

Achieving carbon neutrality in Hong Kong: a comparative policy analysis and introduction to simulation strategies

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ABSTRACT

Climate change presents significant financial risks to businesses, while profoundly impacting people’s daily lives and causing drastic changes in nature. Hong Kong has set an ambitious carbon neutrality target of 2050 to mitigate climate risks. Climate Value-at-Risk (CVaR) is a quantitative metric to evaluate these risks, supporting effective risk management and decision making.

This paper offers a comprehensive overview of CVaR concepts and scrutinises existing policies in Hong Kong, compared to other countries. It presents a brief comparison of common carbon emission data sources, along with an examination of commercially employed benchmarking and CVaR simulation tools. Data quality and availability, however, remain substantial challenges in estimating CVaR accurately. Fuzzy logic application to quantify CVaR is suggested, and it represents an effective approach to professionally manage the decarbonisation journey.

Leveraging advancements in technology, Hong Kong policymakers can draw valuable insights from leading countries’ climate policies and utilise the fuzzy logic model to make necessary changes to achieve more ambitious climate goals, accelerating the city towards carbon neutrality.

KEYWORDS Carbon neutrality, transitional climate value-at-risk, data integrity, fuzzy logic, sustainability, environmental engineering

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1. Introduction

1.1. Climate change and carbon neutrality

Climate change threatens the environment, economy, and well-being of people globally. Countries must reduce their GHG emissions despite challenges including data availability and integrity. Corporates with decarbonisation strategies face obstacles due to a lack of transparent data, especially scope 3 carbon emissions from upstream and downstream sources. Swift action is needed as global warming nears a breach of 1.5 degrees Celsius. The HKSAR has made progress towards carbon neutrality, but there is room for improvement. Comparing policies on a global scale can enhance Hong Kong’s progress.

1.2. Climate risk

The impact of climate change on the economy is significant (UNEP, 2023), and businesses are keen to understand about the potential risks.

1.3. Qualitative risk – physical and transitional

Climate risk can be physical (e.g., typhoons and rising sea levels) or transitional (e.g., changes in energy prices and technology advancement), which refers to the impact of changes in policy and markets towards a low-carbon economy. Figure 1 from the Task Force on Climate-related

Financial Disclosures (TCFD) shows the financial impact of these risks and opportunities (TCFD, 2017).

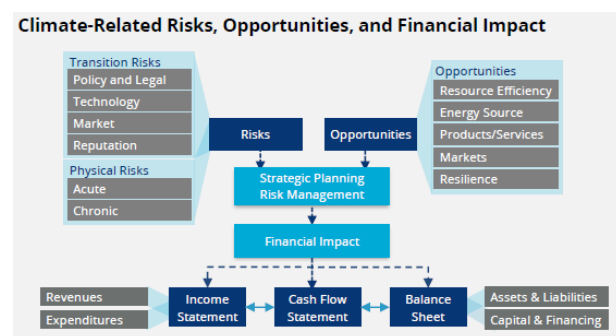


Figure 1. Climate-related risks, opportunities and financial impact (Bloomberg, 2017).

1.4. Quantitative risk – climate-value-at-risk (CVaR)

Climate risk has a huge impact on asset value. As shown in Figure 2, climate risk could affect assets’ incoming cash flows by reducing rents and occupancy; risk premiums and the expected growth rate of capitalisation could also be affected by a reduction in assets’ liquidity and saleability; and financial costs could be raised by increasing risks (UNEP, 2021).

The commercial real estate industry is currently developing different methods to calculate CVaR, and in the later part this paper will examine how fuzzy logic can be leveraged in the CVaR model to resolve data discrepancies.

EXHIBIT 2: ANTICIPATED EFFECTS ON COMMERCIAL REAL ESTATE ASSET PERFORMANCE OF INCREASED EXPOSURE TO CLIMATE RISK

Source: Clayton et al. 2021, developed with reference to de Wilde and Coley (2011)

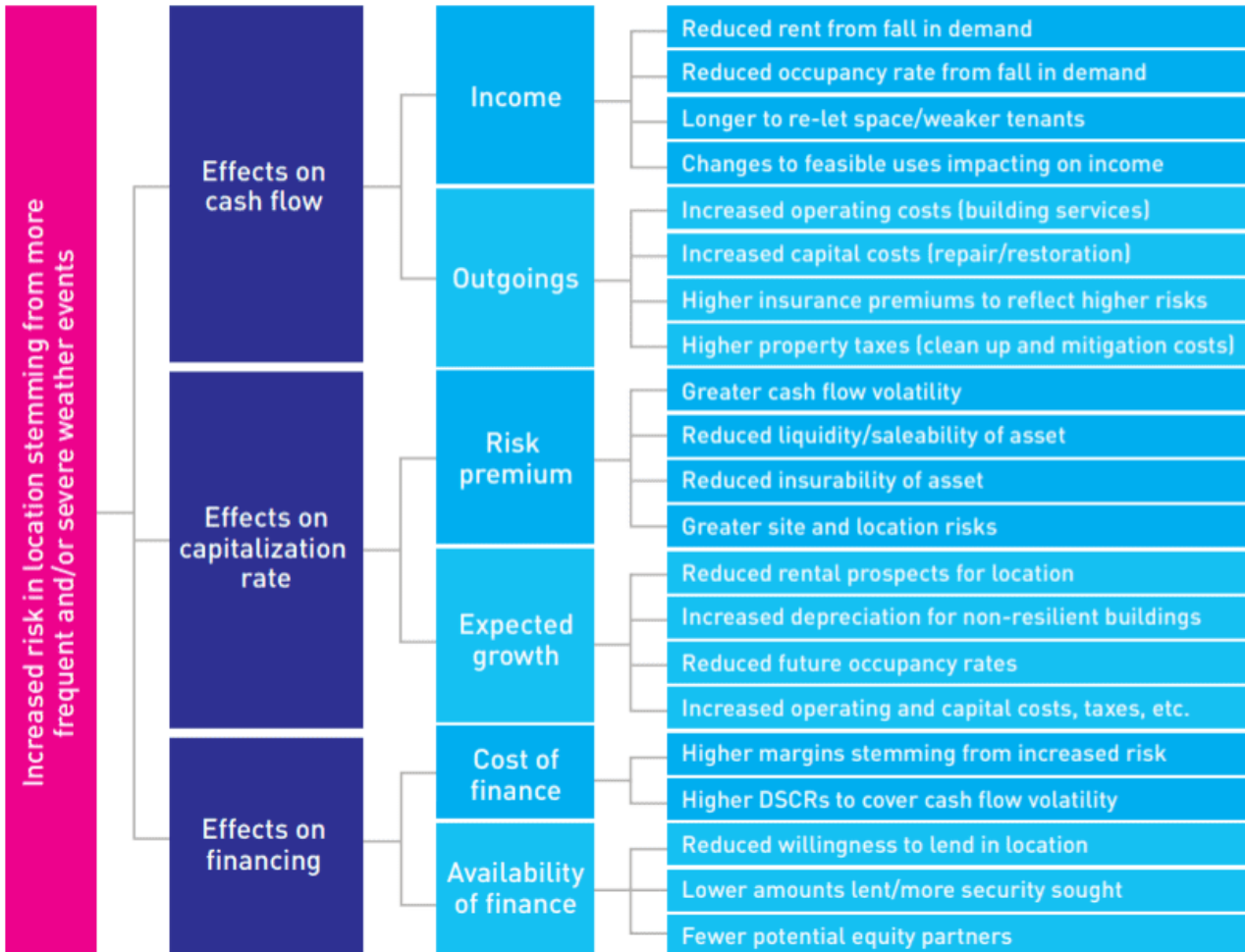


Figure 2. Anticipated effects on the commercial real estate asset performance of increased exposure to climate risk (Clayton et al., 2021).

1.5. Impact of carbon neutrality policies on real estate

Carbon neutrality policies affect buildings’ cash flow, capital costs and tax obligations, and the impact on buildings’ transitional climate risk is dependent on their energy efficiency, reliance on fossil fuels and current volume of emissions.

2. Study of international carbon neutrality policies

Below is listed the major benefits of implementing carbon neutrality policies.

2.1. Technological innovation

- Incentivising research and development: Financial incentives (grants, tax credits, or subsidies) can be provided to support renewable energy use, retro-commissioning, carbon capture and storage technologies.
- Promoting market demand for low-carbon technologies: By setting ambitious carbon reduction targets, this can create demand for businesses to invest in and deploy innovative solutions.
- Supporting infrastructure development: Policies can lead to investments in sustainable infrastructure, such as smart grids and electric vehicle charging stations.

2.2. Behavioural changes

- Raising awareness and promoting sustainable lifestyles: Campaigns are launched to educate individuals about the benefits of energy saving, waste reduction and sustainable transportation.
- Encouraging corporate responsibility: Policies can drive companies to adopt sustainable practices, creating a positive reputation for businesses.
- Influencing consumer choices: Incentives (e.g., tax rebates, subsidies) or disincentives (e.g., carbon taxes, higher fees for high-emission products) can encourage consumers to opt for low-carbon products and services.

2.3. Hong Kong's carbon neutrality policies

Hong Kong is a coastal city that is vulnerable to physical climate risks (tropical cyclones, rainstorms, flooding, extreme temperatures). Buildings accounted for 90% of its total electricity consumption and over 60% of its carbon emissions in 2019. The Hong Kong Government has implemented various measures to improve energy efficiency, including net-zero electricity generation, energy-saving and green buildings, green transportation, and waste reduction. The government aims for carbon neutrality by 2050 and halving emissions by 2035 (HKSAR Government, 2021).

Buildings in Hong Kong are major carbon emission sources, and the government has implemented measures such as through the enactment of the Buildings Energy Efficiency Ordinance (BEEO), and voluntary Energy Efficiency Registration Scheme for Buildings (EERSB) to encourage building owners to achieve better energy performance beyond the statutory requirements (EMSD, 2023).

The government will integrate energy-efficient facilities in development projects, promote greater use of energy management tools, and review and upgrade the Mandatory Energy Efficiency Labelling Scheme (MEELS) (EMSD, 2023). MEELS helps the public choose energy-efficient appliances and educates them on energy-saving practices. The Feed-in Tariff Scheme (HKSAR Government, 2023) encourages individuals to use renewable energies.

2.4. Comparative analysis of selected countries' carbon neutrality policies

Different countries, as below, have successfully implemented ambitious carbon neutrality policies that can serve as a benchmark for Hong Kong.

- China

As the world's largest emitter of GHGs, the Chinese government has announced its aim to achieve carbon

neutrality by 2060, with an interim target of peak carbon emissions by 2030 (Xi, 2020). Strategies include increasing non-fossil fuel use, boosting energy efficiency and investing in low-carbon technologies (National Development and Reform Commission, 2021). China's national and city policies support systematic decarbonisation; please see Appendix 1 for further details.

- South Korea

South Korea targets at carbon neutrality by 2050 and a 24.4% carbon emission reduction by 2030 (The Government of the Republic of Korea, 2020). The government requires all buildings to achieve Zero Energy Buildings (ZEB) grade 1 by 2050 and grade 5 by 2030. Regulations (Korea Energy Agency, 2023) (Kim & Yu, 2020) encourage renewable energy use with an energy independence rate of 20-40%. Subsidies for green remodelling projects, GFA concessions and acquisition tax reduction will be provided. ZEB regulations will accelerate carbon reduction and renewable energy adoption, impacting both new and existing buildings. The ZEB certification process includes performance criteria, and cost implications are mitigated through subsidies and incentives.

- Singapore

Singapore, a low-lying and densely populated tropical city-state, is vulnerable to climate change. It aims at achieving carbon neutrality by 2050 and peak emissions before 2030. Emissions are targeted to be reduced to around 60 million tonnes of CO₂ equivalent by 2030 (SG Green Plan, 2024). Key strategies include improving energy efficiency, adopting low-carbon alternatives like solar power, enhancing land use and urban planning, and developing a green growth economy. Singapore has implemented carbon pricing, incentives for energy-efficient technologies, grants for research and development, and electric vehicle promotion. The BCA Green Mark Scheme encourages environmentally friendly construction practices and awards buildings based on their environmental performance.

- United Kingdom

The UK faces significant climate risks, including flooding, heatwaves, biodiversity loss and infrastructure threats. The UK has set a target of net-zero GHG emissions by 2050, with interim targets defined by legally binding Carbon Budgets (HM Government, 2021). The UK's Net Zero Strategy outlines initiatives to reduce emissions, including clean energy transition, energy efficiency and green buildings, clean transportation, industrial decarbonisation, nature-based solutions, and climate adaptation and resilience. The government has implemented penalties and incentives to encourage low-carbon practices, such as carbon pricing, incentives for energy efficiency, electric vehicle incentives, and business support for low-carbon technologies.

- Japan

As a coastal nation, Japan faces risks such as coastal erosion, flooding, and saltwater intrusion, while rising temperatures threaten infrastructure, agriculture, and human life. Committed to achieve carbon neutrality by 2050, Japan outlines strategies across energy, transportation, industrial and nature sectors (Agency for Natural Resources and Energy, 2021) (Ministry of the Environment, 2021). The plan focuses on increasing renewable energy to 22-24% by 2030, enhancing energy efficiency through the Top Runner Program and Act on the Rational Use of Energy, and promoting clean transportation by phasing out gasoline-only vehicles. Building sector initiatives include the Energy Conservation Act, Zero Energy Building Promotion, Green Building Promotion Act, and financial incentives for energy-efficient construction and renovation.

In terms of carbon neutrality goals, 120 out of 198 countries (60.6%) have committed to reaching carbon neutrality by 2050-2070 (Chen, 2022).

Based on the carbon neutrality goals, there are various strategies to be implemented in order to achieve the goal, including the adoption of electric vehicles, carbon tax, use of renewable energy, and green buildings. The progress of strategies in different locations is compared in the following table:

Table 1. Strategy 1: Adoption of electric vehicles.

By:	Location	Description
2030	South Korea	30% of all new vehicles sold should be EVs
2030	EU	There should be at least 30 million zero-emission vehicles
2030	United States	50% of new passenger cars and light trucks sold should be electric vehicles
2035	China	50% of all new vehicle sales should be electric vehicles
2035	Canada	100% of new passenger cars and light-duty trucks should be zero-emission vehicles
2035	United Kingdom	All new cars should be zero emission
2050	Japan	All new vehicles should be either EVs or hydrogen fuel cell vehicles (FCVs)
2050	Hong Kong	Zero-emission private cars should be achieved
2050	New Zealand	There should be a 100% renewable light vehicle fleet

The table suggests learning from other countries by setting a targeted percentage for electric vehicle adoption phases to enhance strategy effectiveness.

Table 2. Strategy 2: Carbon tax.

Status	Location	Description
Ongoing	China	Pilot carbon trading system - cover more industries and regions
Ongoing	South Korea	National carbon pricing scheme - includes a cap-and-trade system for major emitters
Ongoing	Japan	No carbon tax; introduced a voluntary carbon pricing scheme for companies
Ongoing	Taiwan	Carbon tax on certain industries, with plans to expand it to cover more sectors
Ongoing	Singapore	Carbon tax on facilities that produce 25,000 tonnes or more of greenhouse gas emissions annually
Ongoing	New Zealand	Emissions trading scheme
N/A	Hong Kong	No plan to implement a carbon tax

Carbon tax is a potential strategy for achieving carbon neutrality, and its implementation can take reference from the above countries. Carbon dioxide produced in the atmosphere and use of fossil hinders carbon neutrality (Zou, 2021), but a carbon tax can motivate the shift to low-carbon practices with financial incentives.

Table 3. Strategy 3: Use of renewable energy.

Year	Location	Description
2025	Taiwan	Set a target to achieve a renewable energy share of 20% in its electricity generation
2030	New Zealand	Achieve 100% renewable electricity generation
2030	Australia	Achieve 50% renewable energy in its electricity generation
2030	South Korea	Increase the share of renewable energy in its total energy mix to 20%
2030	Japan	Increase the share of renewable energy to 22-24% of its energy mix
2030	Hong Kong	Increase its renewable energy generation capacity to 10% of its electricity consumption

From the above table, it is recommended that Hong Kong be more aggressive in adopting the use of renewable energies and setting a more ambitious percentage like other locations have. With the active contributions from the researchers on renewable energies such as wind and bio-energy, advancement in technologies will facilitate the use of renewable energies (Fang Wang, 2021).

Table 4. Strategy 4: Green buildings.

By:	Location	Description
2020	China	Have 50% of new urban buildings meet green building standards
2021	EU	Achieve nearly zero-energy buildings (NZEBs) as the standard for new construction
2022	India	Have 1.5 billion square feet of its building stock meet green building standards
2030	Singapore	Have 80% of its buildings achieve the Green Mark certification
2030	United Arab Emirates	Have all new buildings be green buildings

The above table demonstrates that green buildings are gradually gaining more attention around the globe.

3. Benchmarking tools and carbon emissions measurement

The Hong Kong Government conducts regular measurements for carbon inventory, and many listed companies publish their ESG reports, but a significant variation remains in the breakdown of emissions, measurement tools, data sources and guidelines used. Data discrepancies make it difficult for building owners, operators, and investors to make informed decisions on energy efficiency and carbon reduction measures, hindering progress towards carbon neutrality.

3.1. Comparative analysis of major measurement tools

The table below summarises the major carbon emission measurement tools in the market. For more details, please refer to Appendix 2.

Table 5. Major measurement tools comparison.

Tool	Organisation	Purpose	Method
Science-Based Target Initiative (Science Based Targets, 2023)	Carbon Disclosure Project (CDP) United Nations Global Compact World Resources Institute (WRI) World Wildlife Fund for Nature (WWF)	Help companies set and validate science-based emissions reduction targets, aligning with the Paris Agreement	Provides resources, guidance, and case studies to support companies in target setting, implementation, and reporting
Carbon Risk Real Estate Monitor (CRREM Project, 2023)	CRREM Project (funded by the European Union)	Assess the carbon reduction pathways necessary for individual properties and portfolios to align with the Paris Agreement	Excel-based tool that evaluates carbon intensity, energy consumption, and required reduction targets at property level
Electrical and Mechanical Services Department (Electrical and Mechanical Services Department, 2023)	Hong Kong Government	Regulation, promotion, and enforcement of electrical and mechanical safety, energy efficiency, and environmental performance	Provides guidelines, standards, and certification schemes; energy utilisation indexes and online benchmarking tools
Arc Skoru (Skoru, 2023)	Affiliated with Green Business Certification and the U.S. Green Building Council (USGBC)	Measure, manage, and improve the sustainability performance of buildings, communities, and cities	Tracks project performance across various sustainability categories (energy, water, waste, transportation, human experience) and calculates greenhouse gas emissions, generating a performance score
MSCI (MSCI Inc, 2023)	MSCI Inc	Assess ESG performance of companies, including carbon emissions and climate-related risks	MSCI ESG Ratings, MSCI Climate Value-at-Risk, and MSCI Low Carbon Indices

To identify potential discrepancies across different measurement tools, an experiment was conducted using a sample building with designated specifications, and the below outlines the results generated:

Table 6. Baseline Building Information.

Property Type	: Private Grade A Office Building
Reporting Year	: 2022
Location	: Central, Hong Kong
Annual Electricity Consumption (kWh/yr)	: 4,800,000
Gross Floor Area (sq. ft.)	: 220,000
Number of floors	: 17
Annual Operating Hours (hrs/yr)	: 2,880
Average Daily Occupants	: 200

• SBTi

As the tool does not facilitate the calculation of CO₂ emissions, a general emission factor of 0.71 CO₂e/unit (HK Electric, 2023) has been used for target setting.

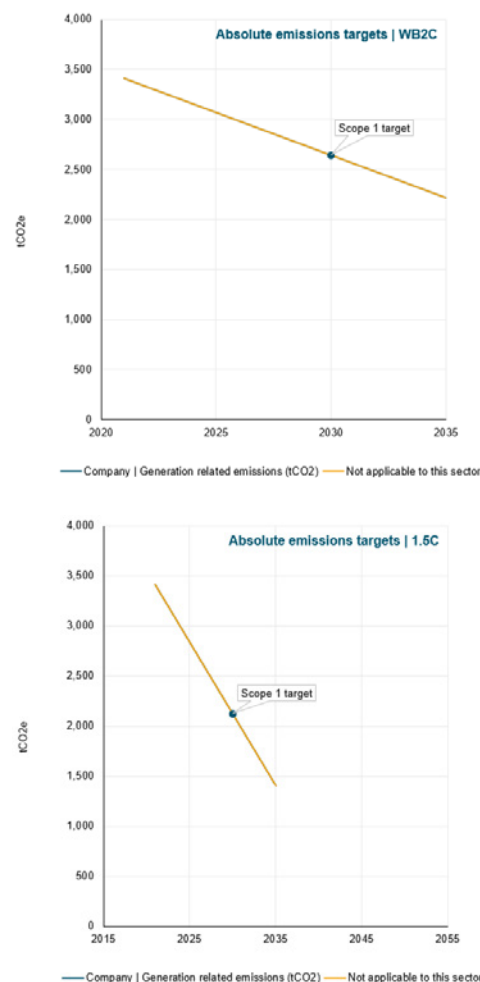


Figure 3. SBTi assessment results.

• CRREM

Result/Benchmark: 125.3/115.2 (kgCO₂e/sq. m./yr)

Result/Benchmark: 235/212 (kWh/sq. m./yr)

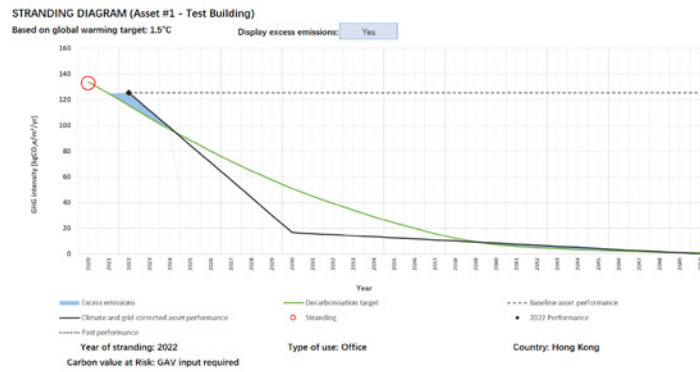


Figure 4. CRREM stranding diagram based on a global warming target of 1.5°C.

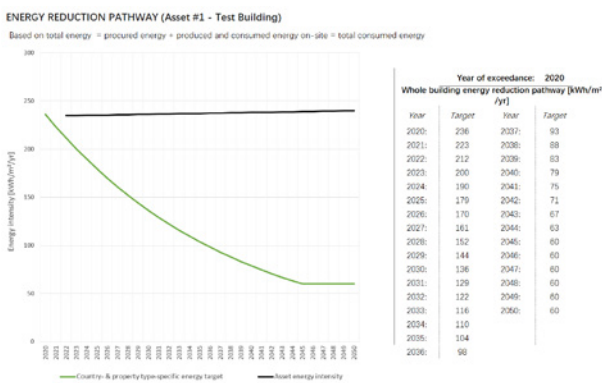


Figure 5. CRREM country- and property-specific energy target.

● EMSD

Due to the upper limit of input on the website, only a maximum of 859,000 kWh electricity consumption per year, 6,000 sq. m. of internal floor area, can be inputted, and it is specifically assumed that 2,000 pieces of key lighting equipment are in operation.

Result/Benchmark (GJ): 3029/2616

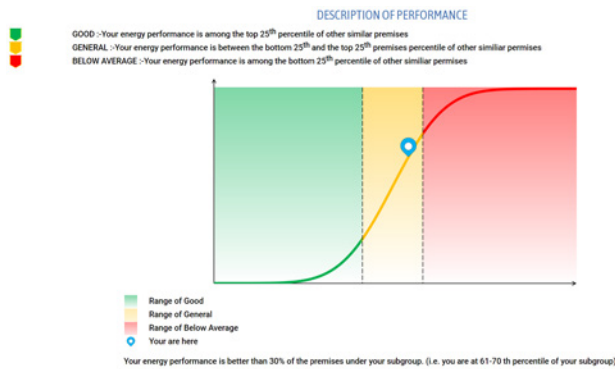


Figure 6. EMSD assessment result.

● Arc

Total Result/Benchmark: 7/73
Energy Result/Benchmark: 22/68

Overall Performance Score

for 12 month performance period ending Jun 22, 2023

7/100



Current Energy Score

for 12 month performance period ending Jun 22, 2023

22/100

[Breakdown](#)

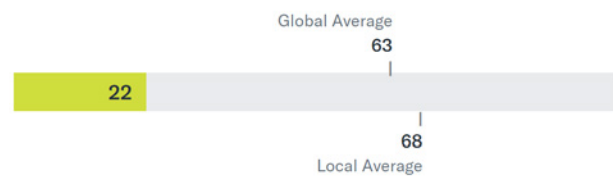


Figure 7. Arc assessment results.

● MSCI

Referring to a transaction of a 23-storey office building with an identical building area in the same location from the MSCI database, the aggregated CVaR for a transition model of 2°C would be a USD47.02 million loss, representing a 10.07% capital value decrease; considering a more strict model, the aggregated CVaR for a transition model of 1.5°C would be a USD103.88 million loss, representing a 22.26% capital value decrease.

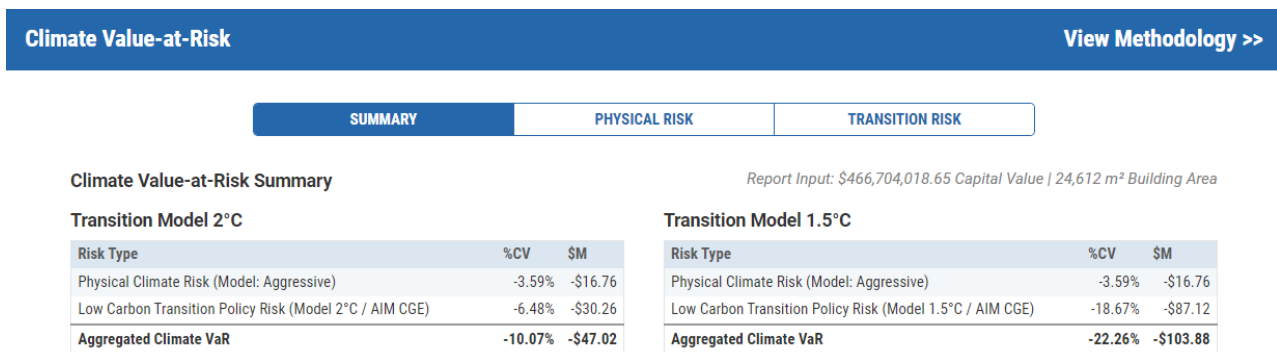


Figure 8. MSCI assessment summary of climate VaR.

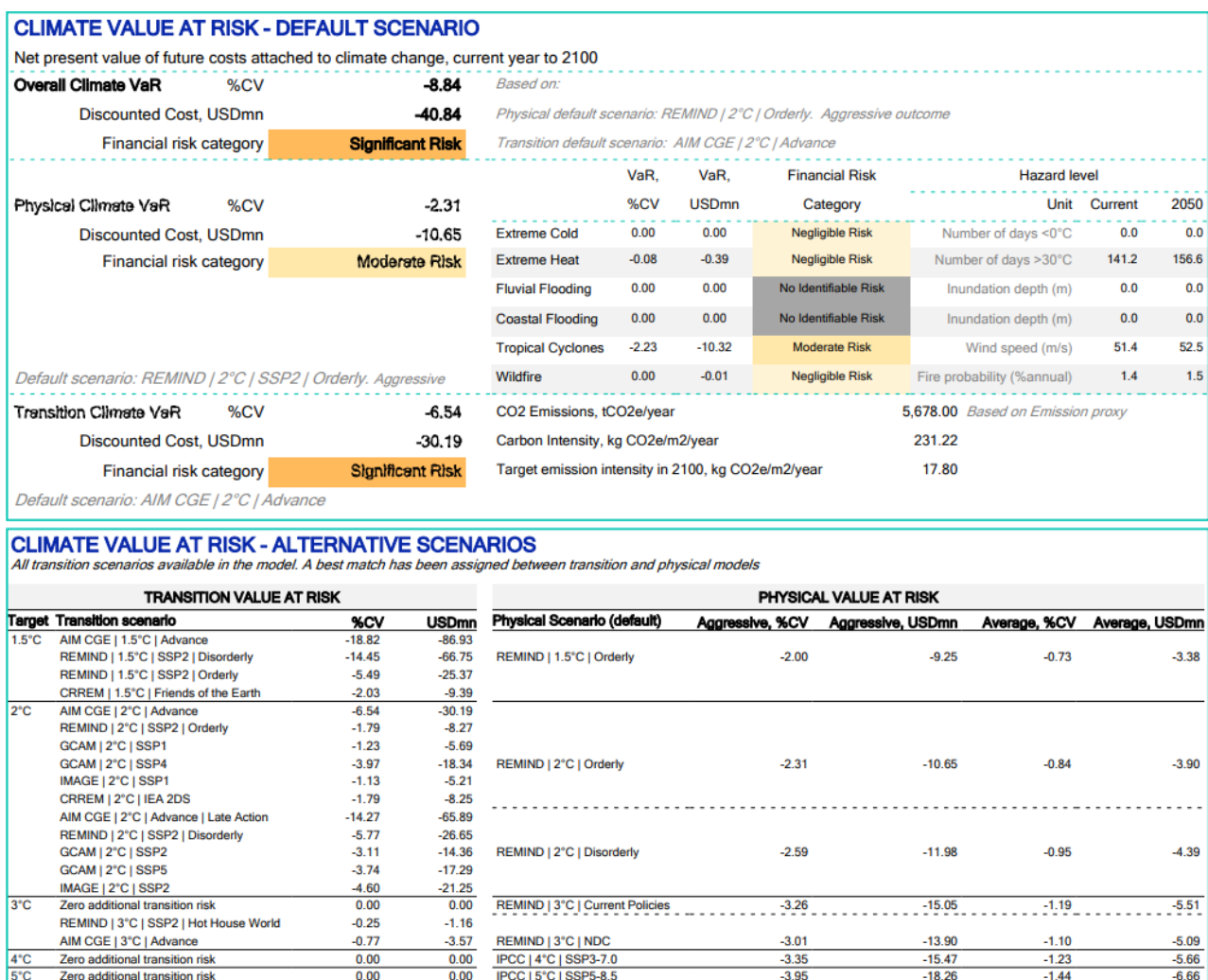


Figure 9. MSCI assessment of default and alternative scenarios.

3.2. Result implication and analysis

The results indicate that the sample building's current carbon emissions are below the market benchmark. However, the extent to which the sample building trails or exceeds the benchmark varies between measurement tools.

This discrepancy can be attributed to regional differences, varying methodologies, data sources and assumptions.

Region-specific tools, such as the EMSD benchmarking tool developed in Hong Kong, focus on local regulations, building codes and energy sources. These parameters can significantly differ from those used in other tools, leading to

result inconsistencies. For instance, the EMSD tool considers key lighting equipment as a factor, while another tool might emphasise renewable energy sources. These variations make it challenging to directly compare the outcomes of different tools.

Globalised tools may also contribute to discrepancies in carbon emissions calculations. These tools often use different methodologies, assumptions, and data sources to determine carbon emissions, which can lead to varying results. In the case of the sample building, the CRREM indicates a result of $10.1 \text{ kgCO}_2\text{e/sq. m./year}$ away from the benchmark, while the overall performance score in the Arc is 7, significantly trailing the benchmark of 73. SBTi urges organisations to identify Scope 1 and 2 emissions and calculate GHG emissions by themselves, which could reduce the reliability of the tool. MSCI quantifies the CVaR of a building but the result is difficult to be interpreted as it gives many scenarios, and professional terms are comparably difficult to be deciphered by non-ESG professionals. It is essential to consider that these scores may not be directly comparable due to different approaches being used for calculation.

In this case, it is crucial to consider factors contributing to discrepancies in carbon emissions calculations across different tools, and adopt strategies to improve the accuracy and comparability of results. This will enable building owners and managers to make more informed decisions in reducing their carbon footprint and meeting sustainability goals.

3.3. Major data sources in Hong Kong

The Hong Kong Government measures GHG emissions in accordance with the Intergovernmental Panel on Climate Change (IPCC) guidelines and methodology, which involve a comprehensive inventory that covers the major sources of GHG emissions. The inventory provides a solid foundation for understanding the sources and trends of GHG emissions in Hong Kong (Environment and Ecology Bureau, 2023).

The Carbon Footprint Repository is an alternative data source, which gathers self-reported emissions data from listed companies to facilitate comparisons between organisations (HKSAR Government, 2023). However, the data are subject to the varying reporting standards and definitions of scopes adopted by each organisation.

3.4. Discrepancy identification and analysis

The current challenge lies in harmonising data from different sources and the various approaches taken by individual companies. For example, according to the data from the Environmental Protection Department (EPD), the total GHG emissions in HK during 2020 amounted to

33,800 kilotonnes (EPD, 2022). The utility sector was the primary contributor, but the carbon disclosure table for listed utility companies in the Carbon Footprint Repository reported a significantly higher figure of 88,697 kilotonnes within the same period (HKSAR Government, 2023).

To better understand the discrepancies between the data, a deep dive analysis was conducted using ESG reports from some listed companies.

The study has identified some potential causes of the discrepancies as below:

- **Reporting methodologies:** Organisations may adopt different approaches to calculate emissions; for example the use of a top-down approach (e.g., extrapolating from national data) and bottom-up approach (e.g., aggregating emissions from individual facilities) could generate a different reported value.
- **Scopes of emissions:** Some organisations might focus on Scope 1 and 2 emissions, while others might include Scope 3 emissions, resulting in an incomplete picture of a company's overall carbon footprint.
- **Data quality and accuracy:** This could vary between organisations due to incomplete or outdated information, differences in the quality of the underlying data sources, and varying levels of third-party assurance or verification.
- **Different reporting frameworks:** Companies may choose to follow different reporting frameworks (e.g., Greenhouse Gas Protocol, ISO 14064, or IEA's Energy Statistics Manual, WRI), leading to variations in the presentation and categorisation of emissions data.

Table 7. Definition and measurement method of available utility companies on the Carbon Footprint Repository.

Name of Listed Company	2020 Reported GHG Emissions in total (Tonnes CO ₂ -e)	Scope 1 GHG Emissions (Tonnes CO ₂ -e)	Scope 1 Definition	Reporting Framework
CLP Holdings Limited (CLP, 2021)	62,138,000	45,105,000	Group's generation and energy storage portfolio Transmission and distribution infrastructure Coal mines and fuel storage facilities that are: Owned by CLP Assets are included on an equity basis (i.e., accounts for the data according to CLP's equity share in the asset)	World Resources Institute (WRI) World Business Council for Sustainable Development (WBCSD) Greenhouse Gas Protocol Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories (2006) ISO 14064
The Hong Kong and China Gas Company Limited (Towngas, 2022)	1,406,000	818,000	Fuel Consumption of production plants, vehicle fleet, etc. (adjusted to reflect the biogenic nature of landfill gas and its associated carbon emissions)	Greenhouse Gas Protocol ISO 14064-1
Power Assets Holdings Limited (Power Assets, 2021)	8,004,671	6,771,988	Fuels processed in sources that were owned and controlled by businesses for their own use Fugitive emissions resulting from intentional or unintentional releases Methane emissions from venting, use of refrigeration and air conditioning equipment SF ₆ emissions from industrial processes	Greenhouse Gas Protocol IEA's Energy Statistics Manual US EPA's Emission Factors for Greenhouse Gas Inventories and Guidelines Report on Greenhouse Gas Emissions and Removals for Buildings in Hong Kong (2010 Edition)
CK Infrastructure Holdings Limited (CKI, 2021)	9,923,680	8,009,254	Fuels processed in sources that were owned and controlled by businesses for their own use Fugitive emissions resulting from intentional or unintentional releases Methane emissions from venting, use of refrigeration and air conditioning equipment SF ₆ emissions from industrial processes.	Greenhouse Gas Protocol IEA's Energy Statistics Manual US EPA's Emission Factors for Greenhouse Gas Inventories and Guidelines Report on Greenhouse Gas Emissions and Removals for Buildings in Hong Kong (2010 Edition)
Towngas Smart Energy Company Limited (Environmental Protection Department, 2021)	34,578	10,506	100% of the emissions of project companies owned 50% or more by the company were incorporated into the calculation (Towngas Smart Energy Company, 2023)	N/A, assuming following Towngas
HK Electric Investments and HK Electric Investments Ltd (HK Electric Investments, 2021)	7,190,000	6,183,400	Power generation (Scope 2 emissions are reported as zero)	ISO 14064-1:2018 (from 2022 ESG report) (HK Electric Investments, 2023)

4. Development of AI-driven transitional CVaR estimation

4.1. Accelerating Hong Kong's carbon neutrality journey

Hong Kong can adopt global best practices for a sustainable future, and listed below are some suggestions:

- Set more ambitious targets (e.g., a 50% GHG reduction by 2035 and carbon neutrality by 2050).
- Take a holistic approach to urban planning. Enhance land use, integrate green spaces, public transportation, and pedestrian-friendly infrastructure to create a sustainable future.
- Promote sustainable transportation and incentivise electric vehicle adoption. Accelerate electric vehicle adoption in Hong Kong through financial incentives, enhanced charging infrastructure and low-emission zones.

- Improve energy efficiency in buildings. Stringent energy efficiency standards for new and retrofitted buildings can improve energy performance.
- Support low-carbon industries by offering subsidies, rewards and certification schemes for encouraging low-carbon business practices.
- Leverage carbon pricing mechanisms. Consider carbon pricing like emissions trading or carbon taxes to encourage businesses to cut their GHG emissions and use low-carbon tech.
- Collaborate with international partners. Hong Kong can enhance its connections with global partners to share knowledge and innovate through international forums, research partnerships, and joint ventures.
- Expand renewable energy capacity and low-carbon technologies. Invest in renewable energy such as solar and wind to boost capacity and urge private sector involvement.

- Invest in circular economy initiatives. Develop partnerships between different sectors and produce sustainable supply chains, creating a more environmentally conscious economy.

Given the current challenges surrounding the carbon measurement and reporting outlined, our study proposes an alternative approach to identify CVaR and a fast-track carbon neutrality process.

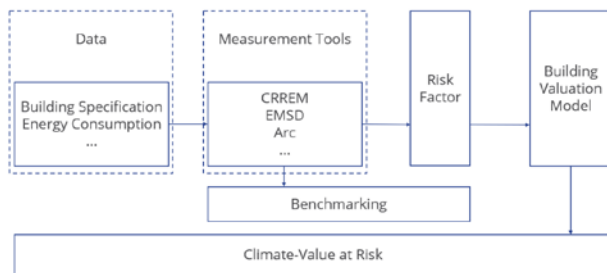


Figure 10. Traditional valuation framework of CVaR.

4.2. Introducing fuzzy logic and CVaR modelling

Fuzzy logic allows for multiple possible truth values to be processed through the same variable and could be a useful tool to apply to decarbonisation modelling and subsequent policy development.

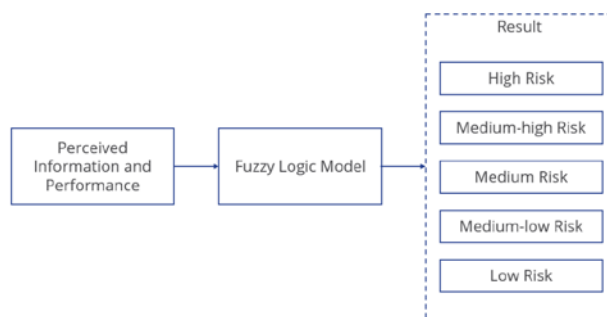


Figure 11. Framework of the fuzzy logic model.

We foresee several applications of fuzzy logic in decarbonisation modelling:

- Type-2 fuzzy logic systems are an extension of traditional type-1 systems, which can handle greater levels of uncertainty and imprecision in data. It uses a second-order fuzzy set to represent uncertainty in the membership function of a fuzzy set, allowing for adaptive representation of data.
- Fuzzy cognitive maps (FCMs) with feedback can represent complex interactions and feedback loops between different variables in a system. Recent developments in FCMs have focused on incorporating feedback mechanisms to improve accuracy and capture the dynamic nature of the system being modelled.

- Fuzzy clustering groups similar data points based on their degree of similarity. Recent developments in fuzzy clustering have focused on incorporating uncertainty and imprecision into the clustering process, allowing for more accurate data representation.
- Fuzzy optimisation is a technique for optimising a model under uncertainty. Recent developments in fuzzy optimisation have focused on incorporating multiple objectives into the optimisation process, allowing for a more comprehensive approach to decision making under uncertainty.

4.3. Benefits of a fuzzy logic model compared to traditional models

A fuzzy logic model excels in the assessment of high uncertainty, complexity, and subjectivity risks. It does not oversimplify risks but takes a holistic multi-factor view. A fuzzy logic model qualitative approach can provide valuable insights into climate risks that go beyond what traditional quantitative CVaR models can offer. A detailed comparison is listed below:

- Traditional CVaR models rely on historical data and assume a normal distribution of risks. However, climate change risks are highly uncertain and unpredictable. The past may not be a good indicator of the future. A fuzzy logic model can handle high uncertainty and does not require historical data or normal distribution assumptions.
- Climate risks often cannot be quantified precisely due to a lack of data and knowledge. Fuzzy logic models allow using linguistic terms like "high risk" or "low risk" and can handle imprecise information. They do not require exact numeric values as inputs.
- Climate change impacts are complex with a lot of interdependencies. Fuzzy logic models are good at modelling complex systems with ambiguities and multiple interacting factors. They can capture non-linear relationships and simulate complex risks.
- Traditional CVaR models often oversimplify risks by looking at single variables in isolation. Fuzzy logic models take a holistic multi-dimensional view of risks which better matches the complex nature of climate change.
- Fuzzy logic can model qualitative and subjective risks in addition to quantitative risks. This is important for climate change where many risks depend on human behaviour and perception. Qualitative risk factors like public opinion or policy changes can be included in the analysis.
- Fuzzy logic allows easily combining inputs from multiple experts. Diverse views from climate scientists, economists, policy experts, etc. can be integrated to develop a comprehensive risk picture. This helps to reduce bias and make the most of all available knowledge.

We have provided a working example of how fuzzy

logic could help project the change in transitional CVaR for a building subject to the proposed policy change.

4.4. Example demonstration of fuzzy logic

Fuzzy logic has been applied to qualify risks. Guerra (2020) has compared the Fuzzy-transform approximation function and Average Cumulative Function with positive indication as a proven method to estimate Value-at-Risk (VaR) for a corporate operation. On the other hand, Schaefer (2020) applied fuzzy logic modelling with Geographic Information System data to assess the climate resilience of a city.

In current practice, the carbon neutrality-related CVaR is calculated based upon expert judgement with supporting data, illustrated by the following diagram.

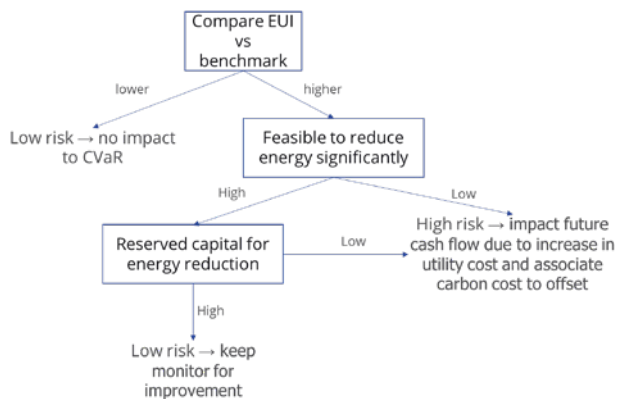


Figure 12. Illustrative diagram to estimate CVaR.

By applying fuzzy logic modelling to big data, the CVaR can be estimated efficiently with big data, and the result represents a higher confidence for capital allocation.

4.5. Potential impact factors and challenges

Climate change policies driving sustainable transitions may affect companies' finances with high costs for upgrades, new infrastructure, and increased operating expenses.

- Reduced energy cost: Transitioning to renewable energy and efficient systems can lower energy costs for companies over time, benefiting financial performance despite significant initial investments in new infrastructure.
- Increased capital cost: Companies face increased capital costs for sustainable energy upgrades like solar panels and wind turbines, leading to substantial investments that may strain short-term finances, based on the extent of infrastructure replacements or upgrades needed.

- Increased tax or government penalty due to non-compliance: Failure to comply with climate-related policies can lead to increased taxes or penalties, such as carbon pricing, emission fines, and environmental levies imposed by governments on non-compliant companies.

However, most data required to calculate CVaR (e.g., HVAC system design, occupancy patterns) are usually unavailable in private equity portfolios, and only building-level energy consumption is available through utility bills.

4.6. Leveraging fuzzy models with artificial intelligence

With rocket speed development of artificial intelligence, system modelling with machine learning features such as fuzzy logic and artificial neural networks allows the system to estimate CVaR with limited data.

Fuzzy logic can be leveraged to represent data uncertainty and imprecision, and to incorporate expert knowledge on the relationships between different variables. The following is how this could work:

- Representing uncertainty or the likelihood of different scenarios or outcomes: Fuzzy sets can represent the uncertainty in the system energy consumption, efficiency and operating conditions.
- Incorporating expert knowledge using fuzzy rules to represent relationships between different variables and their impact on carbon emissions: Expert knowledge can develop fuzzy rules that relate the system energy consumption, system efficiency and project energy savings through changes in the regulation of energy efficiency requirements.
- Using linguistic variables to deal with data imprecision. Instead of using precise numerical values for energy consumption or the emissions of a building, we could use linguistic terms such as "low", "medium-low", "medium", "medium-high" or "high".
- Optimising the model to identify the best combination of energy efficiency measures to reduce carbon emissions: This would involve using fuzzy rules and fuzzy sets to represent data uncertainty and relationships between different variables and optimising the model to identify the combination of measures that would achieve the greatest emissions reductions at the lowest cost.

5. Conclusion

While Hong Kong has shown progress in carbon neutrality, more innovative strategies can be learned from other nations to enhance the acceleration towards achieving this goal.

Our comparative analysis has shown that incorporating tailored simulation strategies can provide valuable insights and inform policy decisions, enabling Hong Kong to expedite its journey toward carbon neutrality. Combining CVaR quantification and qualification can mitigate the discrepancies in measurement tools and promote early decarbonisation initiatives, such that investors can ensure the sustainable growth of their portfolios, while contributing to mitigate climate change.

Achieving carbon neutrality in Hong Kong would make an impactful global contribution to climate change mitigation. Collaboration among policymakers, businesses, investors, and citizens is vital for long-term action. Transitioning from a carbon-intensive economy to a low-carbon, sustainable and resilient city can set a positive example for other urban centres worldwide.

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Appendix

Appendix 1: Summary of incentives and penalties associated with carbon neutrality policies for major cities in China.

City	Incentive	Penalty
Beijing	Offering subsidies of up to 500,000 yuan for "Carbon Neutrality Enterprise" certification, one-time subsidies of up to 1 million yuan for manufacturing companies recognised as "Green Factory", "Green Supply Chain" or "Green Enterprise", and subsidies up to 500,000 yuan for companies that reduce their annual carbon emission intensity by at least 5% and cut CO ₂ emissions by 500 tonnes or more compared to the previous year (Beijing Municipal Commission of Development and Reform, 2021). Companies that meet green factory standards, have strong emergency emission reduction performance, or achieve advanced energy or water consumption levels are eligible for rewards of up to 30% of their total eligible investment, with a maximum annual reward of 30 million yuan per enterprise (Beijing Municipal Commission of Development and Reform, 2022).	Enterprises failing to submit the required carbon emission reports may face penalties from the competent authorities. The Municipal People's Congress "Decision" (Beijing Municipal Commission of Development and Reform, 2016) allows for ordering rectification and imposing fines of up to 50,000 yuan for noncompliance. Key emission units exceeding quotas may be ordered to adhere to emission control responsibilities and penalised based on illegal carbon emissions at 3-5 times the average market price.
Shanghai	Enterprises are incentivised to adopt green practices through various rewards, including 100,000 yuan for obtaining energy-saving certifications or implementing energy metering projects (Shanghai Municipal People's Government, 2022); one-time rewards of 600,000 yuan for national green factories and 300,000 yuan for Shanghai green factories (Shanghai Municipal People's Government, 2022); 200,000 yuan for green factory, supply chain, or park projects on the national or municipal green manufacturing demonstration list, and 100,000 yuan for green product projects (Shanghai Municipal People's Government, 2022). A maximum 100,000 yuan reward for first-time energy-saving product or energy management system certification (Shanghai Municipal People's Government, 2022); Up to 200,000 yuan subsidy (20% of project investment) for the successful creation of national or municipal green factories, parks, supply chains and product designs (Shanghai Municipal People's Government, 2022).	The "Shanghai Carbon Emission Management Trial Measures" (Shanghai Municipal People's Government, 2013) covers penalties for failing to fulfil reporting obligations, non-compliance with verification requirements, and responsibilities of third-party verification institutions, exchanges, and competent department staff. Key emission units failing to pay carbon quotas may be fined between 50,000 and 100,000 yuan and face additional measures, such as credit information record demerits, cancellation of energy-saving support funds for the current and following year, and disqualification from participating in energy conservation initiatives for three years.
Guangzhou	One-time 1 million yuan for inclusion on the national green manufacturing demonstration list; Up to 100,000 yuan for first-time energy management system certification through a third party; Up to 50,000 yuan for obtaining carbon emission or greenhouse gas verification reports; A one-time 50,000 yuan subsidy for carbon emission reduction and peak assessment reports; and up to 100,000 yuan for projects issued on the carbon inclusive platform, based on 10 yuan/tonne of carbon dioxide reduction (Guangzhou Huangpu People's Government, 2023).	In the event that primary emission entities do not fully and promptly pay their carbon emission allowances, their subsequent annual allocation will be reduced by double the unpaid quota, and they will incur a fine of 50,000 yuan (Department of Ecology and Environment of Guangdong Province, 2020).
Shenzhen	Green Factory: the national incentive amount is not more than 500,000 yuan, provincial incentive amount is not more than 300,000 yuan, municipal incentive amount is not more than 200,000 yuan (Shenzhen Municipal People's Government, 2022).	If the principal emitting entities fail to fully and punctually pay their carbon emission allowances in compliance with the violation standards (Shenzhen Municipal People's Government, 2020), they will be subjected to a penalty equal to three times the average fine in the carbon emissions market.

Appendix 2: Major Measurement Tools.

1. Science-Based Targets initiative (SBTi): A collaboration between Carbon Disclosure Project (CDP), United Nations Global Compact, World Resources Institute (WRI), and World Wildlife Fund for Nature (WWF) (Science Based Targets, 2023). It helps companies set and validate science-based emissions reduction targets in line with the goals of the Paris Agreement. By setting science-based targets, companies commit to reducing their greenhouse gas emissions to a level that supports limiting global warming to well below 2°C above pre-industrial levels, and preferably to 1.5°C. The initiative provides resources, guidance, and case studies to help companies develop, implement, and report their progress on the targets, and support companies in their target-setting and implementation journey. In collaboration with the Carbon Risk Real Estate Monitor (CRREM), SBTi is working to provide 1.5°C embodied emissions decarbonisation pathways for the buildings sector. This publication is expected to be released by Q4 2023.
2. Carbon Risk Real Estate Monitor (CRREM): A tool specifically designed for the real estate industry to assess the carbon reduction pathways necessary for individual properties and portfolios to align with the Paris Agreement (CRREM Project, 2023). It helps identify and manage the transition risks associated with climate change, providing real estate investors and asset managers with a comprehensive understanding of the required emissions reductions at the property level. Its Excel-based tool evaluates the carbon intensity of individual properties and portfolios, providing data on the current and projected energy consumption, carbon emissions, and required reduction targets. The tool translates global carbon budgets into property-level carbon budgets, allowing users to assess the alignment of their properties with Paris Agreement goals. The CRREM also enables the benchmarking of properties and portfolios against industry peers, helping users to identify best practices and areas for improvement.
3. Electrical and Mechanical Services Department (EMSD): A government department in Hong Kong responsible for regulation, promotion, and enforcement of electrical and mechanical safety, energy efficiency, and environmental performance (Electrical and Mechanical Services Department, 2023). The EMSD provides guidelines, standards, and certification schemes to support the development of energy-efficient and environmentally friendly technologies and systems. The EMSD plays a role in promoting best practices and regulatory compliance in various sectors, including the residential sector, commercial sector, and transportation, which contribute to emissions reduction. It also has energy utilisation indexes and online benchmarking tools to help users to identify their position against peers in the journey.
4. Arc Skoru: Arc Skoru is a technology platform that is affiliated with Green Business Certification and the U.S. Green Building Council (USGBC), which provides tools to measure, manage, and improve the sustainability performance of buildings, communities, and cities (Arc Skoru, 2023). Arc can be used in conjunction with green building certification systems like LEED to assess and validate sustainability performance. Arc Performance Score users can track their projects' performance across various sustainability categories, including energy, water, waste, transportation, and human experience. It calculates the project's greenhouse gas emissions based on the collected data and assigns a performance score. Users can compare their projects' performance against similar projects or industry benchmarks within the region, identifying areas for improvement and best practices.
5. MSCI: MSCI is a global provider of investment decision support tools, including indices, analytics, and ESG research (MSCI Inc, 2023). MSCI ESG Research offers a range of products and services to help investors assess the ESG performance of companies, including their management of carbon emissions and climate-related risks. MSCI ESG Ratings assess companies' exposure and management of environmental risks, including climate and emissions, as part of its ESG rating process. Companies are rated on a scale from AAA to CCC, enabling investors to incorporate climate-related risks into their investment decisions. MSCI Climate Value-at-Risk (Climate VaR) quantifies the potential impact of climate-related risks on a company's valuation. It considers various climate scenarios and time horizons, providing insights into potential value losses due to climate change. MSCI also offers various climate indices, such as the MSCI Low Carbon Indices, which consist of companies with lower carbon exposure compared to the broader market. These indices help investors build portfolios that are more resilient to climate-related risks.