the pilot which was first launched in Shenzhen in 2013 (Ringius, 2015), and Hong Kong aims to achieve carbon neutrality by 2050.

Socio-Economic and Urban Development

The GBA is pursuing both socio-economic and urban development initiatives as part of its overall strategy for growth and improvement. Key aspects of the socio-economic development effort include reducing poverty through targeted programmes, improving education and healthcare by investing in leading universities and research institutions, developing infrastructure through major projects like the Hong Kong-Zhuhai-Macao Bridge and increasing financial inclusion and access to credit for small and medium-sized enterprises.

A report by the Hong Kong Trade Development Council highlights that the GBA is primarily composed of young professionals in industries such as finance, technology, and tourism, as well as a significant number of workers in traditional industries such as manufacturing and construction. Data from the Seventh Population Census (2020) and the 'Guangdong Province Seventh National Population Census Bulletin' indicate that the total resident population of the nine cities in the PRD region of the GBA is 78.0143 million and has experienced substantial population growth in the past decade (National Bureau of Statistics in China, 2021). The age structure of the nine cities in the bay area is also advantageous in terms of the labour force and education levels, which presents a favourable environment for economic growth and development. These factors suggest that the GBA has a promising future in terms of economic prosperity.

With regard to urban development, the GBA is focusing on various initiatives to enhance the quality of life for residents and support economic growth. This includes addressing the housing shortage and improving housing quality through real estate initiatives, improving transportation systems through investments in high-speed rail and other forms of public transportation, enhancing public services such as water, electricity, and waste management, attracting investment to commercial and industrial areas, developing public spaces such as parks and plazas, building schools, healthcare facilities, and community centres to support the growing population, and prioritising environmental sustainability through measures to reduce greenhouse gas emissions and improve the region's overall environmental quality.

The nine cities in Guangdong Province in the GBA cover an area of about 56,000 km^2. In 2020, the urbanisation rate of the permanent population in Guangdong Province reached 74.15%. Urbanisation in this area has entered a mature stage. Land resources in Guangdong Province are scarce, and the population density is high. Villages are mainly distributed around major cities, and the rural economy tends to be non-agricultural.

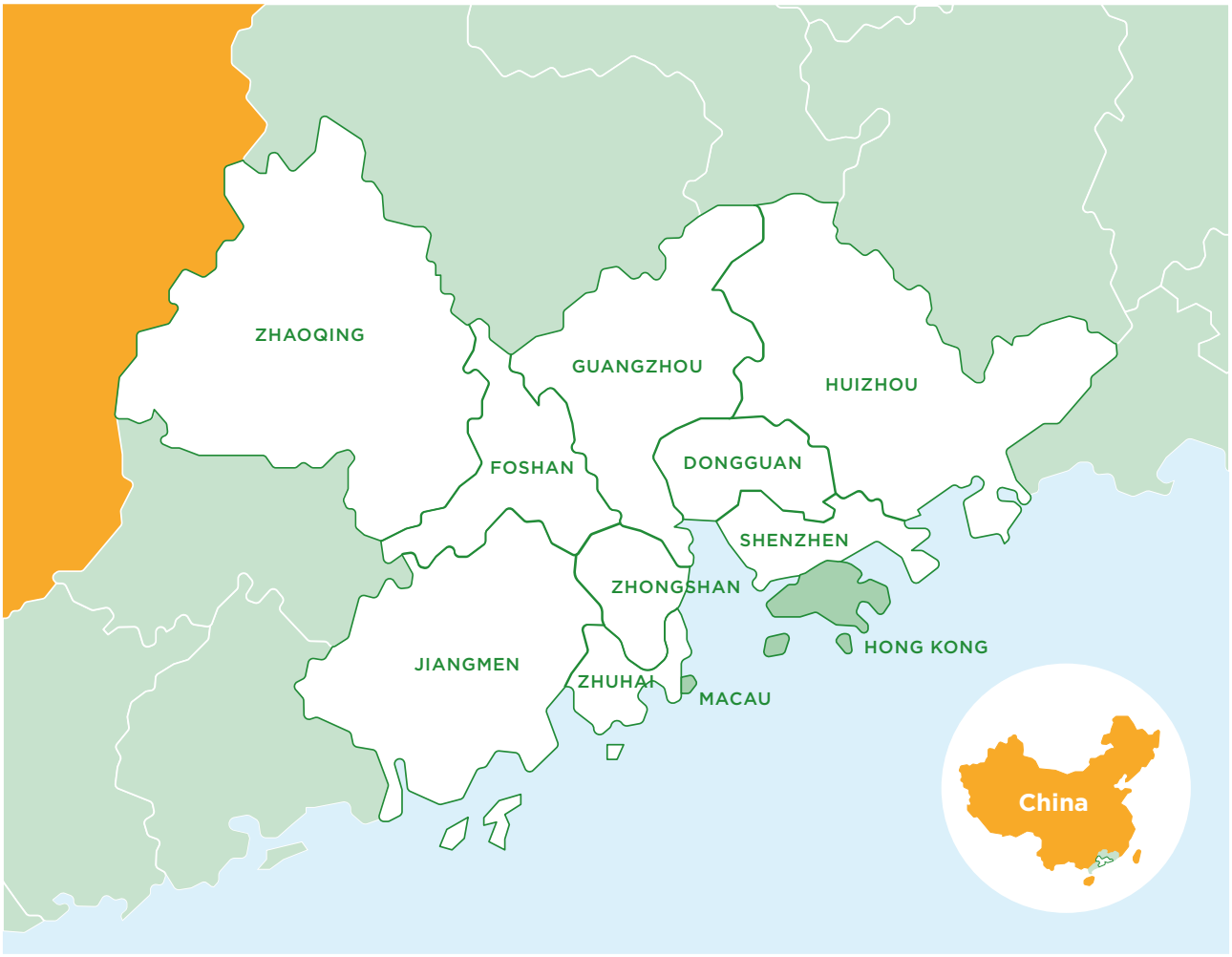
The GBA is known for its ports and aviation hubs that have significant international influence. According to a report by the South China Morning Post, 'The Greater Bay Area is expected to become one of the world's most populous and economically important urban regions by 2030' (Cheung, 2019). In terms of inter-city connections, the GBA relies on high-speed railways, intercity railways, and high-grade highways as the main body of the rapid transportation network. Port and airport clusters are also developed to form a regional economic development axis, achieving a spatial network pattern with efficient connections between major cities, which relies on the advantages of Hong Kong and Macao as free and open economies and Guangdong as the leader of reform and opening up. In the future, the GBA plans to improve the urban agglomeration and the urban development system, making the central cities (including Hong Kong, Macao, Guangzhou, and Shenzhen) more sustainable and liveable.

The GBA is deeply involved in international cooperation. With Hong Kong, Macao, Guangzhou, and Shenzhen acting as both the core engines of regional development and as a bridge to foreign stakeholders, the GBA can exert its advantages and strengthen its leading role in the development of surrounding areas (The State Council, PRC, 2019).

Differentiation of the Sub-Regions

The GBA is a cluster of cities and special administrative regions located within the Guangdong province. It is composed of three sub-regions: the two SARs of Hong Kong and Macao and the PRD economic region. Guangdong province serves as the backbone of the GBA's economy, providing a significant portion of the region's resources, infrastructure, and human capital for the region's rapid development.

Table 2 Differentiation of the GBA sub-regions



Hong Kong and Macao SAR: both SAR are former colonies that were granted a special status by the Chinese government after their return to China. These two regions operate under different legal systems from the rest of the mainland, and are given a high degree of autonomy in areas such as trade and finance. Hong Kong is an international financial hub, while Macao is famous for its historical sites and gambling industry.

The PRD economic region: Located in the southern part of Guangdong province, the PRD is a rapidly developing economic zone composed of nine major cities, namely Guangzhou, Shenzhen, Dongguan, Foshan, Zhongshan, Zhuhai, Jiangmen, Huizhou, and Zhaoqing. The subregion is renowned for its advanced manufacturing capacity, its export-oriented industries and technological prowess. The PRD is also a significant transportation hub, with several ports and airports connecting it to the rest of the world.

The sub-regions of the GBA each have their own unique characteristics and specialities. Hong Kong is a global financial centre; Shenzhen is known for its technology and innovation, particularly in electronics and manufacturing; Guangzhou is an important commercial and manufacturing hub with a rich history and cultural heritage; Macao is a major tourist destination, famous for its casinos and Portuguese colonial architecture. Furthermore, Dongguan is a manufacturing centre, producing a variety of products, including textiles, electronics, and toys. Zhuhai

is famous for its beautiful landscapes, including beaches and parks, as well as its high-tech industries. Foshan is renowned for its traditional ceramics industry, as well as its furniture and appliance manufacturing. Jiangmen is focused on the production of household goods, including cookware and appliances. Zhongshan is known for its lighting and electrical appliance industries, as well as its history as the birthplace of Sun Yat-sen. Huizhou has its industries in electronics and machinery, as well as its beautiful natural scenery.

Because of these differences, there is a need to improve market connectivity in the region. This affects areas such as infrastructure, investment facilitation, trade liberalisation, and ease of exchange for goods and personnel. Currently, customs inspections are required for the movement of goods, and personnel access may require permits in certain sub-regions. Efforts to enhance connectivity and integration are ongoing.

Homogeneous competition[6] and resource mismatch still exist in some regions and fields. The industrial structures between Dongguan and Shenzhen, Zhongshan and Zhuhai, and Zhongshan and Foshan have similarities of more than 90%. Moreover, the geographical and spatial distribution of cities is uneven, and the high-tech and manufacturing capabilities of different cities vary widely. Among the cities in the GBA, Hong Kong and Macao account for more than 90% of the tertiary sector. Hong Kong is dominated by the financial industry, Shenzhen by high-tech industries, and Guangzhou by electronic information, medicine and health, and advanced manufacturing.

Hong 'Kong's economy has been facing challenges in recent years, with a decline in manufacturing and trade activities, and a slowdown in economic growth. However, the city still maintains a high level of economic stability and resilience, thanks to its diversified economy, which includes sectors such as finance, professional services, and retail. Macao's economy is heavily dependent on the gaming and tourism industry, which has been hit by the COVID-19 pandemic and China's anti-corruption campaign. However, Macao's economy also has a strong service sector and the government is actively promoting the diversification of its economy. The economic development of the nine cities in the PRD region is closely tied to the economic growth of the Guangdong province, which has been shifting its focus to high-tech and service industries in recent years.

There are limitations in the regional development of the GBA. Resource and energy constraints are tightening, ecological and environmental pressures are increasing, and the demographic dividend is diminishing. In the long run, promoting the integration of the rule of law in the GBA requires strong coordination by the central government (China Economic Weekly, 2021).

6 Homogeneous competition refers to the phenomenon that products of different brands imitate each other so that the technical content and use value of the products tend to be the same.

Climatic Profile of the Greater Bay Area

Climate Features

The GBA has a humid subtropical climate, which is characterised by hot, humid summers and mild, relatively dry winters. Overall, the GBA experiences high humidity levels and frequent rainfall, particularly during the summer months.

The climate in the GBA is further divided into two zones based on the Köppen-Geiger climate classification system.

- The cities of Guangzhou, Foshan, Zhaoqing, Jiangmen, and Huizhou are located in the northern part of the GBA and fall under the Cfa[7] climate classification, featuring high humidity levels throughout the year, hot and humid summers and mild winters. The Cfa zone is also prone to typhoons during the summer and early fall months.
- The cities of Hong Kong, Shenzhen, Zhuhai, Dongguan, and Zhongshan are located in the southern part of the GBA and fall under the Cwa[8] climate classification, also featuring high humidity levels, hot and humid summers and mild winters. The Cwa zone is prone to thunderstorms, tropical cyclones and heavy rainfall during the summer months.

In terms of sub-regional differences, Guangdong province offers abundant geothermal resources, a warm climate, cold-free winters, and abundant rainfall. Due to the difference between the north and the south and the topographic effect of mountainous hills, Guangdong has various climate types, which form different types of microclimates.

Macao is located in the central and southern parts of Guangdong province and consists of Macao Peninsula, Taipa Island, and Coloane Island. Due to the low latitude, large solar altitude, strong radiation, and surrounding water bodies, the climate in Macao is characterised by high temperatures, abundant sunshine, high precipitation, high humidity, and high average wind speed.

Based on the climate features, buildings in the GBA must meet the requirements of heat protection, ventilation, and rain protection in summer, while cold protection and heat preservation in winter may not be considered. The reduction of building cooling energy consumption is a critical measure to achieve carbon peaking and carbon neutrality in the GBA. Therefore, the overall planning, detailed design, and structure of buildings should avoid the west sunlight and be provided shade. Furthermore, the prevention of rainstorms, floods, moisture, and lightning strikes should be emphasised.

7 The average relative humidity is 70% in winter and 80% in summer. Summer temperatures average 28°C, winter temperatures 13°C. Average annual precipitation is around 1,800–2,000 millimetres, with the majority of rainfall occurring in the summer months.

8 The average relative humidity in the Cwa zone is 72% in winter and 82% in summer. Summer temperatures average 29°C, winters average 11°C. The Cwa zone receives an average annual precipitation of around 1,500–1,800 millimetres, with most rainfall occurring from April to September

Geography and Environmental Considerations

The GBA boasts a coastline of approximately 3,201 km, with unique geological conditions and important environmental carrying capacity[9], according to the Guangzhou Marine Geological Survey (2017). The area is known for its abundant natural resources, including tidal flats and shallow sea areas, which have been identified as potential sites for regional engineering and urban construction by the China Marine Geological Survey (2017). However, it is crucial to consider the environmental impact of development and ensure that resources are used sustainably to maintain the area's environmental carrying capacity. Moreover, there are many rivers in Guangdong province, and the catchment area accounts for 99.8% of the province's area. In 2021, the province had more than 1,300 nature reserves at all levels[10], which is the highest in the country (Su, 2021).

In recent years, Guangdong, Hong Kong, and Macao have faced severe environmental pollution, with prominent trans-boundary water pollution, declining air quality, and deteriorating regional ecological quality. The ecological security system needs to be urgently conserved.

According to analysis and statistics, the urban heat island effect in the Bay Area increased significantly from 2003 to 2018. The annual increase in heat island intensity is 0.05°C, and the annual increase in heat island area is 0.18% (Yujiaov, 2018).

Data from the Guangdong Provincial Department of Ecology and Environment show that the water environment of the urban agglomeration in the PRD region is facing serious pollution. The load and pressure on the marine environment are gradually increasing. However, the sewage treatment rate in China has rapidly increased in the past decade, and water pollution has been alleviated to a certain extent (EED, 2020).

Over the past decade, nine cities in the PRD and Hong Kong have shown steady signs of improvement in air quality, with decreasing concentrations of the most prominent air pollutants. In Macao, the air quality is also improving. Compared with 2006, the annual mean concentrations of sulphur dioxide, PM 2.5, and nitrogen dioxide[11] recorded in 2020 were significantly lower. In terms of the land environment, the rapid urbanisation of the GBA has destroyed a large area of ecological land (arable land, forestland, grassland). Due to the significant differences in geographic conditions, environmental protection policies, and urbanisation processes among the cities in the GBA, the land environment status of each city is different (EED, 2020).

In 2020, the urbanisation rate of Macao China reached 100%. Urban construction land is extremely tight, and building coverage is high. In response to the rapid

9 Environmental Carrying Capacity: The limit of the support ability of the environment of a certain region to human social and economic activities.

10 'All levels' refer to different tiers of government, organisations, and individuals involved in the protection and management of forest and wetland resources.

11 The EPA has identified six pollutants as 'criteria' air pollutants because it regulates them by developing human health-based and/or environmentally based criteria (science-based guidelines) for setting permissible levels. These six pollutants are carbon monoxide, lead, nitrogen oxides, ground-level ozone, particle pollution (often referred to as particulate matter), and sulphur oxides.

urban development and population growth, Macao has adopted reclamation to increase land resources for urban development. According to the research, the total area of the urban ecological protection red line[12] in Macao is 6,714 km^2.

Climate Trends

From 1961 to 2018, the meteorological parameters in the GBA show a significant warming trend and a significant decrease in sunshine hours, consistent with the trend of global changes. While urbanisation is a significant contributor to warming in the GBA, it is important to consider the impact of other natural and human factors, including greenhouse gas emissions, land use changes, and deforestation in understanding and addressing the changing climate in the region (Guangdong Meteorological Bureau, Macao Meteorological and Geophysical Bureau, HKO, 2020).

Evidence shows that the daily maximum temperature in the GBA is gradually rising. From 1970 to 2020, the number of annual high-temperature weather days has increased significantly, and no-rain days of more than three consecutive days in the non-flood season (January to March and October to December) are increasing every year. Rainstorm and heavy rainstorm days recorded by the Hong Kong Observatory and the Mainland Meteorological Stations also follow an annually increasing trend (Guangdong Meteorological Bureau, Macao Meteorological and Geophysical Bureau, HKO, 2020).

In particular, the annual average temperature in the GBA has increased significantly. The average annual precipitation in the Bay Area shows a weak increase (increasing 30.5 mm per 10 years) with significant inter-annual variability. In addition, the increase in aerosols, the greenhouse effect, human activities, and urbanisation have led to a significant decrease in the average annual sunshine hours in the GBA. This decrease rate is much higher than the Chinese average for the same period (Hongyu, 2019).

In 2020, the GBA experienced high temperatures with a record-breaking number of high-temperature days. The temporal and spatial distribution of precipitation was uneven, and heavy floods occurred. The overall impact of typhoons was light, but the meteorological drought was gradually becoming more severe. The cold air activity was generally weak, while the cold wave at the end of 2020 caused a significant drop in temperature (Guangdong Meteorological Bureau, Macao Meteorological and Geophysical Bureau, HKO, 2020).

Natural disasters in the GBA have prominent regional characteristics. The coastal areas are prone to marine disasters, and the delta plains are prone to frequent rainstorms, floods, and soft soil subsidence. Mountain disasters also frequently occur in peripheral mountain areas. Due to the lack of comprehensive disaster prevention planning for urban agglomerations, the coordination and linkage among cities in meteorological disasters still need to be improved.

12 The concept of an 'ecological protection red line' was first introduced in China's 13th Five-Year Plan for Economic and Social Development, which called for the establishment of a nationwide system of ecological protection red lines to guide land use and development.

The Chinese government plans to actively promote the establishment of a disaster prevention and mitigation linkage mechanism between Guangdong-Hong Kong-Macao to address the uneven distribution of disaster prevention infrastructure resources among regions. By 2035, a modern meteorological business, service, technological innovation, and management system will be built in the GBA This meteorological service is strongly related to to the diversification of smart technology systems (China Meteorological Administration, 2020).

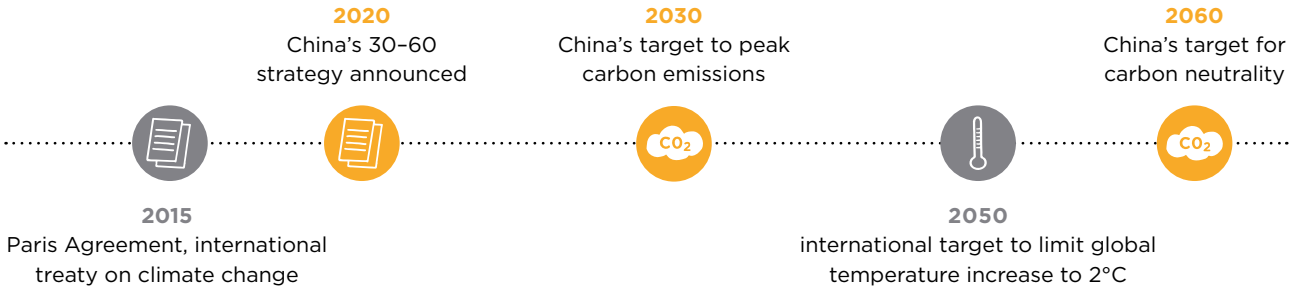
Key National and Regional Climate Policies

China has been actively pursuing its national climate policies aimed at reducing carbon emissions and meeting the goals of the Paris Agreement since its adoption in 2015. The country has established medium and long-term plans to reach carbon peak and carbon neutrality.

On September 22, 2020, Chinese President Xi Jinping announced the 'Chinese Government's Strategic Deployment on Climate Change Mitigation' at the United Nations General Assembly: 'To achieve the peak of carbon emissions before 2030 and strive to achieve carbon neutrality by 2060'. It sets clear goals and a specific timetable for the energy transition revolution in China.

According to China's State Council (2021), the focus of these efforts has been on implementing energy-saving and carbon-reducing projects, particularly in the areas of building construction, transportation, lighting, and heating. The Chinese government aims to promote the demonstration and application of advanced green building technologies, improve building energy efficiency, and optimise the building energy structure through the green and low-carbon transformation of urban and rural construction and while aligning with the country's overall objectives to address its carbon emissions and contribute to global climate action.

Table 3 Overview of the key national climate policies



National Climate Policies

14th Five-Year Plan for Building Energy Efficiency and Green Building Development

The 14th Five-Year Plan for Building Energy Efficiency and Green Building Development, adopted by the National Development and Reform Commission of the People's Republic of China (NDRC) in 2021, aims to improve energy efficiency and promote green building in the country. It covers the period from 2021 to 2025 and is formulated by the NDRC and approved by the National People's Congress, China's top legislative body (Liu, 2020).

These policies aim to achieve a greener and more sustainable future for China's built environment, and to contribute to the country's efforts to mitigate climate change. The key policies of this plan include:

Promoting the construction of green and energy-efficient buildings: The government intends to increase the proportion of newly built green and energy-efficient buildings, and to encourage existing buildings to adopt energy-saving measures.

According to the 14th Five-Year Plan, China aims to construct all new urban buildings as Green Buildings by 2025. The plan proposes the renovation of more than 350 million m^2 of energy-saving buildings, the construction of more than 50 million m^2 of Ultra-Low and Near-Zero Energy Building areas, and prefabricated buildings accounting for 30% of new urban buildings (MOHURD PRC, 2022).

Establishing energy-saving standards for buildings: The plan aims to establish and update energy-saving standards and evaluation methods for buildings, and to promote the implementation of these standards.

The Chinese government, through relevant departments and organisations such as the Ministry of Housing and Urban-Rural Development (MOHURD), the National Energy Administration, and the China Green Building Council, provides the official definition for terms such as 'Ultra-Low Energy Building', 'Near-Zero Energy Building', and 'Green Building'. These organisations implement energy efficiency policies and establish green building rating systems to encourage environmentally responsible design, construction, and operation of buildings.

Encouraging the use of green building materials: The government intends to promote the use of green building materials and products, such as renewable energy sources, energy-saving equipment, and eco-friendly materials.

'Green Building' in the context of China is a concept that refers to the design, construction, and operation of buildings in an environmentally responsible manner, taking into account factors such as energy efficiency, water conservation, indoor air quality, and materials selection. The Chinese government and organisations have established green building rating systems, such as the Three-Star Green Building Evaluation System, to promote and encourage the construction of Green Buildings in the country.

Developing green building technologies: The plan aims to support the development of new green building technologies and to encourage their application in practice.

The 14th Five-Year Plan targets, for example, the installation of solar Photovoltaics (PV) with a capacity exceeding 50 million kilowatts, a geothermal energy applica-

tion area exceeding 100 million m^2, a renewable energy replacement rate in urban buildings reaching 8%, and a proportion of electricity consumption in building energy consumption exceeding 55% (MOHURD PRC, 2022).

Promoting the application of smart building systems: The government intends to promote the application of smart building systems, such as building automation and control systems, to improve energy efficiency.

One example of a smart building initiative planned for China's GBA in line with the 14th Five-Year Plan for Building Energy Efficiency and Green Building Development is the creation of a green building pilot zone. This pilot zone aims to encourage the development of green buildings and promote the use of smart building technologies, such as Building Automation and Control Systems (BACS), in the region. The goal is to set an example for sustainable building practices and drive the adoption of energy-efficient and environmentally friendly building standards across China.

Intended Nationally Determined Contribution

China's INDC under the Paris Agreement are closely linked to the country's 14th Five-Year Plan for economic and social development. According to China's INDCs (National Development and Reform Commission, 2016), some of the key commitments include:

1. Peaking carbon dioxide emissions around 2030 and striving to achieve carbon neutrality by 2060.
2. Increasing the share of non-fossil fuels in primary energy consumption to around 20% by 2030.
3. Increasing the forest stock volume by around 4.5 billion m^3 from the 2005 level.
4. Reducing carbon dioxide emissions per unit of Gross Domestic Product (GDP) by 60% to 65% from the 2005 level.
5. Increasing the total installed capacity of renewable energy to around 1,200 GW by 2030.
6. Implementing an energy-saving plan, including reducing energy consumption per unit of GDP by 15% from the 2015 level.
7. Promoting the development and deployment of low-carbon technologies and encouraging international cooperation on low-carbon development.

It is important to note that INDC are dynamic and may be revised over time to reflect changes in a country's climate policy and progress. Further, the INDCs are not legally binding, but represent a country's voluntary commitment to reducing emissions and addressing the impacts of climate change.

Regional Climate Policies

The key climate policies of the GBA aim to mitigate the effects of climate change, reduce carbon emissions, and promote sustainability. These policies are crucial in achieving the GBA's goal of becoming internationally acclaimed by 2035 while contributing to global efforts to combat climate change.

In 2019, the **Outline Development Plan for the Greater Bay Area** was created with the aim to fully leverage the composite advantages of Guangdong, Hong Kong, and Macao and deepen the cooperation with the Mainland. It was developed to align with and support the implementation of the 14th Five-Year Plan in the GBA region. It's a more specific policy document that provides detailed policy measures and targets for the development of the GBA region. These policies also promote coordinated development and complementary advantages among sub-regions in the GBA, such as:

- **Carbon emissions reduction targets:** The GBA has set targets for reducing carbon emissions, including a commitment to peak carbon emissions by 2030 and to reduce carbon intensity by more than 60% by 2035.

  The GBA has made Carbon Neutrality[13] a crucial objective in its development goals to tackle the global climate and environmental crisis and to achieve high-quality growth. It aims to utilise its geographical advantages, implement pilot projects, and adopt replicable and scalable low-carbon technologies to reach carbon neutrality, contributing to the national effort in the construction sector. Each sub-region within the GBA is expected to report its progress towards low-carbon development, taking into account its unique regional characteristics.

  In 2021, the Macao SAR government officially proposed to actively cooperate with the overall development strategy of national environmental protection, promoting energy conservation, emission reduction, and waste reduction, gradually realising clean energy substitution, striving to achieve carbon peak before 2030, improving environmental protection laws and regulations, and building a green, low-carbon, and liveable Macao (Macau SAR Government, 2022). In the future, Macao will strengthen environmental protection, reasonably plan public infrastructure, build a low-carbon community, and advocate a green lifestyle (Macau SAR Government, 2022).

- **Green development strategy:** The GBA has a green development strategy, which includes measures to promote energy efficiency, renewable energy, and sustainable transportation. This strategy also includes the use of green finance to support sustainable development and reduce carbon emissions.

  The incentive policies on ultra-low energy buildings can be roughly divided into three categories: process support, indirect economic benefits, and direct economic benefits, such as clear planning objectives, fund incentive subsidies, volume rate incentives, land use guarantee, pre-sale, commercial housing price rising, supporting cost reduction, technical support, and process optimisation.

- **Energy efficiency building codes:** The GBA has implemented strict energy efficiency building codes to reduce energy consumption and carbon emissions from buildings. The codes require new buildings to meet high energy efficiency standards, and existing buildings to undergo retrofits to improve their energy efficiency.

13 In the Chinese building sector, 'Carbon Neutrality' refers to the concept of reducing the carbon emissions generated by buildings to the point where they produce no net carbon emissions over their life cycle. This includes emissions from energy use, construction, and demolition. This involves not only designing and constructing new buildings to be low-carbon, but also retrofitting existing buildings to reduce their carbon footprint (MOHURD PRC, 2022).

The Chinese building energy efficiency codes and standards (for building design, construction, operation, and maintenance) have been in effect for nearly 40 years, and are complemented by a series of national, provincial, and city-level subsidy schemes and incentive mechanisms. Currently, the energy efficiency standard has gained broad acceptance and has become common practice in the building sector, and buildings are gradually transitioning toward ultra-low energy consumption buildings, nearly zero-energy buildings, zero-energy buildings, and zero-carbon buildings (The State Council, PRC, 2020). There are over 12 million m^2 of zero-energy buildings under construction or already completed in China, with significant growth expected in 2023.

- **Develop and promote star-rated green buildings:** Among new buildings, the proportion of star-rated green buildings will exceed 30%, including more than 45% in nine cities in the PRD (the Guangdong-Hong Kong-Macao GBA), and the proportion of prefabricated buildings will reach 30%.
- **Renewable energy promotion:** The GBA is promoting the use of renewable energy sources such as solar, wind, and geothermal through financial incentives, technical support, and the integration of renewable energy systems into the building design.
- **Sustainable transportation:** The GBA is investing in public transportation systems and promoting the use of low-carbon transportation, such as electric vehicles, to reduce carbon emissions from transportation and to promote sustainable mobility.
- **Smart technology systems:** It envisions the development of 'smart transport, smart energy, smart municipal management, and smart communities'. Benefiting from the highly connected and innovation-driven entrepreneurial environment of Guangzhou, Shenzhen, and Hong Kong, the GBA consistently develops Artificial Intelligence (AI), robotics, biomedical and healthcare technology, energy distribution systems, and data connectivity. These sectors are critical to smart and sustainable urban development solutions.

Regional Building Policies

As for building policies, the policy environment and priorities vary greatly across the region, and the decarbonisation of buildings needs to be addressed. The main targets by 2025 include, among other, optimising the building energy structure: the installed capacity in new buildings will be 2 million kilowatts, the replacement rate of renewable energy in urban buildings will reach 8%, and the proportion of electricity consumption in building energy consumption will exceed 80%.

In 2022, the Guangdong province government published 'Guangdong Carbon Peaking and Carbon Neutrality Guidance'. The policy further emphasises the building and construction sector as a key area for achieving carbon peaking and carbon neutrality (GPC, 2022). The main actions include:

- Prohibiting large-scale demolition and construction of buildings and promote the energy-saving and green transformation of existing buildings.

- Widely promoting green building materials and green construction.
- Vigorously developing green, ultra-low energy buildings, near-zero energy buildings, and prefabricated buildings.
- Optimising the energy structure of buildings and accelerate the electrification transformation in the building sector.
- Promoting the large-scale application of renewable energy and develop PV building integration in appropriate areas.

The existing 'Macao Building Energy Consumption Optimization Technical Guidelines' and 'Green Building Evaluation Standards (Macao Version)' do not have relevant enforcement regulations. Macao still has a long way to go in developing low-carbon and energy-saving buildings.

In an effort to combat climate change and reduce its carbon footprint, the government of Hong Kong set a goal to decrease its carbon emissions after 2020, which was referred to as the 'Carbon Peak' goal. In 2014, the government developed the 'Hong Kong Climate Action Blueprint 2030+' and 'Hong Kong Climate Action Blueprint 2050' to support this goal. These policy documents outline a pathway for Hong Kong to achieve a zero-emission, energy efficient, and climatically resilient building stock, with the ultimate goal of achieving carbon neutrality in the city.

Regional Roadmap

The Plan for Decarbonising the Buildings and Construction Sector

How to Use this Roadmap

This document is intended to identify common goals, targets and timelines for key actions across eight 'activity areas'. Each activity represents a segment of the buildings and construction sector: urban planning, new buildings, existing buildings, appliances and systems, building operations, materials, resilience and clean energy as each of these represents a key ingredient of how buildings influence our environment and vice-versa.

Activity Area Chapter Breakdown

Each of the activities is structured in a similar manner, illustrated by recent examples, and can be read either in isolation or in conjunction with the other parts of the document. Each activity area chapter covers:

Status Quo and Baseline: represents the current conditions and practices in the buildings and construction sector and provides a reference point against which progress towards sustainability goals can be measured.

Trends and Challenges: trends can be positive or negative and may include changes in technology, policies, and consumer preferences that affect the design, construction, operation, and maintenance of buildings. Challenges are obstacles or barriers that need to be overcome in order to achieve sustainability in the buildings and construction sector.

Targets and Indicators: targets refer to specific goals or objectives that the alliance aims to achieve within a particular timeframe. Indicators are measurable variables that are used to track progress towards achieving these targets.

Key Recommended Actions: on the sub-topics of main, policy, technology, finance and capacity building actions. The timelines serve to raise ambition and frame the respective roadmap development targets.

Table 4 Overview of recommended actions for each chapter.

Key actions	Baseline (2022)	Short term (2030)	Long term (2060)
(Action 1) Titles the recommended action	Describes the current level or immediate targets in short	Describes the medium term targets in short	Describes the long term targets in short

- **Action 1:** A more detailed description of how the policy works and what the key success factors are for successful implementation.

Summary: provides a brief summary of the respective activity area chapter.

Regional Examples

Provides an example of existing or best practice from the GBA region.

Currencies: please note that all monetary figures referenced in this document are presented in Chinese yuan (RMB) followed by euro (EUR) in brackets, based on the exchange rate of 1 Euro = 7.67 RMB, which is the prevailing exchange rate as of May 3rd, 2023. This exchange rate is used consistently throughout the document to ensure accuracy and consistency in all financial calculations.

Collaborating Authors

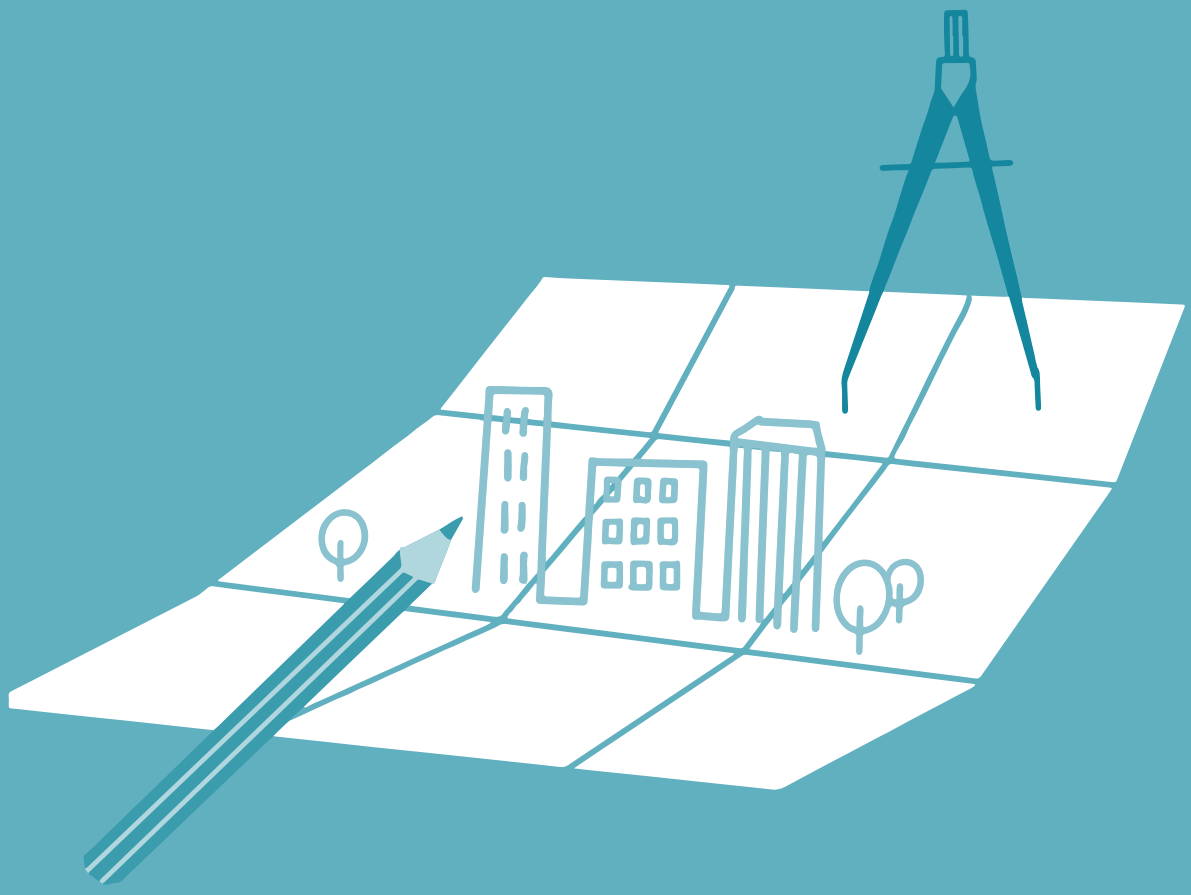
The Regional Roadmap for the GBA is a LIVING document that can be adjusted to meet the sub-regional and local roadmap requirements and keep pace with the evolving trends in the buildings and construction sector. The document incorporates input from key stakeholders in the region who participated in a workshop, and it represents a collaborative effort among three organisations: dena, ICLEI, and CABR.

Table 5 Overview of activity areas and collaborating authors.

Activity area	Area definition	Lead authors
Urban Planning	This activity covers land use, zoning and other planning associated with the buildings, transport and energy systems interact.	dena
New Buildings	This activity covers all aspects of new buildings, including the design process, design strategies, codes and labels.	CABR
Existing Buildings	This activity covers all aspects of the improvements of existing buildings.	dena
Building Operations	This activity covers all aspects of the operations and management of buildings.	CABR
Appliances And Systems	This activity covers lighting, appliance and equipment systems that are used in both new and existing buildings.	CABR
Materials	This activity covers envelope, structural and product materials used in buildings.	dena
Resilience	This activity covers all aspects of building resilience that enables increased capacity to adapt to and mitigate the effects of changing climates and other natural disasters.	dena
Clean Energy	This activity covers the clean energy transition away from carbon-intensive fuels to renewable energy resources.	dena
Enablers	These constitute the key success factors for capacity building, financial tools and multiple benefits and how they can support the achievement of the targets and timelines for the activities.	ICLEI

Activity Area 1

Urban Planning



Status Quo and Baseline

Cities and towns are central to achieving the energy transition and mitigating climate change. According to UN demographic data, the number of people living in cities and towns worldwide grew to 4.2 billion by the end of 2018, which has quadrupled compared to 1950 (750 million) and represents 55% of the total population. The number of urban dwellers is expected to grow by an average of 1.7% per year from 2018 to 2030, and by an average of 1.3% per year from 2030 to 2050. By 2050, 68% of the global population will live in urban areas (United Nations, Department of Economic and Social Affairs, Population Divison, 2019).

80% of global greenhouse gas emissions associated with human activity are concentrated in cities. The huge energy demand and resource consumption, the high density of infrastructure and the multitude of actors involved define the centrality of cities to the energy transition and climate protection. Here, the integrated energy transition has many meaningful enablers. If regional and global climate goals are to be achieved, the potential of cities and towns needs to be leveraged.

China's urbanisation is still growing at a relatively fast rate. Data from China's National Bureau of Statistics show that the number of urban Chinese reached 914 million as of 2021. The urbanisation rate grew from 37.7% in 2001 to 64.72% in 2021. If there is homogeneous growth throughout China, China's urbanisation rate is expected to reach 70% by 2030 (National Bureau of Statistics of China, 2022). The Guangdong-Hong Kong-Macao Greater Bay Area (GBA) had a total population of about 86.17 million by the end of 2020, a Gross Domestic Product (GDP) of over 11 trillion RMB (approximately 1.44 trillion EUR), and an urbanisation rate of over 85%, making it the fourth largest bay area in the world.

The GBA is one of the first regions in China to launch low-carbon construction pilot projects, starting as early as 2010. After 10 years of green and low-carbon development, the carbon intensity of Guangdong province has decreased by 44%, and the total annual emission quota in the carbon emission trading market has reached 400 million t, ranking first in China and third in the world in terms of quota size (Xiaojiang, et al., 2022).

The history of urban and regional planning development in the GBA consists mainly of regional planning in the Pearl River Delta (PRD) and urban planning in Hong Kong and Macao. 1989 saw the first town system planning in the PRD, and the PRD Economic Zone Urban Agglomeration Plan, which was started in 1994, introduced the concept of urban agglomeration for the first time and had a complete spatial structure plan, laying the foundation for subsequent successive plans. In 2004 The Outline Development Plan (ODP) for coordinated development of PRD's urban agglomerations undertook a new exploration, adding ecological, resource and population study topics. In 2008, the ODP was prepared in an attempt to answer new issues such as development transformation. In 2014, Guangdong province formulated a PRD-wide plan in the context of deepening reform, new urbanisation strategies, and the goal of building an excellent city cluster.

With the consent of the Hong Kong and Macao Affairs Office of the State Council and the governments of Guangdong, Hong Kong and Macao, the urban planning authorities of the three districts cooperated in 2006 to conduct a strategic regional planning study on the Coordinated Development of the Greater PRD Townships (Xiangming, et al., 2019). The study focused on areas with cross-border cooperation significance, with spatial structure optimisation, cross-border transportation

cooperation and regional ecological environmental protection as the core research content, and attempted to provide strategic options for spatial cooperation from these three aspects as a reference for the governments of Guangdong, Hong Kong and Macao in producing regional cooperation and cross-border policies to achieve the development goals of the Greater PRD urban agglomeration.

In 2019, the State Council published the ODP for Guangdong, Hong Kong and Macao, which provides a positioning for the future development of the GBA and is a basic platform for urban construction in the area. The main contents regarding city and regional planning include:

- **Optimisation and upgrading of central cities.** Build on the four core cities of Hong Kong, Macao, Guangzhou and Shenzhen as engines for regional development, continue leveraging their comparative advantages in striving for excellence and achievements, and strengthen the radiating effect in leading the development of nearby regions.
- **Build important node cities.** Enhance the coordination of development, strengthen the interaction and cooperation with the central cities, drive the development of the surrounding characteristic towns, and jointly improve the quality of urban cluster development.
- **Develop characteristic towns.** Build smart towns, carry out experiments on the application of intelligent technologies, promote innovation in institutional mechanisms, and explore future urban development models.
- **Promote the integrated development of urban and rural areas.** Establish and improve the institutional mechanism and policy system for integrated development of urban and rural areas.
- **Build a smart city cluster.** Promote low-carbon pilot demonstrations, implement demonstration projects for near-zero carbon emission zones, and accelerate research and development of low-carbon technologies. Promote green and low-carbon development evaluation in the GBA, strive to reach peak carbon emission as early as possible and build a green development demonstration area.

In October 2021, the Hong Kong Development Bureau and the Planning Department released the 'Hong Kong 2030+: Planning Vision and Strategy beyond 2030' document, which aims to make Hong Kong a competitive, sustainable and liveable city in Asia. The plan emphasises sustainable planning, integrated urban design, smart, environmentally friendly and resilient infrastructure systems, and smart mobility. In February 2022, the Macao SAR government announced the 'Urban Master Plan of the Macao SAR (2020–2040)', which focuses on promoting the integration of Macao with the Guangdong-Hong Kong-Macao GBA, diversifying industries, preserving Macao's historical and cultural heritage, and building a 'World Center of Tourism and Leisure' and a 'Beautiful Home'. The plan of Macao complements the regional plan proposed by the State Council, and both Hong Kong and Macao have taken steps towards realising the overall regional vision ((The Development Bureau and the Planning Department Hongkong, 2021), (Land and Urban Construction Bureau of the Macao Special Administrative Region, 2022)).

Trends and Challenges

The high density of population, buildings, facilities and infrastructure, as well as the heterogeneity of urban development scenarios, make the challenge of energy transition in cities and towns imminent. Challenges include how to coordinate the different actors, finding the right technologies and forward-looking business models, the growing digitalisation and the further development of infrastructure in long-term planning (Deutsche Energie-Agentur (dena), 2019).

Cities are multifaceted, with both static characteristics (e.g. structure of residential areas, geographical conditions, energy potential) and dynamic characteristics (e.g. demographics, energy needs, economic situation, demand, and degree of industrialisation). This means that urban areas are characterised by very different local conditions and have various planning forms. Energy and transportation system solutions for cities and towns that are low in CO_2 emissions and can achieve climate neutrality in the long term must be developed with a focus on local realities. A large number of cities have locally adapted energy efficiency and emissions reduction programmes that can significantly reduce greenhouse gas emissions. At the same time, cities are places of knowledge and innovation. With high densities of infrastructure and actors of all kinds, there are tremendous opportunities for success in achieving climate goals.

High density is also a challenge: all transformation processes must be accomplished with limited land resources. In a limited space and with limited available land resources, cities have to meet the different needs and requirements of all sectors (private households, business, trade and services, industry) for energy supply and transportation. There is competition for land use in densely populated urban spaces, particularly with respect to open space, transportation land, roof space, and underground space.

In terms of land-use planning, there is competition between the energy transition of cities and towns (e.g., necessary expansion of renewable energy sources) and other land use purposes. Cities must first provide built space suitable for living and working (residential buildings, commercial and industrial, industrial, administrative institutions, schools, buildings, etc.). The construction of functional transport infrastructure, attractive recreational facilities and nature conservation mechanisms also belong to the core objectives of town building.

The transformation of all sectors creates a range of emerging supply options, and not only the energy sector requires town land for heat and power production. On the transport side, new mobility options also require a change in land use purpose (shared mobility, bike lanes, charging stations, etc.). Climate adaptation measures also have a demand for urban land (ventilation corridors, water management, green spaces, etc.). There is thus a strong competitive relationship for land use.

Low-carbon research in China's urban planning industry is mainly related to energy, industry, transportation, architecture and other fields, and the scale of research is mostly based on urban areas and urban neighbourhoods, mainly focusing on a single dimension and favouring engineering technology. However, the relationship between urban carbon emissions and population, economy, structure and scale is not studied from the perspective of the 'social-economic-natural' ecosystem at a macroscopic regional scale.

The GBA is not a physical geography concept, but an economic geography and a political geography concept. The institutional interface[14] formed by the two SAR and the PRD play a very important role in the regional development, which is not seen in other bay areas in the world, and the planning management is closely related to the legal system. The relative independence and differences among the five places formed by the three jurisdictions also pose challenges to the spatial planning of urban agglomerations as an area management tool.

Taking the construction of smart cities as an example, Guangzhou and Shenzhen started the pilot construction of smart communities as early as in 2012 and 2013, respectively, and have realised some exemplary smart community projects and built a series of widely acclaimed smart community applications. However, there are still the following shortcomings:

- **Lack of unified comprehensive information platform for 'wisdom communities':** Characterised by their knowledge sharing and collective learning practices, these communities may prioritise the sharing of information, skills, and experiences among their members to promote mutual learning and growth. Currently, the construction of wisdom communities is decentralised, with different communities developing their own unique systems for sharing information. This has resulted in a lack of coordination and integration at the street, district, and city levels, with different systems collecting information of varying calibers and lacking integration. Consequently, there are significant barriers to effective resource integration and collaboration among different wisdom communities. It is important to address these challenges by developing a comprehensive and unified information platform to support the growth and development of wisdom communities.
- **Insufficient public participation:** This is a key challenge in the current implementation of smart community[15] projects. The primary driving forces behind such projects are government agencies, property companies, and technology companies, with limited involvement from research institutions and non-profit organisations. Furthermore, community residents are often relegated to passive roles, with limited opportunities for active participation in the process. As a result, residents' needs, opinions, and suggestions are not fully incorporated, leading to a weak sense of ownership and participation. To address this issue,

14 The institutional interface formed by the two SARs, Hong Kong and Macao, and the PRD refers to the mechanism or system established to facilitate communication, cooperation, and coordination among the different administrative bodies, institutions, and stakeholders in these regions. It aims to foster collaboration and synergies in various areas such as trade, finance, infrastructure, and social and economic development, while respecting the differences in governance structures, policies, and legal frameworks of each region. The institutional interface is crucial for promoting regional integration, stability, and sustainable growth in the GBA.

15 Smart community projects typically refer to initiatives that aim to use technology and data to improve the quality of life, sustainability, and efficiency of communities. These projects can include a range of interventions, such as the deployment of smart sensors for monitoring environmental conditions, the implementation of energy-efficient infrastructure, the development of digital platforms for community engagement, and the use of data analytics to inform decision-making. The goal of smart community projects is to create more liveable, connected, and sustainable communities that can adapt to the evolving needs of their residents.

it is important to promote greater public participation and engagement, and to actively involve community residents in the planning and implementation of such projects.

- **Experience summary and publicity is not enough.** The current approach of relying solely on experience summaries and publicity is inadequate. Specifically, there is a lack of tracking and experience summaries for typical pilot and best practice cases of smart communities in practice. This presents a challenge to promoting and replicating successful smart community initiatives across the GBA. In order to fully promote the development of smart communities, it is essential to establish a system for tracking and summarising successful pilot cases and best practices. This will allow for the effective dissemination and replication of successful initiatives throughout the region (Xiaojuan, et al., 2020).

Targets and Indicators

The construction mode of cooperation between the government and enterprises and other stakeholders needs to be optimised. The construction of smart cities in the GBA has seen beneficial exploration of public-private cooperation, with the formation of a collaborative framework between the government, enterprises, and other market forces. The construction of smart cities has seen significant involvement from companies in the technology industry, contributing towards the development of the cities.

- The current deficiencies can be summarised in two main aspects. The current cooperation model between the government and enterprises in constructing smart city projects is relatively unconventional, with most projects being funded through direct government investment or procurement of services. However, this approach has limited exploration into alternative business models that could lead to sustainable economic benefits, resulting in projects that heavily rely on subsequent government investment for maintenance and operation.
- Additionally, there is a lack of a special public participation platform and mechanism that would allow for the extensive involvement of various stakeholders such as city managers, the public, research institutions, and non-profit organisations in the planning, design, construction, and operation of smart city projects. This hinders the potential for these projects to be self-sufficient in terms of economic costs and limits the diversity of perspectives that can contribute to their development.

Key Roadmap Actions for Urban Planning

In order to meet the challenges, corresponding goals and measures need to be set in several areas: policy, technology, finance, and capacity building.

Recommended Policy Actions for Urban Planning

Table 6 Recommended policy actions for urban planning.

Policy Actions	Baseline (2022)	Short term (2030)	Long term (2060)
Establish differentiated policies	Develop a regional synergy mechanism	Build a market-driven emission reduction mechanism	Formation of a differentiated policy system[16]
Cooperation among different stakeholders	Identify the participants	Build communication platform	Implementation of an efficient communication mechanism
Territorial spatial planning	Strengthen the territorial and spatial planning system of the metropolitan GBA	Integrate urban and rural development through city and county-level territorial spatial planning	Formation of a multi-level territorial spatial planning system of 'provincial level – metropolitan area – city and county – township'
Local transportation plans	Development of local transportation plans for carbon-neutral development	All urban plans with low-carbon transportation principles	Efficient location planning and carbon neutral transportation in new and existing developments

Details on the policy targets for urban planning are outlined below:

- **Establish differentiated policies.** Develop local regulations in the field of addressing climate change, and jointly develop regional synergy mechanisms among cities to clarify the differentiated timing of carbon peaking and carbon neutrality in different cities. Regional central cities with higher urbanisation and economic levels should take more responsibility and take the lead in achieving carbon neutrality. This approach recognises that a one-size-fits-all policy may not be effective in addressing the unique challenges faced by each city. By developing local regulations and regional synergy mechanisms, cities can work together to clarify the differentiated timing of carbon peaking and carbon neutrality in different areas.

  Further, improve the method of accounting for the value of ecological resources, promote the formation of a cross-regional carbon compensation mechanism[17], improve the carbon emission trading[18] mechanism, give full play to

16 A differentiated policy system is a framework in which different policies are designed and implemented to address the needs and challenges of different groups or regions within a larger society or economy. This approach recognises that there are diverse needs and circumstances across different populations.

17 Carbon compensation, also known as carbon offsetting, involves compensating for carbon emissions by investing in projects that reduce or absorb carbon dioxide elsewhere. This can include projects like reforestation, renewable energy, or energy efficiency initiatives. The idea is that the reduction of carbon emissions in one place can offset the emissions in another place, creating a net-zero carbon footprint.

18 Carbon emission trading involves the buying and selling of carbon credits, which represent a certain amount of carbon emissions that a company or organisation is allowed to emit. Companies that emit less than their allocated limit can sell their surplus credits to other companies that emit more than their allocated limit. This creates a market for carbon emissions, where the cost of emitting carbon is reflected in the price of the credits.

the platform function of national and local carbon emission right exchanges[19], and build a market-driven emission reduction mechanism. This approach recognises that carbon emissions are not the only factor contributing to climate change, and that preserving natural ecosystems is an important component of mitigating climate change. By accounting for the value of ecological resources, a cross-regional carbon compensation mechanism can be established to allow regions or cities with lower emissions to sell carbon credits to those with higher emissions.

By building a pilot zone for green financial reform and innovation, it is possible to establish a mechanism for cooperation work on green finance on a regional scale. While carbon emission trading systems do rely on market-based mechanisms, they do not typically involve broader financial reforms or innovations. The proposed pilot zone could help to establish a mechanism for cooperation work on green finance on a regional scale, which could be a key driver of emissions reductions in the long term. By accounting for the value of ecological resources, a cross-regional carbon compensation mechanism can be established to allow regions or cities with lower emissions to sell carbon credits to those with higher emissions.

- **Cooperation among different stakeholders.** Local implementation of urban carbon neutral projects often lags behind in time, and management costs tend to increase. In most cases, this occurs mainly due to specific technical, planning and administrative requirements, while planning departments, craft enterprises or management units mostly lack the necessary specific expertise. In order to coordinate and facilitate the cooperation between town participants, a network exchange platform can be set up to encourage towns to do experience exchange. Ensure cooperation between national, sub-national and municipal levels, as well as between sectors including transport, spatial planning, energy supply, social housing and housing.
- **Territorial spatial planning.** The national land needs to have an optimised spatial development pattern that involves strict control of construction land expansion and the reduction of high-intensity carbon sources such as industrial and mining land. Instead, the focus should be on increasing the area of carbon sinks such as woodlands and wetlands. To achieve this, urban spatial control needs to be strengthened with a compact and efficient layout of urban development that promotes the mixing of different land uses. By doing so, it is possible to reduce carbon emissions and control the total amount of emissions from different land uses.
- **Local transportation plans.** Local transport plans play a central role in shaping and promoting short-haul passenger road transport. Short-distance passenger road transport and short-distance passenger rail transport authorities can also define specific climate policy goals and emission reduction pathways and incorporate their monitoring into transport contracts. Green hydrogen should be considered as an emission-free fuel for both local short-distance public passenger transport and short-distance passenger rail transport. In setting cli-

19 Carbon emission exchanges are platforms where carbon credits can be traded, bought, and sold. These exchanges provide a marketplace where companies can buy and sell carbon credits to comply with regulations or voluntarily offset their carbon emissions.

mate policy goals, leeway should be reserved for short-distance public passenger transport companies, taking into account special local circumstances. Considering climate and environmental protection, local transportation plans and neighbourhood plans can be considered as part of the local government's regulatory tools to promote short-distance passenger highway transportation. The future goal should be to coordinate and develop integrated local transport plans between neighbouring municipalities. The national and state governments must also create the basis and initiate projects for this purpose.

Recommended Technology Actions for Urban Planning

Table 7 Recommended technology actions for urban planning.

	Baseline (2022)	Short term (2030)	Long term (2060)
Integrated town planning	Start the preparation of integrated town planning	Completion of the integrated town planning	Continuous improvement of integrated town planning
Regulatory detailed planning	Study the feasibility of including energy conservation and emission reduction in the regulatory detailed plan	Inclusion of energy saving and emission reduction in the formal regulatory detailed plan	Gradually increase the proportion of energy-saving and emission reduction regulations in the regulatory detailed plan
Smart city solution	Develop action plans and project lists for smart city development	Implementation and monitoring of action measures for smart city development	Establishment of urban low carbon planning and design simulation model and decision support system
Infrastructure optimisation	Develop an infrastructure optimisation programme, including urban renewable energy planning	Implement infrastructure optimisation programmes, including urban renewable energy planning	Regular assessment of infrastructure, optimisation and monitoring
Local cooling strategies	Initiating local cooling strategy planning	Completion and implementation of local cooling strategy planning	Regular optimisation of local cooling strategy planning
Low carbon parks and communities	Start carbon neutral park pilot project	Promotion from demonstration projects to region-wide implementation projects	Zero carbon park as a standard for park construction
Short-distance public passenger transportation	Develop short-distance public passenger transportation programmes	Implementation of short-distance public passenger transportation programmes	Optimisation of short-distance public passenger transportation programmes
Water treatment	Develop a water treatment strategy that meets the requirements of carbon neutral development	Develop sponge city programmes for all regions	Carbon reduction in water treatment through programme implementation
Waste treatment	Develop a waste treatment strategy that meets the requirements of carbon neutral development	Develop waste treatment programmes for all regions	All building materials are recycled

The recommended technology actions for urban planning are outlined below:

- **Integrated town planning.** The goal of the town energy master plan is to establish a climate-neutral, demand-driven regional energy supply system. This will facilitate the overall implementation of expansion and renovation projects, optimise the operation of gas and heat networks, exploit the full climate-neutral energy potential, and improve supply and demand. To this end, the urban planning process needs to implement an integrated energy master plan as an important planning component unit. This is already being practiced in the work of cities and towns, but the work still needs to be broadened and deepened. Policies should create appropriate and reasonable incentives.
- **Regulatory detailed planning.** At the detailed planning level, the focus is on community planning, which means analysing the different factors that influence residents' travel patterns and lifestyles, as well as building layout and the use of new technologies. This level of planning aims to promote energy conservation and reduce carbon emissions by incorporating low-carbon concepts into the urban planning system. To achieve this goal, it is essential to abandon the old planning model and incorporate new strategies into the detailed urban control planning. This means that energy conservation and emission reduction should be taken into account when designing and regulating urban spaces. In this way, the goal of carbon reduction is integrated into all aspects of the planning process, from land use to transportation, and from building design to energy usage. By incorporating these concepts into detailed planning processes, urban planners can help reduce carbon emissions and promote environmentally friendly practices.
- **Smart city solution.** In the process of implementing smart cities, action plans and project lists for smart cities should be formulated in conjunction with the actual problems and development demands of each field, and the corresponding plans should be decomposed into specific issues and problems with clear objectives, thus forming action plans and project lists for smart cities in each city and department, so that the relevant deployments can be effectively implemented. By building a carbon emission wisdom monitoring and evaluation platform and establishing a simulation model and decision support system for low-carbon urban planning and design, it will help transform urban management into urban governance.
- **Infrastructure optimisation.** The infrastructure for electricity, heat, transportation and communication systems is densely packed in the urban space, which is a characteristic of towns and cities. In small communities, residential areas or buildings that are closely connected to consumers, more and more integrated devices involved in energy system capacity, storage or conversion will be born in the future. The key to achieving the overall goal of CO_2 emission reduction in an overall system that is as cost efficient as possible lies in the full optimisation of technical equipment and infrastructure.
- **Local cooling strategies.** In terms of climate protection goals, the interests and decisions of individual building owners can be at odds with district cooling programmes. Due to the lack of coordinated strategies, a large potential of carbon neutral energy sources is not exploited. Refrigeration planning can be supplemented with a unified planning tool to create the 'right framework' for climate-friendly cooling solutions.

- **Low carbon parks and communities.** Systems approaches such as community programmes are critical to a successful urban energy transition. Therefore, community programmes should be encouraged within and beyond central heating districts. The use of cross-sectoral, integrated power, heat and transport solutions and smart co-production of various energy sources with other urban infrastructure (e.g. water, wastewater and waste treatment) can transform renewable energy and climate-neutral local thermal energy potential into cost-effective, customer-friendly heating systems. In the long term, emission requirements should therefore be imposed not only for individual consumption units (e.g. single buildings), but also for cross-system and integrated supply solutions, with a focus on reducing greenhouse gas emissions. At the same time, however, it is important to ensure that the energy demand of individual buildings and the resulting energy costs are limited. In addition to clearing community-specific implementation barriers (e.g., customer facilities), it is important to increase participants' understanding of integrated community programmes.
- **Short-distance public passenger transportation.** In order to reduce traffic volumes in urban areas, the reallocation of public road space in sustainable transportation systems should favour bus-only lanes to improve the efficiency and attractiveness of short-distance public passenger transportation relative to individual motorised transportation. In addition, bicycle lanes and sidewalks should also be considered as part of the reallocation. Local governments should also have room to manoeuvre, for example by taking climate friendliness into account when planning costs (motor vehicle licenses, parking spaces). To ensure low emissions from transport, we should also expand rail and electrified public transport services (light rail, metro, tram, regional transport). This also includes increasing the electrification of sections within or through urban areas or converting vehicles to electric drive.
- **Reallocation of public space for sustainable transport modes.** In order to provide innovative, sustainable and low-emission solutions for the transport of goods and cargo, a partial reallocation of public road space is needed. For example, there are special use issues in the road code for distribution areas on public streets and for schemes such as micro-warehouses or parcel stations. In addition, issues related to the 'urban-suburban' theme must also be considered. Therefore, commuter traffic should also be taken into account, such as the planning of interchange points in the reallocation of public road space. Depending on state road laws and administrative practices, guidelines may only need to be issued regarding the acceptability of such programmes within the government. However, the granting of permits for certain distribution areas may also involve bidding and procurement regulations.
- **Digitisation of traffic control and enhancement of low-carbon transportation.** Digital technologies should be used to intelligently manage traffic and reduce traffic emissions. For example, digital tools can reduce the distance to find a parking space and optimise the distance of intermodal and delivery traffic.
- **Water treatment.** Water use and conservation play an important role in energy restructuring, carbon reduction, and the enhancement of natural carbon sinks. For example, multi-stage water recycling and reuse is an important way to reduce carbon emissions from water supply and drainage. The model of urban

residential and production unit sewage, which is collected through sewage network and transported long distances to sewage treatment plants for centralised treatment has high carbon emission intensity. The use of innovative models, such as decentralised containerised reclaimed water processor, not only can realise the 'micro-circulation' of water, but also more energy-saving, land-saving and investment-saving. In rainwater treatment, a 'sponge city' with rainwater collection and utilisation, rainwater infiltration to groundwater, can absorb rainwater, collect small rainfall utilise it instead of casually letting it drain. Different levels of sponge cities have different carbon reduction capacity, and the reduced carbon can be traded in the carbon trading market.

- **Waste treatment.** The GBA is facing significant challenges in solid waste treatment and environmental sustainability due to its rapid urbanisation and industrialisation. Achieving collaborative environmental management and green development in the region requires effective waste recycling measures. In the construction sector, materials such as steel and cement reinforcement are unilaterally consumed, which results in significant energy consumption. However, building with materials such as weathering steel or stainless steel can achieve 100% recycling, reducing energy consumption and helping the steel industry to reduce carbon emissions. By promoting the recycling of all building materials, we can establish a system of internal recycling for both energy and materials supply.

Recommended Finance Actions for Urban Planning

The recommended key actions are as follows:

- **Adopt a new incentive approach.** Incentives (e.g., increased subsidies, increased depreciation, introduction of tax subsidies, and controls through CO_2 pricing if necessary) should be enhanced to accelerate building energy efficiency retrofits. In addition, the implementation of the overall redevelopment strategy (various building energy efficiency retrofit roadmaps) should be strengthened and targeted methods and tools such as series of energy efficiency retrofits should be promoted with a view to achieving carbon neutrality by 2060.
- **Urban Development Fund.** The Urban Development Fund is a pooled investment method that shares benefits and risks by raising funds for urbanisation infrastructure development and providing management services to them. Its investment is directed to local infrastructure construction projects, usually of public interest, such as municipal construction, public roads, public health, and guaranteed housing projects. Repayment is made through fiscal funds, and the repayment mode is mainly debt, and eventually the local government financing platform provides repurchase.
- **Public-Private Partnership (PPP) mode.** A PPP fund is a model of cooperative relationship between government and social capital for providing public goods. PPP is regarded as an important means to resolve the risk of local government debt and reduce financial pressure.
- **Urban Development Fund.** Green Fund is a special investment fund established only for energy-saving and emission reduction strategies, low-carbon economic development and environmental optimisation and renovation projects,

which aims to promote the development of energy-saving and emission reduction through capital investment. Green Fund is an important part of the green financial system. Green Fund can be used for haze control, water environment control, soil control, pollution prevention and control, clean energy, greening and sand control, resource efficiency and recycling, green transportation, green building, ecological protection and climate adaptation, etc.

Recommended Capacity Building Actions for Urban Planning

The recommended key actions are as follows:

- **Public participation.** The active participation of citizens is essential to the success of a project. Involving citizens actively in joint planning and giving them the opportunity to participate in decision making contributes to both transparency and acceptance of the project, and reduces complaints and litigation later in the planning and validation process. Involving citizens directly or indirectly, especially financially, in the project also contributes to social acceptance of the project. Shared use, special use clauses and equity participation are suitable measures for sharing.
- **Improving links between participants and building local networking platforms.** To ensure the successful implementation of the energy transition in towns and cities, all participants must work together in good faith, communicate with each other, and jointly develop new strategies for action. In order to coordinate the cooperation between participants in a targeted manner, it is necessary to first 'bring them to the same table'. To this end, the existing cooperation networks of the local participants should be strengthened, while at the same time promoting and developing the creation of new consortia and ensuring communication between the local government and the administration, local government companies and private enterprises, and citizens. Some specific programmes (also) focus in particular on the relationship between cities and suburbs.
- **Training within government.** Provide training in integrating sustainable urban planning strategies for all relevant departments and levels of government, including those responsible for spatial planning, zoning regulations, and procurement and management of services such as waste and water management. Build capacity to collect and use data to inform policy and urban planning. Finally, training on how to collaborate across stakeholder groups, including governmental and non-governmental actors.
- **Professional training staff.** Build the capacity and awareness of service providers, including urban planners and designers, as well as technical providers, on the broader Sustainability Development Goals (SDG) framework and the implications for urban planning solutions. This is important to ensure coordination and common goals among relevant governmental and non-governmental organisations for better implementation and enforcement of urban planning policies.

Summary: Urban Planning

As a region with a high level of urbanisation, the future development of the GBA should focus on improving the quality of urbanisation as well as optimising the structure of urbanisation. At the policy level, a differentiated policy system and regional synergy mechanism should first be constructed according to the characteristics of different regions within the GBA, so as to guarantee integrated green urban and rural development. At the technical level, urban planning tools, such as integrated urban and energy planning, should be flexibly applied to gradually increase the consideration of energy conservation and emission reduction in the field of urban planning. Within the city, low-carbon development should be actively promoted at different levels, such as urban areas, parks and communities. Meanwhile, as an innovative industrial centre, the GBA has great potential for development in smart city construction, which can help cities better achieve the goal of energy saving and emission reduction by building a carbon emission smart monitoring and assessment platform and a simulation model and decision support system for low-carbon urban planning and design. The flexible use of green finance tools can guarantee the smooth implementation of various low-carbon measures, especially Hong Kong, as an important Asian financial city, can play a more important role in the field of green finance. Finally, it should not be overlooked that carbon neutral development requires the joint efforts of different groups in the social and economic fields, so building platforms and mechanisms for public participation and professional training for practitioners are important development measures.

Activity Area 2

New Buildings

Status Quo and Baseline

China has put forward the construction goals of the GBA for 2022 and 2035: By 2022, the comprehensive strength of the GBA should be significantly enhanced, and by 2035, the GBA should form an economic system and development model with innovation as the main support (The State Council, PRC, 2019). The layout and construction of new infrastructure in GBA are accelerating, and the investment is gaining momentum. According to data released by the Guangdong Provincial bureau of statistics, real estate investment in Guangdong province can be stabilised with the implementation of the new tax reduction policy in 2022.

The local government of the GBA has advanced its policy planning and incentive measures in terms of green buildings and low-carbon buildings, which has in turn promoted the green low-carbon transformation of the region. During the 13th Five Year Plan (2016–2020) period, the total area of green buildings in Guangdong province exceeded 500 million m^2, and the proportion of green buildings completed in new civil buildings had reached 63% by 2020. Enhancing the utilisation of renewable energy in the building is an effective measure to promote low-carbon buildings. Macao released the Macao Environmental Protection Plan (2021–2025), which stipulated actively promoting green buildings, encouraging the application of renewable energy products or equipment (such as solar Photovoltaic (PV)) in buildings, and reducing traditional energy consumption (Macao Environmental Protection Agency, 2022). In the same year, Hong Kong released the Hong Kong Clean Air Blueprint 2035 to build a smart city and reduce urban carbon emissions.

At present, the GBA has carried out a number of low-carbon building pilot projects. Guangdong is the first province in China to carry out a nearly zero carbon emission demonstration project (covering towns, buildings, transportation, urban and rural communities, parks, and enterprises). In 2021, Guangdong province launched the construction of the first batch of 30–60 Goals pilot demonstration projects in Qianhai, Shenzhen, Hengqin and Zhuhai. Several nearly zero and zero-carbon parks have also been established in Shenzhen and Guangzhou. The scale of the park has since been further expanded and it has made a positive impact on the development of low-carbon buildings.

Building Code

Building standards are an important measure to promote the green and low-carbon transformation of building industries. The development of standards in the GBA region is consistent with that in China. Among them, nine cities in the PRD will take the lead in implementing energy efficiency standards for buildings that are higher than the current standards of Guangdong province. With the continuous improvement of building energy efficiency standards, all new buildings will be developed towards lower energy consumption. At present, China has accomplished its three-step '30%–50%–65%' plan for building energy efficiency proposed in the early 1980s.

China's building energy efficiency standards started by focusing on residential buildings in the northern area. China's first building energy efficiency design standard 'Energy conservation design standard for new heating residential buildings'

(JGJ26-1986) has been implemented since 1986, the goal of the standard was a 30% decrease in residential heating energy consumption compared to the baseline buildings built in the early 1980s. The revised version (JGJ26-1995) aimed to achieve a further reduction of 50% from the baseline buildings built in the 1980s. With the comprehensive revision of building energy efficiency standards, JGJ26 debuted in 2010, renamed as 'Design standard for energy efficiency of residential buildings in severe cold and cold zones' (JGJ26-2010), targeting an energy reduction of 30% on the basis of JGJ26-1995, representing a 65% reduction from the baseline buildings built in the 1980s. And in 2012, the 'Design standard for energy efficiency of residential buildings in hot summer and warm winter zone' (JGJ75-2012) was published for the energy efficiency design of new, expanded and rebuilt residential buildings in the hot summer and warm winter climate zone (including the GBA).

Similarly, the 'Design standard for energy efficiency of public buildings' (GB 50189-2005) was issued and implemented as the first energy efficiency design standard for public buildings in China. In 2014, GB50189-2014 was issued with the goal of further reducing building energy consumption by 30% based on the 2005 version.

With the continuous improvement of the requirements for building energy efficiency, on April 1, 2022, the 'General code for energy efficiency and renewable energy application in buildings' (GB 55015-2021) was officially implemented as a full-text compulsory code. Moreover, buildings are gradually transitioning to ultra-low energy buildings, Nearly Zero Energy Buildings (NZEBs), zero energy buildings, and zero carbon buildings. In 2019, China's first 'Technical standard for nearly zero energy buildings' (GB/T 51350-2019) was officially implemented, which provides a comprehensive plan for NZEBs from the whole process of technical indicators, architectural design, construction, and operation management. In 2019, the implementation of the 'Standard for building carbon emission calculation' (GB/T 51366-2019) provided a calculation method for the carbon emissions of buildings throughout their life cycle. Today, the national standard 'Technical Standard for Zero Carbon Building' is in preparation. The standard decomposes and implements the carbon reduction target in the construction sector, which is an important measure and key technical support to achieve carbon peaking and carbon neutrality.

The concept of green building was introduced in China in the 1990s, and slowly developed. In 2006, China released the 'Evaluation standard for green building' (GB 50378-2006), which was the main standard of China's green building evaluation system and was revised in 2019 (GB/T 50378-2019). Since then, green evaluation standards for different types of public buildings have been established, and have been extended from civil buildings to industrial buildings, forming a standard system with GB/T 50378 as the core. The latest data from the MOHURD of China shows that by the first half of 2022, the area of new green buildings in China has accounted for more than 90% of all new buildings.

In Hong Kong, the 'Buildings (Energy Efficiency) Regulations', the Buildings Energy Efficiency Ordinance (BEEO), and the 'Energy efficiency (Labelling of Product) Ordinance' are mandatory standards for the building industry. For new buildings, the purpose of the ordinance is to determine the basic energy efficiency requirements. Currently, Macao lacks unified standards or regulations for building energy

efficiency. The existing 'Technical guidelines for building energy consumption optimisation in Macao' and 'Green building evaluation standards (Macao Version)' do not have relevant enforcement regulations.

In summary, the building energy efficiency standards and green building standards for new buildings in Guangdong province and Hong Kong are strictly enforced, and low carbon building standards are being developed. However, there are still gaps in the formulation and implementation of building energy efficiency standards in Macao. In general, the new building energy code in the GBA is still in the development stage, which requires further development of the standard system.

Building Certification

Building certification can standardise the building market, improve the market recognition of certified buildings, and strengthen the publicity and guidance of green and low-carbon transformation of buildings. Building certification is an important way to promote low-carbon and green development of the building industry, and the existing building certification system in China is also available in all areas of the GBA. China's building certification system involves the design, construction, and operation stages, common certification types can be classified into low-carbon buildings[20], ultra-low/nearly zero/zero energy buildings, green buildings, healthy buildings[21], etc.

The green building certification refers to the evaluation activities according to the 'Assessment standard for green building' (GB/T 50378-2019), which was developed on the merits of other main building certification systems, such as LEED (Leadership Energy & Environmental Design building rating system) in the United States. The main assessment indicator is categorised into safety and durability, health and comfort, convenient life, resource conservation, and liveable environment. Green buildings are certified into four levels: basic, one-star, two-star and three-star. Furthermore, the NZEB certification represents the building energy efficiency certification system at this stage. Buildings that meet the requirements will be provided with NZEB labels and certificates. Construction companies (including owners) or real estate development companies can apply to evaluation agencies for relevant building labels and certificates.

In addition, Hong Kong also has its own green building certification system. Since 2020, the Hong Kong Green Organisation Certification has proposed a certification system for energy efficiency certificates which includes 'Waste reduction certificate', 'Energy conservation certificate', 'Fresh indoor air certificate', 'Product environmental protection practice certificate' and 'Carbon reduction certificate'. According to the contribution of the enterprise/organisation, the certificate is divided into three levels: basic, good, and excellent. The Hong Kong government

20 The use of building energy-saving measures and renewable energy resources enables the use of renewable energy to reduce building carbon dioxide emissions.

21 On the basis of satisfying building functions, healthy buildings provide healthier environments, facilities and services, and promote the physical and mental health of users.

encourages enterprises and organisations to implement environmental protection measures in different areas and commends their contribution and commitment to environmental protection.

The development of building evaluation standards in Macao is lagging behind in comparison. The current green building certification standards in Macao are the 'Assessment standard for green building (Macao Version)' formulated by the China Green Building and Energy Conservation (Macao) Association.

The building certification system of the GBA is comprehensive and continuously updated and developed. This provides a guarantee for encouraging and promoting the low-carbon development of new buildings.

Trends and Challenges

There are still some problems in the green and low-carbon transformation of the construction industry in the GBA. According to the report issued by Deloitte, the top-level design of the ecological and environmental governance in the GBA has not been formed, and the carbon emission control system and target system for new buildings and the mechanism of the collaborative governance (including Guangdong province, Hong Kong, and Macao) still need to be improved (Deloitte, 2021). Meanwhile, the application of new energy technologies (PV technology, DC building technology[22], etc.) in buildings is still in the exploratory stage. In addition, the incentive policy is fragmentary, and the support methods such as floor area ratio incentive, green finance, and green insurance are under development. Furthermore, due to the lack of a market environment driven by building owners and tenants in the GBA, the low-carbon transition of building and construction in this area remains challenging.

In general, the government is constantly improving policies and incentives to promote the green and low-carbon transformation of new buildings in the GBA. With the application of renewable energy, the progress of new building technology, and the continuous improvement of the standard system, the new buildings in the GBA are to achieve zero carbon operation by 2060.

Targets and Indicators

According to the 14th Five Year Plan for Building Energy Efficiency and Green Building Development in Guangdong Province (BHURC of Guangdong province, 2022), the main indicators for 2025 of new buildings are as follows:

22 DC building technology: In a narrow sense, it refers to the buildings with low-voltage DC distribution system. In a broad sense, its important characteristics are 'photovoltaic, energy storage, DC, flexible electricity' and the collaborative application of the four in buildings.

Table 8 Main Indicators for New Buildings

Main indicators	2025
Energy efficiency of new residential buildings in cities and towns (across province)	Improve by 30%
(Compared with the level in 2020)	This activity covers all aspects of new buildings, including the design process, design strategies, codes and labels.
Energy efficiency of new public buildings in cities and towns (across province)	Improve by 20%
(Compared with the level in 2020)	This activity covers all aspects of the operations and management of buildings.
Proportion of one-star and above green new buildings in cities and towns (nine cities in PRD, GBA)	Improve by 45%
Proportion of prefabricated buildings in urban new buildings (nine cities in PRD, GBA)	Improve by 35%
Proportion of prefabricated buildings in urban new government investment buildings (nine cities in PRD, GBA)	Improve by 70%
Replacement rate of renewable energy in urban buildings (across province)	Improve by 8%
Proportion of electricity consumption in building energy consumption (across province)	Improve by 80%

Key Roadmap Actions for New Buildings

Table 9 Key Roadmap Actions for New Buildings

Action	Baseline (2022)	Short term (2030)	Long term (2060)
New building Construction	Newly increased energy efficiency building area reached 950 million m^2 during 2016–2020 Total area of newly built prefabricated buildings exceeded 108 million m^2	Lingnan's characteristic ultra-low energy and NZEBs expected to reach 3.7 million m^2 between 2021 and 2030 Implement higher mandatory energy efficiency standards for new buildings	New urban buildings expected to achieve zero carbon operation by 2060
Building standards	Building energy efficiency standards and evaluation standards are comprehensive at this stage Energy efficiency standards have been developed in different regions	Building energy efficiency standard system will be gradually enriched Nine cities in the PRD will take the lead in implementing higher building energy efficiency standards	Complete the standard system of building energy efficiency and building certification to support new building zero carbon operation
Building investments	Strengthen the territorial and spatial planning system of the metropolitan GBA	Integrate urban and rural development through city and county-level territorial spatial planning	Formation of a multi-level territorial spatial planning system of 'provincial level – metropolitan area – city and county – township'

Details on the key actions for new buildings are outlined below:

- **New building construction.** During the 13th Five Year Plan period (2016–2020), building energy efficiency in Guangdong province has been steadily improved, with the newly increased energy efficiency building area reaching 950 million m^2. In this period, the quantity and quality of low carbon buildings have been improved, and the quality certification and labelling of green buildings have been carried out. Meanwhile, the total area of newly built prefabricated buildings has exceeded 108 million m^2 (BHURC of Guangdong province, 2022). By 2025, Guangdong province will comprehensively promote urban green building construction. The proportion of urban green buildings in Guangzhou, Shenzhen and other cities accounted for 100% of the new buildings. Hong Kong proposes to reduce the electricity consumption of commercial buildings by 15% to 20% and residential buildings by 10% to 15% based on 2015 before 2035. Furthermore, Hong Kong will strive to achieve carbon neutrality by 2050 (Hong Kong Environment Agency, 2021). In the 'Master City Plan of Macao SAR (2020–2040)', Macao proposed the rational planning of public infrastructure to create circular synergies and building low carbon communities to promote green living (Macao SAR Government, 2022).

  From 2021 to 2025, Lingnan's characteristic[23] ultra-low energy and NZEBs in Guangdong province will reach 3 million m^2 and are expected to reach

23 Ultra-low energy buildings adapted to climate characteristics and natural local conditions.

3.7 million m^2 between 2021 and 2030. According to the city level ultra-low energy and NZEB construction plan, Zhuhai will build 200,000 m^2 between 2021 and 2025.

Prefabricated building as a building type of large-scale construction in the GBA, the proportion of prefabricated buildings in new urban buildings in nine cities of the PRD is expected to reach 35% during 2025.

In 2060, new urban buildings are expected to achieve zero carbon operation, with a sound policy system and technical support for building energy efficiency.

- **Building standards.** A complete building energy efficiency and evaluation standard system is the core of building low-carbon development. According to the above introduction to the standard system of the GBA, building energy efficiency standards and evaluation standards are relatively comprehensive at this stage. Meanwhile, energy efficiency standards have also been developed in different regions according to local building and environmental characteristics. By 2030, the building energy efficiency standard system will be gradually enriched, and the energy efficiency of mandatory energy efficiency standards for new buildings will be further raised. Furthermore, nine cities in the PRD will take the lead in implementing building energy efficiency standards higher than the current standards of Guangdong province. By 2060, the standard system of building energy efficiency and building certification will be completed to support new building zero carbon operation.
- **Building investments.** At this stage, financial means such as the carbon trading market have promoted the construction of low-carbon buildings. The government encourages financial institutions to improve green building investment and financing mechanisms, and innovate green financial products and services under the premise of controllable risks, sustainable business, and compliance with relevant policies. In the future, the government will strengthen investment in public welfare buildings and enhance the application of renewable energy. It is also necessary to increase credit support for green buildings and promote the coordinated development of green buildings and green finance next decades.

Recommended Policy Actions for New Buildings

Table 10 Recommended Policy Actions for New Buildings

Key Actions	Baseline (2022)	Short term (2030)	Long term (2060)
Building energy efficiency standard	Newly increased energy efficiency building area reached 950 million m^2 during 2016–2020 Total area of newly built prefabricated buildings exceeded 108 million m^2	Energy efficiency and low carbon emission building standards are used in all new buildings The provincial and municipal energy efficiency and low carbon emission building standard system is significantly improved	
Building labelling	The certification of green buildings and NZEBs is comprehensive, and the low carbon and zero carbon certification is in the initial stage	Higher levels of green building certification, low carbon and zero carbon building certification, and the building area of ultra-low energy building certification are used	The building certification system is widely used Zero-carbon building certification is widely used Majority of buildings have higher certification levels
Labelling of building materials	The transformation from green building materials evaluation to graded certification is in effect	Complete green building materials grading certification system and unified supervision mechanism	Green building materials certification is widely used
Incentives	The government provides financial support, plot ratio incentives, tax incentives, provident fund loan incentives and other incentives Promotion of green finance development has started	Increased use of financial and non-financial incentives to reward high-performance building	

Details on the policy action for new buildings are outlined below:

- **Building energy efficiency standard:** Building energy efficiency standards are the necessary support for low carbon emission of buildings. At this stage, the energy saving rate required by municipal and provincial energy efficiency standards in some areas of the GBA has exceeded the national standard. At the national level, the 'General code for energy efficiency and renewable energy application in buildings' is mandatory for all buildings, the 'Technical standard for nearly zero energy buildings' guides buildings to gradually achieve nearly zero energy consumption, and the 'Technical standards for zero energy buildings' are being prepared. In Hong Kong, the 'Buildings (Energy Efficiency) Regulations' and BEEO are mandatory standards for the building industry. Meanwhile, the development of building energy efficiency standards in Macao is lagging behind and is expected to catch up with the development process of national standards in the future.
- **Building labelling:** At this stage, the certification of green buildings and NZEBs is comprehensive. In the national standard of 'Evaluation standard for green building', a green building evaluation technical index system is constructed, and the green building grades are divided. Hong Kong mainly implements the

'Hong Kong Building Environment Assessment Method', which aims to assess the new and used office and residential buildings. The current green building certification standards in Macao are the 'Assessment standard for green building (Macao Version)' formulated by the China Green Building and Energy Conservation (Macao) Association. In the future, Guangdong province will promote the development of star-rated green buildings, and incorporate the green building grade and green performance of residential buildings into commercial housing sales contracts, residential quality certificates and residential use instructions (BHURC of Guangdong Province, 2021).

- **Labelling of building materials:** The certification of green building materials has completed the transformation from green building materials evaluation to graded certification at this stage. In 2020, Guangdong province released the 'Implementation plan for Guangdong Province green building materials product certification, promotion and application' to promote the improvement of the grading certification system of green building materials. Hong Kong legislation also requires building products to have energy labels. In the future, it will further improve the certification of green building materials, and the government will establish and improve the credit mechanism for green building materials. Green building materials will be required to be used in green buildings, prefabricated buildings and other projects invested by the government, so as to increase the proportion of green building materials used in new urban buildings.
- **Incentives:** At the current stage, the government has formulated a series of incentive measures, including financial support, floor area ratio incentives, tax incentives, provident fund loans, etc. Furthermore, the government should provide special funds and increase the loan limit for new low-carbon buildings. At the same time, the government should encourage green finance pilot projects and provide green financial services for new buildings through green credit, green insurance, green bonds, etc.

Regional Examples

On January 1, 2021, Guangdong province implemented its 'Green Building Regulations', marking a significant step towards promoting high-quality development and improving human settlements. These regulations are the first of their kind in the region, establishing legal standards and guidelines for constructing environmentally friendly buildings.

To ensure compliance with these standards, new buildings must adhere to a comprehensive green building standard system. This includes establishing guidelines for planning, design, review, construction, supervision, detection, acceptance and operation, involving multiple departmental responsibilities.

Municipal and provincial governments can implement even higher standards, based on local conditions. By bringing the development of green buildings into the track of legalisation, and defining the responsibilities of various departments according to law, in which each entity can work together to promote the development of green buildings, leading to a better and more sustainable future.

Recommended Technology Actions for New Buildings

Table 11 Recommended Technology Actions for New Buildings

Key Actions	Baseline (2022)	Short term (2030)	Long term (2060)
Building envelope	Comply with the mandatory building energy efficiency standards, and the heat transfer coefficient (K=[W/(m^2 x K]) of the external wall is less than 1.5	More application of new exterior enclosure materials	Popularisation of high-performance building envelopes
Building shading system	External shading system is widely used in high-performance buildings	A variety of external sunshade systems are applied	Building shading system is widely used, with diversified forms of external shading
Windows	Comply with the mandatory building energy efficiency standards, K value and window Solar Heat Gain Coefficient (SHGC) value are specified according to window to wall area ratio	The performance of windows is improved (no thermal bridge, air tightness, sound insulation of external windows, etc.), and diversified window forms (wooden windows, aluminium alloy windows, etc.) are applied	
Lighting	LED fixtures are widely used, reducing lighting power density substantially	LED fixtures with higher efficacy and intelligent lighting control technology are adopted	Power over Ethernet (PoE) and Direct Current (DC) lighting technology are more widely used
Design tools	Limited use of building performance design tools in the design process of new buildings	Building performance design tools are widely used in the whole process of building design and integrate more application functions (carbon emission calculation, etc.)	More convenient and efficient design tools are widely used
Digital technologies	Pilot application of digital technologies such as Building Information Modelling (BIM) and City Integrated Modelling (CIM)	Large-scale development of intelligent buildings by using digital technologies	
Prefabricated technologies	Large-scale construction of prefabricated buildings	New industrial buildings represented by prefabricated buildings are developed rapidly, and the standardisation level and construction quality of prefabricated buildings is further improved.	
Renewable energy	The scale of renewable energy applications is expanded	The installation rate of solar PV in buildings is significantly improved, and the application forms of PV are diversified The forms of renewable energy are diversified and the technology is gradually maturing	
DC technology	Demonstration application of DC lighting and DC household appliances	DC technology continues to improve Diversified DC equipment and products The new building power system characterised by solar Photovoltaic, Energy storage, Direct current and Flexibility (PEDF) is widely used.	

Details on the technology action for new buildings are outlined below:

- **Building envelope:** Buildings in the GBA are exposed to a lot of solar radiation. The temperature is generally high throughout the year, and the energy consumption of air conditioners is high. The adoption of a scientific and reasonable envelope is conducive to optimising the thermal performance of the envelope, thereby improving the thermal insulation performance of the envelope and meeting energy efficiency standards. For example, Hong Kong is continuing to analyse the heat transfer coefficient of building envelopes, and the government plans to improve the statutory standards by 2025.
- **Building shading system:** Building shading technology is an integral part of building thermal protection technology. Shading technology is essential in preventing the environmental overheating of civil buildings in southern China, reducing the energy consumption of air conditioners, and enriching the building facade's artistic effect. At present, the external shading system is the most widely used building sunshade in the GBA area.
- **Windows:** The GBA is located in an area with hot summers and warm winters, and the thermal performance requirements of external windows are relatively high. The current 'General code for energy efficiency and renewable energy application in buildings' and 'Technical standard for nearly zero energy buildings' has made specific requirements for the energy-efficiency performance of windows. For NZEBs, SHGC≤0.15; for≤2.5W/(m^2·K) residential buildings, it is K≤2.5W/(m^2·K); ≤2.8W/(m^2·K) for public buildings it is K≤2.8W/(m^2·K).
- **Lighting:** The design concept of daylighting and the use of energy-saving lighting fixtures are effective ways to reduce building energy consumption, and the use of intelligent lighting and DC lighting systems will be further popularised in the future to improve building illumination energy efficiency and people's demand for lighting comfort.
- **Design tools:** Different from traditional architectural design tools, new design software and tools not only enable various stakeholders to work together but also greatly improve work efficiency. For new buildings, new design software and tools can save project costs and help engineers assist in building energy efficiency design.
- **Digital technologies:** The application of BIM and CIM will promote the development of smart cities, which will help new building energy efficiency to reach a higher level.
- **Prefabricated technologies:** Different from traditional cast-in-situ construction, most of the structures and components are prefabricated in the factory and assembled on-site. A stable production environment is conducive to controlling product quality. Furthermore, the digital tools used in the prefabricated building can minimise the construction period, ensure the quality of the project, effectively reduce the loss of building materials, and improve the service life of the new building.
- **Renewable energy:** The application of renewable energy in buildings refers to the activities of reasonably utilising non-fossil energy (solar energy, shallow geothermal energy, etc.) in buildings to improve the energy consumption

structure and reduce conventional energy consumption. In the future, the building solar PV installation rate will continue to increase, PV roofs, PV pavement, PV walls and other PV applications will be highlighted.

- DC technology: The purpose of using DC power supply system in buildings is to make use of the characteristics of DC that is simple and easy to control, so as to facilitate the flexible and efficient access and regulation of PV, energy storage and other distributed power sources. DC technology can realise the large-scale building application of renewable energy, and make use of the characteristics of low-voltage DC safety to create an intrinsically safe electricity environment.

Regional Examples

The 'Zero Carbon World of Construction Industry' is a groundbreaking project and the first zero-carbon building in Hong Kong. It is an exhibition, education and information centre that aims to promote the design and technology of zero-carbon buildings and smart cities, while also enhancing public awareness and understanding of low-carbon lifestyles. The building incorporates various cutting-edge features and techniques to achieve a net-zero carbon footprint.

One of the notable features of the project is the adoption of passive design measures, which can save up to 20% energy compared to buildings with standard designs (Hong Kong Construction Industry Council, 2022).

Additionally, the construction process utilises methods that consume less energy and emit less carbon, such as balanced cut and fill construction for basement and filling of urban native woodland. Resource conservation is emphasised through a lean construction approach, with the use of fair-faced concrete and unpainted metal works. Moreover, gabion wall construction utilises construction debris salvaged from demolition (Hong Kong Construction Industry Council, 2022).

The Zero Carbon World in the construction industry also utilises renewable energy for on-site power generation. The building is equipped with solar PV panels that generate solar power. Biodiesel, which is made from waste cooking oil, is also used for power generation (Hong Kong Construction Industry Council, 2022). These features and techniques help to ensure that the Zero Carbon World of Construction Industry achieves a net-zero carbon footprint, making it a remarkable achievement in sustainable building design and construction.

Recommended Finance Actions for New Buildings

Local governments in GBA provide financial support for green buildings and energy efficiency buildings (for example: financial support, floor area ratio policy and enterprise subsidies, etc.). The following specific cases are given according to different types of support in different city, which reflect the determination of local governments to green and low-carbon transformation of the construction industry.

- **Financial subsidies for green buildings:** Government subsidy amount for star green buildings (two-star subsidy is 25 RMB (3.27 EUR) per m^2, and the maximum unit project does not exceed 1.5 million RMB (200,000 EUR); three-star subsidy is 45 RMB (5.88 EUR) per m^2, and the unit project maximum subsidy is 2 million RMB (260,000 EUR)).
- **Financial subsidies for NZEBs:** For national or Shenzhen ultra-low energy consumption or (nearly) zero carbon and zero energy demonstration projects that meet the standards, Shenzhen will subsidise 150 RMB (19.62 EUR) per m^2 of building area, and the maximum amount of subsidy for a single project is 5 million RMB (650,000 EUR).
- **Floor area compensation[24]:** Research and formulate incentive policies for floor area ratio, and guide all localities to clarify the proportion of green buildings when setting the planning conditions for land-use right transfer. Guangzhou is formulating a new method to approve the floor area ratio of green buildings, which will provide 1% to 2% of the floor area compensation for buildings with good implementation, following the practice of Singapore and other places.
- **Enterprise support:** For enterprises in Shenzhen that have obtained the title 'Green Product', the subsidy amount at the national level is less than or equal to 100,000 RMB (13,074 EUR), at the provincial level is less than or equal to 50,000 RMB (6,537 EUR), and at the municipal level is less than or equal to 20,000 RMB (2,614 EUR).
- **Tax credit:** In order to encourage the development of green buildings in Hong Kong, the Hong Kong SAR Government has launched many preferential policies, offering tax relief and expansion to projects that have passed green building certification.
- **Green financial services:** Hong Kong's financial services industry also adds momentum to its green building market. According to the 'Hong Kong Green Bond Market Briefing' released by the Climate Bond Initiative in May 2020, nearly two-thirds of the funds were invested in low-carbon buildings.

At this stage, stakeholders in GBA are exploring green financial service mechanisms. In the future, a complete and unified financial support system for green and low-carbon buildings will be gradually formed.

Recommended Capacity Building Actions for New Buildings

Capacity building can be mainly divided into professional training, government planning and financial institution training.

Among them, the cultivation of professional competence (including the competence of practitioners and stakeholders) is the basis for green and low-carbon transformation of the construction industry in the GBA. As the policy maker and main supervisor, the government plays an important role in the process of city

24 Floor area compensation incentive' means that the land development management department cooperates with the developer to reward the developer with a certain building area on the premise that the developer has achieved certain building energy efficiency targets.

building and planning. Meanwhile, as the driving force for the development of the construction industry, the financial institution will have a decisive impact on the speed and depth of the green low-carbon transformation. The following suggestions are given for different roles:

- **Professional training:** The government should vigorously advertise the positive experiences of advanced projects. The laws, regulations, policies and measures of building energy conservation, green buildings, prefabricated buildings, green building materials, etc. can be widely publicised through TV, newspapers, the Internet and other media.

  Stakeholders should actively carry out publicity and training, technology promotion, information consultation, exhibition and other activities to create a good development atmosphere and advocate a green lifestyle. Professional training for design, construction, operation management and other personnel should be carried out based on colleges and universities, vocational schools, scientific research institutes and industry associations.

- **Government planning:** As the supporting policies for green building management are formulated by the government, the government should establish a mechanism for promoting the whole life cycle of green buildings, and strengthen the regulatory responsibilities of all parties and relevant departments, meanwhile incorporating the development of green buildings into the law.

- **Financial institution training:** Stakeholders should promote the concept of green development and green finance, strengthen financial practitioners' knowledge and understanding of green finance-related knowledge and products, guide financial institutions to strengthen innovation in green financial products, and improve the green financial service system.

  Government agencies can develop information display tools and provide training for developers and financial practitioners to assess the relative benefits of green buildings, thereby increasing access to funding and demand for green buildings.

Projected Timeline and Accelerators

Table 12 Projected Timeline for New Buildings

Key Actions	Baseline (2022)	Short term (2030)	Long term (2060)
Policy	Encouragement policies to promote green buildings, prefabricated building, ultra-low energy building technologies and projects, issue relevant incentive policies for new buildings	Promote the application of building energy consumption measurement and carbon emission measurement Low carbon green transformation in the building operation stage The government incentive policy is continuously improved	A well implemented policy system to fully support these actions
Technology	The use of new technologies in new buildings is in the exploratory stage	Renewable energy is widely used in new buildings, helping the low carbon transformation of new buildings	Building energy conservation and low carbon plus intelligent building technology become mainstream
Finance	The government guides financial support and conducts green finance pilot projects	The international financial market is further consolidated and expanded	A sound financial system fully supports the development of building energy
Capacity building	Building management ability and management system and refined construction technical measures are gradually strengthened	Fine construction and Building Management Systems (BMS) are widely used	The capacity building model and system are complete and mature in application

Summary: New Buildings

At this stage, the low carbon transformation of new buildings has been well promoted from the policy, standard, technology and other aspects, and the low carbon transformation of buildings is in a rapid development period.

In terms of building energy efficiency standards and policies in the GBA. At present, the coverage of building energy efficiency standards and policies continues to expand, and an independent building energy efficiency standard system with special building energy efficiency standards as the core has initially taken shape. The establishment of ultra-low energy consumption building standards and corresponding technical systems suitable for regional characteristics is the focus of future development of policy and standard formulation.

As for building energy efficiency technology, the GBA building energy efficiency technology has been greatly improved compared with the past, the application of PV and other renewable energy has enabled buildings to achieve higher energy efficiency levels, and the large-scale application of prefabricated buildings and BIM technology has accelerated the low-carbon process of building life. With the

guidance of policies and the continuous improvement of building energy efficiency technology, building efficiency technology will make new buildings efficient operation and help the construction industry in the GBA reach peak carbon.

Financial action is a necessary guarantee to support the green and low-carbon development of new buildings in the GBA. With the establishment of the carbon trading market and the release of a series of incentive measures, the existing green financial system is promoting the rapid development of new green buildings. In the future, the institutional framework and incentive policies of green finance will also be further improved, and the public and functional departments will be mobilised in a market-oriented way to guide and encourage more social capital to participate.

In order to ensure the implementation of the green and low-carbon transformation of new buildings, professional personnel capacity training is also the focus of attention. Therefore, the ability training for policymakers, professional technicians and financial institutions is the focus of future improvement, and also the direction that the local government needs to guide.

Overall, the energy efficiency of new buildings in GBA is developing towards ultra-low energy consumption, and it is expected to achieve zero carbon operation of new buildings by 2060.

Activity Area 3

Existing Buildings

Status Quo and Baseline

As a result of the GBA's rapid urbanisation, the existing building stock is substantial, and the energy consumption of these buildings is a significant concern. According to a study conducted by Zhang and Tan (2020) analysing the impact of energy consumption on economic growth in Guangdong province, the energy consumption of buildings in Guangdong province, where the majority of the GBA is located, accounted for approximately 23.4% of the province's total energy consumption in 2018 (Zhang, et al., 2020).

Furthermore, a recent report by Wang et al. (2020) revealed that the energy consumption per unit area of existing residential buildings in the GBA is higher than the national average, with an average energy consumption of 221 kWh/m^2 per year, compared to the national average of 164 kWh/m^2 per year (Wang, et al., 2020). The report also found that energy-saving measures, such as insulation and shading, are not widely adopted in existing buildings in the GBA, and the lack of energy-efficient technologies and equipment is a significant challenge to achieving energy-saving goals in the area.

At the practical level, it is much more difficult to promote energy efficiency in existing buildings than in new buildings. Due to differences in age, construction methods, and technologies, as well as typology, environmental factors, use and maintenance, the buildings themselves are complex and diverse. Therefore, it is difficult to retrofit existing buildings with uniform standards, materials, and construction/technology. In terms of funding, compared to new construction, retrofitting existing buildings is complex, as different building users or occupants have different needs or goals for renovation and relatively low commercial development value. Therefore, it is difficult to rely solely on private capital for large-scale retrofits.

In recent years, there have been increasing efforts to improve the energy efficiency of existing buildings in the GBA. The GBA governments have also introduced a range of policies and incentives to promote energy efficiency transformation, such as subsidies for building energy audits and energy-efficient equipment, tax incentives for building retrofits, and energy-saving performance evaluation standards for buildings (Guangdong Provincial Development and Reform Commission, 2021). In 2021, the GBA governments jointly issued the GBA Green Building Development Plan (2020–2035), which aims to promote green building and energy efficiency transformation in the region. The plan sets a target of reducing the energy consumption per unit area of existing buildings by 15% by 2025 and 30% by 2035 (Guangdong Provincial Development and Reform Commission, 2021). While progress has been made in improving the energy efficiency of existing buildings in the GBA, there is still significant room for improvement, and continued efforts are necessary to achieve the region's energy and climate goals.

However, the difficulty of retrofitting existing buildings should not lead to advocating for major demolition and construction in urban renewal. Fortunately, this point is now acknowledged by the Guangzhou Municipal Committee and the Guangzhou Municipal People's Government. On November 18, 2021, they issued the Implementation Opinions of Guangzhou Municipality on Preventing the Problem of Large Demolition and Large Construction in Urban Renewal Actions. This makes Guangzhou the first city to issue the Implementation Opinions of the Ministry of Housing and Construction, continuing the recent urban renewal policy of prohibiting large-scale demolition and construction. For the old city, the emphasis is on

strict control of large-scale demolition. Unless the buildings are illegal or identified as dangerous by professional institutions and have no repair or preservation value, existing buildings should not be subject to large-scale, concentrated demolition in large areas. For urban villages, large-scale demolition is prohibited, and renewal should be based on expert evidence, public participation, scientific decision-making, and reasonable determination of the renewal model. The concept of 'restricted demolition and redevelopment area' and 'organic renewal' was proposed by Shenzhen as early as in the 2015 Thirteenth Five-Year Plan. This restricts the demolition and redevelopment area within the scope of the prohibition of 'big demolition and construction'.

In 2018, Shenzhen has also changed zoning laws for urban villages, which left more than half of urban villages as a 'comprehensive improvement area' and excluded them from demolition and reconstruction of urban renewal plans. Whether from the perspective of ecological civilisation and historic building preservation, or from the perspective of sustainable urban development and other factors, limiting demolition and redevelopment has become the primary consideration when carrying out urban renewal in great bay area. This provides a great opportunity for the widespread implementation of energy efficiency retrofits in existing buildings in the GBA.

There is still more room for improvement in the standard of existing building renovation. Take the 'General Office of the Guangdong Provincial People's Government on the implementation of the comprehensive promotion of urban old district transformation work' as an example: The transformation tasks are mainly focused on the upgrading of municipal supporting infrastructure and repair of the damaged building envelope, as well as increasing public service facilities etc. Energy-saving renovation of small district buildings is mentioned, but no clear criteria are given.

The GBA is home to a substantial number of old buildings, including various types of structures such as old neighbourhoods, shantytowns, public buildings, industrial buildings, and industrial parks. Many urban renewal projects have been implemented by nine cities in the PRD region, and a significant proportion of these projects involve industrial building renovation and adaptive reuse. This highlights the importance of repurposing industrial buildings in the area. Despite challenges such as inadequate funding and regulatory frameworks, these projects offer significant opportunities to address environmental concerns, conserve cultural heritage, and create new economic and social value.

In China as in the GBA, due to the large inventory of existing buildings, their low energy efficiency and high potential for retrofitting, energy efficiency retrofitting of existing buildings is a crucial part of achieving China's ambitious goals of carbon peaking and carbon neutrality.

Trends and Challenges

The importance of retrofitting existing buildings in China's GBA has been acknowledged at both national and local levels. The number of buildings renovated during the 13th Five-Year Plan has increased, and the renovation of existing buildings

has been included in the local 14th Five-Year Plan. However, there are still several challenges to improving the energy efficiency and reducing carbon emissions of existing buildings.

Firstly, while the 14th Five-Year Plan proposes the goal of retrofitting existing buildings, there are no detailed instructions on how to achieve this. Secondly, there is a lack of specific standards for retrofitting buildings in the region's climate. Although energy retrofitting is presented as a goal, there are no clear indicators, and provincial green building design codes do not mention clear standards for retrofitting existing buildings.

Thirdly, the current focus on retrofitting is mainly on large public buildings, with little attention given to retrofitting residential projects, which have a much more urgent need for retrofitting. This lack of attention results in more carbon emissions and energy consumption. Finally, while there has been a growing trend of energy-efficient building materials and Mechanical, Electrical and Plumbing (MEP) products, there is still a lack of performative building materials and products for energy efficiency retrofitting of existing buildings.

All of these challenges have resulted in a lack of motivation and enthusiasm to retrofit existing buildings with energy efficiency as the target. Moving forward, the renovation process of existing buildings needs to be weighed and integrated at all levels. Although the road ahead may be difficult, the benefits of energy efficiency retrofitting are significant, and it is important to push through.

Targets and Indicators

To address the challenges for existing buildings in the GBA, the following targets and indicators can be used:

- **Clear instructions for planning:** To achieve the goal of retrofitting existing buildings, clear instructions for planning are needed. The instructions should be specific to the region's climate and consider the unique characteristics of each building. These instructions should include guidelines for energy efficiency retrofits, post-occupancy monitoring, and quality control in all renovation phases. The instructions should also consider the retrofitting of residential buildings, which are often overlooked but have significant energy consumption and carbon emissions.
- **Energy efficiency and carbon emission standards[25]:** To ensure that the retrofitting of existing buildings is effective in reducing energy consumption and carbon emissions, clear energy efficiency and carbon emission standards should be established. These standards should be specific to the region's cli-

25 The target value of energy saving and green transformation of existing buildings is set out in the existing policies, such as the 14th Five-Year Plan for Building Energy Efficiency and Green Building Development in Guangdong Province. This plan outlines the specific targets for energy savings and carbon reduction in the building sector, and provides guidance for green building development and renovation of existing buildings. The target value for energy savings and green transformation can serve as an important indicator for the success of retrofitting existing buildings in the GBA.

mate and consider the unique characteristics of each building. The standards should also consider the retrofitting of residential buildings, which have a significant impact on energy consumption and carbon emissions.

- **Focus on residential projects:** While the current focus on retrofitting is mainly on large or representative public buildings, there is a need to focus on residential projects. Residential buildings have large inventories and much urgent retrofitting needs, which can significantly reduce energy consumption and carbon emissions. Therefore, the focus should be shifted to include residential buildings in the retrofitting process.
- **Performative building materials and MEP products:** There has been a growing trend of energy-efficient building materials and MEP products on the market in recent years. However, there is a need for performative building materials and products specific to energy efficiency retrofitting of existing buildings. These materials and products should be able to reduce energy consumption and carbon emissions, and should also consider the unique characteristics of each building.

The retrofitting of existing buildings in the GBA with energy efficiency as the target is a process that needs to be weighed and integrated at all levels. The lack of clear instructions, energy efficiency and carbon emission standards, and focus on large public buildings have hindered the progress of retrofitting existing buildings. To achieve the goals, clear instructions for planning, energy efficiency and carbon emission standards, a focus on residential projects, and performative building materials and MEP products should be established. These targets and indicators will ensure that the retrofitting process is effective in reducing energy consumption and carbon emissions.

Key Roadmap Actions for Existing Buildings

Table 13 Key Roadmap Actions for Existing Buildings

Current status (2022)	Necessary actions towards long-term goal	Long-term goal (2060)
Incomplete standards and policies Lack of energy efficiency / environmental performance building products and approaches Lack of stable financial support Lack of motivation for retrofitting Few buildings renovated for energy performance purposes	Incomplete standards and policies Lack of energy efficiency / environmental performance building products and approaches Lack of stable financial support Lack of motivation for retrofitting Few buildings renovated for energy performance purposes	Most buildings operating at net-zero carbon emissions

In view of the current situation of energy efficiency retrofitting of existing buildings, the recommended key actions are mainly as follows:

- **Investigation of the current stock and status of existing buildings:** A general investigation of the existing building stock, construction age, physical condition, energy efficiency level as well as carbon emission level, ownership distribu-

tion etc. is an important prerequisite for administrators to develop reasonable plans, strategies, standards and retrofitting approaches for existing buildings retrofitting in their respective jurisdictions. It is the first step in the entire process of retrofitting existing buildings.

- **Develop a roadmap strategy:** Once the condition of the existing building is understood through a survey, an appropriate retrofit strategy should be developed to reduce carbon emissions. The strategy should identify when, by what means, and with what objectives the retrofit will be carried out.
- **Improvement of policies, energy-efficiency standards and guidelines:** To introduce energy efficiency standards for retrofitting existing buildings, clarify the calculation method for energy consumption and carbon emission of existing buildings, specify the maximum energy consumption of existing buildings, and classify the energy efficiency after retrofitting. Considering Life Cycle Assessment (LCA) and carbon trade in retrofitting in the long-term plan. Issue technical guidelines for retrofitting that correspond to the standard and meet the characteristics of the local climate. Increase the policy support for the retrofitting of existing buildings, simplify the approval process, and expand the public awareness in order to promote the motivation of retrofitting.
- **Improve industry and technology chain.** Develop relevant building materials, products and technologies for energy-efficiency retrofitting of existing buildings. In addition to introducing advanced materials, products and technologies from abroad, this will also support local production, technology and research units to form a complete industry chain for retrofitting energy-efficient existing buildings.
- **Introduce a subsidy system linked to retrofitting content and standards.** Introduce financial subsidy systems corresponding to the standards of energy-efficiency retrofitting. The subsidy system should include provisions for overall and partial energy efficiency retrofits, and should be corresponding to the energy efficiency level and carbon emission level achieved after the retrofit. The application system for subsidies should be as simple and uncomplicated as possible. There should be a corresponding regulatory mechanism to monitor whether the subsidies are used effectively.

Recommended Policy Actions for Existing Buildings

Table 14 Recommended Policy Actions for Existing Buildings

	Baseline (2022)	Short term (2030)	Long term (2060)
Energy retrofit standards	Lack of energy efficiency standards for existing buildings in this climate zone	Implementing energy retrofit standards for existing buildings	The requirement for full life-cycle calculations is introduced in energy retrofit standard
Energy certificates	There is currently no energy certificate policy in the real estate market	Mandatory energy certificates of all existing buildings in real estate markets	100% coverage of energy certificates for existing buildings
Technology enhancement	No selection of specialised building products technologies, and insufficient technical personnel reserve	Intensify external exchanges Promote local retrofitting producers and technical chain	The region has a complete and comprehensive energy saving retrofitting industrial chain
Incentives	No systematic incentives available in the region	Introduce systematic incentives bound to energy efficiency standards in the region	The entire region has a clear, proven incentive system for energy efficiency retrofits in existing buildings
Promotion and publicity	Insufficient publicity, the general public does not know much	Expand publicity and reach out to the local community	Public awareness of energy efficiency retrofits is created

Details on the policy targets for existing buildings are outlined below:

- **Energy retrofit standards:** Setting clear energy standards for retrofitting existing buildings is the basis for effective energy efficiency retrofits. The method of calculating energy consumption and carbon emission of existing buildings should be clearly specified in the standards. The development of such standards should be in line with the current conditions of existing buildings in the local area, so in-depth research should be conducted on the existing building stock and current conditions in the jurisdiction before the standards are developed. The standards should be graded according to the status of existing buildings, their importance and the amount of money that can be invested in their renovation, and not a one-size-fits-all approach. Standards should be developed with respect to particular segments (e.g. commercial, multifamily residential, single homes) and should ensure that refurbishments are carried out to align the performance of existing buildings to their cost-effective potential.
- **Energy certificates:** The introduction of energy certificates in the real estate market is an effective tool to increase motivation for retrofitting. The energy consumption level and the carbon emission level should be recorded in the certificate. Consider energy consumption a market entry principle, so that no building can be traded in the real estate market without meeting minimum energy consumption standards. In real estate transactions, it should be mandatory for sellers to present energy certificates to buyers, so that building energy efficiency can be used as an important indicator of the economic value of buildings in the real estate market, thereby increasing the motivation for energy-saving renovation through market demand.

- **Technology enhancement and personnel reserve:** The introduction of advanced retrofit technologies and the expansion of relevant external exchanges is necessary. However, the ultimate goal is to improve the ability of local related enterprises and Research & Development (R&D) institutions to develop technologies and products for energy efficiency in existing buildings, and to form a complete and advanced local energy efficiency retrofitting industry chain. Establish and manage a database of energy experts by the government or a commissioned third party.
- **Incentives:** Incentives should be diverse, thus targeting a variety of energy efficiency retrofit requirements. Incentives can be in the form of direct subsidies, low-interest loans, tax breaks, and various other forms. In terms of content, they can be categorised according to the function, volume, the level of energy efficiency to be achieved, and whether it is a partial or total retrofit. While the reward policy is diverse, the process of reward approval should be simplified.
- **Promotion and publicity:** The purpose of promotion and publicity is to build public awareness of energy efficiency retrofits in existing buildings and to publicise the positive impact of energy efficiency retrofits as well as the policies and incentive systems that promote them. The ultimate goal is to promote the process of energy efficiency retrofits in private buildings, especially in large stock of residential buildings.

Recommended Technology Actions for Existing Buildings

Table 15 Recommended Technology Actions for Existing Buildings

	Baseline (2022)	Short term (2030)	Long term (2060)
Energy efficiency calculation	Few energy calculations used in the retrofit	All retrofits are accompanied by energy consumption calculations	Life cycle energy calculation and carbon calculation for all retrofits
Renewable Energy (RE)	The focus is primarily on improving energy efficiency through retrofits	RE sources such as solar and wind power are expected to become more widely adopted	RE sources are expected to be widespread in the GBA, with all existing buildings utilising renewable energy to meet their energy needs.
Windows	The energy-saving standard of windows is not high	Use of energy-efficient windows in retrofits	Widespread use of energy-efficient windows
Building envelope	Low thermal performance requirements	Improve thermal performance to match energy-saving standards	Raising thermal standards to achieve zero carbon building requirements
External shading	Not commonly used or not effective in saving energy	Widespread use of external shading	Widespread use of high efficient movable or static external shading

HVAC and smart systems	No standardised requirements for energy efficiency of HVAC equipment Older buildings are less energy efficient	Most existing buildings replaced with high-efficiency equipment	High efficiency HVAC equipment and smart system used for all existing buildings
Technology innovation	Lack of technical push for retrofitting	Increase the technical innovation of retrofitting, such as 3D printing, 3D surveying, serial retrofitting, urban mining etc.	Strong R&D capability in retrofitting

Details on the recommended technology actions for existing buildings are outlined below:

- **Energy efficiency calculation:** Energy consumption calculation is not a new technology, but it has not been widely used in retrofitting existing buildings. The underlying reason is that many retrofits are not currently being done with a target of energy and carbon reduction. Calculation of energy efficiency before retrofitting is a prerequisite for setting energy efficiency targets and a basis for establishing retrofitting strategies. The process of energy-saving retrofitting should be accompanied by energy efficiency calculations to determine the technical instruments and costs that will be used in the retrofitting.
- **Renewable energy:** In order to achieve these targets, it will be important to develop policies and incentives that promote the adoption of renewable energy in existing buildings. This can include subsidies for the installation of solar panels or other renewable energy systems, as well as regulations mandating the use of renewable energy in new and retrofitted buildings.
- **Windows:** Replacement of energy-efficient windows is the least expensive, most convenient to implement, least structurally altering and most effective means of retrofitting. Windows also provide noise protection and improve thermal comfort and can enable passive architecture and natural ventilation. Replacement should be implemented as a priority.
- **Building envelope:** In hot summer and warm winter regions, the thermal performance of the building envelope has not been given much attention. However, the thermal performance of the building envelope plays a considerable role in energy saving and indoor comfort even in hot regions. The building envelope is an indispensable part of building renovation, and it is important to pay attention to the waterproofing of insulation materials and avoiding thermal bridges.
- **External shading:** Exterior shading is also a simple and cost-effective way to improve building energy efficiency through blocking out solar radiation, especially important in hot summer and warm winter regions. The movable shade can be adjusted for indoor sunlight and shading needs. It should be used on a large scale as a priority.

- **HVAC and smart systems:** The building operation part, which is an important part of energy efficient retrofitting, is described in a separate chapter in this report.
- **Technology innovation:** The new technology will bring substantial improvement to the energy-saving performance of existing building retrofitting and the simplicity of retrofitting implementation. For example, 3D scanning of the existing building's current condition and combining the scanning results with BIM will simplify the design process of retrofitting. 3D printing technology combined with BIM will greatly reduce the complexity of on-site construction. It will also reduce the cost of retrofitting when used on a large scale or serial retrofitting with similar conditions. Strengthening the R&D application of such new technologies can be used to form local industries with special characteristics while improving the level of retrofitting of existing buildings in the region.

Recommended Finance Actions for Existing Buildings

China has been supporting the development of energy efficient buildings through certain financial support policies for years. This has largely improved the energy efficiency level of new buildings. But the intensity and systematisation of specific financial support for energy efficiency retrofits needs to be improved. Energy efficiency retrofits in buildings require more initial capital and have a longer payback period through energy savings. Especially for a large stock of residential buildings, individual residents carry out the retrofitting, so the amount of capital invested is relatively limited. Therefore, financial support for energy efficiency retrofits in existing buildings is more important than for new buildings.

- **Low/zero-interest loans for retrofitters:** Provide financial support from the national level or local level, and entrust banks to provide special loans to retrofitters in order to increase the motivation of private retrofitting. To ensure fairness and transparency, loan preferences should be determined based on various factors such as the scope of renovation, the achieved energy-saving grade, and other relevant criteria. The size of the loan preference should correspond to these factors, and clear and explicit requirements should be established to achieve this. This loan could be a revolving loan, which collects repaid energy efficiency project loans and reinvests them in additional energy efficiency projects.
- **Tax exemptions or rebates:** In order to reduce the burden of one-time investment in energy-saving renovation for the retrofitters, if the retrofitters purchase related energy-saving products such as PV modules, energy storage devices, energy-efficient ventilation systems, etc., then tax exemption or rebate incentives will be given.
- **Reimbursement of energy-saving consulting expense:** A range of working packages on retrofitting existing buildings should be carried out by professional energy efficiency experts. The government should partially or fully cover the cost of energy-saving consulting on building retrofits. The government may commission a third party to audit, accept, and pay or reimburse invoices to reduce the burden of the retrofitters.

- **High-interest provision deposits:** For property owners with potential energy efficiency retrofits, the government can entrust banks to offer special deposit terms with above-market interest rates. The property owner makes a regular deposit to the bank, and that deposit can only be withdrawn when it is invested in the building's energy efficiency retrofit.
- **Low-interest loans and tax benefits for producers:** A certain amount of low-interest loan policies and tax incentives can be adopted for local manufacturers who invest in establishing building energy efficiency-related building materials and products to encourage the development of the local building energy efficiency industry. It boosts the local economy, while reducing the carbon emissions and energy consumption caused by the transportation of building materials and products.
- **Carbon trading:** Introduce carbon trading into building sector. The property owner of a retrofitted zero carbon emission building or building group can trade its excess carbon emission market share for a profit.
- **Community retrofitting reserve:** A small amount of the retrofitting reserve should be collected from each household on a monthly basis. The reserve should have a separate account, should be open and transparent and managed by the property owners' committee. It can be withdrawn and used by the owners' committee after a resolution is passed when the building has a need for renovation.

Recommended Capacity Building Actions for Existing Buildings

The retrofitting of existing buildings involves many aspects of society, so the improvement of capacity involves not only the technical improvement of construction practitioners, but also the improvement of other aspects of capacity.

- **Establishing building energy expert databank:** Building energy experts are present throughout the process of retrofitting. At the technical level, building energy experts are responsible for monitoring the current energy consumption of existing buildings from the pre-renovation stage, to the development of renovation strategies, to the review of renovation drawings and the supervision and acceptance of construction sites. At the economic level, energy efficiency experts work with owners to estimate costs and apply for retrofit subsidies. The first purpose of establishing building an energy expert databank is to professionalise building energy efficiency consulting and to separate building energy efficiency consultants from designers. The second is to train quality building consulting personnel through unified training, auditing and management of building energy experts.
- **Training within government:** Training within government at various local, provincial, national levels can help develop staff's awareness of energy efficiency in retrofitting existing buildings. It can improve work efficiency by making them aware of policy guidelines, subsidy policies and processes for energy efficiency retrofits. In addition, it can improve the optimisation of energy efficiency retrofitting policies.
- **Training of building professionals:** Training for architects, HVAC engineers, building contractors and construction technicians can improve the technical

capabilities of the entire industry to ensure high quality and completion of energy efficiency retrofits. This can be implemented through a variety of training paths such as university education, adult education, special training programmes and training on projects. Thresholds can be set for personnel access to the industry, and personnel can enter the field only after they have passed a training test.

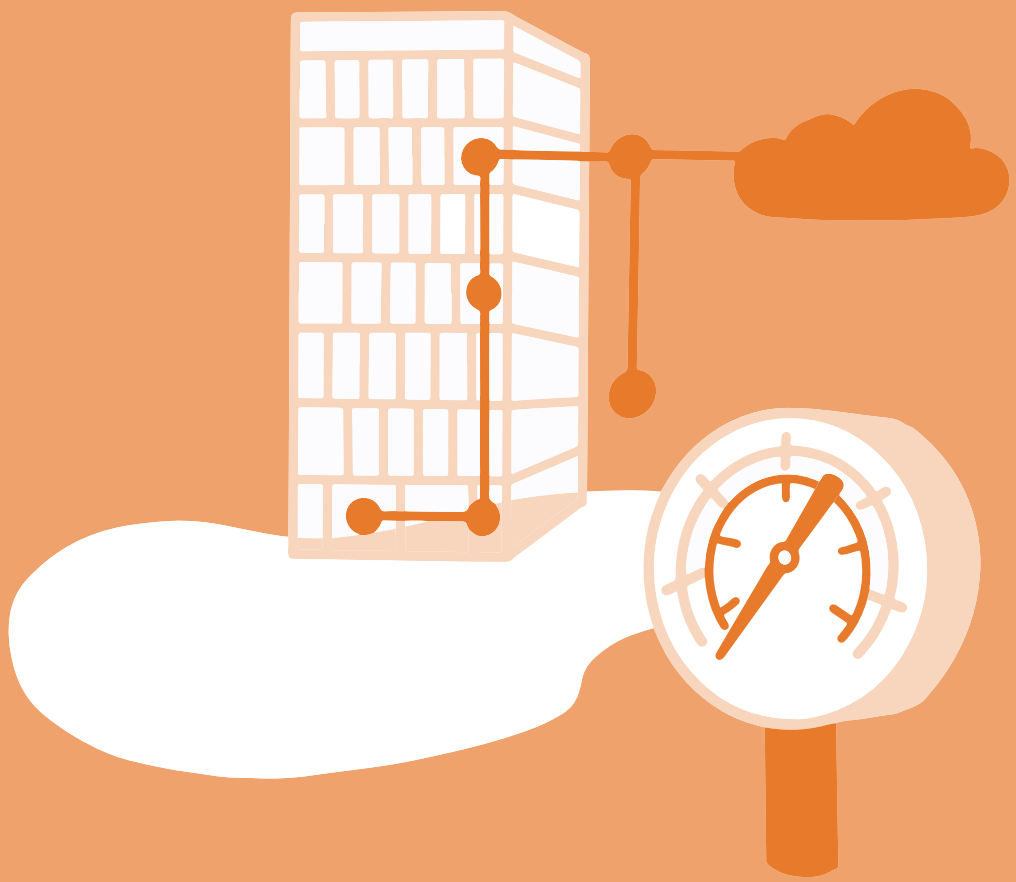
- **Training for producers:** Training manufacturers of building materials and products can facilitate the transformation of the general building materials sector towards low-carbon, energy-efficient building materials and products. It will also provide the retrofit market with a wider selection of high-quality products.
- **Training for investors and property owners:** Training for investors and owners, explaining to them the advantages brought by energy-saving renovation, proclaiming the preferential subsidy policies, and displaying energy-saving demonstration projects, can be used in raising awareness and enthusiasm for energy-saving renovation and expanding private capital into the energy-saving renovation market.

Summary: Existing Buildings

There are multiple advantages to promoting energy efficiency retrofits in existing buildings. Energy-saving retrofitting of existing buildings is an essential part of the process of achieving China's peak carbon and carbon neutrality goals. It has an important significance in the improvement of ecological environment level. At the energy security level, it can save a lot of energy and even produce renewable energy, which can have a positive impact on national and regional energy security. At the level of building comfort, energy efficiency retrofitting of buildings can improve the thermal performance of buildings, thus improving the thermal comfort. It also improves the light and acoustic performance of the building. On the economic level, for the property owner, it can reduce building performance costs. At the same time, it can promote local economic development and increase employment as a new industry. It is also an important part of circular economy and sustainable development. However, energy efficiency retrofitting of existing buildings is a complex and long-term process. China is still in the early stages of energy efficiency retrofitting. Promoting energy efficiency in existing buildings does not rely on one or a few parties to complete, but requires coordination and integration between all levels of society to form a complete system. It will take a time process to form, but it will bring great benefits.

Activity Area 4

Building Operations



Status Quo and Baseline

While delivering zero-emission, energy-efficient and environmentally resilient new or renovated buildings is essential, it is equally important to ensure that buildings are operated efficiently – behavioural and operational management influence the energy consumption and emissions performance. Reducing energy consumption and carbon emissions during building operation is one of the key tasks in the 14th Five-Year Plan (2021–2025) period of building energy conservation in the GBA.

Under the continuous efforts of the state and local government during the period of the 12th (2011–2015) and 13th Five-Year Plan (2016–2020), building operations have received more and more attention from various levels of society and have achieved great success under the support of high-performance technology, financial and policy support, and improved labour capacity.

- **Technology:** 01. Advanced systems, such as BMS and Energy Management Systems (EMS), have been integrated into architectural design for new buildings, and adopted into operation for most public buildings. These systems provide great help in building operations, assure high-quality indoor environment levels and energy conservation. 02. Energy consumption monitoring is generally accepted, and energy consumption data plays important role in optimising the building operation. 03. An increasing number of buildings have been awarded the Green Building evaluation label during the operational stage, and effective technologies have been adopted to enhance their operational efficiency.
- **Policy:** It is mandatory to improve energy consumption management in a public building and promote sharing data about the buildings' operation with relevant departments to fully leverage the low carbon potential of buildings in the 14th Five-Year Plan for Building Energy Efficiency and Green Building Development of the local government of the GBA area, such as Zhuhai, Dongguan, Zhongshan, and Huizhou ((HURDB of Huizhou, 2022), (DHURD of Guangdong, 2022), (HURDB of Zhongshan, 2022), (HURDB of Dongguan, 2022), (HURDB of Zhuhai, 2022)). Some cities are considering promoting the assessment and evaluation of the actual operation effect of green buildings (Huizhou). In Hong Kong, it is required that owners of commercial buildings (including commercial parts of mixed-use buildings, such as shopping malls under residential floors) comply with the Code of Practice on Energy Auditing for Buildings Category 4 and conduct an energy audit every 10 years for 'central building installations'. To comply with the Code of Practice, the report of the audit must be submitted to the BEEO Online Submission System, which is managed by the Electrical and Mechanical Services Department (EMSD) in Hong Kong.
- **Financial incentives:** Some regions, such as Shenzhen and Guangdong province, have promulgated clear financial subsidy policies to support low-carbon and energy-saving operations during the past years. And the scope and region of subsidies are expected to expand continuously (DHURD of Guangdong, 2022).
- **Capacity building:** Capacity building initiatives are underway to improve the quality and effectiveness of building operation and maintenance. These initiatives include continuous investment in skill training, standardisation efforts, and implementation measures for building managers and labourers.

Energy costs of residential buildings are paid by residents or occupants. This typically includes the costs associated with heating, cooling, and lighting their homes,

as well as any other energy-related expenses such as the use of appliances or electronic devices. Furthermore, there are no clear policies requiring people to save energy. Therefore, energy costs largely depend on the awareness of energy saving of the household in residential buildings. Users make their homes more comfortable and energy-efficient by replacing older appliances with more energy-efficient ones or adopting smart home systems.

Trends and Challenges

Despite the important role that building operations has played in building energy conservation and providing a comfortable indoor environment for users, it has not received sufficient attention in recent years. Many buildings still rely on manual operation, and the adoption of new technology has been slow for various reasons. Additionally, operational data is not widely collected, indicating that there is still significant work to be done in building operations and management to improve the level of operation in public buildings. Looking ahead, there is hope that building operations, particularly intelligent operation using BMS and Integrated Building Management Systems (IBMS), will become more widely accepted and adopted. The implementation of IBMS will enable buildings to monitor energy consumption and CO_2 emissions more effectively, with low-carbon operation becoming a core objective for future operation. Overall, there is significant potential for improvements in building operation and management, and it is important that more attention is given to this crucial aspect of sustainable building design and operation.

Targets and Indicators

Some of the key targets include:

- Improve the building operation level, and prioritise the renovation of buildings (government agency offices, large public buildings, and buildings investigated by the government) that do not meet energy consumption requirements.
- Strengthen the data collection during the operation period to guide the system to operate more efficiently, and encourage data disclosure to help a building or system achieve and maintain low-carbon operation.
- Encourage the adoption of Energy Performance Contracting (EnPC) models to improve the operation efficiency of the public agency or large public buildings (DHURD of Guangdong, 2022).
- Encourage local government to formulate higher requirements of energy consumption limit standards for public buildings and gradually implement a public building energy consumption exceeding limit notification system (HURDB of Huizhou, 2022).

Table 16 Main indicators and timelines for Building Operations

Indicators	Short term (2030)	Long term (2060)
Application of EMS in public buildings	50% of green public/government buildings install EMS and realise energy consumption data sharing through EMS.	100% of green public/government buildings realise energy consumption data sharing through EMS
Application of BMS in public buildings	50% of green public buildings or government public buildings operate with BMS.	100% of green public buildings or government public buildings operate with BMS
Operation commissioning[26]	Enhance technical sharing and manufacturing of commissioning of existing electrical and mechanical building systems in the GBA, promote the establishment of a public building operation and commissioning system	Establish a public building operation commissioning system and carry out post-operational assessments

Key Roadmap Actions for Building Operations

Table 17 Key Roadmap Actions for Building Operations

	Baseline (2022)	Medium-term goal (2030)	Long-term goal (2060)
Building operations	Tools such as BMS, EMS, IBMS, and smart controls are used in public buildings to realise efficient operation and data collection.	BMS, EMS, and EnPC will be widely used in building operation.	Big data is widely utilised in optimised operation, and Artificial Intelligence (AI) algorithms will show their great advantage.

Key actions to improve energy management of buildings include:

- **Energy audits:** The use of regular energy audits to identify inefficiencies in building operations should be further promoted. Audits are an effective measurement to encourage buildings, especially public buildings, to decrease energy consumption. Across the GBA, energy audits are currently not widely carried out due to insufficient financial support and motivation , but should be in the future to help energy-saving renovation, and they can be efficiently combined with EMS, BMS in the 14th Five Year Plan period (BHURC of Huizhou, 2022).
- **EMS:** EMS need to be introduced as a requirement to energy management processes in public buildings for energy conservation. The main energy consumption equipment and systems are monitored by smart meters, which collect data to the EMS and manage energy consumption through the system[27].

26 Operation commissioning is a systematic and documented process of testing, adjusting, and balancing building systems and equipment to ensure they meet design requirements and operate as intended.

27 In a study conducted by the Energy Information Administration (EIA) (2020), the use of EMS in commercial buildings was found to result in an average energy savings of 5–15%. Furthermore, the study found that the use of BMS in commercial buildings can result in an average energy savings of 10–30% (U.S. Energy Information Administration (EIA), 2020).

- **IBMS:** integrated building management systems have become increasingly popular in new buildings as a means of achieving efficient and effective equipment and system control and management. Although their advantages failed to convince in previous years due to issues such as unstable integration, data interconnection, and a lack of user-friendly human-computer interface, the development of information technology and AI has revealed their potential. By analysing operational parameters, IBMS can adopt energy-saving control algorithms at the system level, resulting in significant energy savings and reduced carbon emissions. As a result, IBMS are now widely accepted as an effective tool for optimising building control.
- **Operation commissioning:** by performing operation commissioning, building owners and managers can identify and correct any issues affecting the performance of their building systems, resulting in improved energy efficiency and indoor environmental quality. In recent years, operation commissioning has gained more attention from building owners and managers as an effective measure for improving equipment and system performance, and achieving energy conservation and a comfortable indoor environment. The Building and Housing Administration of Guangdong Province (BHURC of Guangdong province, 2022) has also recognised its benefits.
- **EnPC:** EnPC is a model in which an energy-saving service company is contracted to provide services aimed at reducing energy consumption in a certain period. The energy cost savings achieved during this period are used to compensate the service company for its services and profits. This model is especially effective for government agencies, large public buildings, schools, and hospitals, as it reduces the owner's investment in financial, human, and material resources.
- **Smart control:** Smart control measures are required in green buildings to achieve energy savings. These measures include operating water pumps and fans with variable frequency according to terminal requirements, and using group control, frequency conversion speed regulation, or energy feedback in vertical elevators. These measures rely on control interfaces, which are especially important for larger pumps and fans. Additionally, smart control measures like variable frequency drives can also be used in smaller pumps and fans, as well as some vertical elevators, depending on their size and application.
- **AI applications and services:** By 2060, advancements in big data, information technology, and 5G will have enabled HVAC systems to increasingly utilise AI methods such as machine learning, deep learning, and reinforcement learning. These AI methods will involve a combination of algorithms, mathematical models, and statistical analysis that will allow computers to learn from data and make decisions. These AI methods will allow HVAC systems to operate more efficiently and effectively, resulting in significant energy savings and reduced environmental impact. Furthermore, Big Data, information technology, and 5G will have provided the necessary infrastructure, tools, and resources for processing and analysing large amounts of data in real-time to support the use of AI in HVAC systems. This will enable quick and accurate analysis of data from smart sensors in buildings and other sources, identifying areas where energy can be saved and optimising building operations. The

integration of AI in HVAC systems will be a promising trend that will have the potential to significantly reduce energy consumption and improve building efficiency.

Recommended Policy Actions for Building Operations

Table 18 Recommended Policy Actions for Building Operations

Key Actions	Baseline (2022)	Short term (2030)	Long term (2060)
Energy consumption quota	Dual control[28] of energy consumption work plan has been promulgated for public buildings	50% of the government offices operate under the energy consumption quota	100% of public buildings finish energy-saving renovations, and buildings operate under controlled energy consumption
Certification for operational performance	Currently, there are limited certifications available for building operations management. However, there is a growing trend among building owners to prioritise operation certification and seek out qualified professionals in this area	Large-scale public buildings and government offices are actively involved in obtaining certification for operational performance, and are implementing post-operation evaluation mechanisms	Large-scale public buildings and government offices all participate in operation certification
Energy audits	Some public buildings have carried out energy audits to improve building energy efficiency	More public buildings join in energy audits pilot projects	Energy audits are popularised in public buildings
Commissioning	Commissioning is gradually gaining recognition and value among the public, although few projects have actually implemented it so far	Establish the operation commissioning system of public buildings	Gradual popularisation in large public buildings and government offices
Energy contract management	Encourage to use energy contract management model to carry out energy conservation operation	More government buildings adopt the EnPC model to realise low-carbon operation	More than 50% of government buildings adopt EnPC to achieve low-carbon operation
Incentives	Incentives or disincentives related to performance are rarely used	Buildings under green operation or energy consumption quota have a subsidy fund	

28 In this context, 'dual control' refers to a system of control that involves both top-down regulatory approaches and efforts to encourage energy-saving behaviours at the building level. The work plan aims to regulate and control energy consumption in public buildings by setting energy consumption quotas or targets and implementing measures to achieve those targets.

Details on the policy action for building operations are outlined below:

- **Energy consumption quota:** Encourage prefecture-level and above listings based on actual conditions. Formulate higher requirements for public building energy consumption limit standards. Gradually implement public building energy consumption exceeding limit notification system. For government buildings, large-scale buildings that exceed the energy consumption limit are given priority to be included in the renovation plan. It is encouraged to formulate higher requirements for energy consumption quota standards for public buildings and local government, especially in the GBA.
- **Certification for operational performance:** The certificate or label can enable increased information sharing and documentation for consumers and financial decisions. The certification of operational performance can also allow the development of green lease agreements, where there is a binding agreement between the landlord and the tenant to enable the landlord to operate the building according to its potential. Some cities have carried out operation certification at the city level, while some large public buildings are trying to do this. It is estimated that public or government buildings are encouraged to get operation certification, and under the low carbon target, most public or commercial buildings are required to get operation certification by 2060.
- **Energy audits:** Regular audits are powerful tools to assess opportunities for energy-saving measures, particularly in buildings with high energy consumption. It is required to carry out energy audits. There is a consensus that audits will be gradually accepted and carried out in public and commercial buildings by 2030, and it will be required that audits will be done in buildings that are owned and operated by government or other public entities every few years to monitor the operation of the building by 2060.
- **Data disclosure:** Mandatory disclosure of energy performance, certificates, and/or energy consumption quotas for buildings can support improved data collection, decision-making, and competition. Currently, the region uses a voluntary disclosure system, but there is a consensus among stakeholders that performance disclosure will become widespread after 2025. All operational data will be connected to the public platform of the government to achieve unified management.
- **Commissioning:** Strengthen the sharing of re-adjustment technologies for the mechanical and electrical systems of existing buildings in the Guangdong-Hong Kong-Macao GBA, formulate corresponding technical guidelines, and promote the establishment of a public building operation adjustment system.
- **Incentives:** Financial incentives, such as subsidy funds, can encourage sustainable buildings operation. It is a very effective measure to promote efficient operation or green operations.

Recommended Technology Actions for Building Operations

Table 19 Recommended Technology Actions for Building Operations

Key Actions	Baseline (2022)	Short term (2030)	Long term (2060)
BMS	Most public buildings already have BMS	100% of public buildings have well-installed and well-operated BMS systems.	The implementation of BMS in public buildings has popularised its use among the general public.
EMS	Few buildings have EMS	EMS is widely installed in building with perfect functions	EMS is involved in smart operations with BMS
Sensors and controls	Traditional wired sensors are widely used, and few Internet of Things (IoT) sensors are applied	IoT sensors and equipment are a mainstream market and perform well	With advancements in technology, sensors and control systems are now more accessible and easier to integrate into buildings
BIM	Light BIM has been integrated into IBMS or EMS to simplify operations, although few buildings have adopted this system.	More buildings adopt BIM for operation	

Details on the technology action for building operations are outlined below.

- **BMS:** BMS can range from full-scale building software to simple controls that manage individual technologies within a building. The aim of a BMS is to improve a building's operation, automation and overall functionality, thus improving maintenance and comfort. Digital tools connect multiple systems within a building with learning and fault detection to improve the overall management of the building system controls. BMS can also be key enablers of energy management strategies and systems. The use of BMS is currently mainly in buildings constructed after 2000. Furthermore, after the renovation of old systems, it is estimated that BMS will be widely used in buildings, and IBMS will be widely used to better operate the building by 2060.
- **EMS:** energy management systems enable monitoring of energy consumption of systems, components and/or the building as a whole to identify anomalies and understand energy consumption trends. A network of digital energy meters or sensors or a simple, smart meter can form the basis of an EMS. The infrastructure for energy management can enable the adoption of an energy management strategy or protocol, such as those required to gain ISO 50001 certification.
- **Sensors and controls:** Sensors and controls are fundamental to smart maintenance, audit, energy management, and building management. Control systems can range from fully centralised systems to simpler systems, such as programmable thermostats. Sensors and controls are increasingly starting to incorporate machine learning to understand occupant preferences and behaviour and optimise system settings based on internal and external conditions. There is consensus among stakeholders that the adoption of smart sensors and controls will become common practice by 2030 and will be widespread in most public buildings by 2060.

- **BIM:** Although BIM is required in the design and construction phase of buildings, its advantages in the operation period are not yet fully utilised. Currently, few buildings have installed EMS or BMS with BIM. However, it is estimated that BIM technology will be more widely used in conjunction with other systems for building operation in the future.

Recommended Finance Actions for Building Operations

- **Provide financial incentives for green building certification:** Encourage building owners to invest in energy-efficient technologies and renewable energy sources by providing tax credits, grants, or other financial incentives for obtaining green building certification.
- **Establish a green bank:** Establish a green bank that provides low-interest loans, grants, and other financial support for energy-efficient building retrofits and green building projects.
- **Encourage private investment:** Encourage private investors to finance energy-efficient building retrofits and green building projects by providing financial incentives such as tax credits or subsidies.
- **Implement performance-based contracting:** Use performance-based contracting to finance energy-efficient building retrofits. Under this approach, building owners pay for retrofit costs using the savings achieved from energy efficiency improvements.
- **Leverage public-private partnerships:** Use public-private partnerships to finance green building projects. Private sector partners can provide funding, technical expertise, and other resources, while the government provides policy support, regulatory oversight, and other incentives.
- **Implement energy performance contracting:** Use energy performance contracting to finance energy-efficient building retrofits. Under this approach, an Energy Service Company (ESCO) provides upfront funding for retrofit costs and is repaid through the energy savings achieved over the contract term.

Recommended Capacity Actions for Building Operations

To ensure the sustainable development of buildings in the region, it is recommended to implement capacity actions for building operations.

- Establish a comprehensive framework for building management, which includes policies and regulations that ensure the safe and efficient operation of buildings. This framework should be designed to address the unique challenges of the GBA, such as high humidity, typhoons, and air pollution.
- Building operators should prioritise energy efficiency and environmental sustainability in their operations. This can be achieved through the use of green building technologies, such as solar panels, green roofs, and efficient HVAC systems. Building operators should also develop strategies for waste reduction and recycling to minimise the environmental impact of their operations.
- Building operators should promote occupant health and safety by implementing measures such as regular air quality monitoring, pest control, and

emergency preparedness plans. In addition, building operators should provide educational resources for occupants on sustainable living practices and emergency procedures.

- Building operators should leverage emerging technologies such as IoT and AI to optimise building performance and improve operational efficiency. For example, IoT sensors can be used to monitor energy consumption and building occupancy, while AI algorithms can be used to predict maintenance needs and optimise building systems.

Projected Timeline and Accelerators

Table 20 Projected timeline within Building Operations

Key Actions	Baseline (2022)	Short term (2030)	Long term (2060)
Policy	Strengthen building property management and operation data collection of green buildings; prepare technical guidelines for post-assessment of green buildings; use BMS/EMS in the operation of buildings; start to establish system and mechanism for building carbon statistics, carbon audit, and carbon monitoring	Promote transparency in energy consumption, monitor and encourage data disclosure in most public buildings during the operation period Establish a comprehensive system and mechanism for carbon statistics, auditing, monitoring, and publicising results to raise awareness and promote energy conservation and emission reduction culture in the GBA	Monitor energy consumption in operation period in all kinds of buildings; require carbon statistics and carbon audits in all kinds of buildings
Technology	BMS and EMS are utilised in government-invested or large public buildings	BMS and EMS with the function of carbon statistics and carbon audits are widely utilised in public buildings Apps[29] and Applets[30] with carbon statistics, audits are widely used in the system's daily operation The efficient Chilled-Water Plant System[31] is widely adopted in public or commercial buildings	Itemised measurements of carbon consumption and carbon audits are popularised More and more buildings carry out operation commissioning and post-operation evaluation for carbon conservation

29 Application (App): A software program designed to run on a mobile device or computer, typically used to perform specific tasks such as accessing information, managing data, or providing entertainment.

30 Applets: A small application designed to perform a specific function, often within a larger software program or operating system.

31 A Chilled-Water Plant System is a type of HVAC system commonly used in large commercial or public buildings that uses chilled water to cool the building's air and equipment. The system typically consists of a chiller, cooling tower, pumps, and piping to circulate the chilled water throughout the building.

Finance	The government gives financial support for buildings with energy consumption under the energy consumption quota Finance subsidy is provided to buildings with green operation certification	Finance subsidy is provided to buildings with lower or zero carbon emissions Finance subsidy is provided to buildings with lower or zero carbon renovation	Continued finance subsidy is provided to buildings with lower or zero carbon emissions
Capacity building	Training within government to strengthen the awareness of the importance of energy conservation and low carbon emission in society	Provide training for managers and professionals to improve their skills in building operation and maintenance. Develop educational programmes, including primary, secondary, vocational, university and adult education, to increase knowledge of how to efficiently operate buildings Provide certification or accreditation for professionals in the sector	Train the general public Develop information and awareness campaigns regarding low-carbon actions

Summary: Building Operations

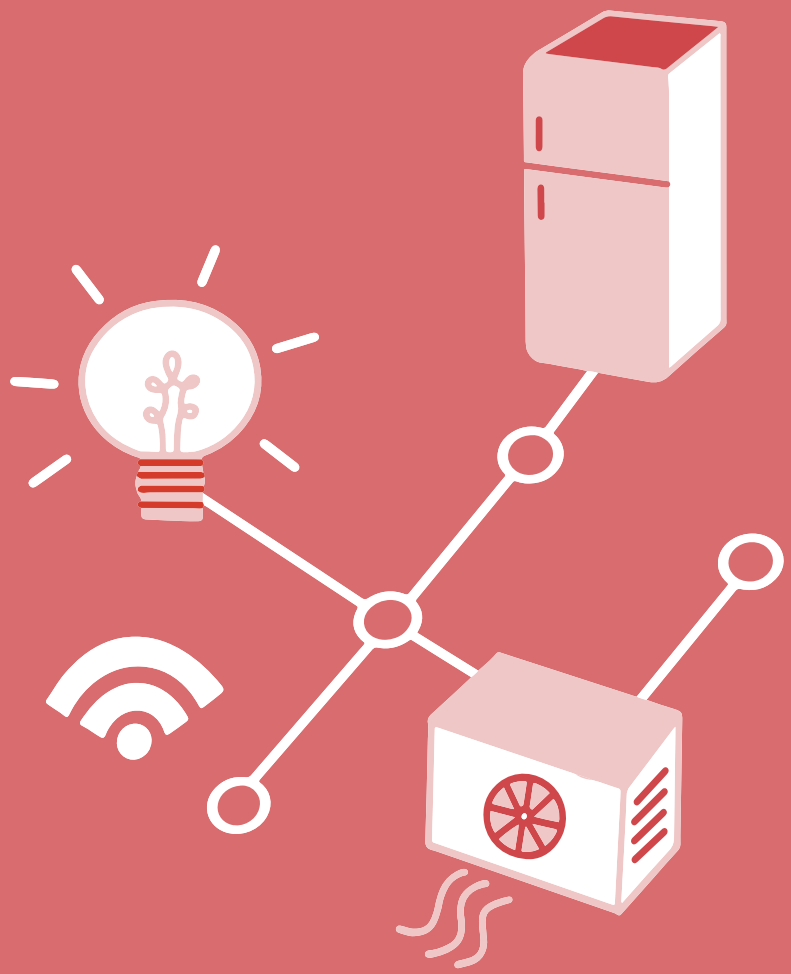
Building operation management plays a significant role in achieving low-carbon emission targets. The local government of the GBA has promulgated several policies to ensure the implementation of efficient and sustainable operation of public buildings. One of the key policies is to encourage the formulation of stricter energy consumption limit standards for public buildings and gradually implement a notification system for buildings exceeding the limit. Buildings with higher energy consumption are required to prioritise energy-saving renovations. The GBA should also promote the sharing of mechanical system commissioning, establish public building commissioning institutions, and strengthen energy-saving management in super high-rise buildings.

To achieve better building operation and energy conservation, public buildings require data audits and EMS. BMS has been used in public buildings constructed after 2000 and will be adopted in public, commercial, and government buildings for delicate operations. BIM is starting to be employed in operations alongside BMS or EMS to show real-time electro-mechanical system operation. BIM is expected to be welcomed in large public building operations. With the development of big data, cloud computing, and 5G, more AI will be utilised in HVAC system operations, such as neural networks, deep learning, and decision trees. Algorithms can be used to forecast building load, and the load forecasting information can be transferred to BMS to optimise the operation of the chillers, pumps, or chiller plant control strategy.

A sound system and mechanism for building carbon statistics, carbon audits, monitoring, and publicity will be built and executed smoothly. More buildings will participate in green operation certification, and financial subsidies will be awarded to buildings with green certification. It is encouraged to build green buildings in the following years and to establish green buildings and intelligent transportation line management platforms that make use of modern information technology to achieve real-time monitoring of building energy and resource consumption and statistical analysis of indoor air quality.

Activity Area 5

Appliances and Systems



Status Quo and Baseline

In recent years, under China's 30–60 Targets, along with global warming and residents' increasing income and living standards, residents' demands for higher-performance buildings, intelligent air conditioners, lighting, elevators, and other equipment and systems have grown significantly. In 2020, urban residents had an average of 149.6 air conditioners per 100 households, and rural residents had an average of 73.8 air conditioners per 100 households, showing an increasing trend year by year (NBSC, 2021). The Guangdong-Hong Kong-Macao GBA, a dynamic world-class city cluster and an international scientific and technological innovation centre with global influence, is located in a climate zone with hot summers and warm winters and has refrigeration needs throughout the year. It is even more necessary to adopt efficient and sustainable building high-performance equipment and systems to fully tap into the energy-saving and low-carbon potential of intelligent appliances and systems.

From 2018 to 2020, China's household air conditioner production accounted for more than 80% of the world's total (Statista, 2021), and the high sales volume and high inventory of China's air conditioner industry coexisted. In 2018, the overall sales volume of air conditioners in China was 81.53 million, and consumers favoured high-end cabinets, central air conditioners, and smart air conditioners. In China's domestic market, Midea, Gree, and Haier air conditioners are in a three-way competition. In the future, the research, development, and promotion of intelligent appliances will become a new economic growth point for the industry (Industry Online, 2021).

China is a critical player in global home appliance energy use. In 2019, residents' per capita domestic electricity consumption was 756 kWh. The electricity consumption in Guangdong province was at the forefront of the electricity consumption statistics of different regions. In 2019, the domestic electricity consumption of the construction industry was 99.1 billion kWh, and the residential electricity consumption was 1,063.7 billion kWh. The annual installed power generation capacity in 2020 was 2,202.04 million kWh (2,010.06 million in 2019), showing the increasing trend of renewable energy (nuclear power, wind power, solar power) power generation year by year (NBSC, 2021). The electricity production in Macao is decreasing yearly, while the electricity imported is rising annually. In 2021, Macao produced 495.5 million kWh of electricity and imported 5,192.3 million kWh of electricity. In the future, Macao will gradually increase its dependence on imported electricity (SCS, 2022).

The relevant standards for building energy efficiency in Mainland China and Hong Kong give energy efficiency minimums for appliances and systems. In contrast, Macao lacks a unified energy efficiency standard for reference. For public buildings, air conditioning accounts for about 50% of the energy consumption, lighting accounts for about 40%, and other energy consumption is about 10%. China has continuously increased its research funding to improve the energy efficiency of appliances and systems. In 2020, China's R&D expenditure was about 24.4 billion RMB (approximately 3.2 billion EUR), accounting for 2.4% of the GDP (NBSC, 2021).

In China, the Advanced Energy Label includes three categories:

- High-performance building energy-efficiency products
- Best practice cases
- High-performance and energy-efficient buildings (engineering)

For example, the products include insulation materials, doors and windows, lighting, HVAC devices, and energy-saving control systems. The air conditioners sold in China all have the 'China Energy Label', and the market access index is level 5 (Energy Efficiency Ratio (EER) is higher than 2.6 W/W) (NBECQSIC, 2014). However, labelling application is voluntary, and the market uptake of high-performance products is lower than that of low-energy-efficient products. China is the largest manufacturer of LED lighting products. The penetration rate of the domestic LED lighting market has rapidly climbed to over 70%, as lighting fixture developers focus on LED lighting technology in response to market demand. According to statistics, the output value of China's LED lighting market has increased from 301 billion RMB (approximately 39 billion EUR) in 2016 to 526 billion RMB (approximately 68 billion EUR) in 2020, with an average annual compound growth rate of 14.95%. The market share of LED lighting products in China has increased from 42% in 2016 to 85% in 2021, and the market share of LED lighting products in China will further increase in 2022 (CBIRI, 2021).

About 90% of total electricity consumption in Hong Kong is contributed by buildings. Through enhancement of building energy efficiency, greenhouse gas emissions can be effectively reduced (EMSD, 2022). Hong Kong has stronger enforcement of energy efficiency standards for building equipment and product labelling, which are fully enforced through laws and regulations. In October 1998, the EMSD launched the voluntary Hong Kong Energy Efficiency Registration Scheme for Buildings (EERSB) to promote the application of the Building Energy Code. To further promote building energy efficiency, the Government enacted the BEEO (referred to as 'the Ordinance') which has come into full operation since September 21, 2012 (EMSD, 2022). The three key requirements of the Ordinance are:

- The developers or building owners of newly constructed buildings should ensure that the four key types of building service installations therein, namely, air-conditioning installation, lighting installation, electrical installation as well as lift and escalator installation, comply with the design standards of the Building Energy Code (BEC).
- The responsible persons (i.e., owners, tenants or occupiers etc.) in buildings should ensure that the four key types of building service installations therein comply with the design standards of the BEC when 'major retrofitting works' are carried out.
- The owners of commercial buildings (including the commercial portions of composite buildings, e.g., shopping malls under residential storeys) should carry out energy audits for the four key types of central building services installation therein in accordance with the Energy Audit Code (EAC) every 10 years.

The support of the national industrial policy is one of the most favourable factors in promoting the development of the LED lighting application industry. China at-

taches great importance to the LED lighting industry. In recent years, industrial policies have been formulated, and policy support has been given to capital, technology, and industry norms, effectively promoting the diversification and energy-saving development of high-efficiency lighting systems. With the advancement of LED technology and cost reduction, the market size of the lighting industry will further expand in the future, and the global LED industry will accelerate its transfer to China (CBIRI, 2021).

Trends and Challenges

At present, Chinese residents' energy consumption accounts for about 13% of China's total energy consumption. Refrigerators, air conditioners, water heaters and lighting systems are the main electric products. China is the world's largest producer, consumer and exporter of end-use energy products and equipment. For example, the revenue of home appliances industry reached 1.74 trillion RMB (approximately 22.74 billion EUR) in 2021. In China, the production and marketing quantity of building end-use energy products is large, the application range is wide, the total energy consumption is large, and it is closely related with daily production and life. Improving the energy efficiency of key energy-using appliance and systems is an important measure to promote energy conservation and carbon reduction. It will not only help achieve carbon emission peaking and carbon neutrality, but also help improve the quality and upgrading of the manufacturing industry. In China, highly energy-efficient appliances and systems are not fully promoted and applied in existing buildings. High initial investment and a long return cycle are the main constraints to the promotion of energy-efficient products and equipment. The promotion of highly energy-efficient appliances and systems needs both incentives and constraints to give full play to the role of market mechanisms, to take effective measures to guide the market, and to orderly promote the upgrading of energy-using products and equipment. In addition, the innovation capability and core competitiveness of energy-efficient appliances and systems need to be continuously improved. And the existing incentive policies mainly focus on buildings, not on appliances and systems. The research and development and promotion of efficient products should make full use of the green finance mechanism and improve the existing policies and mechanism (The National Development and Reform Commission and other departments, 2022).

Targets and Indicators

To promote energy efficiency and scale application of building appliances and systems in the GBA, the targets and indicators as follows (The National Development and Reform Commission and other departments, 2022):

- Reasonably set the energy efficiency level of appliances and systems, improve the energy efficiency standard system and energy efficiency labelling system of appliances and systems, improve the energy efficiency standards for market access, and promote the quality and upgrading of related manufacturing industries.

- Continue to improve the energy efficiency of appliances and systems, increase the research and development of high energy efficiency products and systems and capital investment, especially smart systems and renewable energy application systems, and improve the electrification level of building end-use energy products.
- Vigorously promote highly energy-efficient appliances and systems, improve government policies related to green procurement, give priority to purchasing appliances and systems with advanced energy efficiency, refine incentive policies and mechanisms related to energy-efficient appliances and systems, develop diversified green financial support policies, stimulate market vitality, and fully mobilise the enthusiasm of investors and users.
- Speed up the replacement of older appliances and systems, actively carry out the construction of demonstration projects, strengthen publicity and guidance, and improve the application rate of highly energy-efficient appliances and systems. Market regulatory authorities should intensify quality supervision, eliminate old and outdated products and equipment in accordance with laws and regulations, and crack down on false publicity of energy efficiency levels.

Key Roadmap Actions for Appliances and Systems

Table 21 Key Roadmap Actions for Appliances and Systems

	Baseline (2022)	Short term (2030)	Long term (2060)
Appliances and systems	Most appliances and systems are limited in their energy efficiency standards and codes, resulting in low levels of energy efficiency Incomplete government policies and business models Little use of intelligent appliances Low investment in efficient and green appliances and systems	Sustained improvement of energy efficiency, standards and policies Rising use and procurement of intelligent appliances Increased investment in efficient and low-emission appliances and systems	Widespread use of intelligent appliances Complete progressive standards and policies systems Sustainable high investment in the promotion of efficient systems

Details on the key roadmap actions for appliances and systems are outlined below:

- **Standards and codes:** Develop, enforce, and progressively improve standards that set product quality and performance requirements. Minimum Energy Performance Standards (MEPS) and codes are becoming more widely adopted globally and for many system types. For example, Guangdong and Hong Kong have adopted mandatory MEPS for lighting, air conditioning, and appliances. In contrast, Macao has not yet had a unified set of standards or regulations for building energy conservation standards. Further implementing mandatory standards for critical energy services, such as lighting and air conditioning, will curb the growth in demand. Furthermore, under China's 30–60 Goals strategy, with the development of cities and residents' growing needs, intelligent

equipment will be popularised. The corresponding intelligent standards will be gradually improved, providing technical guidance for applying intelligent equipment and systems.

- **Government policy:** Governments lead by example with the sustained improvement of related policies. Develop policies that ensure all government buildings invest in low-emission and efficient systems. Nationally or locally legislated procurement mechanisms for efficient appliances and systems help secure demand for manufacturers and help transform the market. Within the GBA, several subregions, including Guangzhou, Shenzhen, and Hong Kong, are adopting higher standards in building construction and system performance across the public sector. Guangdong government has proposed that new buildings should focus on improving the energy-saving performance of key components (e.g., building doors and windows) and establish building appliance standards as soon as possible.
- **Investment:** Enable investment for efficient systems. Enable increasing use of sustainable products by increasing access to and using finance to enable private investment. Investments in capacity building for manufacturers to produce more efficient appliances also help support the effort to increase the setting of MEPS progressively. The rate of investment across the GBA in the research and development of clean and energy-efficient systems should be increased from its current levels.

Recommended Policy Actions for Appliances and Systems

Table 22 Recommended Policy Actions for Appliances and Systems

Key Actions	Baseline (2022)	Short term (2030)	Long term (2060)
MEPS	Most appliances have mandatory and voluntary but not complete MEPS for entering the market	All appliances with mandatory and recommended MEPS, and sustainable improvement in the standard system of appliances	All appliances with mandatory and progressive MEPS, widespread use of high-efficiency and low-carbon appliances with better performance
Labels	Many appliances with mandatory but not uniform and complete energy efficiency labels Lack of green/low-emission labels for appliances and systems	Most appliances with mandatory energy efficiency labels, and part of appliances with green/low-emission labels	All appliances with mandatory energy efficiency labels, and most with green labels Full use of labels of energy efficiency and green performance of appliances
Testing and evaluation	Appliances with factory performance testing Lack of technical guidelines for performance testing and evaluation during operation	Complete the testing and evaluation of technical guidelines for appliances and systems during operation and build a devices database	Widespread use of dynamic monitoring and evaluation platform and sustained improvement of the devices database

R&D	Low levels of investment in the energy efficiency of appliances and systems Focus on independent R&D of the key technology and product localisation	Increase investment in energy efficiency and green performance of appliances and systems Promote the R&D of technologies and appliances for efficient electrification and flexible DC power consumption Increase rate of the key appliances' localisation rate and market share	Continuously increase R&D investment in efficient and low-emission appliances and systems Complete building energy efficiency and green building technology R&D system Widespread use of independent R&D of products and technologies
Procurement	Incomplete laws and regulations about green procurement Low use of green procurement in appliances and systems	Almost eliminate equipment and products with high energy consumption and high pollution Rising use of green procurement in appliances and systems	Complete laws and regulations of green procurement Widespread use of green procurement in appliances and systems
Incentives	Incomplete incentives for the purchase and application of highly efficient systems	Increase incentive investment, refine incentive policy, build sustainable incentive policy system, and form long-term mechanism	Rising penetration of financial and non-financial incentives to encourage the production and purchase of low-emission efficient systems Build a complete long-term incentive policy system in zero-emission and highly efficient systems

Details on the policy action for appliances and systems are outlined below:

- **MEPS:** Except for Macao, the performance indicators of lighting, electrical appliances and equipment in the existing standards in the GBA are gradually being updated and improved with the needs of the national dual-carbon strategy. For high-performance products and equipment systems in buildings, China has developed standards for different levels of energy efficiency. Taking Guangdong province as an example, green buildings are divided into different star ratings, and near-zero energy buildings are divided into ultra-low energy, NZEBs, and zero energy buildings. Their related building products and equipment have different energy efficiency levels. In addition to energy efficiency grades, the existing minimum standard system is not perfect. It is necessary to supplement the formulation of minimum carbon emission indicators for high-performance products and equipment, constraining the carbon emission level of their whole life cycle. The effective implementation and popularisation of MEPS are critical to the performance improvement efforts of building products and systems in the GBA. In addition, there is no heat load in the GBA, and seasonal indicators can better reflect the actual consumption of electrical appliances during the cooling season. MEPS for building appliances will be widespread across the region by 2060.

- **Labels:** Product labels on systems and appliances can provide product performance information, including energy consumption levels and carbon emissions. Such information can remind consumers of the importance of energy conservation and low-emission, promote the popularisation of high-performance and low-carbon appliances in new and existing buildings, and phase-out low energy efficiency appliances and systems. The GBA has green buildings and building evaluation labels with different energy conservation levels and intends to supplement the building carbon emission evaluation labels in the future, especially the green/low-emission labels of building appliances and systems. Labeling schemes can be supported through educational efforts to motivate GBA buildings to move towards more low-carbon design, procurement, construction, and operation management.
- **Testing and evaluation:** The efficient operation of building equipment and systems is an effective measure to ensure a comfortable indoor environment and reduce energy consumption throughout the life cycle of the equipment. Electrical performance testing and evaluation during the building operation phase can effectively ensure the efficient operation of equipment. However, at this stage, electrical appliances in China only have factory performance test reports and lack technical guidelines for performance testing and evaluation during operation. In the long-term planning, the GBA aims to improve the monitoring and evaluation system of building appliances and systems and establish the evaluation index system for the high-quality development of the building sector, such as building appliances database and building system monitoring platform with feedback and dynamic adjustment mechanism.
- **R&D:** Build a market-oriented building energy efficiency and green building technology innovation system, and carry out scientific research and project R&D on critical links in key areas. Increased research funding can facilitate the invention of new products and services (e.g., renewable energy utilisation and smart homes) and improve the energy efficiency of building appliances and systems, while increasing the ability to bring improved technologies to market more cost-effectively. In recent years, China's scientific research investment has increased yearly. By 2060, scientific research investment and the energy efficiency of related products should be significantly improved. In the future, the GBA plans to give full play to large state-owned enterprises' R&D and application capabilities to promote strong alliances between enterprises and scientific research institutions. The GBA aims to establish technological innovation consortia between enterprises and institutions of higher learning and develop new technologies, construction methods, and materials and equipment, especially for the independent R&D of key technology and product localisation.
- **Procurement:** In recent years, China has issued some laws, regulations, and policy documents to promote green government procurement. However, the existing laws and regulations related to the government's green procurement system are not perfect, and the efficiency and intensity of green procurement need to be improved. Therefore, it is first necessary to improve the laws and regulations related to the government green procurement system and issue a government green procurement law as soon as possible to provide a legal ba-

sis for implementing green government procurement. The efficiency of green government procurement needs to be improved, and the understanding that green government procurement will help achieve the goal of carbon peaking by 2030 and carbon neutrality by 2060 needs to be deepened.

- **Incentives:** Incentive measures can be divided into financial and non-financial incentives, such as promotion rewards and plot ratio subsidies. Existing incentive policies for building energy efficiency and green buildings all take buildings as the minimum evaluation scale, which are indirect incentive policies. There is no direct incentive policy for high-efficiency equipment. The institutional system and related standards for incentive policies should be supplemented and improved in the future.

Regional Examples

Financial incentive policies in Guangdong province

Following the release of Guangdong province's 14th Five-Year Plan, multiple measures have been adopted to improve the quality of green and low-carbon development buildings. These include, among others, improving policy guarantees, implementing incentives, strengthening system construction, and promoting technological innovation. The development and application of deep integration of green building technology and prefabricated and smart technologies is to be promoted. A provincial-level achievement library of scientific and technological applications is to be established to facilitate industry-university-research cooperation in construction. Large state-owned enterprises is to play a leading role in R&D to drive critical breakthroughs in new technologies, processes, and equipment in the industry.

In addition, green financial standards and services in the Guangdong-Hong Kong-Macao GBA is to be mutually recognised. Guangdong is to cooperate with Hong Kong and Macao to research the standards, systems and products of carbon finance. Moreover, the mutual exchange of green finance standards, such as environmental information disclosure, product standards of green finance, identification standards of green enterprise projects, assessment of green credit ratings, and Green Bond Principles (GBP) in Guangdong, Hong Kong and Macao is to be promoted.

Recommended Technology Actions for Appliances and Systems

Table 23 Recommended Technology Actions for Appliances and Systems

Key Actions	Baseline (2022)	Short term (2030)	Long term (2060)
Cooling	New residential buildings with cooling electricity consumption of less than 23 kWh/(m^2a) Typical Seasonal Energy Efficiency Ratio (SEER) of room air conditioners for new buildings is 4 to 5 W/W Mainly use of Alternating Current (AC) appliances	Typical SEER of room air conditioners for Urban Environment Buildings (UEBs) is 4.5 to 5.4 W/W Rising use of electrified equipment, such as air-source heat pumps and electric cold-storage air conditioners, in public buildings Increased proportion of DC appliances	Sustained improvement of energy efficiency of appliances and systems Widespread use of electrified, low-emission, and highly efficient devices and systems
Efficient chilled-water plant system	Conducting pilot projects of efficient chilled-water plant systems	More application in large-scale public and commercial buildings	Wide application in large-scale reconstructed public buildings
Ventilation	Little use of sensible or latent heat recovery	Rising use of energy recovery with a recovery rate higher than 70% for NZEBs	Most buildings with high-energy recovery ventilation systems where appropriate
Domestic hot water supply	Typical use of gas water heaters with a Coefficient of Performance (COP) of 85% or heat pumps with a COP of 4.4 W/W	Increased application of heat pumps and Solar Water Heating Systems (SWHS)	Continuous improvement of energy efficiency Widespread use of renewable energy, such as highly efficient heat pumps or SWHS
Lighting	Most use of LEDs with luminous efficacy higher than 60 lm/W and little use of fluorescent lamps for new buildings	Widespread use of LEDs with luminous efficacy higher than 80 lm/W Significant increase in the application of intelligent lighting systems Little use of DC lighting systems	Widespread use of intelligent lighting systems and DC lighting systems
PEDF	Distributed PV is widely used in buildings, and the installed capacity of building PV continues to increase Flexible electricity technology needs to be further developed and improved	Gradually optimise the energy structure of buildings Improve the level of building electrification significantly, with electricity accounting for more than 80% of building energy consumption	Widespread construction of 'PEDF' new building power system and flexible electricity buildings
Smart systems	Low-level use of smart systems in new buildings Apps developed in many systems as end products of operation and maintenance	Rising use of smart appliances and systems based on advanced technologies, such as 5G, IoT and AI	Widespread use of smart systems with multi-terminal operation and maintenance management

Details on the technology actions for appliances and systems are outlined below:

- **Cooling:** With cooling loads throughout the year in the GBA, cooling technologies can be used to provide thermal comfort more efficiently by increasing SEER. The overall performance of a building refrigeration system depends on the efficiency of the refrigeration equipment and delivery system. Building cooling loads can be reduced through appropriate design strategies. In addition, unit energy efficiency can be improved. With the use of variable-frequency refrigeration units and the improvement of heat transfer efficiency, the refrigeration efficiency of the overall air conditioning system will increase. The cooling electricity consumption of new residential buildings is less than 23 kWh/(m^2a), and the typical SEER of room air conditioners for new buildings is 4–5 W/W. For ultra-low-energy buildings, the typical SEER of room air conditioners is 4.5–5.4 W/W, which is better for higher-efficiency buildings. With the development of electrification in China, the energy efficiency of electrified equipment, such as air-source heat pumps and electric cold-storage air conditioners, in public buildings will be optimised in the future.
- **Efficient chilled-water plant system:** It is currently designed and adopted, as a low-carbon operation measure, in large public or commercial buildings. It is welcomed by big stakeholders and will be adopted in nearly 30% of newly constructed buildings. It can achieve nearly 50% energy saving improvement in the HVAC system from system design and operation. According to estimates, 50% of large public buildings or government offices will adopt this technology.
- **Ventilation:** Controlled ventilation is essential to improve indoor air quality and thermal comfort and can be divided into three types, i.e., mechanical, natural, and mixed ventilation. In buildings, sufficient natural ventilation is typically combined with mechanical ventilation to achieve the effects of cooling, comfort and energy saving. To improve the ventilation efficiency, in the mechanical ventilation mode, the system should be equipped with energy recovery devices, which can be divided into two types, i.e., sensible heat recovery and latent heat recovery, to achieve heat exchange. The exhaust heat/cold pretreats fresh air and recovers part of the energy. At this stage, for ultra-low energy consumption buildings, the recovery efficiency of the fresh air heat recovery system should not be lower than 70%. As the research progresses, the energy recovery efficiency will be further improved, and its application scope will gradually expand to buildings with different energy consumption levels.
- **Domestic hot water supply:** Using the existing domestic hot water supply technologies, a more sustainable and efficient hot water supply can be achieved by entirely using renewable energy sources and improving system efficiency. Efficient heat pump systems, solar water heaters, and the comprehensive utilisation of biomass energy and other energy sources can be used to solve the supply of low-carbon hot water systems effectively. At this stage, the COP of typical gas water heaters is not less than 85%, and that of heat pumps is not less than 4.4. At the medium and long-term development stages, solar domestic hot water and heat pump hot water systems will be gradually widely used. Energy efficiency will also be further improved.

- **Lighting:** Lighting technology can be used to meet visual comfort more efficiently by increasing luminous flux and reduce lighting energy consumption by controlling power density. At this stage, in most places in China, LED lamps with a luminous flux of not less than 60 lm/W are used, and in some places, fluorescent lamps are used. The lighting power density of residential buildings should not be higher than 5 W/m^2. For the lighting of public buildings, an energy-saving control system should be adopted to regulate illuminance in sub-regions and subgroups to meet the comfortable indoor light environment and maximise energy savings in lighting. The DC lighting system has better safety and flexibility and is more suitable for intelligent lighting control systems. With the popularisation and promotion of Building-Integrated Photovoltaics (BIPV) system applications, the utilisation rates of intelligent and DC lighting systems will increase. The luminous flux limit of LED lighting will also increase to more than 80 lm/W.
- **PEDF:** PEDF refers to the construction of a new building power distribution system that adapts to the carbon neutral target demand through PV and other renewable energy generation, energy storage, DC distribution and flexible energy use. The PEDF can realise flexible and adjustable electricity demand, adapt to the large proportion of PV power generation access, make the building power supply and distribution system simple and efficient. In the future, the GBA will vigorously develop distributed PV, actively promote the gradual optimisation of building energy structure, and develop clean power systems and flexible power systems for buildings. Guangdong plans to increase the installed solar PV capacity of buildings by 2 million kWh, replace 8% of urban buildings with renewable energy, gradually optimise the energy structure of buildings, and make electricity consumption account for more than 80% of building energy consumption.
- **Smart systems:** The intelligent building system participates in the operation, maintenance and management of buildings and can achieve about 30% building energy savings. The intelligent building system will play an important role in realising the 30–60 Goal of China. New technologies, such as big data, AI, 5G, and the IoT, have developed rapidly in smart homes and innovative parks. However, they are rarely used in intelligent systems of public buildings. With the development of intelligent technology and empowerment of buildings, IoT products will obtain many opportunities in the intelligent systems of office and commercial buildings, the application potential of building big data will be gradually tapped, and the multi-terminal operation and maintenance management model will gradually become the mainstream.

Regional Examples

Highly efficient appliances and systems in Guangzhou

Guangzhou Infinity Plaza is located in Baiyun District, Guangzhou city, with a total construction area of 185,600 m^2. It is a low-carbon, environmentally friendly and comfortable office and commercial complex building designed based on the regional climate characteristics of Guangzhou. During the operation phase of the project, carbon emissions can be reduced by 8.7%, with 1.76 million kWh of electricity saved annually, 6,300 m3 of rainwater recycled, 3.48% utilisation of non-traditional water sources, and 37,700 t of CO_2 emissions reduced.

Various efficient construction equipment and systems have been integrated for this project. The main technical highlights are as follows. (1) Long-span hyperbolic perforated aluminium shading plates and outer galleries were used to achieve comprehensive shading and natural ventilation. (2) A translucent Ethylene Tetrafluoroethylene (ETFE) film lighting roof evaporation cooling heat insulation device was used to ensure light transmittance of 40% and filter ultraviolet rays; in addition, it is equipped with an automatic cooling system, effectively adjusting the indoor temperature, with 15% energy consumption decreased, 264,500 kWh of electricity saved annually, and 139.42 t of CO_2 emissions reduced. (3) Through fine design, load prediction, big data analysis and other measures, an efficient refrigeration room was achieved, with an energy efficiency of up to 5.5. (4) An intelligent management system was used to monitor indoor air quality parameters, such as CO_2 and PM 2.5 concentration and linkages, with a fresh air system for control. (5) Renewable energy was fully utilised, and 70% of the project's domestic hot water is provided by SWHSs. (6) Intelligent business services, such as intelligent touch elevators, intelligent parking, energy management, and WiFi in the park, were adopted to provide intelligent and efficient integrated office life.

PEDF new power system in Shenzhen

Shenzhen Future Building is located in the core boot area of Shenzhen International Low Carbon City in Longgang district, with a total investment of about 700 million RMB (approximately equivalent to 91.48 million EUR) and a total construction area of 62,900 m^2. It includes offices, conference rooms, apartments and other business areas. A steel-structure modular construction method was adopted for it. The project is a green three-star building and a net-zero energy building in regions with hot summers and warm winters.

The main technical highlights of this project are as follows. (1) Low-voltage DC power distribution technology with PEDF was used. Based on the intelligent group control technology, a terminal power module, integrating 48 V DC power supply, emergency energy storage and intelligent group control system, was developed, solving the problems of power safety protection and intelligent control of the DC distribution system and realising the organic combination of strong and weak power systems in buildings. (2) Demand-side response technology for interaction with the power grid was used. In this pro-

ject, the combination of centralised and decentralised configuration building distributed energy storage system was adopted, and the adaptive technology based on DC-bus voltage was used, solving the fluctuation problem due to the random output of the traditional AC grid PV system, which requires a PV coupling to control the stability. Therefore, the distributed PV systems and energy storage battery can be automatically adjusted by the response signal according to the requirements of the higher power grid. The project did not rely on the municipal power grid for off-grid operation for 80% of the year; the annual peak power load of the building was reduced by 64%, and the self-use rate of rooftop PV power generation was up to 97%. The system could provide an efficient, flexible and safe power supply function according to load changes and demands.

Recommended Finance Actions for Appliances and Systems

The following are several finance actions that can be used to encourage the wide application of high efficiency appliances and systems in the building and construction area.

- **Special funding incentives and subsidies:** Expand the scope of special fund support, focusing on technology research and development, demonstration project construction and promotion, standard formulation and other related work of green buildings, ultra-low energy buildings and NZEBs using advanced energy efficiency appliances and systems.
- **Green financial services:** Actively conduct green financial pilot and provide green financial services for green efficient appliances and systems through green credits, green insurance, green bonds and other means.
- **Qualification of priority recommendation:** Prioritise projects constructed with the highest level of standards (e.g., NZEBs with high-efficiency and low-emission appliances) in the evaluation of various construction engineering awards. In the evaluation of various building engineering awards, priority will be given to green buildings, ultra-low energy buildings, NZEBs and other projects using advanced energy efficiency appliances and systems.
- **Tax incentives:** Provide tax incentives to enterprises that manufacture and develop high energy efficiency appliances and systems, guide and support enterprises to actively upgrade technology and improve the energy efficiency of appliances and systems.
- **Purchase subsidy:** Consumers can buy energy-efficient appliances with trade-ins and a percentage of government subsidies.

Recommended Capacity Building Actions for Appliances and Systems

- **Strengthen the guidance and supervision of the government:** Under the guidance of the government, all sub-regions should formulate local implementation plans for efficient and low-emission building appliances and systems.

They should refine the goals and tasks, implement incentive policies, improve supervision and evaluation mechanisms, identify responsibilities, and jointly promote the development of green and low-carbon buildings.

- **Strengthen publicity and guidance:** Use newspapers, the Internet and other media to build a multi-dimensional publicity system, widely publicise laws, regulations and policy measures, such as efficient and low-carbon building appliances and systems, and vigorously promote the successful experience of advanced cities. Actively conduct publicity and training, technology promotion, information consultation, and exhibitions to create a good atmosphere for development and advocate green living consumption.
- **Strengthen professional training:** Develop professional training for design, construction, operation management and other personnel by relying on colleges and universities, vocational schools, scientific research institutes, and industry associations. The government and companies should improve the comprehensive quality of managers and employees to enable efficient equipment and systems to realise their full energy-saving potential.

Summary: Appliances and Systems

Creating a comfortable building interior environment requires the use of appliances and systems. However, while most appliances have MEPS and labels, they may not always be comprehensive. Additionally, there are various incentive policies to promote energy efficiency in buildings, but these policies do not focus specifically on appliances and systems. During the operation phase of buildings, the potential for energy saving and carbon reduction of building appliances and systems needs to be further explored by sustainable improve its energy efficiency. With the development of electrification transition in China, the distributed PV is widely used in buildings, and the installed capacity of building PV continues to increase. The intelligent building system participates in the operation, maintenance and management of buildings and can achieve about 30% building energy savings. New technologies, such as big data, AI, 5G, and the IoT, have developed rapidly in smart homes and innovative parks. However, they are rarely used in intelligent systems of public buildings. Furthermore, the R&D of appliances and systems focus on the key technology and product localisation, the energy efficiency of appliances and systems are sustainable improved. For PEDF, the flexible electricity technology needs to be further developed and improved.

Table 24 Projected timeline within Appliances and Systems

Key Actions	Baseline (2022)	Short term (2030)	Long term (2060)
Policy	Incomplete standards, labels and incentives policies systems	Sustained improvement of policies for low-emission and high-performance appliances and systems	Formulation of a sound and sustainable policy mechanism and diverse incentive policies
Technology	Insufficient penetration of smart systems and renewable energy Focus on the independent R&D of key technology and product localisation	Sustained improvement of the energy efficiency of appliances and systems Increasing rate of the key appliances' localisation rate and market share	Widespread use of high-energy-efficient technologies in appliances and systems, such as PEDF, smart systems
Finance	Various financial incentives for sustainable buildings but not focused on appliances and systems	Gradual increase in financial investment for R&D of high-efficiency appliances and systems	Building and widespread application of a sustainable system of green financial incentives
Capacity building	Lack of extensive publicity, guidance and professional training	Effective capacity building measures are in the application and promotion of appliances and systems	Gradual maturation and widespread application of the mechanism of sustainable capacity building

In the future, building appliances and systems in the GBA are progressively transforming towards low-carbon, efficient and sustainable development. In the GBA, efforts should be made to perfect relevant standards, increase the use of new technologies and renewable energy, establish sustainable long-term incentive policies, strengthen publicity, promotion and professional training, and widely apply efficient appliances and smart systems to achieve carbon neutrality in the building sector as soon as possible.

Activity Area 6

Materials

Construction activities in the building sector generate significant material flows worldwide, and the construction and demolition of buildings account for approximately one-third of global material consumption and waste generation (United Nations Environment Programme (UNEP), 2019). The production of building materials such as steel, cement blocks, and uncertified wood (a deforestation issue) is a major source of CO_2 emissions in the construction industry (Kibert, 2016). In fact, carbon emissions associated with the extraction, manufacture, and construction of building materials currently account for nearly 11% of total global emissions (United Nations Environment Programme (UNEP), 2019). Reducing the carbon embedded in major building components will be the key to decarbonising buildings in the GBA. This roadmap aims to provide policy actions, technology actions, financial actions, and capacity building measures to promote low-carbon building materials and improve the efficiency of the production process of building materials in the GBA.

Life Cycle Assessment of Building Materials

The environmental impacts of building materials and building products are central to the sustainability assessment of buildings. LCA is a multi-step procedure for calculating the lifetime environmental impact of a product or service, and it is widely used in the construction industry to assess the environmental performance of building materials. LCA considers the entire life cycle of building materials, which includes raw material extraction, manufacturing, construction, use/operation, maintenance/modernisation, conversion/reuse, deconstruction/demolition, and recycling.

The use of the EN 15978 LCA methodology would be highly relevant for assessing the environmental performance of buildings in the GBA. This is due to several factors, including the area's rapid growth and the associated environmental pressures, China's sustainability goals, the growing demand for green building certification, and the international recognition of the EN 15978 standard. LCA can help identify significant environmental impacts of buildings, support green building certification, and contribute to global efforts to reduce the environmental impact of buildings.

Table 25 Building's LCA stages as defined in the EN 15978

<table>
<tr><th colspan="14">Building assessment information</th></tr>
<tr><td colspan="13">Building assessment information</td><td rowspan="3">Supplementary Information beyond the building life cycle</td></tr>
<tr><td colspan="3">A1–3</td><td colspan="2">A4–5</td><td colspan="5">B1–7</td><td colspan="4">C1–4</td></tr>
<tr><td colspan="3">PRODUCT stage</td><td colspan="2">CONSTRUCTION PROCESS stage</td><td colspan="5">USE stage</td><td colspan="4">END OF LIFE stage</td></tr>
<tr><td>A1</td><td>A2</td><td>A3</td><td>A4</td><td>A5</td><td>B1</td><td>B2</td><td>B3</td><td>B4</td><td>B5</td><td>C1</td><td>C2</td><td>C3</td><td>C4</td><td>D</td></tr>
<tr><td rowspan="2">Raw material supply</td><td rowspan="2">Transport</td><td rowspan="2">Manufacturing</td><td rowspan="2">Transport</td><td rowspan="2">Construction installation process</td><td rowspan="2">Use</td><td rowspan="2">Maintenance</td><td rowspan="2">Repair</td><td rowspan="2">Refurbishment</td><td rowspan="2">Replacement</td><td rowspan="2">Deconstruction demolition</td><td rowspan="2">Transport</td><td rowspan="2">Waste processing</td><td rowspan="2">Disposal</td><td>Benefits and loads beyond the system boundary</td></tr>
<tr><td>Reuse
Recovery
Recycling</td></tr>
<tr><td colspan="5"></td><td colspan="5">B6 operational energy use</td><td colspan="4" rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td colspan="5"></td><td colspan="5">B7 operational water use</td></tr>
</table>

The EN 15978 defines four stages of the life cycle assessment (LCA) of buildings, which are as follows:

Stage 1: 'Module A – Preparation and pre-processing of input data': This stage includes the preparation and collection of all necessary data for the LCA, including information on the materials used in the building, the energy consumed during its construction, operation, maintenance, and end-of-life phase, and the transportation of materials and products to the building site. It also involves pre-processing this data to ensure it is compatible with the LCA software and analysis tools.

Stage 2: 'Module B – Construction': This stage covers the construction phase of the building, including the manufacturing and transport of materials, the construction process itself, and the use of energy on the construction site. It also includes any waste generated during construction and the associated environmental impacts.

Stage 3: 'Module C – Use': This stage covers the use phase of the building, including the energy consumption for heating, cooling, ventilation, lighting, and the operation of equipment and appliances. It also includes the water consumption, the generation of wastewater and solid waste, and the associated environmental impacts.

Stage 4: 'Module D – End of life': this stage covers the end-of-life phase of the building, including the demolition and disposal of the building and its components, the recovery of materials, and the environmental impacts associated with these activities.

Carbon Emissions in the Life Cycle of Building Materials

An important indicator in the whole life cycle of a building is carbon emissions. Embodied carbon is the sum of all the carbon emissions attributed to the materials throughout their life cycle, including extracting from the ground, manufacturing, construction, maintenance, and end of life/disposal (United Nations Environment Programme (UNEP), 2020). Achieving carbon peak by 2030 and carbon neutrality by 2060 is an important government strategy in China, and the life cycle of materials is an important target-oriented measure in the industrial and building sectors (Zhao et al., 2020). If appropriate software and databases are developed, they can be integrated with CO_2 trade, and through market- and government-approved policy and calculation methods, a transparent framework for carbon trade for industrial and construction uses can be established.

Status Quo and Baseline

Although several government standards on Environmental Product Declaration (EPD) and LCA have been adopted from international ISO standards, for assessing and reporting the environmental impact of building materials, the GBA currently lacks corresponding regulations, standards, or databases for the entire life cycle of building materials. While these standards provide useful guidance, they are not policy-focused and do not impose specific requirements on the industry. Additionally, the available data and information from the industry is limited, making it difficult to fully understand the environmental impact of building materials.

Table 26 Comparable GB/T standards in relation to ISO standards.

Chinese GB Standards	ISO Standards
GB/T 24001-2004 Environmental Management Systems	ISO 14001 Environmental management systems – Requirements with guidance for use
GB/T 24020-2000 Environmental Labels and Declarations – General Principles	ISO 14020 Environmental labels and declarations – General principles
GB/T 24021-2001 Environmental Labels and Declarations – Self-Declared Environmental Claims (Type II Environmental Labelling)	ISO 14021 Environmental labels and declarations – Self-declared environmental claims (Type II environmental labeling)
GB/T 24024-2001 Environmental Labels and Declarations – Type I Environmental Labelling – Principles and Procedures	Not related to any ISO standard
GB/T 24025-2009 Environmental Labels and Declarations – Type III Environmental Declarations – Principles and Procedures	ISO 14025 Environmental labels and declarations – Type III environmental declarations – Principles and procedures
GB/T 24040-2008 Environmental Management – Life Cycle Assessment – Principles and Frameworks	ISO 14040 Environmental management – Life cycle assessment – Principles and framework
GB/T 24044-2008 Environmental Management – Life Cycle Assessment – Requirement and Guidelines	ISO 14044 Environmental management – Life cycle assessment – Requirements and guidelines
GB/T 24050-2004 Environmental Management – Vocabulary	ISO 14050 Environmental Management – Vocabulary
Note: GB/T stands for Guobiao, which means National Standard in Chinese.	

Despite having a relatively well-known EPD database with software available in China, there are difficulties in collecting data from the industry. Additionally, there are a lot of standards on general principles for green product assessment for building materials, but the assessment indicators only require resource, energy, environmental, and quality attributes (e.g. environmentally friendly, energy efficient, water efficient, recyclable, low carbon, recycled, organic, limited use of hazardous substances, etc.) and do not include greenhouse gas indicators, including carbon emissions, and other environmental impact indicators. These standards include GB/T 33761-2017 for General Principles for Green Product Assessment, GB/T 35608-2017 for Green Product Assessment – Thermal Insulation, GB/T35605-2017 for Green Product Assessment – Wall Material, and GB/T35606-2017 for Green Product Assessment – Solar Water Heating System.

The China Engineering Construction Standardisation Association issues the Green Building Materials Label, which grades and certifies green building materials products according to the requirements of the Green Building Materials Evaluation Standard. The certification results are graded (from low to high) as one star, two stars, and three stars, and a total of 51 types of building material products can be certified as green building materials. There are 20 third-party certification bodies and seven testing bodies, which are all under the Green Building Materials Technical Committee.

Although there is a government standard GB51366-2019 for the calculation of carbon emissions from buildings, the issue of the life cycle of the building was not a focus in China before the two CO_2 climate targets were officially published in 2020. Supposedly, new standards for zero-carbon buildings with life cycle and software were planned to be published by the end of 2022.

The lack of initiative and motivation from the market, low awareness of impacts and options on carbon content in materials, and little data and information are significant challenges in establishing the status quo for materials in China's GBA. In addition, the traditional industrial sector and the low level of information technology in the building materials industry further exacerbate these challenges. The traditional industrial sector is known for its conventional methods and resistance to change, which poses a significant challenge in the development of the entire life cycle of building materials. The slow adoption of new technologies by the sector limits the availability of data and information on the carbon content and other environmental impacts of building materials. The low level of information technology adoption in the industry further makes it difficult to monitor and optimise the entire life cycle of building materials. However, there are promising signs of progress in this area, such as the adoption of international standards on EPD and LCA, the existence of a relatively well-known EPD database with software in China, and the government's focus on promoting green and low-carbon development in the region.

In the 14th Five-Year Plan for the development of energy efficiency of buildings and green construction in Guangdong province, the promotion of green development and application of building materials is listed as a key task, with a focus on improving the standard system and policy, improving concrete batching plants with environmentally friendly measures, and promoting the use of environmentally friendly building materials through the Green Building Materials Label. The ODP

for the Guangdong-Hong Kong-Macao GBA also outlines initiatives to promote low-carbon pilot projects, accelerate research and development of low-carbon technologies, and build a green industrial system.

As China continues to prioritise sustainable development and implement policies and standards to promote environmentally friendly practices in the building materials industry, it is expected that the status quo for materials in China's GBA will continue to evolve and improve.

Trends and Challenges

There are several trends and challenges for materials in China's GBA that must be addressed to achieve the goal of carbon neutrality in building construction. These include:

- **Precast and assembled ratio:** Both central and provincial governments in China have set higher requirements for the precast[32] and assembled ratio[33] in construction projects. For instance, the state standard GB/T51129-2015 'Evaluation standard of industrialised building' specifies that the precast ratio should not be less than 20%, and the assembled ratio should not be less than 50%. The greater or more demanding standard, the more points the project receives from the evaluation (General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, 2015)
- **Cradle to Cradle (C2C) principle:** The cradle-to-cradle principle is a crucial tool for the construction industry to achieve a continuous and consistent circular economy with building materials. This principle emphasises the use of materials that can be reused or recycled at the end of their life cycle.
- **Digitalisation:** Digitalisation is an essential tool for the management of the entire life cycle of building materials. This includes not only the production of materials but also warehouse logistics, transport in the supply chain, and tracking of products through to final disassembly and recycling.
- **Top-down strategy:** To make material recycling a matter of course in the construction sector, a top-down strategy is required to change the industry's workflows and standards. This will involve collaboration between upstream and downstream sectors of the industrial chain.
- **Integration of technology:** The GBA should leverage its strengths of policy, economy, and technology to promote the integration of the Internet, Big Data, AI, and the real economy. This will drive the transformation, modernisation, and optimal development of the industry.

32 The volume ratio of the concrete used in the prefabricated part of the main structure and the envelope above the floor level outdoors of an industrial building to the total volume of concrete used in the corresponding part.

33 The ratio between the number (or area) of prefabricated elements and components to the total number (or area) of similar elements or components in industrially manufactured buildings.

Targets and Indicators

- **Carbon footprint:** The carbon footprint of building materials is a critical target that should be addressed. This includes the embodied carbon of materials used in construction, as well as the emissions generated during the production, transportation, and disposal of materials. Indicators for this target could include the adoption of low-carbon materials, the reduction of greenhouse gas emissions throughout the supply chain, and the implementation of circular economy principles to reduce waste and promote material reuse.
- **Resource efficiency:** The efficient use of resources is another key target that should be addressed. This includes reducing the consumption of natural resources, minimising waste, and promoting the use of sustainable materials. Indicators for this target could include the adoption of recycled and bio-based materials, the reduction of waste and energy consumption during the production of materials, and the implementation of green procurement policies to promote the use of sustainable materials.
- **Health and wellbeing:** The health and wellbeing of building occupants is a critical target that should be addressed in the materials chapter. This includes the promotion of healthy and non-toxic materials, as well as the reduction of indoor air pollution. Indicators for this target could include the adoption of low-emitting materials, the use of sustainable and non-toxic insulation materials, and the implementation of air quality monitoring systems.
- **Innovation and research:** Innovation and research are critical targets that should be addressed. This includes promoting the development of new and sustainable materials, as well as the implementation of new technologies to improve the efficiency of material production and construction. Indicators for this target could include the adoption of innovative materials and technologies, the implementation of research and development programmes, and the establishment of partnerships between industry, academia, and research institutions.
- **Social responsibility:** Social responsibility is another critical target that should be addressed in the materials chapter. This includes promoting the use of sustainable materials that are produced in an ethical and socially responsible manner, as well as the promotion of fair labor practices throughout the supply chain. Indicators for this target could include the adoption of sustainable and socially responsible sourcing policies, the implementation of fair labor practices, and the establishment of partnerships with local communities.

Regional Examples for Resource Efficiency Potential

Agriculture products: Guangdong is located in the subtropical zone with high temperatures and long sunshine hours, which has natural climate conditions for high quality and high yield of rice, and a long history of rice cultivation. As one of China's 13 major grain production areas, Guangdong has achieved what is now called the 'Guangdong rice phenomenon'. The total grain production in Guangdong province in 2021 was 12.799 million t; 123,000 t more than in 2020, an increase of 1.0%, reaching the highest level in the past nine years. Due to the stable food policy[34] and high grain production, the main material potential for GBA lies in rice by-products from the harvest, namely rice straw and milling (husk).

Rice straw is a rice by-product produced when harvesting a rice paddy. It is commonly used in energy generating products (thermal: combustion/gasification/pyrolysis, etc.; chemical/bio: biogas/ethanol/hydrogen) and in non-energy generating building materials (Medium-Density Fibreboard (MDF), bricks, high-end Materials (silica/biofibre)).

Rice husks or hulls are the coating on a seed or grain of rice. It is formed from hard materials, including silica and lignin, to protect the seed during the growing season. Common products that can be derived from rice husk include solid fuel in various forms such as loose, briquettes, and pellets. Another potential product is carbonised rice husk, which is produced after burning and used as a raw material or binder. Additionally, rice husk ash is a by-product of combustion and can be used, among other things, as a cement substitute, in bricks, as filler, or for waterproofing (Huang, et al., 2021).

Forestry products: China's timber industry has a long history of development, and in 2021 Guangdong's timber production was 10.17 million m^3, accounting for 10.29% of the total national timber production, ranked second in China. The 14th Five-Year Plan for the development of the forestry industry in Guangdong province specifies that by 2025, the total output value of the forestry industry in the province is projected to reach 1 trillion RMB (approximately 131 billion EUR), the support capacity of forest resources will be significantly enhanced, and a modern forestry industry development system will be built. This will provide a solid supply base for timber for building materials in the GBA (Forestry Administration of Guangdong Province, 2021).

34 The 'stable food policy' refers to existing government policies aimed at ensuring food security and maintaining stable food supplies in the region. These policies include measures such as subsidies for farmers, price controls, and stockpiling of grain reserves.

Aquaculture products: Guangdong is a major fishery province, with synergistic development in the field of mariculture and freshwater aquaculture, both of which are in the leading position in the country. In 2021 Guangdong province's total aquatic production of 8,844,900 t, including 7,568,100 t of aquaculture, ranked first in China. In the future, Guangdong province will continue to strengthen the protection of aquaculture resources, promote the transformation of aquaculture towards environmental sustainability, and build an ecologically harmonious development space. By 2025, the province's total fishery economic output will reach more than 450 billion RMB (approximately 58 billion EUR), the total aquatic product output will remain above 9 million t, the aquatic product processing rate will reach more than 30%, the core aquatic seed self-sufficiency rate will reach more than 80%, and a model national aquaculture economic zone will be built. By-products from the aquaculture industry may also have potential for use in building materials, including chitosan from shrimp and crab shells, collagen from fish scales for biodegradable plastics, and calcium carbonate from seashells for biocement (People's Government of Guangdong Province, 2022), (Sina Finance, 2021).

In summary, the by-products from the agricultural and forestry industries, namely rice straw, rice husk, and timber, have the potential to be utilised as building materials. Rice straw can be used to produce MDF, bricks, and high-end materials. Rice husks or hulls can be transformed into various forms of solid fuel. Carbonised rice husk and rice husk ash are also potential products in the construction industry. The availability of timber for building materials is expected to increase as the province aims build a modern forestry industry by 2025. Finally, aquaculture products can reduce waste, promote sustainability, and create economic opportunities in the GBA. By utilising these by-products, the building sector of the GBA can enhance its resource efficiency and contribute to a more sustainable and circular economy.

Key Roadmap Actions for Materials

Table 27 Key Actions and timelines for Materials

Current status (2022)	Necessary actions towards long-term goal	Long-term goal
No official software for LCA No official government database of EPD No official material database with label from life cycle Low awareness of impacts of embodied carbon in materials Lack of financial support Lack of motivation from market	A central government initiative is required to integrate building standards with carbon indicators, stimulate markets for low-carbon products and materials, promote reuse and recycling, support the circular economy, provide information and raise awareness, as well as support research, development, and innovation.	100% of new buildings with at least zero carbon standard, some are plus-energy houses 80% of refurbishment buildings with zero carbon standard

Key actions to enable increased sustainability of materials in buildings and buildings products include:

- **Initiative from central government:** The central government needs to take initiative and implement policies and measures to promote the use of environmentally friendly life-cycle building materials. This can be achieved by funding projects that pioneer the adoption of green building materials and creating a series of demonstration projects for their application.
- **Accelerating energy efficiency in industry:** the Ministry of Industry and Information Technology (MIIT) in China should focus on standard development with an emphasis on carbon reduction and energy efficiency in both production and the supply chain, to accelerate energy efficiency in industry.
- **Integrate building standard with carbon indicator:** To integrate building standards with carbon indicators, a state standard should be published first, followed by the requirement for more widespread standards at the provincial level, with adaptation to respective climate zones.
- **Stimulating markets for low-carbon products and materials:** The government should stimulate markets for low-carbon products and materials by implementing push factors such as carbon pricing or tax incentives, and develop policies to ensure that all LCA public buildings calculate and use low-carbon materials.
- **Reuse and recycling:** strategies should be developed for the reuse of demolished components, and processes for deconstruction and waste sorting should be improved. Additionally, the government should support the development of material reuse and recycling processes for products and materials to reduce energy and emissions in the life cycle. This can be achieved by providing funding or policy subsidies in the form of grants for the establishment of building materials recycling and logistics companies.
- **Promote the circular economy:** The government should promote the circular economy in the building sector by developing cradle-to-cradle concepts for the entire life cycle, enabling a systemic, material-neutral, and performance-based approach and business models, and integrating life cycle thinking into planning and design processes.
- **Providing information and raising awareness:** To raise awareness, the government should launch a multifaceted campaign and commission an agency to set up an information platform on the entire life cycle of materials for communication, promotion, and technology exchange.
- **Supporting research, development and innovation:** The government should also support research, development, and innovation in construction materials, industry, buildings, and logistics, as well as data collection, software development, digitalisation, and innovative technology.

Recommended Policy Actions for Materials

Table 28 Recommended Policy Action and timelines for Materials

	Baseline (2022)	Short term (2030)	Long term (2060)
LCA	No official software and database for LCA	A market recognised software and database for LCA 30% of projects use LCA	A state-designated software or several recognised software products with the same calculation methods and a state-recognised database All projects use LCA
EPD	No official creation point No state database of EPD	An official creation point One of the most used databases for EDP	A state unified database for EDP
Material labelling	No official material database with label from life cycle	A country-sponsored materials database with life cycle label for most building materials	A complete materials database with life cycle labels
Building standards	Only one building life cycle standard, GB51366-2019, for the calculation of carbon emissions from the building life cycle	Some life-cycle building standards from provincial level as pioneers	Each province has its own building standard with life cycle
Research and development (R&D)	Low investment in R&D for low-carbon materials and resource efficiency	Increased investment and regional cooperation in data collection and research	
Incentives and procurement	No subsidies for the use of low-carbon materials in public procurement	Increased promotion for consumers and producers Legal requirement for public procurement	

Key policies to enable increased sustainability of materials in buildings and buildings products include:

- **LCA:** The Chinese government collaborates with research institutes and companies to develop standards, software, and a database for LCA of buildings. The database used is the Chinese Reference Life Cycle Database (CLCD), which is expected to be compatible with international databases such as Ecoinvent[35], European Reference Life Cycle Database (ELCD), Gabi[36], and U.S. Life Cycle Inventory (LCI).
- **EPD:** The government should commission a third-party organisation to carry out an official process for the creation of an EPD, such as EPD China. An EPD is a verified and registered document that communicates transparent and comparable information about the environmental impacts of a product or service across its entire life cycle. The EPD should follow international standards, such as ISO 14025 and EN 15804, to ensure its credibility and comparability.

35 The world's leading LCA database developed in Switzerland.

36 A life cycle assessment software developed in Germany.

By creating an official EPD process, the government can promote the use of EPDs in the building sector and provide reliable information to consumers and manufacturers.

- **Material labelling:** The government should integrate the embodied carbon indicator with the current green building materials label. The current green building materials label is a voluntary label that recognises products with low environmental impacts in terms of resource consumption, pollution, and health. By adding the embodied carbon indicator, the label can communicate the carbon footprint of materials and encourage the use of low-carbon materials. The government should also provide clear guidance on how to calculate and verify the embodied carbon of materials.
- **Building standards:** The government should publish a national standard for green building with a life cycle approach as a benchmark for further development of provincial standards. The national standard should cover both new and existing buildings and address the full range of environmental impacts, including energy consumption, water use, indoor environment quality, and material impacts. The standard should also provide clear guidance on how to calculate and verify the life cycle impacts of buildings. The provincial standards should be adapted to the local climate and context but should not deviate significantly from the national standard. By providing a clear and comprehensive standard, the government can promote the adoption of green building practices across the country.
- **R&D:** The government should increase investment in R&D for low-carbon materials and resource efficiency. This could involve providing funding for universities, research institutions, and private companies that are working on developing and testing new technologies and materials.
- **Incentives and procurement:** To encourage the adoption of higher standard materials, reuse and recycling, the government could offer various incentives to both consumers and manufacturers. For example, tax breaks could be given to companies that use recycled materials in their products or that invest in research and development of low-carbon materials. Consumers could also receive tax breaks or other incentives for choosing low-carbon products. In addition, the government can act as a role model by mandating the procurement of low-carbon materials for government projects. This can help to create a market for these materials, and demonstrate the government's commitment to reducing its carbon footprint.

Recommended Technology Actions for Materials

Table 29 Recommended technology action and timelines for Materials

	Baseline (2022)	Short term (2030)	Long term (2060)
Reduce carbon	Embodied carbon is not yet the focus of the building's life cycle	New buildings with a net zero carbon standard in operational phase	New buildings with net zero carbon standard throughout the life cycle
Material efficiency	'Green building materials' label	Embed efficiency and carbon content of the material as measurable and more calculable indicators in the 'green building materials' label	80% building materials have the label
Energy manufacture	'Action Plan to Improve Energy Efficiency in Industry' in June 2022	Development and use of technical solutions	-10% energy use for cement and -20% for steel
Local material alternative	Due to the unequal economic situation of the provinces, there is no effective local supply chain	Local supply chains by using the province as a radial area for local main materials	
Tools for efficiency	Digitisation of building materials and BIM technology	Digitisation of building materials and BIM technology	Widespread use of tools such as BIM, standardisation, prefabrication, etc.

Key technology to enable increased sustainability of materials in buildings and buildings products include:

- **Reduce embodied carbon:** Standards for building life cycles must be further developed. The associated software and databases are to be created. By 2030, all new buildings should be built with a net zero carbon standard in the operational phase. By 2060, all new buildings should be built with net zero carbon standard in the whole life cycle. It can start from a few pilot provinces first.
- **Material efficiency:** Continuous improvement of the energy saving rate in the production of materials by optimising the production process. This includes a more disassembly-friendly combination method through the way materials are combined to achieve optimal recycling and reuse. And this should be embedded as measurable and calculable indicators in the 'green building materials' label.
- **Energy efficiency in manufacture:** Strengthen the optimisation of energy systems, the use of waste heat and pressure, the use of renewable energy and the renovation of public facilities and ancillary facilities in key industries. Fully exploit the impact of digital technology on energy efficiency in industry, promote the construction of an energy control system with state awareness, real-time analysis, scientific decision-making and precise execution, and accelerate the digitalisation of production methods.[37]

37 Action plan to improve energy efficiency in industry.

- **Local material alternatives:** The government should encourage the establishment of novel regional production and supply chains based on local needs and commonly used materials in each province. This approach could help reduce costs and improve the availability of materials while also promoting sustainable practices.
- **Tools for resource efficiency:** The use of simulations, production calculations and traceability tools can help promote resource efficiency and reduce waste throughout the material life cycle. The development of such tools would enable manufacturers, builders, and regulators to make more informed decisions based on data-driven insights. The government could support the development and adoption of such tools by providing funding and technical assistance to developers, as well as through policy measures such as regulations and incentives.

Recommended Finance Actions for Materials

Financial tools particularly relevant to materials include:

- **Urban development funds:** These funds are aimed at promoting sustainable urban development projects that prioritise the use of low-carbon materials and resource efficiency. By allocating specific funding to such projects, the government can encourage the private sector to invest in sustainable building and infrastructure development.
- **Investment fund and subsidies:** This refers to the creation of a special fund dedicated to supporting the development of green building plans, research and development of technologies and products (such as efficient equipment and systems), construction and promotion of demonstration projects, and development of standards. These funds can also be used to offer subsidies to incentivise the use of sustainable materials and practices in construction projects.
- **Green financial services:** Green financial services are designed to facilitate the implementation of sustainable building projects by providing funding and financial support for buildings and neighbourhoods that use more green materials. This could include green bonds or other innovative financial instruments that are specifically tailored to support sustainable building projects.
- **Incentives:** Tax incentives can be used to promote the development of new technologies, processes, and building materials that are more sustainable and environmentally friendly. This could help reduce the costs associated with research and development, making it more attractive for companies to invest in sustainable building solutions.
- **Carbon pricing:** Carbon pricing is a policy tool that puts a price on carbon emissions, encouraging companies to reduce their carbon footprint and shift towards low-carbon alternatives. This would be particularly relevant for materials like cement and steel, which are high-emitting and difficult to decarbonise.
- **Commissioning:** Commissioning is a process that involves verifying and documenting that a building's systems and equipment are designed, installed, and operate according to the owner's requirements and that the systems are energy-efficient and sustainable. This process can help identify opportunities for reducing waste and improving the performance of building materials, ensuring that they are used in the most sustainable and efficient way possible.

Recommended Capacity Building Actions for Materials

The following are the recommended capacity-building actions for materials in the GBA:

- **Training for government officials:** One of the key capacity-building activities is to train government officials on the standards and labels for materials and construction projects, such as LCA, EPD, Zero Carbon Standard, and C2C. These tools are essential to raise awareness among builders and consumers, enabling them to make better decisions and promote lower carbon construction.
- **Professional training for building practitioners:** Another vital capacity-building activity is to provide professional training for architects, building services engineers, energy consultants, software developers, property staff, manufacturers, contractors, and property managers. This training should include assessing embodied carbon, using EPDs, conducting LCA, adapting design and construction techniques to reduce embodied carbon in construction, proper end-of-life planning, and other circular design principles. It is also important to collect and analyse data so that databases and resource platforms can be established to increase knowledge on sustainable building materials. Finally, certification or accreditation should be provided for sustainable construction professionals.
- **Training for producers:** The third key capacity-building activity is to provide training to the industry on how to reduce the embodied carbon of materials and buildings, improve the efficiency of manufacturing and construction processes, increase the use of local materials, plan for end-of-life, increase recycling and reuse, and comply with labelling guidelines and EPDs. Such training would help producers adopt best practices in the industry and contribute to the reduction of carbon emissions.

Summary: Materials

The construction industry is responsible for a significant amount of global material consumption and waste generation, with the production of building materials being a major source of CO_2 emissions. To address this, policies such as the development of a life cycle assessment database, official environmental product declaration processes, and incentives for sustainable building practices are necessary. Strategies such as reducing embodied carbon, improving material efficiency, and promoting the use of local materials can increase sustainability in building materials and products. Financial tools such as urban development funds, investment funds, and carbon pricing can also encourage sustainable building practices. Finally, capacity-building activities such as training for government officials, building practitioners, and producers can increase awareness and knowledge of sustainable building practices, circular design principles, and compliance with labeling guidelines and EPDs. By implementing these policies, strategies, financial tools, and capacity-building activities, the government can promote sustainable building practices, reduce carbon emissions, and support the development of sustainable building materials and products in the GBA.

Activity Area 7

Resilience

Status Quo and Baseline

Urban resilience is a crucial factor in ensuring the long-term sustainability and liveability of urban areas, especially in megaregions such as the GBA. It refers to the capacity of urban and peri-urban systems to adapt to unplanned climatic, socio-economic, and environmental stressors in a holistic and sustainable way (UN-Habitat, 2018). Addressing urban resilience in the GBA is crucial due to the region's unique and complex challenges and requires a multidisciplinary and integrated approach involving various stakeholders, including government, academia, civil society, and the private sector.

Current Conditions

The GBA is a rapidly developing region with a high population density, which exposes it to various environmental, social, and economic stressors. To evaluate the region's resilience, the cross-cutting nature of these stressors should be considered.

- **Environmental stressors:** The GBA is facing challenges related to air pollution, water pollution, and habitat degradation, especially in marine and forest areas near industrial zones in Guangdong province. Extreme weather events such as typhoons, heavy rainfall, and flooding have also become more frequent due to global warming and urbanisation. For instance, in the north-western part of the GBA, droughts and wildfires have become more frequent due to these factors. In the north-east, snow-cover changes have affected infrastructure and tourism. Similarly, the south-western cities have experienced subway flooding, mudslides, and freshwater disruptions due to heavy rains. Moreover, the southern port cities have suffered from power and internet outages caused by tropical cyclones, typhoons, and tornadoes.
- **Social stressors:** Intense urbanisation in the GBA adds pressure on natural resources, increases energy consumption, and exacerbates the Urban Heat Island (UHI) effect[38]. The population growth and increased demand for housing, transportation, and infrastructure have led to the rapid expansion of urban areas, leading to pressure on natural resources and the environment. The UHI effect has become a major problem in cities such as Guangzhou, Shenzhen, and Hong Kong, where urbanisation has led to the loss of green spaces and the increase of impervious surfaces, exacerbating the urban warming effect. The COVID-19 pandemic has highlighted the importance of urban resilience, as it has disrupted the region's economy and social fabric. The pandemic has also exposed the vulnerabilities of the region's healthcare system and highlighted the need for greater investment in public health infrastructure.
- **Economic stressors:** The GBA's economy heavily relies on its manufacturing industry, which contributes significantly to the region's GDP. However, the recent trade tensions between China and the United States have had a significant impact on the region's economy, as the region serves as a crucial hub for trade between the two countries. Additionally, the COVID-19 pandemic has

38 The urban heat island effect is a phenomenon where urban areas are warmer than their surrounding rural areas due to human activities like construction, transportation, and industrialisation.

disrupted global supply chains, which has further affected the manufacturing industry in the GBA. The region is also vulnerable to natural disasters, which can disrupt trade and commerce, causing significant economic losses.

Current Practices

Despite the interdependence of different stressors in the GBA region, current approaches to addressing them often focus on individual areas or issues. Urban resilience challenges often include the key areas of population growth, deteriorating infrastructure, the impacts of climate change, economic inequality, and rapid urbanisation. Below is a breakdown of each of these as they relate to the GBA.

- **Population growth:** The GBA is facing rapid population growth, causing strain on its infrastructure and resources, which could impact the region's resilience. To address this challenge, the ODP has been proposed, emphasising collaboration among different regions and cities in the GBA to enhance regional resilience, promote sustainable transportation systems, reduce carbon emissions, and enhance water resource management. Circular economy principles have also been proposed to reduce waste and promote resource efficiency. However, the effectiveness of these measures may be limited by challenges in achieving collaboration among different regions and cities due to political and economic differences, limited feasibility of investment, and practicality challenges in some industries.
- **Infrastructure:** The GBA is experiencing rapid growth, which has led to significant infrastructure challenges, such as transportation bottlenecks and housing affordability issues. To address these challenges, the local governments in the GBA have implemented various initiatives, including the Sponge City programme, green corridors, and circular economy industrial parks, to enhance urban resilience and improve infrastructure. However, the effectiveness of these initiatives is subject to debate, as they may not necessarily address the root causes of the challenges. Further research is needed to determine the long-term effectiveness of these initiatives in enhancing the GBA's infrastructure resilience.
- **Climate change:** The GBA is vulnerable to climate change impacts, including sea-level rise, extreme weather events, and other natural disasters, which could pose a significant threat to the region's resilience. The region's heavy dependence on fossil fuels has contributed to air pollution, which exacerbates the impacts of climate change (Tian et al., 2020). To address these challenges, the 2019 ODP emphasises the importance of promoting ecological conservation, developing green infrastructure, and improving disaster prevention and mitigation measures (Development Bureau, 2019). The plan proposes incorporating green roofs, walls, and facades into building design to mitigate the UHI effect and improve air quality. These measures align with global best practices for green infrastructure and have been shown to have positive impacts on climate change adaptation and mitigation (International Energy Agency (IEA), 2018). However, it remains to be seen how effectively the proposed measures will be implemented in the GBA context and how much they will contribute to improving the region's resilience.

- **Economic inequality:** Economic inequality is a significant challenge in the GBA, which may impact the region's resilience. The area has significant disparities in wealth and development, making low-income households and migrant workers more vulnerable to disasters, with limited access to resources and support. To promote urban resilience and tackle economic inequality, various measures have been taken, such as the development of affordable housing and community centres. However, these initiatives may not fully address the root causes of the issue, such as land and property rights that perpetuate inequality, and cultural and linguistic barriers faced by migrant workers in accessing services and support. Therefore, although the measures are commendable, they may not be sufficient to tackle the underlying challenges and achieve robust long-term resilience in the region.
- **Urbanisation:** The GBA is undergoing rapid urbanisation that is leading to the displacement of communities, the loss of green space and cultural heritage sites, and the exacerbation of the UHI effect. To mitigate these negative impacts, sustainable urbanisation, green infrastructure development, and conservation of cultural heritage sites have been proposed as solutions. However, these strategies may not be sufficient given the region's high population density and rapid urbanisation, political and financial constraints, and potential unintended consequences. Therefore, additional efforts should be made to address these challenges, such as prioritising infrastructure development and monitoring potential unintended consequences. These measures promote sustainable development, reduce the negative impacts of urbanisation, and enhance the region's ability to adapt to change.

Baseline

While there have been several efforts to assess the GBA's overall resilience, to date there has been no established baseline for measuring its urban resilience progress towards sustainability goals. This is, however, an essential step towards achieving sustainability goals and addressing existing vulnerabilities.

In the context of buildings and construction in the GBA, some of the key areas have already been partially addressed by the ODP and other targeted legislations and measures (Hong Kong Trade Development Council, 2020). Given the multi-disciplinary nature of resilience for buildings and construction, as well as the sub-regional particularities of the chain of mega-regions that comprise the GBA, it is challenging to establish a comprehensive baseline for measuring progress towards sustainability goals in this activity area. While several organisations and institutions[39] have conducted studies and assessments on the GBA's sustainability

39 The United Nations Development Programme (UNDP) and the Guangdong Provincial Government jointly launched the 'Sustainable Development Goals (SDGs) Localization and Planning' project in 2020, which aims to support the GBA in achieving the SDGs. The project includes a comprehensive assessment of the GBA's baseline status with regard to the SDGs and identifies key priority areas for sustainable development. Further, a study conducted by the University of Hong Kong in 2018 analysed the GBA's resilience to natural disasters and identified areas that require improvement, such as emergency response mechanisms and the availability of disaster risk information (Li et al., 2018).

and resilience, their focus may vary widely, and the unique features of each sub-region may not be fully accounted for in these assessments. Therefore, it remains important to continue efforts to establish a comprehensive baseline that can account for these complexities and guide progress towards sustainability goals in the GBA.

Trends and Challenges

To overcome the challenges posed by the key conditions in the GBA region, an integrated approach is required. This approach should recognise the interconnections between different stressors and activity areas and promote collaboration and coordination across sectors.

- **Infrastructure:** The trends for infrastructure in the field of resilience in the GBA region are positive, as local governments are implementing initiatives aimed at enhancing urban resilience and improving infrastructure. However, there are significant challenges that need to be addressed, including transportation bottlenecks and housing affordability, which have implications for the region's resilience in responding to emergencies and other disruptions. Further research is needed to determine the long-term effectiveness of the initiatives in enhancing the GBA's infrastructure resilience.
- **Climate change:** The GBA faces significant challenges related to climate change impacts and achieving sustainability in the buildings and construction sector. The trends of incorporating green infrastructure and regional collaboration show promise in addressing these challenges, but more concrete actions and solutions are needed to enhance the region's resilience. Technical, economic, social, and political factors may also pose obstacles that need to be overcome to achieve sustainability in the buildings and construction sector.
- **Economic inequality:** The trends towards affordable housing and community centre development are positive developments in the GBA. However, the challenges related to economic inequality and the limited scope of measures taken to address them must be addressed to achieve robust long-term resilience in the region. Political factors, such as government policies, play a critical role in promoting urban resilience and addressing these challenges.
- **Urbanisation:** in the context or resilience is a major challenge in the GBA region, but there are also promising trends that could help address some of its negative impacts. One such trend is the rise of compact, mixed-use development, which can help reduce the need for car use, improve public transport options, and enhance walkability and cycling infrastructure (Organization for Economic Co-operation and Development (OECD), 2012). This approach can also help promote social and economic diversity, which can contribute to greater resilience in the face of change.

  Another trend is the growing focus on green and blue infrastructure, such as parks, green roofs, and water management systems. These solutions can help mitigate the negative impacts of urbanisation, such as the UHI effect, air and water pollution, and flooding (Ying, et al., 2022). In addition, efforts to preser-

ve and integrate cultural heritage sites into urban development can help maintain a sense of community identity and support sustainable tourism (Tweed, et al., 2007).

However, there are also ongoing challenges related to urbanisation in the GBA. These include issues such as loss of green space and natural habitats, high population density and rapid urbanisation, political and financial constraints, and unintended consequences of urban development (Lian, et al., 2022). To address these challenges, an integrated approach is needed that recognises the interconnections between different stressors and activity areas and promotes collaboration and coordination across sectors.

Targets and Indicators

Targets for building resilience include establishing a baseline for sustainability goals, measuring progress through indicators that focus on social equity and collaboration among stakeholders. The indicators can track the effectiveness of policies and regulations promoting sustainability and resilience.

Targets for building resilience in the GBA include reducing reliance on the manufacturing industry and mitigating climate change through sustainable urban design practices. Indicators such as the share of manufacturing in the economy, adoption of sustainable design practices, and greenhouse gas emissions can be used to track progress.

Strategies for reducing vulnerability to environmental stressors in the GBA include implementing green infrastructure, promoting sustainable land use practices, and encouraging clean energy sources. Indicators such as frequency and intensity of extreme weather events and pollution levels can track progress.

Targets for biodiversity conservation in the GBA include increasing green spaces, protected areas, and wildlife habitats, and promoting sustainable land use practices. Indicators such as the area of protected natural areas and the extent of green spaces can be used to track progress.

Improving social equity in the GBA involves increasing healthcare capacity, ensuring equitable access to healthcare, and investing in pandemic preparedness. Indicators such as availability and accessibility of public health infrastructure and resilient communities and businesses can track progress.

Strategies for improving social resilience in the GBA include promoting green roofs, increasing green spaces, and adopting sustainable transportation practices. Indicators such as the UHI effect and access to affordable housing, transportation, and infrastructure can track progress.

To promote a multidisciplinary and integrated approach, stakeholders should recognise interconnections between different stressors and encourage collaboration and coordination across sectors. Indicators such as the level of coordination and collaboration and the degree of integration of resilience measures can track progress.

Key Roadmap Actions for Resilience

The long-term goal is to ensure that the GBA is able to withstand and recover from any disruptive event, including natural disasters, economic downturns, and pandemics. By adopting a holistic approach to resilience that includes risk assessment, resilient design principles, updated building codes and standards, infrastructure investment, and collaboration among stakeholders, the GBA can build a strong foundation for long-term resilience.

Table 30 Key Roadmap Actions for Resilience

Key actions	Necessary actions towards long-term goal	Long-term goal (2060)
Risk assessment	Identify and evaluate potential hazards and risks to buildings and infrastructure	All buildings and infrastructure in the GBA are designed, constructed, and maintained to withstand and recover from natural disasters and other disruptive events
Resilient design principles	Incorporate resilience into building and infrastructure design and construction	All new buildings and infrastructure in the GBA are designed and constructed using resilient design principles that prioritise safety, durability, and adaptability
Building codes and standards	Update building codes and standards to include resilience requirements	All buildings in the GBA meet or exceed updated building codes and standards that prioritise resilience
Resilient infrastructure	Develop and maintain resilient infrastructure	The GBA has a well-maintained and resilient infrastructure network that supports economic growth and ensures the safety and well-being of its residents
Foster collaboration	Foster collaboration among stakeholders and promote a culture of resilience	A culture of resilience is ingrained in the GBA, and all stakeholders work together to ensure the region is prepared for and able to recover from disruptive events

Recommended key actions for resilience include:

- **Risk assessment:** Conducting risk assessments can help identify potential hazards and risks to buildings and infrastructure in the GBA, and develop plans to mitigate and respond to them.
- **Resilient design principles:** Adopting resilient design principles can help design buildings and infrastructure to withstand natural disasters and other disruptive events, which are common in the GBA.
- **Building codes and standards:** Enhancing building codes and standards to include resilience requirements can help ensure that buildings in the GBA are built to withstand disasters and continue to function after them.
- **Resilient infrastructure:** Investing in resilient infrastructure like roads, bridges, and public transportation can help the GBA to maintain its connectivity and mobility during disasters. Green infrastructure like parks and green roofs can mitigate the impacts of climate change on the GBA, and integrating smart technology can improve the efficiency and resilience of infrastructure systems.

- **Foster collaboration:** Fostering collaboration among government, industry, and community organisations in the GBA to facilitate information sharing and awareness about the importance of resilience.

Recommended Policy Actions for Resilience

Policies play a critical role in promoting resilience in buildings and construction, as they can set the regulatory framework, standards, and incentives for stakeholders to prioritise resilience in their activities. The recommended actions provided involve various policy measures, such as the development and implementation of building codes and standards, public-private partnerships, and the integration of resilience into urban planning and design.

Table 31 Recommended Policy Actions for Resilience

	Baseline (2022)	Short term (2030)	Long term (2060)
Risk assessment	Establish a comprehensive risk assessment framework	Continued evaluation and adjustment of risk assessment framework	Continued evaluation and adjustment of risk assessment framework
Building codes	Develop and implement building codes and standards	Upgrade existing buildings to meet resilience standards	Integrate resilience and sustainability into urban planning
Resilient tech	Encourage use of resilient construction materials	Promote public-private partnerships for resilient tech	Develop innovative building technologies that prioritise resilience
Awareness	Enhance public awareness of resilience importance	Develop and implement early warning systems and disaster plans	Enhance international cooperation and knowledge sharing
Emergency response	Develop a policy framework for emergency response	Implement a comprehensive emergency response system	Integrate the emergency response system with other resilience systems in the region
Monitoring and evaluation	Develop a policy framework with key indicators and metrics for monitoring and evaluating resilience policies and initiatives	Establish a continuous improvement process	Enhance the monitoring and evaluation system to cover emerging risks and challenges

Recommended policy actions for resilience include:

- **Risk assessment:** A comprehensive risk assessment framework can prioritise potential hazards and risks faced by buildings and infrastructure in the GBA.
- **Building codes:** Developing and implementing building codes that incorporate resilience requirements can promote the use of resilient construction materials and enhance safety and resilience in the GBA.

- **Resilient tech:** Encouraging the use of resilient construction materials and innovative building technologies can enhance the durability and functionality of buildings and infrastructure in the GBA.
- **Awareness:** Enhancing public awareness through education and outreach campaigns, establishing early warning systems, and disaster plans can improve the readiness and response of the GBA to natural disasters and other disruptions.
- **Emergency response:** To enhance emergency response in the GBA, a comprehensive emergency response system should be developed based on a policy framework that involves all relevant stakeholders. This system should be continuously improved by conducting exercises, updating it with new technologies, and integrating it with other resilience systems in the region.
- **Monitoring and evaluation:** To effectively monitor and evaluate the effectiveness of resilience policies and initiatives, a policy framework should be established that outlines key indicators and metrics. A continuous improvement process involving all stakeholders should be implemented to regularly assess the effectiveness of policies and initiatives, identify gaps and challenges, and propose solutions. The monitoring and evaluation system should be enhanced by incorporating new technologies, data analytics, and AI, and expanded to cover emerging risks and challenges.

Recommended Technology Actions for Resilience

Table 32 Recommended Technology Actions for Resilience

	Baseline (2022)	Short term (2030)	Long term (2060)
Seismic retrofitting	Conduct seismic assessments of existing buildings	Prioritise seismic retrofitting of high-risk buildings	Retrofit all buildings to withstand major earthquakes
Green infrastructure	Implement green roofs and walls to reduce UHI effect	Increase use of green infrastructure in new projects	Make green infrastructure mandatory for all projects
Smart building tech	Install smart sensors for energy and water management	Use AI-powered building management systems	Develop interconnected smart buildings for resilience
Renewable energy	Install solar panels for on-site energy generation	Increase use of renewable energy in new projects	Transition to 100% renewable energy in all buildings
Disaster response	Develop emergency response plans for major disasters	Conduct regular disaster drills and simulations	Establish regional coordination for disaster response

Recommended technology actions for resilience include:

- **Seismic retrofitting:** Identify high-risk structures and retrofit them to improve their ability to withstand earthquakes. Ensure all buildings meet seismic building codes to withstand major earthquakes.

- **Green infrastructure:** Use green roofs and walls to reduce heat island effects and improve air quality. Make green infrastructure mandatory for new projects to promote sustainable and resilient urban development.
- **Smart building tech:** Install smart sensors for energy and water management. Develop interconnected smart buildings for resilience to improve communication and coordination during emergencies.
- **Renewable energy:** Install solar panels for on-site energy generation to reduce reliance on fossil fuels. Increase use of renewable energy in new construction projects to promote sustainability and resilience.
- **Disaster response:** Develop emergency response plans and conduct regular disaster drills to improve preparedness and response times. Establish regional coordination for disaster response to improve efficiency and effectiveness of response efforts.

Recommended Finance Actions for Resilience

Table 33 Recommended Finance Actions for Resilience

	Baseline (2022)	Short term (2030)	Long term (2060)
Risk assessment	Conduct a comprehensive risk assessment of buildings in the GBA to identify potential hazards and vulnerabilities	Regularly review and update risk assessments to reflect changing climate and environmental conditions	Conduct regular risk assessments in line with the latest scientific data and modelling
Resilience upgrades	Develop a plan to invest in upgrades to buildings and infrastructure in areas identified as high risk in the risk assessment	Increase funding for resilience upgrades and incentivise property owners to make resilience investments	Expand investment in resilience upgrades to cover all vulnerable areas and buildings
Resilience fund	Establish a dedicated resilience fund to support resilience investments and incentivise private sector participation	Expand the resilience fund to cover a wider range of projects and support research and innovation in resilience	Ensure the resilience fund is sustainable and able to support resilience investments in the long term
PPPs	Develop PPPs to leverage private sector resources and expertise in resilience investments	Expand PPPs to cover a wider range of projects and promote innovation in resilience	Develop a comprehensive PPP framework to support resilience investments across the GBA
Resilience insurance	Promote the use of resilience insurance as a tool to manage risks and reduce the financial impact of disasters	Expand the availability of resilience insurance and increase public awareness of its benefits	Ensure resilience insurance is affordable and accessible to all residents and businesses in the GBA

Recommended finance actions for resilience include:

- **Risk assessment:** Conducting risk assessments to identify potential hazards and vulnerabilities of buildings can help prepare for changing climate and environmental conditions in the GBA.
- **Resilience upgrades:** Investing in resilience upgrades in high-risk areas can help mitigate the impact of disasters on buildings and infrastructure, and incentivising property owners to make resilience investments can help achieve this goal.
- **Resilience fund:** Establishing a dedicated resilience fund can support resilience investments and promote private sector participation, while also supporting research and innovation in resilience.
- **PPPs:** Developing PPPs can leverage private sector resources and expertise in resilience investments, promoting innovation and supporting resilience investments across the GBA.
- **Resilience insurance:** Promoting resilience insurance can help manage risks and reduce the financial impact of disasters, making it more affordable and accessible to all residents and businesses in the GBA.

Recommended Capacity Building Actions for Resilience

Table 34 Recommended Capacity Building Actions for Resilience

	Baseline (2022)	Short term (2030)	Long term (2060)
Resilience guidelines and standards	Develop and publish guidelines and standards for building resilience in the GBA, taking into account regional climate, topography, and geology	Continuously update guidelines and standards to incorporate new technologies and knowledge specific to the GBA	Ensure guidelines and standards are well-established and followed by all stakeholders in the GBA
Training and education	Offer training and education programmes for stakeholders in the GBA on resilience measures and technologies, tailored to local needs and context	Continuously update training and education programmes to incorporate new technologies and knowledge specific to the GBA	Ensure all stakeholders in the GBA are well-trained and educated on resilience measures and technologies
Research and Development	Conduct research and development on resilience technologies and measures that are relevant to the GBA context, such as earthquake-resistant building design, flood management, and typhoon-resistant construction	Continuously invest in research and development to improve resilience measures and technologies specific to the GBA	Ensure continuous innovation and improvement of resilience measures and technologies that are relevant to the GBA context

Risk assessment and management	Conduct risk assessments and develop risk management plans for buildings and construction projects in the GBA, taking into account regional risks such as seismic activity, flooding, and typhoons	Continuously update risk assessments and management plans to incorporate new risks and vulnerabilities specific to the GBA	Ensure all buildings and construction projects in the GBA have adequate risk assessments and management plans
Collaboration and partnership	Establish partnerships with relevant government agencies, industry associations, and academia in the GBA to promote resilience in buildings and construction	Continuously expand partnerships and collaborations with local stakeholders in the GBA to promote resilience in a holistic way	Ensure effective collaboration and partnership with local stakeholders in the GBA to achieve resilience goals

Recommended capacity building actions for resilience include:

- **Resilience guidelines and standards:** Develop and publish guidelines and standards for building resilience in the GBA, update them regularly, and ensure compliance by all stakeholders.
- **Training and education:** Offer training and education programmes tailored to local needs and context on resilience measures and technologies, updating them regularly, and ensuring that all stakeholders are well-trained.
- **Research and development:** Conduct research and development on resilience technologies and measures specific to the GBA, continuously investing in innovation and improvement.
- **Risk assessment and management:** Conduct risk assessments and develop risk management plans for buildings and construction projects in the GBA, considering regional risks and continuously updating plans to address new vulnerabilities.
- **Collaboration and partnership:** Establish partnerships with relevant government agencies, industry associations, and academia in the GBA to promote resilience in buildings and construction, expanding collaborations with local stakeholders to achieve holistic resilience goals.

Summary: Resilience

The GBA is facing significant challenges related to environmental, social, and economic factors that threaten its resilience. Urbanisation and global warming have resulted in more frequent stressors such as air and water pollution, habitat degradation, and extreme weather events. Social stressors such as population growth and the urban heat island effect have added pressure on natural resources and the environment, while economic stressors such as trade tensions and the COVID-19 pandemic have further affected the region's resilience. However, the current approach to addressing these challenges often focuses on individual issues without recognising their interdependencies. To build resilience in the GBA, a comprehensive approach is needed that promotes collaboration and coordination across stakeholders and recognises the interconnections between different stressors and activity areas. Many of the recommended actions for resilience are interconnected and can be developed together to create comprehensive plans and strategies for building resilience in the GBA.

Table 35 Cross-cutting Resilience Actions

Cross-cutting resilience actions	Main	Policy	Technology	Finance	Capacity building
Emergency response		X	X		
Risk assessment	X	X	X	X	
Infrastructure	X		X		
Building codes and standards	X	X			
Construction materials and technologies		X	X		
Collaboration and partnership	X				X

Examples of cross-cutting actions that could be developed together:

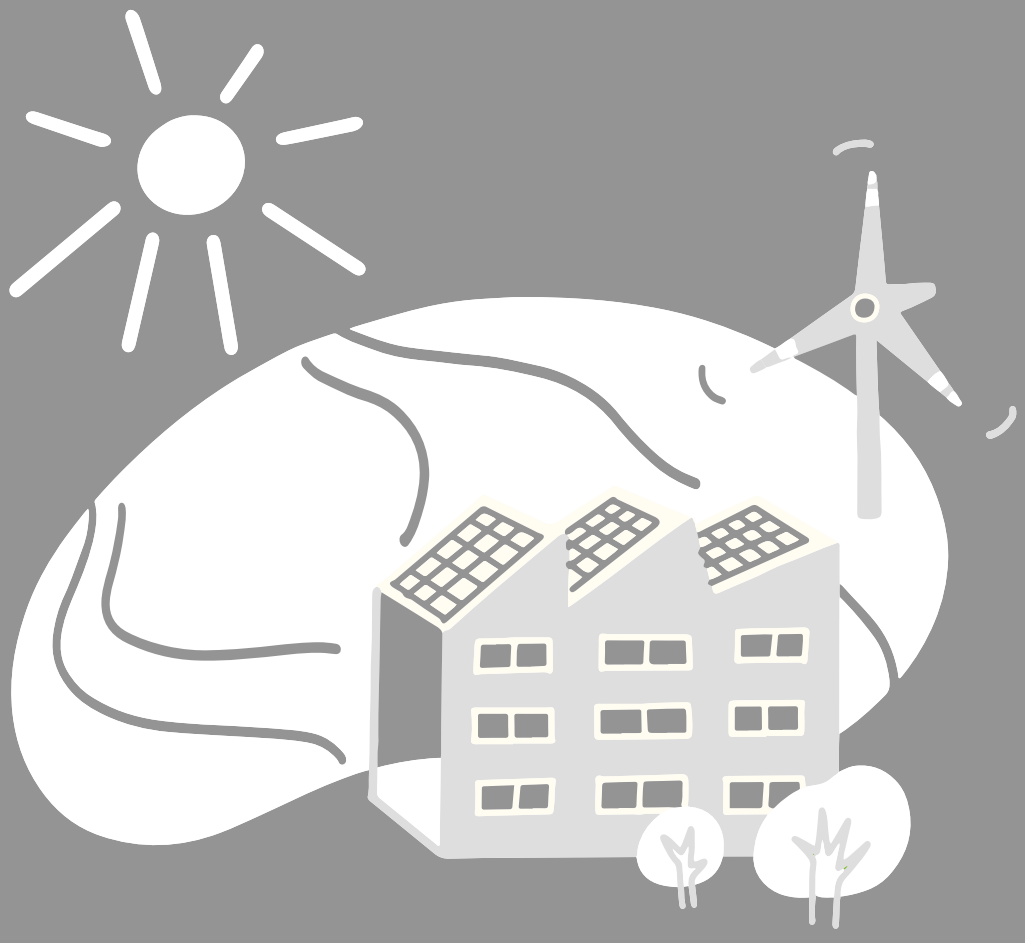
- **Emergency response** is mentioned in both the policy and technology categories. These could be developed together to create comprehensive plans for emergency response that incorporate technology solutions.
- **Infrastructure** is mentioned in both the main and technology categories, with specific examples of green infrastructure and smart technology. These could be developed together to create comprehensive plans for resilient infrastructure that incorporate both types of solutions.
- **Building codes and standards** are mentioned in both the main and policy categories. These could be developed together to create a comprehensive framework for building codes and standards that prioritise resilience.

Key actions such as conducting risk assessments, adopting resilient design principles, enhancing building codes and standards, and investing in infrastructure, are

essential to building a more resilient GBA. The establishment of a comprehensive baseline for measuring progress towards sustainability goals and the adoption of targets and indicators are also necessary. Strategies such as increasing green spaces and adopting sustainable transportation practices should be considered. While initiatives such as the ODP, Sponge City programme, circular economy industrial parks, and building code improvements are steps in the right direction, their long-term effectiveness remains to be seen. The key to building resilience is to enhance the GBA's ability to adapt to change, and a comprehensive approach is necessary to address challenges related to population growth, infrastructure, climate change, economic inequality, and urbanisation.

Activity Area 8

Clean Energy



Status Quo and Baseline

Switching to clean energy sources allows for less dependence on fossil fuels, and at the same time less environmental impact from greenhouse gas emissions. China is the world's largest investor in renewable energy, like hydro and wind power, followed by PV. Electricity from renewable energies has priority in the grid feed-in (Abele, 2022). The Chinese government's industrial policy has made China the world's leading solar manufacturer through subsidies and tax breaks for solar companies (Yvonne, 2022). In the PV industry in particular, China has seen strong growth in innovation in recent years. The government has strongly promoted Research and Development (R&D) in this area. Several government bodies and agencies play an official role in China's energy innovation decision-making process, such as the Ministry of Science and Technology (MOST). Overall, responsibilities for energy innovation are divided among a wide range of actors under the State Council (International Energy Agency (IEA), 2022).

China aims to generate 80% of its total energy mix from non-fossil sources by 2060 but still relies heavily on coal for power generation, making it the world's largest emitter of greenhouse gases. Given that buildings in China consume more than 25% of primary energy and that this share will continue to rise to around 35% by 2030 due to rapid urbanisation (Zhang, et al., 2019), it is increasingly important to drive the transition to renewable energy in China and, to expand urban supply options. Besides, limited space in cities requires expansion of power grids as well as legislation regulating supply.

Trends and Challenges

In China, including the GBA, the priority given to the use of fossil fuels like coal and crude oil is largely determined by the government's energy policies and regulations. Despite efforts to promote the use of renewable energy and reduce coal consumption, fossil fuels still account for over half of the energy supply in the region. However, the Chinese government has recognised the need to shift towards cleaner energy sources to meet its carbon neutrality goal by 2060, and is taking steps to promote the use of renewable energy. Nonetheless, balancing the need for energy security with the need to reduce carbon emissions remains a complex challenge for the government, and the priority given to fossil fuels is likely to remain for some time.

When talking about clean energy in reports on this region, it is important to consider the definition of this term. In the Think Tank Report on Ecological Protection and Ecosystem Governance in the Guangdong-Hong Kong-Macao GBA, published in November 2021 by the Ecological Environment Consortium of the Chinese Association for Science and Technology and the Chinese Forestry Society, clean energy primarily refers to the use of nuclear energy (Wei, 2021). It also includes, to some extent, low-polluting fossil energy like natural gas.

Natural gas as a bridge to clean energy produces fewer harmful pollutants and emits only half as much carbon dioxide as coal when generating electricity. Nevertheless, this fossil fuel releases significant greenhouse gases that escape into the atmosphere. CO_2 emissions resulting from the use of nuclear power are significantly lower than fossil fuels. However, they still emit more than renewable

energies, which are generated from sun, wind and water. In addition, they are significantly more cost-intensive in terms of production and the complex disposal of radioactive waste.

The utilisation rate of renewable energy sources like wind power, PV, biomass and others is still relatively low at 7%. At the end of October 2021, the installed capacity of renewable energy sources in Guangdong was 19.97 million kW, with PV accounting for the largest share with 45%, followed by biomass with 17% and offshore wind with 12% (Wei, 2021).

As mentioned in the regional context chapter, The 14th Five-Year Plan in China sets ambitious goals to make buildings greener and more energy efficient. By 2025, all new municipal buildings should be constructed as 'green buildings', designed to be energy efficient, sustainable, and environmentally friendly (National Development and Reform Commission, 2021).

In addition, the plan targets a replacement rate of renewable energies in urban buildings to exceed 8%, with non-renewable energy sources being replaced by renewable energy sources such as solar or wind power. This is a modest target, but it may still contribute to achieving the overall goal of making buildings greener.

Furthermore, the plan aims to reduce the share of non-electricity energy consumption in buildings to below 45% by ensuring that the share of electricity consumption in the energy consumption of buildings exceeds 55%. This implies a reduction in the amount of non-renewable energy sources used to generate electricity for buildings.

Due to the warm climate and high urbanisation rate in the GBA, the UHI effect has increased significantly during the last years. Therefore, the focus in energy consumption in buildings is mainly on electricity for ventilation and cooling. Electricity generation is the largest contributor to carbon emissions. In Hong Kong it accounts for about 70% (Du, et al., 2020).

Target and Indicators

The GBA region has sufficient solar energy resources. Nevertheless, small urban areas of Hong Kong and Macao have limited options for renewable energy generation, such as wind or solar farms. The possibility for PV installation in the urban area of Hong Kong is limited due to little roof space on high-rise buildings. Macao has unfavourable conditions for the use of wind and hydropower. However, here the government plans to accelerate the expansion with a programme to install PV systems on the roofs of at least one-third of new public facilities, including residential complexes, by 2025 (Lai, 2022).

One of the challenges in the field of PV roof systems is the load-bearing capacity of roofs, which in some cases differ greatly in terms of construction. In addition to the question of the general suitability of the roof, the question of ownership also plays a role. The spread of solar systems among private households is still extremely low in China. In Hong Kong, however, all power generation, transmission and distribution assets are owned by private operators. The two electricity companies in Hong Kong conduct their business independently of the government and are

entitled to an allowed rate[40] of return on average net assets to encourage continued investment in plant and equipment to ensure security of supply. Most of the electricity in Macao is generated by the China Southern Grid Company in mainland China. It is supplied through a private company that has been granted a concession contract by the government for the generation, transmission, distribution, sale, import and export of electricity. The concession was renewed for another 15 years in 2010, with the exclusivity for power generation removed because the government wanted to be able to introduce competition (Du, et al., 2020).

While in Guangdong province there is not enough space for on-shore wind plants, offshore wind energy has great potential due to its favourable location on the PRD. According to the implementation plan to promote the orderly development of offshore wind energy and the sustainable development of related industries, by the end of 2025, offshore wind energy capacity is planned to be increased significantly by more than 7 times compared to 2021. To support the continued expansion of offshore wind power capacity, it is planned that the Guangdong Provincial Ministry of Finance will subsidise the investment of projects in the province (Wei, 2021).

Guangdong started providing district cooling from 2004. Here, ice storage technology is used to reduce peak daytime loads. This can significantly reduce the pressure on the regional power grid during the peak summer season. Central cooling can also save a lot of energy and reduce emissions compared to conventional air conditioning systems. However, the investment costs for the district cooling network are high and the system must be planned sensibly from the beginning (Zhou, 2022).

As a highly urbanised economic centre, agriculture and forestry play only a subordinate role for the use of biomass in the GBA and are rather limited to the potential of municipal waste utilisation.

Pumped storage is a common and widely developed form of energy storage in China. Guangdong offers good conditions for hydro power energy storage applications. In May 2022, two pumped storage power plants were commissioned in this province. The total installed capacity of the Greater Bay pumped storage power grid thus reaches a total installed capacity of almost 10 million kW (China Global Television Network (CGTN), 2022).

A particular challenge is the lack of transmission capacity and the resulting high settlement rates. China Southern Power Grid, as the country's leading electricity supplier, aims to build a smart grid by 2030. Most of the electricity for the GBA comes from the Guangxi Zhuang autonomous region in southwest China, Guizhou province and Yunnan province, where there are plenty of water and wind resources (Yukun, 2019).

40 An 'allowed rate of return' refers to the rate of profit that the two electricity companies in Hong Kong are allowed to earn on their average net assets. The Hong Kong government sets this rate as a way to encourage continued investment in plant and equipment by the electricity companies to ensure a secure and reliable supply of electricity to consumers. This rate is typically set based on a regulatory formula that takes into account various factors, such as the cost of capital, operating expenses, and depreciation. By setting an allowed rate of return, the government aims to strike a balance between providing a reasonable return on investment for the electricity companies and protecting the interests of consumers by ensuring that electricity prices remain reasonable and affordable.

Key Roadmap Actions for Clean Energy

Table 36 Key Roadmap Actions for Clean Energy

Current status (2022)	Necessary actions towards long-term goal	Long-term goal (2060)
Significant use of fossil fuels Insufficient connection to the energy supply infrastructure of mainland Missing possibility to trade or offset local emissions Missing green financing arrangements	Increase of renewable energy share Eliminate on-site fossil fuel burning equipment Development of electricity market and access to national emissions trading system Establishment of a solid policy framework and implementation of zero-carbon strategies Development of innovative green financing arrangements	Most buildings with net-zero carbon emissions over whole life

Recommended key actions to enable the clean energy transition for buildings include:

- **Increase of renewable energy share.** With its rich natural sources of sunlight in the GBA the expansion of PV and solar thermal systems should be mandatory where possible. Another opportunity lies in the further expansion of off-shore wind energy in Guangdong province. The capacity to which can be expanded needs to be examined.
- **Eliminate on-site fossil fuel burning equipment.** Replace on-site fossil fuel burning systems with equipment that uses clean energy, e.g. for heat pump/ chiller technology. Connect buildings to clean district energy systems when they are planned and can upgrade to clean energy.
- **Development of electricity market and access to national emissions trading system.** The development of an electricity market should be pushed and green electricity procurement be made possible in cases where local distributed generation is insufficient to meet local energy needs. In such cases buildings can purchase clean energy from the grid through power purchase agreements. If the SARs Hong Kong and Macao become part of the developing national emissions trading system, this will open up an additional opportunity to reduce emissions.
- **Establishment of a solid policy framework and implementation of zero-carbon strategies.** Stable regulatory frameworks are essential to incentivise and provide investors with the long-term certainty needed to invest in renewable energy.
- **Development of innovative green financing arrangements.** The GBA has a special national guiding function in many policy areas, and it would be desirable to attract additional public and private sector capital to the region through innovative green financing arrangements. At the same time, more ambitious emission reduction targets could be achieved by involving the private sector, including energy companies, building owners and other energy consumers.

Recommended Policy Actions for Clean Energy

Table 37 Recommended Policy Actions for Clean Energy

	Baseline (2022)	Short term (2030)	Long term (2060)
Decarbonisation of electricity grid and hot water	Significant use of fossil fuels with high carbon intensity	Increased fuel substitution, increased share of renewables	Fossil fuels phased out
Renewable energy strategy	7% utilisation rate of renewable energy sources. Small share of renewable energy use in buildings	Significant share of buildings with renewable energy strategies	All buildings include renewable energy strategies
Regulatory framework	Partial regulation framework in place to support the RE use in buildings	Extended regulation framework in place to support the RE use in buildings	Strong framework in place to support the RE use

Details on the policy targets for clean energy are outlined below:

- **Decarbonisation of electricity grid and hot water:** The decarbonisation of electricity in the GBA has a great significance. Currently, coal-fired power plants account for more than 50% of the installed electricity generation capacity in the bay. Almost half of the electricity has to be supplied from outside the GBA. The high solar and wind potential in GBA serves as an indication of the possibilities of decarbonisation for electricity and heat generation. For Hong Kong and Macao the connection to the energy supply infrastructure of Chinese mainland is an opportunity for decarbonisation.
- **Renewable energy strategy.** The introduction of decentralised energy generation can be promoted through feasibility studies for the installation of on-site generation projects in new and existing buildings. In addition, central cooling can save a lot of energy compared to conventional air conditioning, although careful planning is required from the beginning. The goal would also be to replace the bridge technology of natural gas and nuclear power in the future.
- **Regulatory framework.** The legal framework defines operating rules, connection permits and the use of grids, as well as targets, incentives, market conditions, feed-in tariffs and other factors. Therefore, a clear, well-designed, updated and coherent regulatory framework is important. Frameworks for technical and regulatory frameworks for PV or solar thermal installations in buildings can also contribute to greater uptake. For decentralised systems, building capacity and space should be optimised and secured through regulations and building supervision. Furthermore, policies that liberalise ownership structures, support wholesale price arbitrage, and enhance ancillary markets have the potential to substantially strengthen the market for e.g. battery storage, thereby enabling the scaling up of renewable energy deployment.
- **Support existing pipeline and accelerate new deployment:** Governments and the private sector should prioritise supporting the implementation of existing renewable energy projects, as well as accelerating the deployment of new projects. To support private sector actors, governments can increase

tenders for power delivery contracts, implement renewable portfolio standards, and launch competitive auctions to open up markets. Utilities should also retire their dependence on fossil fuels and focus on grid-scale renewable energy.

Recommended Technology Actions for Clean Energy

Table 38 Recommended Technology Actions for Clean Energy

	Baseline (2022)	Short term (2030)	Long term (2060)
Solar PV	Minimal proportion of buildings with solar PV system	Increased proportion of buildings with solar PV system	Where cost effective, all building stock equipped with solar PV systems
Solar thermal	Minimal proportion of buildings with solar hot water production	Increased use of solar hot water systems	Where cost effective, all building stock use solar hot water systems
Wind energy	Minimal proportion of wind use for electricity production	Increased proportion of wind use for electricity production	Maximal proportion of wind use for electricity production
Energy storage	Minimal proportion of energy storage use	Increased introduction of integrated energy storage systems	Wide availability of technologies for energy storage
Waste to energy	Minimal proportion of waste use for energy	Increased proportion of waste use for energy	Total use of waste as energy resource
Transmission & Distribution (T&D) grid	Lack of transmission capacity	Improved electricity transmission, distribution and risk resistance of the grid, development of a smart grid	Wide availability of smart and stable power grid
District energy systems	Minimal proportion of district energy use	Increased proportion of district energy use	Maximal proportion of district energy use where applicable

Details on the technology targets for clean energy are outlined below:

- **Solar PV.** The GBA has sufficient solar energy resources, which should be used for electricity generation. Building-integrated or roof-mounted PV systems can enable the generation of electricity for self-consumption. The load-bearing capacity of the roofs must be ensured for this purpose and space should be optimised. Depending on the size of the installed system, buildings could cover their annual electricity demand proportionally themselves. Coupling with energy storage can provide the necessary flexibility to meet their electricity needs at times when no electricity is generated (e.g. at night).
- **Solar thermal.** Thermal solar collectors also use solar energy and produce hot water on site. They have significant potential to replace electricity consump-

tion for water heating in private households. The space requirement must be coordinated with the need for PV installation.

- **Wind energy.** Offshore wind energy has great potential due to its favourable location on the PRD. Offshore wind farms with 66 gW are to be installed off the coast of Guangdong province, which surrounds Hong Kong and Macao, by 2030. The capacity should be further expanded.
- **Energy storage.** As the share of variable renewables in the energy supply increases, energy storage becomes an important element in balancing supply and demand. Coupled with solar thermal systems, thermal storage can ensure a continuous supply of hot water. In combination with electric heat pumps, heat, cold water or ice storage systems allow to avoid excess electricity generation from variable renewable sources during periods and to shift the load to off-peak periods to relieve the grid.
- **Waste to energy.** Building waste can be used as an additional fuel in municipal waste incinerators. Although variations in the physical and chemical properties of the waste make it a less profitable fuel, waste-to-energy can be an alternative to landfilling.
- **T&D grid.** For the distribution of the electricity it is necessary to extend the transmission and distribution grid in order to be able to use the new installed capacity and to have a stable power grid.
- **District energy systems.** District cooling solutions include the possibility of using large-scale technologies based on renewable energies. It reduces the power demand and load peaks in the electrical grid. In addition, compared to conventional air conditioning systems energy can be saved and emissions be reduced.
- **Scale up energy storage deployment:** Scaling up the deployment of battery energy storage systems is crucial for the expansion of renewable energy. Batteries can provide supplementary power during peak demand and offer ancillary services to grids such as frequency control, spinning reserves, and reactive voltage. These services can ensure a stable and uninterrupted supply of renewable energy to users while maintaining the integrity of the power grid.
- **Invest in transmission and distribution systems:** The grid is the most complex infrastructure system in any economy, and it represents the backbone of the energy system. However, the supply of intermittent renewable energy, which can quickly and substantially change depending on the availability of sun or wind, is not as flexible as traditional fossil fuels that can be ramped up and down on demand. While this can pose some challenges to aging grid infrastructure with lower response times, newer smart grids can easily handle these variability challenges. Additionally, grids are subject to geographical contexts and sociopolitical forces, and many are owned and operated by State-Owned Enterprises (SOEs) with monopolistic characteristics that can crowd out private sector participation, thereby reducing the amount of new renewable energy that can access the grid due to low competition. Post-COVID green infrastructure rebuilding programmes will inevitably include the grid in some form to increase capacity and resilience, improve access to electricity, and

reduce emissions. This can be achieved by prioritising grid improvement projects already in the pipeline while pursuing long-term planning and investment in T&D operations.

National Example

In China, Ultra-High Voltage (UHV) transmission lines are being prioritised, with Bloomberg New Energy Finance (BNEF) estimating that around 195 billion RMB (approximately 25.5 billion EUR) will be invested in such grid projects in 2020. The reinforcement of transmission nationally can also improve balancing between regions and create new jobs in the process.

Recommended Finance Actions for Clean Energy

- Finance can enable increased action towards clean energy for buildings. Examples of financing options could be urban development funds, infrastructure funds, dedicated credit lines or government tax credits for renewable energy projects.
- Credit lines for national or local governments can also be used to establish a revolving credit fund that collects repaid loans from renewable energy projects and invests them in further additional energy efficiency or renewable energy projects.
- Energy Service Companies (ESCOs) develop, design, build and finance projects that save energy. Generally, ESCOs act as project developers and assume the technical and performance risks associated with a project.
- Green power procurement: Electricity consumers can purchase electricity directly from renewable energy projects or from green electricity traders, thus increasing the demand for renewable electricity generation and boosting the implementation of renewable energy production.
- Energy prices: Pricing strategies should be aligned with decarbonisation goals. This includes time-of-use and location-based pricing.
- Implement a Levelised Cost of Energy (LCOE) approach: LCOE is a method used to determine the average cost of producing a unit of electricity over the lifetime of an energy generating asset, and while it is primarily used in the energy sector, it can also be applied to the building sector. In this context, LCOE can be used to compare the cost-effectiveness of different clean energy systems or technologies used in buildings. For example, LCOE can be used to compare the lifetime cost of a solar PV system versus a conventional HVAC system for a building. This comparison can help building owners and developers make informed decisions about which energy system or technology to invest in based on their long-term economic benefits.

Recommended Capacity Building Actions for Clean Energy

- All levels of government should be trained to integrate clean energy into policy planning, design, and implementation. This includes policymakers, planners, and implementers at the national, regional, and local levels.
- Financiers and developers should be trained to identify, assess, and finance clean energy projects, both utility-scale and distributed generation. This includes building capacity to create and maintain stakeholder networks between policy makers, developers, and financiers.
- Investment in skills training is necessary to create a local workforce capable of installing and maintaining grid-scale renewable energy installations. This includes investment in training programmes for activities such as storage installation, which will become a marketable skill. There will also be a need for retraining as technologies evolve.
- Workers trained in digital technology will be needed to support the development and implementation of smart-grid technologies.

Summary: Clean Energy

Conventional energy sources such as coal are still the primary technologies in the GBA as well as in China as a whole. They account for around 50% of the installed electricity generation capacity. Almost half of the electricity has to be supplied from outside the GBA. The purchase of clean energy currently relies mainly on nuclear energy. Renewable energies such as wind power and PV account for a relatively low share of use of 7%, although the GBA is rich in renewable resources like solar and wind. In the small urban areas of Hong Kong and Macao, conditions for renewable energy generation as well as the opportunity to obtain energy from renewable sources by connecting to the mainland energy supply infrastructure are limited. Also, they have no possibility to trade or offset local emissions.

With its rich natural sources of sunlight and wind in the GBA renewable energy share can be increased significantly. This will significantly reduce greenhouse gas emissions while improving air quality. With the appropriate storage technology and a secure power grid, a reliable energy supply can thus be established.

The legal framework defines operating rules, connection permits and the use of grids, as well as targets, incentives, market conditions, feed-in tariffs and other factors. Therefore, a clear, well-designed, updated and coherent regulatory framework is important.

The introduction of decentralised renewable energy generation can be promoted through feasibility studies for the installation of on-site generation projects in new and existing buildings. In addition, central cooling can save a lot of energy compared to conventional air conditioning, although careful planning is required from the beginning. The goal would also be to replace the bridge technology of natural gas and nuclear power in the future.

For the distribution of the electricity it is necessary to extend the transmission and distribution grid in order to be able to use the new installed capacity and to have a stable power grid.

The development of an electricity market should be pushed and green electricity procurement be made possible in cases where local distributed generation is insufficient to meet local energy needs. In such cases buildings can purchase clean energy from the grid through power purchase agreements.

The GBA has a special national guiding function in many policy areas, and it would be desirable to attract additional public and private sector capital to the region through innovative green financing arrangements. At the same time, more ambitious emission reduction targets could be achieved by involving the private sector, including energy companies, building owners and other energy consumers.

The transition to clean energy is essential for climate and environmental protection. It will significantly reduce green-house gas emissions while improving air quality. With the appropriate storage technology and a secure power grid, a reliable energy supply can thus be established. The GBA is well on its way and has a special place in China's development towards carbon neutrality.

Key Integrated Actions for the GBA across all Activity Areas

The GBA has a pressing need to develop ambitious and comprehensive strategies and roadmaps to decarbonise its building and construction sector. To accelerate action, strategic collaboration and greater integration between the sub-regions and the administrative zones is key to addressing the challenges that come with advances towards their climate goals and improve the sustainability of their building and construction sectors.

Outlined below is an overview of the recommended key integrated actions and strategies applicable across and which benefit all activity areas, focusing on how different sub-regions can contribute towards a unifying goal. Given the various levels of government responsible for the development and management of the GBA, the key actions and strategies are proposed on three levels: city municipality level, province administration level, and GBA/national ministries level.

Identifying Stakeholders and Baseline Collaboration Networks

To accelerate decarbonisation in the building and construction sector of the GBA, strategic collaboration and greater integration between sub-regions are crucial. At the city/municipality level, local governments can identify key stakeholders and build baseline collaboration networks to achieve sustainable building goals. At the province/administration level, provincial governments can coordinate and integrate efforts across municipalities to ensure a unified strategy for sustainable building and construction. Finally, at the national/GBA ministries level, strategic collaboration and coordination between different sub-regions can help to develop comprehensive policies and standards for sustainable building design and construction. Through these collaborative efforts, the GBA can achieve its nationally determined contributions and climate goals, while also improving the sustainability of its building and construction sectors.

At the city/municipality level, local government agencies can take the lead in identifying key stakeholders and building baseline collaboration networks. For instance, in Shenzhen, the city government could collaborate with local universities and research institutions, such as the Shenzhen Institute of Building Research Co. Ltd., to bring together experts in sustainable building design and construction. Through such partnerships, the municipality could develop comprehensive plans for retrofitting existing buildings and constructing new ones with low-carbon materials and efficient energy systems. The collaboration between stakeholders at the city level can help to leverage local expertise and resources to achieve sustainable building goals.

At the province/administration level, provincial governments can play a significant role in coordinating and integrating the efforts of different municipalities within their jurisdictions. For instance, the Guangdong provincial government could establish a task force to oversee the development of sustainable building practices across the province. This task force could work in collaboration with local governments, industry professionals, and research institutions to create a unified strategy for sustainable building and construction. Furthermore, the task force could oversee the implementation of building codes and regulations that promote energy efficiency and carbon reduction. By establishing a coordinated

approach, the province could ensure that all sub-regions are working towards a shared goal, and that best practices are shared and adopted throughout the region.

At the national/GBA ministries level, strategic collaboration and coordination between different sub-regions can help to accelerate the decarbonisation of the building and construction sector. For example, MOHURD could establish a working group that includes representatives from different sub-regions, such as Guangdong, Hong Kong, and Macao. This working group could coordinate efforts to develop national policies and standards for sustainable building design and construction. Furthermore, the working group could promote cross-border collaboration on research and development of new low-carbon building materials and energy-efficient technologies. By leveraging the expertise of stakeholders across the GBA, the working group could facilitate the development of a comprehensive and integrated strategy for decarbonising the building and construction sector.

Establishing Data Collection Systems and Methodologies

To support the development of decarbonisation and efficiency planning, governments and industry coalitions should work towards closing information gaps on building performance in the GBA. This is because accurate and reliable data is essential for informing sustainability interventions and quantifying the benefits of efficiency planning. Collaboration and integration between the different sub-regions in the GBA is necessary to ensure that data collection is comprehensive and covers all building types. This can be achieved by establishing data collection systems and methodologies that cover the entire GBA, providing essential evidence to inform sustainability interventions and quantify the benefits of efficiency planning. This will enable evidence-based interventions that improve building efficiency and contribute to the achievement of the GBA's climate goals.

At the city/municipality level, it is recommended that local governments establish data collection systems that focus on building performance metrics such as energy consumption, water usage, and waste management. For example, the Guangzhou municipal government can collaborate with the construction industry to implement building performance assessment and rating systems, similar to those implemented in other cities such as Shanghai and Beijing. This will enable the identification of buildings with high energy consumption and facilitate targeted interventions to improve their energy efficiency.

At the province/administration level, it is recommended that provincial governments work together to establish a common framework for data collection and analysis. This could involve the creation of a centralised database that collects and analyses building performance data from across the GBA. This would allow for benchmarking and comparison of building performance metrics between different regions and identification of best practices. For instance, the governments of Guangdong and Hong Kong can collaborate on the creation of a standardised building performance database to improve the sharing of information between the two regions.

At the national/GBA ministries level, it is recommended that national ministries work closely with industry stakeholders to establish data collection methodolo-

gies that cover the entire GBA. This will require the development of a comprehensive inventory of building stock in the region, including data on building age, size, and construction materials. For example, MOHURD can work with the construction industry to establish a comprehensive database that covers all building types in the GBA, including residential, commercial, and industrial buildings.

Multi-level: Innovative solutions encompassing all three levels could involve the use of blockchain technology to establish a transparent and decentralised database for building energy performance monitoring, or the use of AI and machine learning to optimise building design and construction for energy efficiency. However, it is important to note that these solutions may face challenges such as regulatory barriers, data privacy concerns, and the need for significant investment in new technology and infrastructure. It will be important for stakeholders to carefully consider the costs and benefits of these solutions and to collaborate effectively to ensure successful implementation.

Advancement of Integrated Urban Planning Policies and Climate Resilience Frameworks

In addition, city-level actors in the GBA should collaborate across sectors and government levels to develop integrated urban planning policies and climate resilience frameworks. These should prioritise equitable and sustainable land use, transit-oriented design, accessible greenspace, climate resilience, and clean energy district planning.

At the city/municipality level, it is crucial that sub-regions collaborate to develop and implement integrated urban planning policies and climate resilience frameworks. The aim is to develop integrated urban planning policies and climate resilience frameworks, with a particular focus on advancing equitable and sustainable land use, transit-oriented design, accessible greenspace, climate resilience, and district clean energy planning. For instance, the Shenzhen municipality, known for its innovative urban planning and technology, could share its experience in developing a comprehensive urban planning framework that incorporates climate resilience and sustainability goals. This could be emulated by other sub-regions in the GBA, such as Zhuhai and Zhongshan, which could benefit from the implementation of transit-oriented design and the prioritisation of sustainable land use. Furthermore, collaboration between municipalities such as Hong Kong and Macao could focus on the development of accessible greenspace and district clean energy planning to improve the sustainability of their urban environments.

At the province/administration level, the GBA could benefit from the establishment of a joint committee that oversees the development of integrated urban planning policies and climate resilience frameworks. Such a committee could be led by the Guangdong provincial government and could include representatives from each sub-region. The committee could focus on establishing a unified vision for sustainable development in the GBA and could coordinate efforts towards the implementation of shared sustainability targets. In addition, the committee could prioritise capacity-building and knowledge-sharing to ensure that sub-regions have access to the latest research and best practices. For instance, the collaboration between the Dongguan and Foshan municipalities could lead to the

development of an integrated regional plan for the sustainable development of the manufacturing sector. Dongguan, with its expertise in manufacturing, can provide insights into the potential for green manufacturing practices, while Foshan, with its focus on tourism and service industries, can contribute its knowledge of sustainable urban development. By working together, these two sub-regions can develop a blueprint for sustainable development that can be adapted by other sub-regions within the GBA.

At the national/GBA ministries level, the key recommended integrated actions and strategies should focus on developing policies and incentives that encourage the adoption of integrated urban planning policies and climate resilience frameworks. This could involve the development of a national framework for decarbonising the building and construction sector, which provides guidelines for sub-regions within the GBA. For example, the collaboration between the Hong Kong SAR and the Macao SAR could lead to the development of a framework for green building and construction practices that could be adopted by other sub-regions within the GBA. Hong Kong, with its extensive experience in green building practices, can provide expertise in the development of green building codes and certification schemes. Macao, with its focus on sustainable tourism and heritage conservation, can contribute its knowledge of sustainable urban development. By developing a national framework for decarbonising the building and construction sector that draws on the strengths of each sub-region, the GBA can accelerate its transition towards a low-carbon future.

Multi-level: Another effective solution that could be implemented across all levels is the use of digital twin technology. Digital twin technology involves creating a virtual replica of a physical asset or system, which can be used to model and test different scenarios and identify potential issues before they occur in the real world. The GBA could develop a digital twin of its built environment, which could be used to test the effectiveness of different climate resilience strategies and urban planning policies. This could help to identify the most effective solutions and reduce the risk of costly mistakes.

Improvement of Regulatory and Cross-Regional Incentive Frameworks

To promote the adoption of energy-efficient and low-carbon-driven construction in the GBA, regulatory agencies should establish clear regulatory and incentive frameworks. Collaboration and coordination between sub-regions can help in the development of such frameworks, prioritising investment in energy efficiency improvements, and reducing carbon emissions from major building materials. Overall, collaboration and coordination between these sub-regions can help in developing clear regulatory and incentive frameworks that promote the use of on-site and building-integrated renewable energy and prioritise investment in energy efficiency improvements.

At the city/municipality level, one of the proposed solutions could be to establish local energy efficiency standards for new construction projects. For example, in Shenzhen, a leading green city in the GBA, the city government could develop and enforce regulations that mandate the use of energy-efficient building designs, materials and equipment, as well as green building certifications, such as Leadership in Energy and Environmental Design (LEED) and China's Green Building Evalua-

tion Label (GBEL). This could also be achieved through local financial incentives, such as tax rebates or subsidies, that encourage the adoption of low-carbon and energy-efficient building practices.

At the province/administration level, the GBA could establish a cross-regional carbon trading system that incentivises low-carbon construction practices and promotes collaboration between sub-regions. For example, in Guangdong province, the local government could encourage the use of green building materials and practices through a province-wide carbon market that enables developers to buy and sell carbon credits. This could create a market-based mechanism that rewards the adoption of low-carbon construction practices and encourages sub-regions to collaborate in order to meet their respective emissions reduction targets.

At the national/GBA ministries level, the Chinese government could establish a national regulatory and incentive framework that harmonises energy efficiency standards across different sub-regions and promotes collaboration between them. This could involve the development of a national green building certification scheme that is recognised across the GBA and sets a minimum standard for energy efficiency and low-carbon construction practices. The Chinese government could also introduce financial incentives, such as tax breaks, to encourage the use of renewable energy in buildings, such as solar panels and geothermal systems.

Multi-level: It is worth noting that while there are existing policies and initiatives aimed at promoting energy-efficient and low-carbon-driven construction practices in the GBA, the current regulatory and incentive frameworks may not be comprehensive or ambitious enough to achieve the necessary reductions in carbon emissions. Therefore, the recommendations provided above are aimed at enhancing and building upon existing policies and initiatives to accelerate progress towards the GBA's climate goals and nationally determined contributions. Furthermore, while there are some initiatives in place, there may be variations in the extent to which they are being implemented across different sub-regions of the GBA. Thus, the proposed strategies and actions are aimed at promoting greater collaboration and integration between sub-regions, such that best practices and knowledge can be shared and adapted across the GBA as a whole.

Development of a Living Roadmap and Iterative Implementation Plan (LRIP)

National governments, provincial and city agencies in the GBA should develop comprehensive strategies and roadmaps for the building and construction sector that outline the pathway towards zero-emission, efficient, and resilient buildings. This recommendation is made to address the current high construction rates in the area and to focus on early action, while also addressing the data and ambition gaps identified in the roadmap. The development of a LRIP[41] is a crucial step towards decarbonising the GBA's building and construction sector. Collaboration and coordination between different sub-regions is key to achieving this, with each

41 LRIP is a concept that has been used in some sustainability and climate action planning contexts, such as the United Nations SDGs, to describe a dynamic and adaptive approach to achieving long-term goals. The idea is that the roadmap is a living document that is updated and refined based on new data and insights, and the implementation plan is iterative, with regular monitoring and evaluation to ensure progress towards the stated goals.

sub-region contributing its unique strengths towards a unifying goal. The development of city-level roadmaps, a province-wide LRIP, and a national LRIP will ensure that decarbonisation efforts are targeted and effective, while also allowing for flexibility and adaptation in response to new data and insights[42]. The strategies should be developed through consultation and engagement that brings in a range of disciplines of urban planning, building design and construction, materials, resilience, and clean energy.

At the city/municipality level, the LRIP recommendations should focus on tailoring strategies and roadmaps to address the unique strengths and challenges of each individual sub-region. For example, in Dongguan, a sub-region with a large manufacturing industry, the LRIP could focus on developing green buildings for industrial use, as well as promoting circular economy principles in building design and construction. On the other hand, in Zhuhai, which has a high number of coastal developments, the LRIP could focus on resilience and adaptation strategies to address the risks of climate change and sea level rise. Some GBA sub-regions that have already started initiatives in line with LRIP recommendations include Hong Kong, which has implemented the BEAM Plus certification system for green buildings, and Shenzhen, which has established a low-carbon building materials industry. Other sub-regions that could benefit from LRIP implementation include Foshan, which has a high number of existing buildings that could be retrofitted for improved energy efficiency, and Jiangmen, which has a high potential for renewable energy generation.

At the province/administration level, the LRIP should be developed in a way that ensures effective coordination between the different sub-regions within the province. This could involve the establishment of a provincial level working group that includes representatives from each sub-region, industry associations, and academic institutions. The working group could be responsible for identifying common challenges and opportunities, setting targets, and monitoring progress towards the implementation of the LRIP. For example, the working group could establish a target for all sub-regions within the province to achieve a certain level of green building certification by a certain date, and could develop a roadmap for achieving this target. The working group could also coordinate efforts to establish a provincial database for building energy performance monitoring and could provide financial incentives for building owners to improve energy efficiency. Some GBA sub-regions that have already started initiatives in line with this approach include Guangzhou, which has established a green building policy framework that includes financial incentives for building owners, and Shunde, which has established a low-carbon building materials research centre. Other sub-regions that could benefit from this approach include Zhongshan, which has a high number of industrial parks that could be targeted for green building certification, and Zhanjiang, which has a high potential for renewable energy generation.

42 Overall, the key differentiating characteristic of the LRIP recommendations at each level is the scale and scope of the plan. While the city-level roadmaps are focused on individual cities within the GBA, the province-wide and national plans are designed to coordinate and integrate efforts across multiple cities and provinces. Additionally, the LRIP recommendations at each level may also differ in terms of the specific policies and regulations that are recommended, depending on the unique characteristics of each level.

At the national/GBA ministries level, the LRIP should be developed with a focus on establishing national standards and targets that reflect the collective goals of the different provinces and sub-regions within the GBA. This could involve the establishment of a national level working group that includes representatives from each province, industry associations, and academic institutions. The working group could be responsible for developing national standards for green building certification, establishing a national database for building energy performance monitoring, and providing financial incentives for building owners to improve energy efficiency. For example, the working group could establish a target for all new buildings in the GBA to be constructed with low-carbon building materials by a certain date, and could develop a roadmap for achieving this target. The working group could also coordinate efforts to establish a national-level green building materials research and development centre, which could provide technical support for the development of innovative and sustainable building materials. Some GBA sub-regions that have already started initiatives in line with this approach include Hong Kong, which has established a target for all new buildings to achieve a certain level of green building certification, and Macao, which has established a green building rating system. Other sub-regions that could benefit from this approach include Guangxi, which has a high potential for renewable energy generation, and Jiangxi, which has a high number of existing buildings that could be retrofitted for improved energy efficiency.

Multi-level: The use of blockchain technology and AI to optimise building design and construction for energy efficiency mentioned under the recommendation 'Data Collection Systems and Methodologies' can also help improve the accuracy and reliability of the data collected, which is crucial for effective decision-making and tracking progress towards the LRIP's goals. The same can be said for the also aforementioned 'Integrated Urban Planning Policies and Climate Resilience Frameworks' digital twins approach to model and simulate building performance in real-time. Both can help stakeholders make informed decisions about how to allocate resources and prioritise actions to achieve the LRIP's goals.

Leveraging of Circular Economy and Resource Efficiency

The adoption of circular economy principles and resource efficiency measures in the building and construction sector can have a significant impact on reducing waste and increasing sustainability in the GBA region. By prioritising the use of recycled materials and promoting circular design practices, the region can create a more sustainable and resilient built environment. One effective way to achieve this is through the use of BIM, which is a digital tool that allows for collaboration and coordination among all stakeholders in a construction project. BIM can facilitate the use of recycled materials and circular design practices by allowing for the efficient tracking and management of materials throughout the construction process. In addition, the use of serialised dry construction approaches can further promote circularity and resource efficiency in the building and construction sector. This approach involves prefabricating building components off-site and assembling them on-site, reducing waste and improving construction speed and quality. Overall, the adoption of circular economy principles and resource efficiency measures in the building and construction sector not only promotes sustainability and resilience but also reinforces multi-stakeholder par-

ticipation and assists in achieving longevity of the project. By taking a holistic approach to building and construction, the GBA can create a more sustainable and liveable built environment for its residents.

At the city/municipality level, local governments should focus on implementing specific measures that promote circular economy and resource efficiency in the building and construction sector. For example, Guangzhou municipality could mandate the use of recycled concrete in construction projects to reduce waste and decrease the carbon footprint of the construction industry. On the other hand, Dongguan municipality could promote the use of prefabrication and modular construction methods to reduce construction waste and increase efficiency. Key stakeholders that should be involved in implementing these measures include local building departments, construction companies, and waste management agencies.

One example of a GBA sub-region that has already started in something similar is Shenzhen. The city has implemented a zero-waste policy that requires construction companies to use at least 30% recycled materials in their projects. This policy has led to an increase in the use of recycled materials and a reduction in construction waste. Another good example of a sub-region in the GBA that has already made progress in circular economy practices is Hong Kong. Hong Kong has implemented various initiatives, including waste reduction campaigns and recycling programs, to reduce waste and promote a circular economy.

At the province/administration level, the focus should be on promoting collaboration and coordination between different sub-regions to achieve common sustainability goals. For example, Guangdong province could establish a regional circular economy platform[43] to facilitate information sharing and collaboration between local governments, industry stakeholders, and research institutions. The platform could provide a forum for sharing best practices, developing joint initiatives, and tracking progress towards sustainability goals. An example of a GBA sub-region that could benefit most from this type of collaboration is Zhongshan. The city is known for its manufacturing industry and has a large number of small and medium-sized enterprises. By participating in a regional circular economy platform, Zhongshan could learn from other sub-regions and develop its own strategies to promote resource efficiency and circularity in the building and construction sector. Other sub-regions in the GBA, such as Shenzhen and Guangzhou, also could benefit from collaboration with Hong Kong and the establishment of a regional circular economy platform to accelerate circular economy practices and innovation. By involving diverse stakeholders and encouraging collaboration, the GBA can accelerate the adoption of circular economy practices and contribute to the transition towards a more sustainable and resilient economy.

At the national/GBA ministries level, setting targets and implementing regulations that promote the adoption of circular economy practices and resource

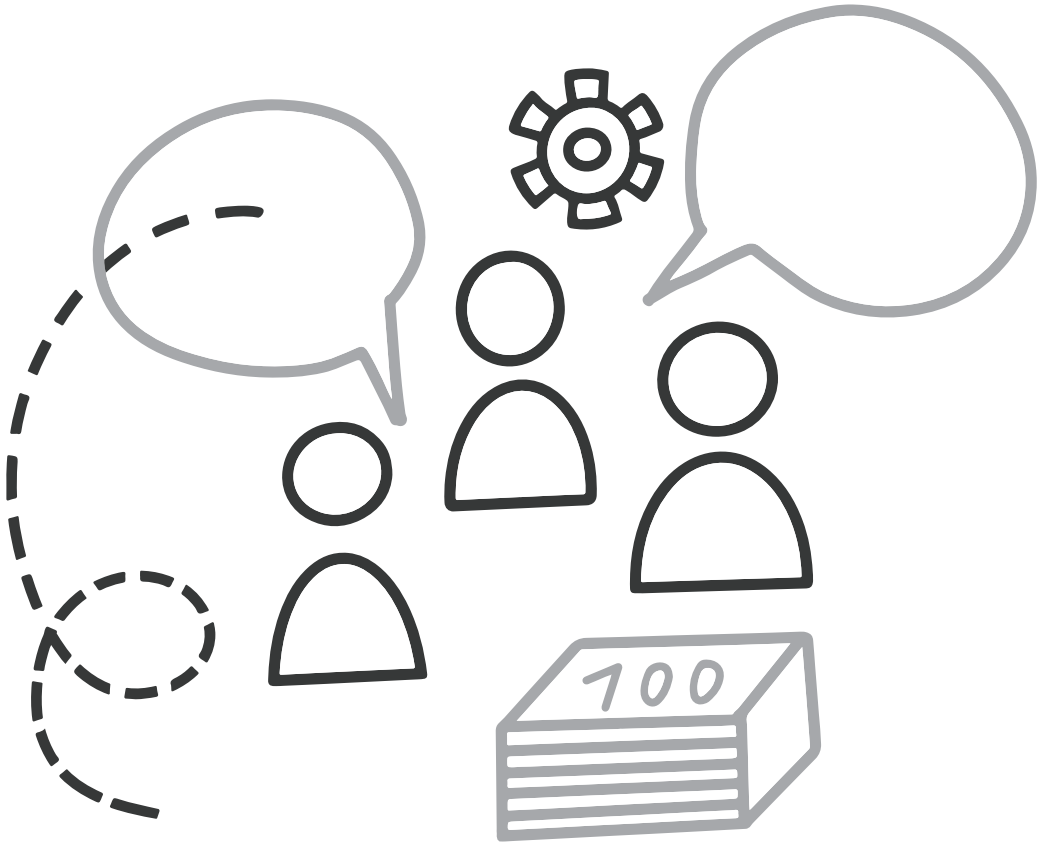
43 One best practice example of a regional circular economy platform is the Nordic Circular Hotspot. It's a regional platform that promotes and supports circular economy practices and innovation in the Nordic countries of Denmark, Finland, Iceland, Norway, and Sweden. This platform could serve as a best practice example for the GBA to create a similar regional circular economy platform that fosters collaboration and exchange of knowledge and expertise among the sub-regions.

efficiency in the building and construction sector require national level coordination and support is essential[44]. This includes the establishment of standards for sustainable building design, the development of guidelines for construction waste management, and the promotion of eco-labelling and certification schemes. Such initiatives require national-level stakeholder engagement and cross-sectoral collaboration to ensure effective implementation. Further, national-level policies and incentives can play a crucial role in promoting the adoption of circular economy practices and resource efficiency in the building and construction sector. For example, the introduction of tax incentives for businesses that adopt sustainable practices, or the allocation of funding for research and development of sustainable building materials and technologies. These types of initiatives require a national level budget and coordinated policy-making process. Finally, international collaboration and engagement on sustainability issues in the building and construction sector is another area where the national/GBA ministries level can play a critical role. This includes participation in international forums, sharing best practices with other countries, and collaborating on research and development of sustainable building materials and technologies. Such initiatives require a national-level strategy and coordinated approach to effectively engage with the international community.

Multi-level: The key factor in the recommended actions and strategies is the emphasis on a holistic and collaborative approach that involves diverse stakeholders, such as local governments, industry stakeholders, research institutions, and communities, to promote circular economy practices and innovation. The establishment of a regional circular economy platform and the adoption of BIM and serialised dry construction approaches are also novel solutions that can facilitate more efficient and effective resource management in the building and construction sector. By leveraging these innovative approaches, the GBA can accelerate the transition towards a more sustainable and resilient built environment.

44 There are some existing initiatives at the national and GBA ministries level that are related to promoting circular economy and resource efficiency, such as China's Green Building Action Plan and the GBA ODP. However, these initiatives may not fully address the specific needs and challenges of the building and construction sector in the GBA region.

Working Together: Stakeholder Involvement and Enabling Conditions



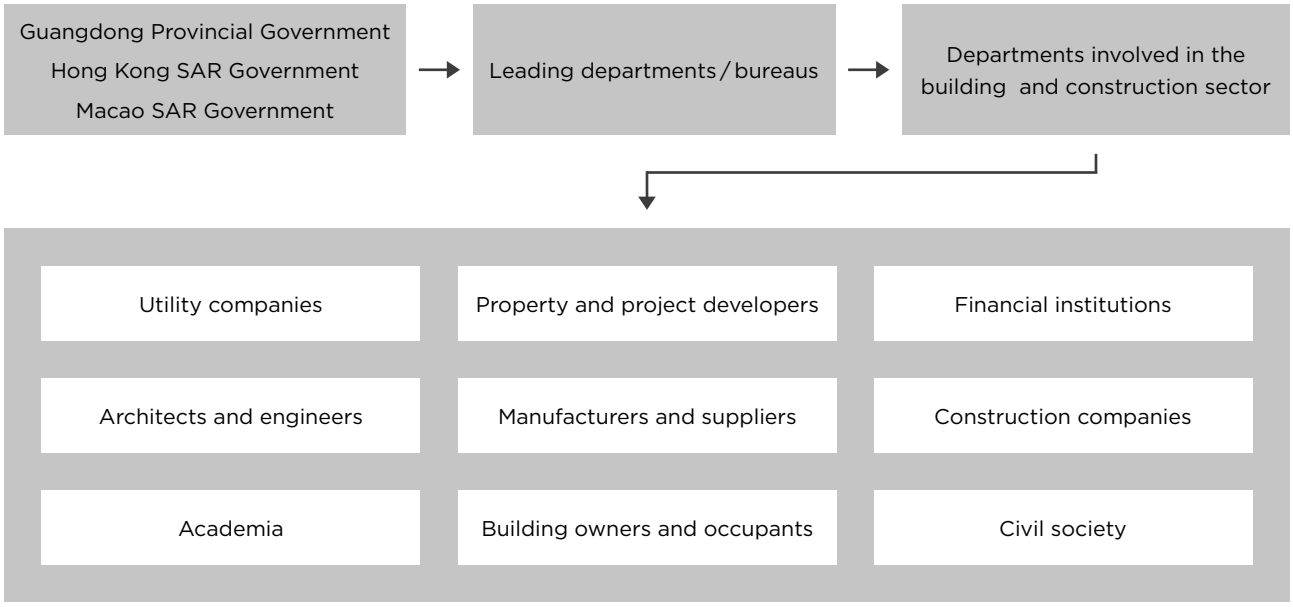
Overview of Key GBA Stakeholders in all Activity Areas

The stakeholder selection process in China's Greater Bay Area (GBA) presents several challenges, including a complex political landscape, cultural diversity, economic disparities, regulatory complexity, and limited resources. Stakeholder engagement plays a crucial role in the success of climate policy implementation in the building and construction sector of the GBA. Effective stakeholder engagement can address potential risks such as inadequate risk management, lack of stakeholder buy-in, insufficient planning, unrealistic schedules and budgets, and poor communication, resulting in the successful completion of projects within budget, on time, and to desired standards. The engagement of stakeholders serves several important functions, including the utilisation of stakeholders' expertise and knowledge, promotion of transparency, securing and sustaining support, improvement of risk management, and optimisation of project deliverables and efficiencies. Stakeholder dialogues, through various forms such as consultations, partnerships, or multi-stakeholder platforms, facilitate communication and cooperation between all stakeholders, leading to enhanced project outcomes and greater success.

Multi-Stakeholder Engagement

Engagement with stakeholders across sectors offers the opportunity to gain feedback from a variety of perspectives, especially those that will support the implementation of the roadmap (especially across the private sector) and those who will be affected by the policies. Multi-stakeholder engagement also creates strong community buy-in to maintain momentum through leadership transition. It also incorporates feedback from implementers and those affected, and builds trust. By involving a diverse range of stakeholders in the planning and implementation process, the GBA can ensure that its low-carbon building and construction initiatives are aligned with stakeholder needs and preferences.

Table 39 Multi-stakeholder engagement workflow in the GBA



Successes in multi-stakeholder engagement have been seen in the form of joint efforts to promote energy-efficient buildings and low-carbon construction practices. For example, some cities in the GBA have implemented building codes that require new constructions to meet certain energy efficiency standards. Additionally, there have been initiatives to retrofit existing buildings to improve their energy performance.

Regional Example

Established in 2015, the Hong Kong Zero Carbon Partnership aims to build a platform for the public and other stakeholders in Hong Kong to collaborate on the building sector transition toward carbon neutrality and sustainability. The Partnership organises various types of activities, including online knowledge portal, workshops and seminars.

However, there are also gaps in the interaction between the different stakeholders in the GBA, particularly when it comes to coordinating policies and initiatives across the different administrative regions. This is due in part to the fact that each city in the GBA has its own government and policies, which can sometimes lead to conflicting priorities and a lack of coordination between the different cities. In addition, there can also be a lack of communication and collaboration between the public and private sectors, which can limit the effectiveness of climate policies in the building and construction sector. For example, there may be a lack of incentives for private sector companies to invest in low-carbon construction and energy-efficient buildings, or a lack of support from government agencies to help these companies overcome the challenges they face in implementing these practices.

Public Sector's Key Stakeholders

The public sector's buildings and construction industry in the GBA involves a range of important stakeholders. These include government authorities responsible for implementing policies and regulations, regulatory agencies tasked with enforcing building codes and safety standards, public works departments in charge of constructing and maintaining public infrastructure, urban planning and design institutes responsible for designing urban areas and buildings:

- **The National Development and Reform Commission** (NDRC) is responsible for devising and implementing economic and social development strategies in the GBA.
- **The Ministry of Housing and Urban-Rural Development** (MOHURD) promotes the growth of the construction industry, as well as urban and rural development and housing.
- **Provincial and municipal government authorities** are tasked with implementing building and construction policies and regulations within the GBA.
- **Public works departments** are responsible for constructing and maintaining public infrastructure, including roads, bridges, and public buildings.

- **Urban planning and design institutes** are involved in the planning and design of urban areas and buildings[45].
- **Regulatory agencies**, responsible for enforcing building codes and regulations and ensuring that safety and quality standards are met[46].

The table below shows the key stakeholders and the activity areas they influence under each aforementioned zone[47].

Table 40 Key public stakeholders for the building and construction sector in the GBA under the GlobalABC Activity Areas.

Stakeholders	Governance			Activity areas								Finance
	PRD	HK SAR	MC SAR	A1	A2	A3	A4	A5	A6	A7	A8	
Development and Reform Commission of Guangdong Province	X			X	X	X	X	X	X		X	X
Department of Natural Resources of Guangdong Province	X			X					X			
Department of Housing and Urban-Rural Development of Guangdong Province	X			X	X	X	X	X	X	X	X	X

45 Noting that the UP Institute Guangdong underwent a transition from being a state-owned entity to a privately-owned enterprise prior to 2020, resulting in its current status as a predominantly private institution.

46 In the GBA, regulatory agencies for construction standards are primarily government authorities, responsible for setting and enforcing standards to ensure safety and quality in building projects. According to the Guangdong Provincial Government (2021), the government is responsible for formulating and implementing policies, plans, and regulations related to construction, and regulatory agencies such as the Guangdong Provincial Department of Housing and Urban-Rural Development play a key role in overseeing the implementation of these policies. While there may be some involvement of private sector entities in construction and related industries, the overall regulatory framework is overseen by government authorities.

47 Some agencies may have a stronger impact on a particular activity area, while others may have influences on multiple activity areas. For example, the Energy Bureau oversees the clean energy development (Activity 8), whilst the Development and Reform Commission has mandates on multiple activity areas.

Department of Ecology and Environment of Guangdong Province	X									X	X	
Energy Bureau of Guangdong Province	X				X	X	X	X			X	
Department of Emergency Management of Guangdong Province	X									X		
Municipal Development Bureaus	X	X	X	X	X	X			X		X	X
Municipal Planning and Natural Resources Bureaus	X	X	X	X								
Municipal Housing and Urban-Rural Development Bureau	X	X	X	X	X	X	X	X	X	X	X	X
Municipal Ecology and Environmental Bureau	X	X	X							X	X	
Public energy suppliers, utility companies and grid operators	X	X	X				X	X	X		X	
Public real estate developers and operators	X	X	X		X	X	X	X	X	X	X	

The data suggests that there is significant stakeholder involvement in several of the activity areas. Specifically, the activity areas of New Buildings, Existing Buildings, Building Operations, Materials, and Clean Energy exhibit a high level of engagement from both government agencies and private sector stakeholders. This suggests a strong focus on sustainable building practices and energy efficiency in the region.

However, there are also indications of potential sector complementation in some areas, such as Urban Planning, Resilience, and Appliances and Systems. While government agencies are involved in these areas, there is relatively low involvement from private sector stakeholders. For example, in the area of Urban Planning, the Department of Natural Resources of Guangdong Province is involved, but there is no involvement from public real estate developers or operators. In the area of Resilience, there is no involvement from public or private energy suppliers, utility companies, or grid operators, despite their potential role in ensuring critical infrastructure remains resilient.

Therefore, it is suggested that there may be opportunities for greater collaboration and engagement across sectors in certain areas to maximise sustainability outcomes within the GBA. This could involve increased involvement from private sector stakeholders in Urban Planning, as well as closer collaboration between government agencies and energy stakeholders in the areas of Resilience and Appliances and Systems. By leveraging the insights and resources of diverse stakeholders, the GBA may be better positioned to achieve sustainable development outcomes across all activity areas.

In addition to the public sector, stakeholders in other sectors also influence the development of low-carbon, efficient, and resilient buildings and construction.

The Role of Government Departments and Bureaus in Promoting Low-Carbon Building and Construction in the Greater Bay Area

The GBA encompasses two Special Administrative Regions (SARs), Hong Kong and Macao, and an additional administrative region in Guangdong province known as the Pearl River Delta (PRD). Each of these three administrative zones has its own distinct government structure. However, the differences in government structures across the GBA can create barriers for the development of low-carbon building and construction projects, leading to inconsistent legal and regulatory frameworks for stakeholders when launching projects in the region.

Addressing these challenges presents a significant opportunity for positive impact. By overcoming these barriers, stakeholders in the region can collaborate and innovate on new sustainable building practices and technologies. This could lead to a reduction in carbon emissions and other environmental degradation factors, as well as the creation of new jobs and economic opportunities in the region. Furthermore, the development of low-carbon building and construction projects in the GBA could also contribute to global efforts to mitigate climate change, given the region's significant economic and environmental influence.

In Guangdong province, the PRD cities follow the top-down administration system of the provincial government, which is comprised of 22 departments and several management agencies, such as the Energy Bureau and the Financial Supervisory Authority. In contrast, Hong Kong and Macao, due to their historical reasons, have separate government structures from those in mainland China. The Hong Kong SAR Government is comprised of 15 administration and financial bureaus, as well as offices under the Secretariat for Justice. Macao SAR, as a smaller city, has a streamlined government structure of five comprehensive secretariats.

For the PRD, the Department/Bureaus of Housing and Urban-Rural Development leads strategy development for the building and construction sector, while other departments are responsible for some specific works based on their mandate. For example, in 2021, Guangdong issued Measures to Promote the High-Quality Development of the Building Sector in Guangdong Province, in which 18 actions points were listed (Guangdong Provincial Government, 2021). The Department of Housing and Urban-Rural Development leads most actions, while other departments also involve in actions. Table 41 shows the stakeholder organigram for these actions.

Table 41 Simplified stakeholder organigram and respective responsibility clusters in Guangdong provincial government

Policy approval	Government of Guangdong province			
Policy development, coordination & reporting	Department of Housing and Urban-Rural Development	Comission of Development and Reform		
Action planning, implementation & monitoring	Department of Science and Technology	Department of Industry and Information Technology	Department of Finance	Department of Natural Resources

In Hong Kong SAR, three bureaus play a key role in the building and construction sector. The Environmental and Ecology Bureau leads Hong Kong's overall climate strategies. For example, the Bureau led the development of the Hong Kong's Climate Action Plan 2050 and the Energy Saving Plan for Hong Kong's Built Environment (2015–2025+). The Development Bureau and the Housing Bureau also influence the building sector. The main mandates are listed in the following table.

Table 42 Key bureaus and their mandates for the building and construction sector in Hong Kong

Bureaus	Relevant mandates
Environment and Ecology Bureau	Clean energy, including energy supply, energy efficiency and conservation, promotion of renewable energies, and electricity charges Climate strategies, tools, and initiative, including low-carbon buildings
Development Bureau	Land use Building safety and maintenance Public infrastructure development
Housing Bureau	Housing supply Provision of public rental housing units Promotion of good sales and tenancy practices for private residential properties

Under the Secretariat for Transport and Public Works, several offices affect the building and construction sector in Macao. Like Hong Kong, the Environmental Protection Bureau leads the building decarbonisation. The Bureau published the Macao Environmental Protection Plan (2021–2025) in which one pillar is to build green and low-carbon buildings to mitigate climate change.+

Table 43 Key bureaus and their mandates for the building and construction sector in Macao

Bureaus	Relevant mandates
Environmental Protection Bureau	Climate actions, including building decarbonisation Green building programme
Land and Urban Construction Bureau	Urban planning Land management, land licensing, and inspection Electrical installation management
Housing Bureau	Housing policy development Public housing provision Housing management and renovation
Public Construction Bureau	Public construction project development and implementation Public building and infrastructure design, development, and maintenance

Civil Society's Key Stakeholders

There is relatively widespread coverage across most activity areas, with some areas that are benefitting more from the involvement of certain stakeholders than others. There may be opportunities for sector complementation in areas such as new buildings, existing buildings, building operations, materials, and clean energy, where certain stakeholder groups are less involved.

Civil society and citizens, particularly associations on urban planning, architecture, energy, climate, and green business, are involved in all eight activity areas. This suggests that they have a broad influence on sustainability efforts in the GBA, and may play a key role in advancing sustainable development goals in the region.

Local Non-Governmental Organisation (NGOs) and community groups are also involved in all eight activity areas, which highlights their important role in advocating for sustainable practices and engaging local communities in sustainability initiatives.

Building owners and occupants have a strong influence on existing buildings, building operations, appliances and systems, and resilience, but are less involved in new buildings, materials, and clean energy. This suggests that there may be an opportunity for greater engagement with this stakeholder group in those areas.

The general public is involved in all eight activity areas, which underscores the importance of public awareness and engagement in sustainability efforts.

Informal sector stakeholders, particularly communal and self-help groups, are involved in materials, resilience, and clean energy. This suggests that there may be opportunities for greater engagement with these stakeholders in new buildings, existing buildings, and building operations.

International development organisations, particularly UN agencies focusing on climate and energy, are involved in all eight activity areas. This highlights their important role in promoting sustainable development globally, and suggests that they can contribute to advancing sustainability efforts in the GBA.

Multilateral development banks are involved in all eight activity areas, which indicates their strong commitment to promoting sustainable development in the region.

Table 44 Key GBA stakeholders from civil society organisations under the GlobalABC Activity Areas.

Sectors	Stakeholders	Activity areas								Finance
		A1	A2	A3	A4	A5	A6	A7	A8	
Civil society and citizens	Associations on urban planning, architecture, energy, climate, and green business	X	X	X	X	X	X	X	X	
	Local NGOs and community groups	X	X	X	X	X	X	X	X	
	Building owners and occupants		X	X	X	X		X	X	
	General public	X	X	X	X	X	X	X	X	
Informal sector	Communal and self-help groups			X	X	X		X	X	

International development organisations	UN agencies focusing on climate and energy	X	X	X	X	X	X	X	X	
	Multilateral development banks		X	X	X	X	X	X	X	X

Academia & Research Institutions' Key Stakeholders

There is relatively widespread coverage across most activity areas, with some areas benefiting more than others from academic complementation.

One area that appears to have significant academic complementation across multiple stakeholder groups is clean energy. Private universities, trade schools, charter schools, incubators and accelerators, maker spaces and innovation centres, research and development centres, and vocational training centres all have potential influence in this area. This suggests that there is likely to be a strong emphasis on developing clean energy technologies and training programmes for related occupations in the GBA.

Another area with relatively widespread academic complementation is materials, which may be influenced by public universities, private universities, think tanks and research institutions, and maker spaces and innovation centres. This suggests that there may be significant research and development efforts focused on developing new sustainable building materials and technologies.

In contrast, some activity areas may have relatively limited academic complementation. For example, while public universities, private universities, and charter schools may all have influence in the area of new buildings, there are no trade schools, think tanks and research institutions, incubators and accelerators, maker spaces and innovation centres, research and development centres, or vocational training centres listed as potential contributors to this area. This suggests that there may be room for greater collaboration and academic complementation in this area.

Table 45 Key GBA stakeholders from academia & research institutions under the GlobalABC Activity Areas.

Sectors	Stakeholders	Activity areas								Finance
		A1	A2	A3	A4	A5	A6	A7	A8	
Academia	Public universities	X	X		X		X	X	X	
	Private universities		X				X		X	
	Trade schools				X				X	
	Charter schools		X	X					X	
	Think tanks and research institutions	X	X	X	X	X	X	X	X	
	Incubators and accelerators		X						X	
	Maker spaces and innovation centres		X				X		X	
	Research and development centres						X		X	
	Vocational training centres				X				X	

Private Sector's Key Stakeholders

The building and construction industry in the GBA has significant stakeholder involvement in several key activity areas. The stakeholders that are best represented in these areas include property developers, manufacturers, construction firms, urban planners, architects, engineers, facility managers, building operators, energy plant operators, private energy suppliers, and chambers of commerce.

In particular, stakeholders in the activity areas of New buildings, Existing buildings, Building operations, Materials, Resilience, and Urban planning are well-represented, indicating commitment to sustainability across the industry. These activity areas involve a lot of construction, design, and operations, which require significant input from the aforementioned stakeholders.

However, there are a couple of activity areas that could benefit from more sector complementation. The activity areas of Appliances and Systems, and Clean Energy could potentially benefit from more involvement from manufacturers and suppliers of materials, energy equipment, and home appliance systems. While these stakeholders are involved in some capacity in these areas, it may be beneficial to have greater collaboration and investment in sustainable technologies for appliances and systems, as well as in clean energy production and distribution.

Furthermore, financial institutions, represented in the activity areas of Appliances and Systems and Clean Energy, could potentially play a greater role in promoting sustainable technologies and practices in these areas through funding and invest-

ment. This could help to accelerate the adoption of sustainable technologies and practices across the industry, further advancing sustainable development goals in the GBA.

While there is a strong commitment to sustainability across the building and construction industry in the GBA, there is room for improvement in certain activity areas. More collaboration and investment in sustainable technologies for appliances and systems, as well as in clean energy production and distribution, could help to advance sustainable development goals in the region. Financial institutions could also play a greater role in promoting sustainable practices and technologies through funding and investment[48].

Table 46 Key GBA stakeholders from the private sector under the GlobalABC Activity Areas.

Sectors	Stakeholders	Activity areas								Finance
		A1	A2	A3	A4	A5	A6	A7	A8	
Private sector and business	Property developers		X	X	X	X	X	X	X	X
	Manufacturers and suppliers of materials, energy equipment, and home appliance systems		X	X	X	X	X	X	X	
	Construction firms		X	X		X	X	X		
	Urban planner and architects and engineers	X	X	X	X	X	X	X	X	
	Facility managers, building operators, and energy plant operators			X	X	X		X	X	
	Home brokerage companies			X	X	X		X		
	Property management companies			X	X	X		X	X	
	Private energy suppliers and utility companies		X	X	X	X		X	X	
	Chambers of commerce		X	X	X	X	X		X	

48 In the GBA, financial institutions such as the China Development Bank and the Industrial and Commercial Bank of China are involved in financing large-scale infrastructure projects and property development ventures. These institutions play an important role in shaping the real estate and construction industries in the region, providing capital and expertise to support development initiatives and promote economic growth.

Financial institutions	Banks, funds		X							X
	Emergency-, prevention-, and mitigation-oriented funding institutions		X	X	X	X	X	X	X	X

Overview of Key GBA Enabling Conditions

To ensure the successful implementation of low-carbon building and construction across all eight activity areas of the GBA, certain enablers are crucial. Capacity building, financing, and multi-stakeholder engagement are three such enablers. By prioritising these, the GBA can improve awareness, decision-making, and sustainable choices in the building and construction sector. With effective green financing mechanisms, the GBA can leverage public and private investments to scale up low-carbon and sustainable building projects. By engaging a variety of stakeholders, including the public sector, private sector, and civil society, the GBA can build trust, create buy-in, and maintain momentum to achieve its low-carbon building and construction goals.

Capacity Building

The challenges faced by the main administrative regions in the Guangdong-Hong Kong-Macao GBA in achieving carbon neutrality by 2060 are multifaceted. While the GBA governments have taken initial steps towards the development of low-carbon buildings, challenges remain in policy, data collection and analysis, institutional coordination, financing, educational and professional training, and awareness. For example, the lack of regulatory and incentive support for low-carbon and sustainable buildings, limited data availability on building carbon emissions and sustainable building investment, and inconsistent definitions and calculation methodologies for zero-emission buildings hinder effective measurement and benchmarking.

Capacity-building activities can target key areas to overcome these challenges, including training within the government for a clear transition roadmap towards net-zero, efficient, and resilient buildings, promotion of emerging low-carbon approaches, materials, and technologies, and low-carbon and green building programmes at colleges and professional schools. The training of product and material manufacturers and financiers and developers is also crucial to assess the financial feasibility of zero-emission, efficient, and resilient building and construction projects and to develop innovative business models for building renovations. Finally, training of the general public on behaviour change towards a low-carbon lifestyle and the benefits of low-carbon buildings can increase awareness and promote a more sustainable built environment.

Green Financing

The development of low-carbon and sustainable buildings is critical to addressing climate change, and green financing is an essential tool to accelerate this

development. The Guangdong-Hong Kong-Macao GBA is a region with a great need for green investment, particularly in the building sector. According to the International Finance Corporation (IFC) in 2021, the cumulative investment in energy-efficiency retrofits between 2020 and 2030 in four major emerging economies in East Asia and the Pacific, including the GBA, is estimated to be 3,398 billion RMB (approximately 445 billion EUR) (International Finance Corporation, 2021). This investment represents a significant opportunity for public and private actors to collaborate and implement various green financing mechanisms to drive the growth and scaling of investment activities in the building sector. Stakeholders in the region, including governments, financial institutions, developers, and building owners, must recognise the potential benefits of green financing and work together to allocate resources to promote sustainable building development. Therefore, a coalition of public and private actors, as well as various financial mechanisms, is required for rapid growth and scaling of investment activities in the buildings sector.

To support low-carbon building development, some cities in the GBA have launched green financing pilots, which other GBA cities can refer to for best practices. Various financing tools can be implemented, such as dedicated funding for zero-emission, efficient, and resilient building projects, green insurance to reduce the financial risk of building projects, environmental impact bonds to bundle funding for projects with climate or environmental benefits, green building funds to support technical innovation and low-carbon building projects, integration of criteria related to low-carbon and sustainable buildings in public procurement, Public-Private Partnership (PPP) models to leverage private investment and reduce risks facing the public and private sectors, and embedding the building sector into an Emission Trading System (ETS) to encourage building owners or operators to reduce carbon emissions. By utilising these green financing mechanisms, the GBA can accelerate the development of low-carbon and sustainable buildings, contributing to the region's overall efforts to combat climate change.

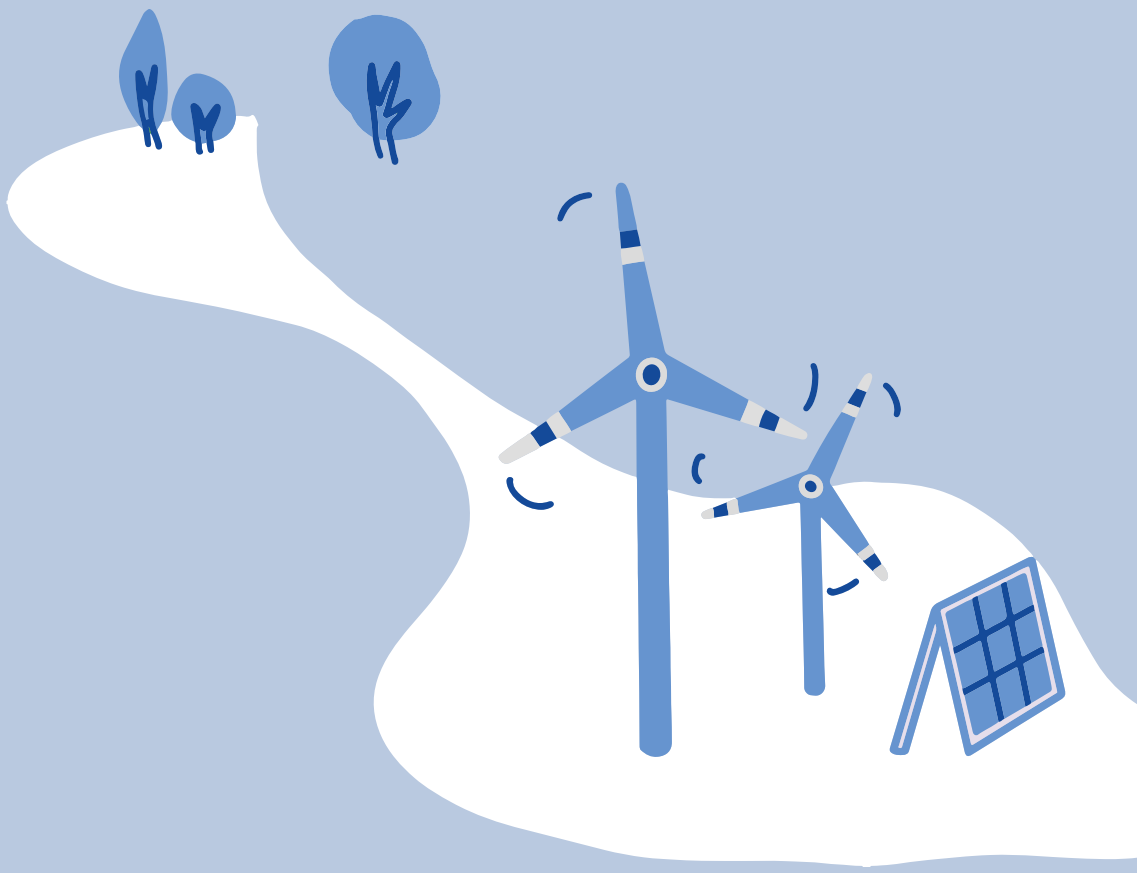
Multi-Stakeholder Engagement

Effective multi-stakeholder engagement is a crucial aspect of promoting sustainable building practices in the GBA. To achieve this, it is necessary to establish clear goals and objectives for the engagement process, provide adequate resources such as funding, staff, and time, develop effective communication strategies, and put in place feedback mechanisms to ensure stakeholders can provide input and feedback on the engagement process (Kolk, et al., 2008).

An example of successful multi-stakeholder engagement practices can be seen in Germany's Energiewende (Energy Transition) initiative, which aims to transition the country's energy system to one that is more sustainable and renewable. This initiative involves collaboration among a range of stakeholders, including government, industry, academia, and civil society, and has resulted in significant investments in renewable energy and energy efficiency measures (Quitzow, et al., 2016). Similarly, Denmark's PPPs have been successful in promoting sustainable building practices. For instance, the Danish Energy Agency has partnered with private companies to develop energy-efficient solutions for buildings, while the Danish Building Research Institute has worked with stakeholders from academia, industry,

and government to develop sustainable building standards (Mernild, 2022). These best practice examples highlight the importance of collaborative efforts among diverse stakeholders in achieving sustainable building practices.

Achieving effective multi-stakeholder engagement requires a collaborative effort from all parties involved. By utilising effective communication strategies, feedback mechanisms, and innovative examples from the international community, stakeholders in the GBA can work towards a more sustainable future in the building and construction sector.



Moving Forward: Outlook & Next Steps

This publication represents an important step in the roadmap process towards the complete decarbonisation of buildings and construction in China's Greater Bay Area (GBA), but **it is not the end of the journey**. Our ultimate goal of carbon neutrality can only be achieved through a collaborative effort by all stakeholders, and we encourage our readers to take an active role in shaping the future of this initiative.

The development of the roadmap, specifically tailored for the Guangdong-Hong Kong-Macao GBA, was initiated by the core project team consisting of the German Energy Agency (dena), the Chinese Academy of Building Research (CABR), and the ICLEI – Local Governments for Sustainability, who followed the Global Alliance for Buildings and Construction (GlobalABC) regional roadmap framework. The document was designed to follow a **living document approach**, which is intended to be adapted to the changing circumstances in the future, feedback from the growing multi-stakeholder groups, and new data over time. The team hereby aims to provide a robust sector-integrated overview and baseline to facilitate the effective implementation towards achieving the mega-region's carbon neutrality goals.

Considering the complexity of the building sector and its interlinked activity fields highlighted in this roadmap, the selection of focus areas by local stakeholders could be the reasonable next step. To that end, we suggest that stakeholders choose their respective actions, focusing on applicable **ownership, implementation, and monitoring**. These three interdependent topics are crucial for the success of the endeavour. In doing so, further actions can be taken into account, e.g. identification and realisation of pilot projects in the GBA Region, overall market development and the improvement of financial instruments accordingly.

In parallel to calling for ownership and implementation, the role of effective monitoring and evaluation is also to be taken into consideration. To achieve the goal in the appointed time, an effective monitoring process is vital to be able to adapt to progress and needs as well as effectiveness and impact of actions. In a well-balanced monitoring process several aspects have to be considered, such as frequency of reporting or updates, level of detail, work and time required for the development.

We acknowledge that this is a complex undertaking, and the engagement of a multi-stakeholder group is essential for success. Therefore, we also recommend the ongoing dissemination of this study to inspire further stakeholders to get involved and take specific ownership in the various fields of this initiative. It's worth noting that many stakeholders relevant to this initiative are not only active in the GBA, but some operate internationally. We hope that the decarbonisation efforts in the highly dynamic GBA can have a **leverage effect** and will be part of international knowledge sharing on the journey to climate neutrality.

Therefore, we urge all stakeholders to take an active role in this initiative and work towards a sustainable future. While this roadmap can serve as a stepping stone, a broader group of ambitious drivers taking ownership is absolutely essential for growing success. **Let us continue this journey** together towards a decarbonised future for buildings and construction in the GBA.

Sincerely,

the Project Team

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Table of Tables

Abbreviations

AI	Artificial Intelligence
AC	Alternating Current
BACS	Building Automation and Control Systems
BEC	Building Energy Code
BEEO	Buildings Energy Efficiency Ordinance
BIM	Building Information Modelling
BIPV	Building-Integrated Photovoltaics
BMS	Building Management Systems
BNEF	Bloomberg New Energy Finance
C2C	Cradle to Cradle
CABR	China Academy of Building Research
CIM	City Integrated Modelling
CLCD	Chinese Reference Life Cycle Database
COP	Coefficient of Performance
DC	Direct Current
dena	German Energy Agency GmbH
EAC	Energy Audit Code
EER	Energy Efficiency Ratio
EERSB	Energy Efficiency Registration Scheme for Buildings
EIA	Energy Information Administration
ELCD	European Reference Life Cycle Database
EMS	Energy Management System
EMSD	Electrical and Mechanical Services Department
EnPC	Energy Performance Contracting
EPD	Environmental Product Declaration
ESCO	Energy Service Company
ETFE	Ethylene Tetrafluoroethylene
ETS	Emission Trading System
GBA	China's Greater Bay Area
GBEL	Green Building Evaluation Label
GBP	Green Bond Principles
GDP	Gross Domestic Product
GlobalABC	Global Alliance for Buildings and Construction
HVAC	Heating, Ventilation & Air Conditioning
IAEA	International Atomic Energy Agency
IBMS	Integrated Building Monitoring System
ICLEI	International Council for Local Environmental Initiatives
IEA	International Energy Agency
IFC	International Finance Corporation
INDC	Intended Nationally Determined Contributions
IoT	Internet of Things
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LCOE	Levelised Cost of Energy
LEED	Leadership in Energy and Environmental Design
LRIP	Living Roadmap and Iterative Implementation Plan
MDF	Medium-Density Fibreboard
MEP	Mechanical, Engineering and Plumbing
MEPS	Minimum Energy Performance Standard
MIIT	Ministry of Industry and Information Technology
MOHURD	Ministry of Housing and Urban-Rural Development
MOST	Ministry of Science and Technology
NDRC	National Development and Reform Commission
NGO	Non-Governmental Organisation
NZEB	Nearly Zero Energy Building
ODP	Outline Development Plan
PEDF	Photovoltaic, Energy storage, Direct current and Flexibility
PoE	Power over Ethernet
PPP	Public-Private Partnership
PRD	Pearl River Delta
PV	Photovoltaic
R&D	Research & Development
RE	Renewable Energy
SAR	Special Administrative Region
SDG	Sustainability Development Goal
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar Heat Gain Coefficient
SOEs	State-Owned Enterprises
SWHS	Solar Water Heating System
T&D	Transmission and Distribution
UEB	Urban Environment Building
UHI	Urban Heat Island
UHV	Ultra-High Voltage
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change

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