



# Accelerating carbon neutrality in China: Sensitive intervention points for the energy and transport sectors in Beijing and Hong Kong

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## ABSTRACT

To limit the detrimental impacts of climate change, large-scale and rapid decarbonization is required. China announced their plan to peak carbon emissions before 2030 and to reach carbon neutrality by 2060, which faces many challenges including rising energy consumption and a significant, ongoing expansion of coal-based electricity generation capacity. This study employs mixed methods to explore a portfolio of climate policies related to the transport and energy sectors for two leading Chinese cities: Beijing and Hong Kong. A total of 32 expert interviews were conducted with four stakeholder groups in both cities to canvas opinions on the most important policies for decarbonization. With the aim to understand how local policy measures can be prioritized for disproportionately large emissions reductions, the Sensitive Intervention Points (SIPs) framework was applied to identify city-level policy interventions with the potential for high impact, speed, feasibility, persistence, and low risk, based on these expert interviews and literature review. With all attributes combined, leveraging the global cost declines in renewable energy was identified as a shared accelerated carbon neutrality pathway for both cities, facilitated by policies to promote the import of low-carbon energy and accelerating the electrification of transport. Alignments were found between this final list of SIPs and policies perceived as important by the experts, indicating that SIPs are generally intuitive, with alternative policy prioritizations likely influenced by additional factors such as the national agenda, budgetary constraints, and the availability of co-benefits.

## 1. Introduction

At the 75th United Nations General Assembly, China surprised the world by announcing a pledge to achieve carbon neutrality before 2060, a pledge with substantial implications for global low-carbon development and multilateralism (Colenbrander et al., 2021). Around a year later, the IPCC Sixth Assessment Report (AR6), stating it is “unequivocal” that human influence has warmed the planet, and net-zero emissions must be achieved by around 2050 to limit warming within 1.5 °C (IPCC, 2021).

China is currently the world’s largest producer of greenhouse gases (GHGs), accounting for 27% of global emissions (Kumar et al., 2022; Mikhail et al., 2021). Over the last decade, China has been demonstrating increased effort in pollution control and climate change mitigation in accordance with the eco-modernization discourse (Geall and Ely, 2018). The 2060 carbon neutrality pledge steps up China’s

nationally determined contributions (NDCs) under the Paris Agreement and acknowledges the need for long-term action after meeting their emissions peaking plans for 2030 (Wagner, 2020). This pledge, if achieved, could lower global warming projections by 0.2–0.3 °C over the previously stated policies (Climate Action Tracker, 2020). As stated in AR6, “From a physical science perspective, limiting human-induced global warming to a specific level requires limiting cumulative CO<sub>2</sub> emissions, reaching at least net-zero CO<sub>2</sub> emissions, along with strong reductions in other greenhouse gas emissions” (IPCC, 2021). This demonstrates robust climate science around the necessity to reach net-zero CO<sub>2</sub> emissions to halt global warming, which China’s carbon neutrality pledge is aligned with.

Energy-related sectors account for approximately 78% of GHG emissions in China, highlighting energy policy as the key factor influencing whether China can deliver the carbon neutrality commitment (Zheng et al., 2023; Qi et al., 2020). This research is positioned to investigate carbon neutrality through the lens of energy supply and

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### Abbreviations

AR6	Sixth Assessment Report of the Intergovernmental Panel on Climate Change	HKEPD	Hong Kong Environmental Protection Department
CCS	Carbon Capture and Storage	HKSARG	The Government of the Hong Kong Special Administrative Region of the People's Republic of China
CO <sub>2</sub>	Carbon Dioxide	IEA	International Energy Agency
EU	European Union	IPCC	Intergovernmental Panel on Climate Change
EV	Electric Vehicle	JJJ	Jing-Jin-Ji Region
FIT	Feed-in Tariff	PV	Photovoltaic
FYP	Five-Year Plan of China	RE	Renewable Energy
GBA	Greater Bay Area	SDC	Hong Kong Council for Sustainable Development
GHG	Greenhouse Gas	SIP	Sensitive Intervention Point
GDP	Gross Domestic Product	SR1.5	IPCC Special Report on Global Warming of 1.5 °C
GWP	Global Warming Potential	UNFCCC	United Nations Framework Convention on Climate Change
		WRI	World Resources Institute

demand policies. The scope of the study is narrowed to the city level, as sufficient research effort is concentrated on national decarbonization (Energy Foundation China, 2020; He, 2020; WRI, 2020). Such a gap can be bridged through investigating effective interventions at a subnational level that promote rapid and disproportionately large emissions reduction required to align with the national goals.

China has an established history of strategic planning and target setting for parameters like poverty alleviation and pollution control. Mandatory environmental targets are proposed by the central government, distributed to provinces, and subsequently divided into cities and lower-level administrative units for implementation (Wang, 2021). Field studies in China reveal it is mostly internal rather than external forces that push for environmental enhancements, which is strongly influenced by local power structures (Sheng, 2019). Through case studies of Beijing<sup>1</sup> and Hong Kong, this paper explores the carbon neutrality pathways of two unique economically advanced Chinese cities and seeks ways to accelerate their progress by identifying “Sensitive Intervention Points” (SIPs) in the energy and transport sectors. SIPs are interventions that take advantage of socio-economic dynamics, such as learning-by-doing, or viral contagion, to generate disproportionately large emissions reductions compared with standard policy instruments. Context-specific constraints in policy implementation will also be investigated.

Beijing and Hong Kong are high-density cities with advanced economic development, characterized by dependence on tertiary sectors. The two cities face challenges in decarbonizing energy supply, demand and pursuing offsets. Given that electricity generation is dominated by fossil fuels, Beijing and Hong Kong governments have plans to reduce emissions by transitioning from coal to natural gas and sourcing renewable energy (RE). The “Natural Gas Transition City” configuration is observed in both cities, leading to the risk of locking-in natural gas as a substitute for renewables (Tozer and Klenk, 2018), creating vulnerability to gas price volatilities. One defining difference between the cities is the amount of electricity imported from external electric grids. Beijing imports close to 65% of electricity from other parts of China. Hong Kong imports 25% of electricity from mainland China, one of the lowest fractions of imported electricity among major cities in China (Qu et al., 2017). In addition, policies in Beijing are largely shaped by the central government. Hong Kong has developed political institutions different from the mainland overtime, with a high degree of autonomy in energy and climate policymaking (HKSARG, 2021). Comparing these two cities provides insights on how the spectrum of urban carbon neutrality plans may look like for other Chinese cities with similar economic structures.

This paper revolves around two interconnected themes related to

<sup>1</sup> There is a practice of using “Beijing” to represent the Chinese central government, but “Beijing” in this research refers to the Beijing municipal city government, not the central government.

urban carbon neutrality, with an interrogation of Beijing and Hong Kong as case studies. The first theme is the conceptualization of carbon neutrality and the factors influencing it, covering perspectives across the academia, industry, green groups and government. This links to the second theme of exploring city-level SIPs to accelerate the progress towards carbon neutrality. The two parts are connected through the implications of stakeholders’ interpretation of carbon neutrality on policy preferences, illuminating future pathways to accelerate decarbonization. Two rounds of expert interviews and literature reviews are used to identify the sensitive SIPs for attaining carbon neutrality in the two cities. The underlying factors and embedded structures that influence carbon neutrality pathways are then assessed. Both energy supply and demand infrastructures are considered, with a focus on electricity generation, built environment, transport and industry.

Most of the existing carbon neutrality literature in China focuses on national level interventions. This study complements the literature with a geographical focus on cities, the scale at which many national climate policies will be implemented on the ground. Given China is the world’s largest GHG emitter, it is not surprising that China has the highest number of publications on decarbonization, low-carbon development and low-carbon transition from 1995 to 2019 (Wimbadi and Djalante, 2020). Over 77% of the research focuses on the national level, the remaining is spread across provinces, cities and smaller administrative units (Wimbadi and Djalante, 2020). Given 85% of the country’s total emissions comes from urban energy use (Shan et al., 2019), there is a need for a more in-depth investigation on how climate action will take place in Chinese cities, especially in energy-related sectors. Through collecting primary data from interviews and surveys, this research contributes to a comprehensive narrative on how carbon neutrality is conceptualized in Beijing and Hong Kong, filling an epistemic gap. It also presents an opportunity to apply the SIPs prioritization framework at the city level. While cities are influenced by global or national SIPs, this study strives to explore SIPs that underlie concrete actions by local actors in hopes of accelerating decarbonization, and enriching the body of research with city-level insights and multilevel perspectives.

## 2. Description of the study area

Beijing, with a territorial area of total area of 16,410.54 km<sup>2</sup>, is situated in the northern tip of the North China Plain (39°28′ N - 41°05′ N; 115°20′ E - 117°30′ E) and surrounded by mountains in the Northwest and plains in the Southeast (Fig. 1a). Hong Kong, on the other hand, is a populous city located on China’s Southeast coast at 22°08′ N - 22°35′ N; 113°49′ E - 114°31′ E and has a total area of 1114.35 km<sup>2</sup> (Fig. 1b).

The use of Beijing and Hong Kong as case studies is strategically significant for their policy implications. Latest reports forecast that economically advanced cities will be the first to lead China towards carbon neutrality, including the Jing-Jin-Ji Region (JJJ) and the Greater

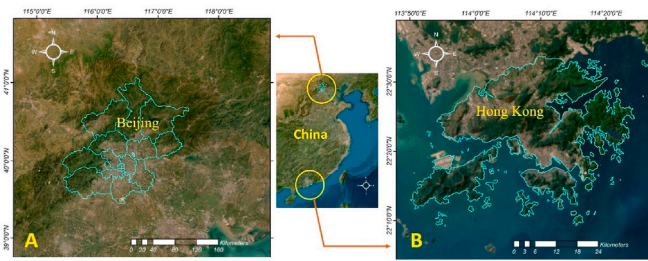


Fig. 1. Geographical location and administrative boundaries of (a) Beijing and (b) Hong Kong in Eastern China.

Bay Area (GBA) (WRI, 2020). As the leading cities in JJJ and GBA, Beijing and Hong Kong collectively set benchmarks for other Chinese cities by showcasing best practices in carbon neutrality planning. This research explores how the two differing governance structures influence the decisions made in climate and energy policies under the same national regime. As the capital of China where key decision-making authorities are situated, considerable pressure is exerted on Beijing to achieve carbon neutrality following President Xi's pledge. With the track record of being the command-and-control centre of China, policies in Beijing are expected to align with top-down authoritarian governance at the national level (Hu, 2015). Meanwhile, climate policies in Hong Kong rely more on market mechanisms with influence from an array of stakeholders. Understanding the underlying factors that influence policy adaptability, outcomes and challenges in each city will enable more effective decision-making for climate and energy policies.

Beijing is one of the pilot low carbon cities, which is a sustainable urbanism initiative in China (Hunter et al., 2019). Using a city development-stage framework to analyze the driving factors for carbon emissions in Beijing, Shen et al. (2018) find that the low carbon cities initiative has fostered structural change in industries, leading to more green industries and increased employment. The industrial structural change during Beijing's second development stage (1991–2004) led to significant emissions reduction, which corresponds to results from other studies (see Mi et al., 2015; Xu et al., 2016). While economic output is identified as the primary factor leading to an increase in carbon emissions across different stages. Enhancing energy efficiency (EE) is regarded as one of the key approaches for Beijing to achieve carbon reduction along with sustainable economic growth (Shen et al., 2018). Since the mid-20th century, Hong Kong experienced rapid socio-economic development and urbanization, reaching 100% urbanization in 1993 (World Bank, 2020b). Akin to Beijing, economic growth (indicated by GDP per capita) is the main driver for increasing GHG emissions from energy use between 2000 and 2017 (Civic Exchange, 2020). Although the time periods differ, there are significant similarities in the factors contributing to the rise and decline of emissions in Beijing and Hong Kong. Energy intensity plays a declining role in emissions reduction for Hong Kong, because most low-hanging fruits in energy efficiency measures have been reaped. Conversely, as a substantial portion of emissions from Beijing still originate from manufacturing industries (31% in 2018), technological innovations and investments in more efficient industrial processes have become crucial for Beijing's quest to drive down emissions in the coming decade.

### 3. Materials and methods

#### 3.1. Framework overview and literature review

To achieve net-zero emissions by mid-century, global emissions have to be drastically reduced by 25 GT in the next decade (IPCC, 2018). Taking advantage of non-linear dynamics within the global socio-economic system might offer an avenue for meeting the rapid pace of decarbonization required. Just as the climate system is characterized

as a complex dynamic system within nested and interlinked subsystems (Snyder et al., 2011), the global economy is also recognized as a complex adaptive system that exhibits non-linear dynamics, such as reinforcing and balancing feedbacks (Abson et al., 2017; Meadows, 1999). Consequently, Farmer et al. (2019) proposed the concept of SIPs, that apply an understanding of such dynamics to identify interventions likely to have disproportionately large effects on emissions reductions. Two broad types of interventions are kicks and shifts, the former making use of existing dynamics (such as investment in renewables with consistent cost declines), whereas the latter seeks to change the underlying dynamics of the systems (such as by enacting a climate change act into law) (Farmer et al., 2019; Hepburn et al., 2020). Social tipping intervention (STI) and upward scaling tipping points (USTP) are similar concepts, which can activate the contagious spreading of technologies, behaviours, and social norms in complex socioeconomic systems for accelerated decarbonization (Otto et al., 2020; Sharpe and Lenton, 2021).

Positive feedback loops are typically achieved through economies of scale, network and coordination effects, and learning effects. Most intervention points serve to unlock investments in new clean technologies with consistent cost declines triggering learning-by-doing, which is a key feedback dynamic that can accelerate global energy system decarbonization (Ives et al., 2021). An intervention is usually defined as one that can reduce a region's emission by at least 10%, with the combined aim of halving emissions by 2030. The defining features we seek in identifying SIPs are feedbacks (particularly self-reinforcing); criticality (whether a system is "ripe for change" or "windows of opportunity"); speed (how quickly change can happen); impact (decarbonization potential); scalability (geographic and across sectors); and persistence (hysteresis) (Mealy et al., 2023). Trigger potential, impact potential and risk potential are the three prioritized pillars of SIPs based on Mealy et al. (2023).

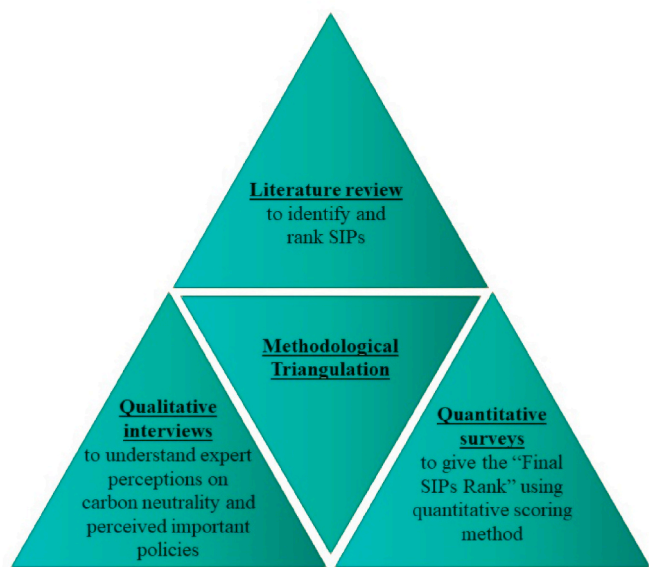
SIPs have been adopted to guide policymaking towards carbon neutrality targets. In a UK Committee on Climate Change advisory report, expert elicitation and literature review were employed to identify 40 SIPs divided into nine categories, which translate to policy-relevant recommendations to accelerate the UK's decarbonization (Hepburn et al., 2020). Five energy related SIPs were subsequently identified for the UK to reach carbon neutrality by 2050 (Castle and Hendry, 2022). Expert workshops were also used for identifying STIs to speed up global decarbonization (Otto et al., 2020). Unlike STIs that have been reviewed with stakeholder consultation (e.g. Van Ginkel et al., 2020), SIPs have yet to be tested extensively with stakeholders and decision-makers at a city level. This paper fills this gap by employing a novel method to identify SIPs for energy decarbonization pathways with stakeholder interviews and surveys. The aim is to reveal the fastest route to carbon neutrality through understanding critical points that kick or shift the system into accelerating progress. Maintaining a portfolio of interventions is important given the uncertainties in the actual impact delivered by non-linear dynamics (Hepburn et al., 2020). Some SIPs may face too great an opposition or lack sufficient hysteresis. By employing a range of SIPs progress is more likely and can result in cascade effects (Sharpe and Lenton, 2021). It is therefore important to identify and trigger a number of different SIPs. Based on four recent studies about interventions in complex systems (SIPs, STIs and USTPs), some common interventions are identified in Table 1.

#### 3.2. Research process

A mixed method approach was adopted for this research, with three components of qualitative expert interviews, literature review, and quantitative surveys, as shown in Fig. 2. First-round expert interviews were conducted with 16 experts in Beijing and Hong Kong respectively to understand their perceptions of carbon neutrality and what policies were perceived as important for decarbonization, deducing a "Stakeholder Rank". Next, a literature review was employed to identify and rank SIPs for Beijing and Hong Kong to accelerate carbon neutrality

**Table 1**  
Common interventions in literature to achieve carbon neutrality targets.

Category	Examples of interventions	Farmer et al. (2019) (Sensitive intervention points)	Otto et al. (2020) (Social tipping interventions)	Hepburn et al. (2020) (Sensitive intervention points)	Sharpe and Lenton (2021) (Upward scaling tipping points)
Energy technology	<ul style="list-style-type: none"> <li>Remove fossil fuel subsidies</li> <li>Divest from fossil fuel assets</li> <li>Align incentives to support research and development of low-carbon energy technologies</li> <li>Redirect capital in favour of technologies that develop rapidly</li> </ul>	✓	✓	✓	✓
Engagement	<ul style="list-style-type: none"> <li>Public engagement and consultation</li> <li>Moral education and political mobilization</li> </ul>	✓	✓	✓	
Financial market	<ul style="list-style-type: none"> <li>Financial disclosure on GHG emission</li> </ul>	✓	✓		✓
Institution	<ul style="list-style-type: none"> <li>Government reorganization for climate leadership</li> <li>Political mobilisation</li> <li>Corporate engagement</li> </ul>	✓		✓	✓
Legal	<ul style="list-style-type: none"> <li>Enhance legal framework</li> <li>Establish climate change related laws</li> </ul>	✓		✓	
Urban configuration	<ul style="list-style-type: none"> <li>Set up carbon neutral cities</li> <li>Facilitate learning and capacity building</li> <li>Land use rezoning</li> </ul>		✓	✓	



**Fig. 2.** Representation of the methodological triangulation method adopted in the current study.

based on the existing literature, generating the “Preliminary SIPs Rank”. Finally, feedback surveys were distributed to the same group of expert stakeholders to comment on “Preliminary SIPs Rank”, giving a “Final SIPs Rank” using a quantitative scoring approach. The research process was a dynamic and iterative process, with its limitations, remedies, and improvements explored in detail in Supplementary File A.

**3.3. First-round expert interviews**

The first stage of the research process composed of in-depth, semi-structured interviews with experts from Beijing and Hong Kong to investigate their perceptions of carbon neutrality and strategies for achieving it. The interviews were divided into three sections, covering background information, conceptualisations of carbon neutrality, and discussions on energy supply and demand measures. Referencing the

sampling strategy of Metz et al. (2016), energy and climate experts from diverse background were selected, representing four different categories, including regulators and government advisors (R), industry practitioners (I), academics (A) and green group representatives (G). A total of 32 interviews were conducted, equally split between Beijing and Hong Kong and across the four categories. Purposive sampling was used to identify interviewees with rich information and decision-making power in carbon and energy policies (Palinkas et al., 2015; Patton, 2002). The selection process also considered experts in different parts of the energy sector value chain, including supply, demand, and infrastructure. Anonymizing codes were used to identify respondents based on their city, stakeholder group, and assigned number. The full list of interviewees and their codes is presented in Table 2. The full interview question list, background information of expert interviewees (field of specialization, affiliation’s scope, years of experience in the energy or transport sector) and details of the interviews can be found in Supplementary File B.

**3.4. Preliminary SIPs from literature review**

Six attributes of SIPs were identified from the literature review, namely feedbacks, criticality, impact, speed, scalability and persistence. 10 policies taken from the literature review that rated well on most of these six attributes and have close relevance to the contexts of Beijing and Hong Kong were selected as SIPs for discussion. We ranked the top 10 SIPs based on two attributes of impact and speed, using literature and government documents to estimate the magnitude of these two attributes. SIPs were given a traffic light rating with green colour designating a track record of large impact, yellow for a medium impact, and red for low impact. Similarly, SIPs shown to deliver impact quickly were marked green, medium yellow, and slow red. The colour green was translated into a score +1, yellow 0 and red -1. Aggregating the scores resulted in rankings, where SIPs with high scores translating into a higher ranking. Based on this scoring rubric, the “Preliminary SIPs Rank” was obtained.

**3.5. Second-round feedback surveys**

After obtaining the “Preliminary SIPs Rank”, the results were presented to all 32 experts from the first-round interviews using feedback surveys. Simple questions were used to help experts validate and

**Table 2**  
Interviewees by stakeholder groups.

Stakeholder group	Description	Number of interviewees (anonymizing codes)	
Academia (A)	Representatives from Hong Kong and Beijing universities and institutes that have a strong presence for climate change-related energy and transport issues (Beijing: includes state-funded public universities, non-governmental think tanks)	Beijing (B) 4 (B-A1, B-A2, B-A3, B-A4)	Hong Kong (H) 4 (H-A1, H-A2, H-A3, H-A4)
Green group (G)	Representatives of environmental advocacy groups in the civil society (Beijing: includes international environmental NGOs operating in Beijing)	4 (B-G1, B-G2, B-G3, B-G4)	4 (H-G1, H-G2, H-G3, H-G4)
Industry (I)	Industry practitioners from energy utilities and renewable energy industries	4 (B-I1, B-I2, B-I3, B-I4)	4 (H-I1, H-I2, H-I3, H-I4)
Regulatory body (R)	Civil servants and members of government advisory committees responsible for energy and climate policies (Beijing: includes research institutes funded by the government)	4 (B-R1, B-R2, B-R3, B-R4)	4 (H-R1, H-R2, H-R3, H-R4)

critique the SIPs based on their impact, speed, and persistence. Extra parameters of feasibility and potential risks were added to reveal potential constraints and challenges in local policy implementation.

Experts were asked to evaluate and score each of the 10 listed SIPs based on their impact and speed on a scale of 0–10, while categorizing persistence into high, medium, and low. In order to take the average score without the extreme values, median scores were adopted for the impact and speed attributes. At times when experts had vastly different views on the scoring, their reasoning was reviewed to decide which side to support. High scores translated to higher ranking, formulating the “Final SIPs Rank”. For the persistence attribute, the most frequent answers from the experts were selected. As persistence is more subjective and depends on more variable environmental factors (such as political leadership), it was not included in the calculation for “Final SIPs Rank”, rather served as an additional information for consideration in policy prioritization.

The purpose of the second-round of surveys was twofold. Firstly, it provided feedback from interviewees on the impact of SIPs that could inform the results of first-round interviews. Through assessing the impact and speed of the various SIPs derived, individual interviewees could gain a perspective of what their peers and other stakeholder groups perceive of mitigation solutions in their respective cities. The survey also served as an awareness-raising exercise that demonstrates the value of SIPs as a framework for prioritizing climate action. Undergoing such an exercise could potentially change the way key

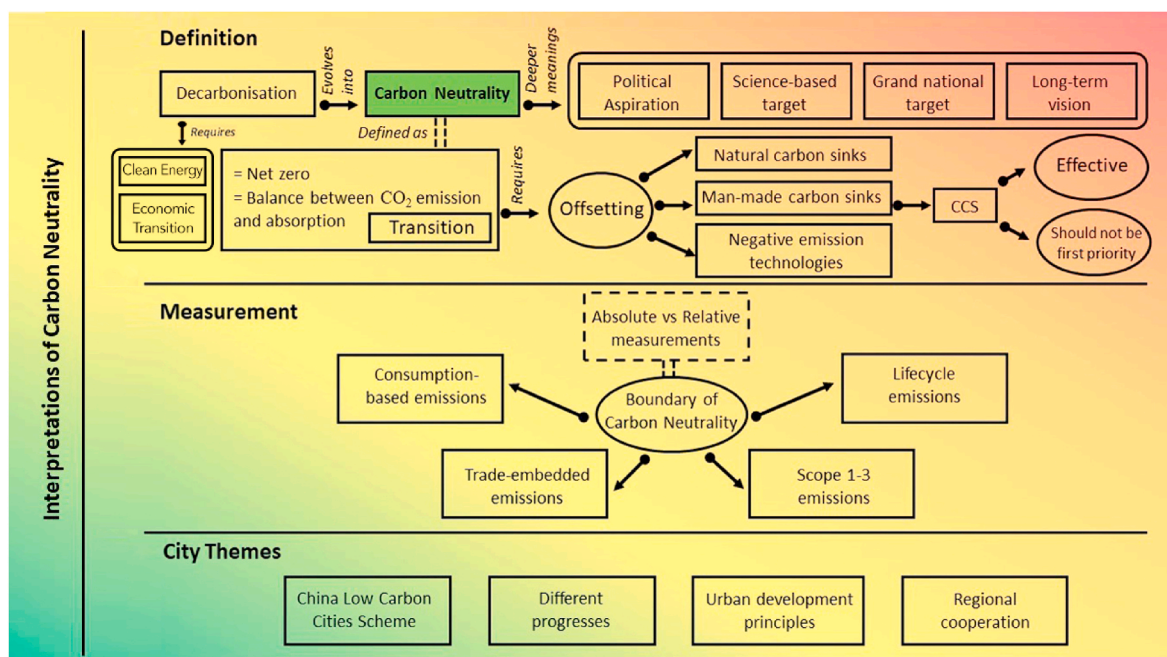
information brokers, such as civil servants and advocacy groups, might design, advocate, and plan policy measures.

## 4. Results

### 4.1. Interpretations of carbon neutrality

Expert interviews revealed multi-layered conceptualisations on carbon neutrality that captured some of the underlying differences between Beijing and Hong Kong stakeholders. Carbon neutrality is a constructed concept to shape social behaviour, which is simultaneously shaped by social agents with continually evolving ways to define it. The majority (80%) of respondents from both cities defined carbon neutrality as “net-zero” or a “balance between the emission and absorption of CO<sub>2</sub>” (Fig. 3). The conceptualisation of carbon neutrality also “changes the focus of government research from decarbonization to achieving net-zero”, as pointed out by a Beijing government-affiliated interviewee (B-R1). A clear consensus among respondents is that carbon neutrality exceeds what is required for decarbonization, involving long-term planning and offsetting after attaining the maximum level of carbon reduction (B-A1, B-R1, H-A2).

When defining the “balance” of emissions, “offsetting” was mentioned by over 60% of respondents in both Hong Kong and Beijing, where carbon capture and storage (CCS) was the most discussed solution (52%). CCS was seen as a viable option to remove CO<sub>2</sub> emissions,



**Fig. 3.** Summary of core themes derived from stakeholders’ interpretations and conceptualisations of carbon neutrality.

especially for hard-to-abate sectors, that is, for the final fraction of emissions that cannot be easily decarbonized with cheaper clean energy technologies (B-A2, B-A3, B-R2). Almost all of the IPCC's stylized pathways, and those produced for China that achieve net-zero emissions (Mylllyvirta, 2020) require CCS to mitigate carbon emission. Besides CCS, some narratives in Beijing pointed towards offsetting by afforestation (B-A4). One interviewee estimated that "Beijing might use CCS for the last 8–10% of hard-to-abate emissions" (B-R2). This estimate aligns well with those of the Global CCS Institute (Global CCS Institute, 2022) as well as other studies carried out on CCS for coal-fired power plants in China (Wang and Du, 2016). Among respondents who mentioned CCS, both Beijing and Hong Kong experts believe it should not be the priority for reaching neutrality, because they were concerned about CCS diverting attention from more effective or progressive policies (B-G1, H-A1, H-A2). An academic believed that "CCS should not be the first priority for Hong Kong because there are no large-scale industrial plants" (H-A2). The respondent added that "Hong Kong needs to work with mainland China" to obtain CCS capacity.

The concept of the carbon neutrality involving a "transition" emerged as important among Beijing stakeholders, but not those in Hong Kong. (B-R1, B-G4). One green group representative defined carbon neutrality as a "deep low-carbon transition in energy and economy" (B-G4). A government advisor opined that policy priority should be placed on facilitating the low-carbon transition of energy systems instead of negative emissions technologies, such as direct air capture (B-R1). The advisor further added that "China's energy transition pathway will follow that of the USA with capacity to produce zero-carbon energy, including renewable and nuclear energy. Whereas the transition pathway of cities will be more similar to smaller countries like Korea and Japan" (B-R1). Cities need to rely more on energy carriers like green hydrogen to assist the transition. Carbon neutrality pathways are heavily influenced by path dependencies, such as energy infrastructure installed decades ago (Tong et al., 2019). The approach of prioritizing energy system transitions "instead of negative emissions technologies" may lead to insufficient capacity of carbon storage by 2060, which cannot be matched despite aggressive policies in a few years' time. Sustainable transition pathways have long been discussed, factors driving sustainable energy transitions are revealed to be energy technology innovations, the energy market, and socio-technical regimes (Guo et al., 2019; Tyfield et al., 2015). The absence of the "transition" theme in Hong Kong suggests less of a systems thinking approach, and a relatively weak connection with China's national carbon neutrality planning.

Carbon neutrality is not merely technical concept but embodies wider implications. Multiple interviewees iterated the political implications of the Chinese President announcing a carbon neutrality goal (B-G2, B-R1, B-R2, H-A2, H-A4). The magnitude of the changes required by the announcement has not only been felt by Beijing regulators (B-R1, B-R2), but also by academics in Hong Kong (H-A2, H-A4). One respondent framed carbon neutrality as a "grand target that changes national development goals" (B-R1), driving a total revolution of China (H-A2). "The announcement indicates China has entered in the global race for net-zero technological advancements" (B-G2). When it comes to measuring carbon neutrality, most stakeholders were conscious of system boundaries, which is increasingly contentious for city-level emissions (Hsu et al., 2016). Interviewees proposed Hong Kong should account for consumption-based emissions (Fig. 3) due to the reliance on imported goods (H-G3, H-I4). Analytical work showed Hong Kong was among those regions where net imports make up the largest fraction of consumption emissions (Davis and Caldeira, 2010). Beijing industry practitioners spoke of the need to focus on all scope 1–3 emissions and lifecycle analysis for a more comprehensive accounting approach (B-I1, B-I2). One of them claimed it is only "fair for China" if trade-embedded emissions are accounted for by importing countries rather than manufacturing bases in China (B-I2). The theme of "fairness" emerged again on the target year. China's 2060 carbon neutrality pledge is

reasonably 10 years later than the EU as China is a "developing country yet to fully industrialize" (B-A1). Important themes on the interpretations and conceptualisations of carbon neutrality are summarized in Fig. 3 below.

## 4.2. Prioritization of energy policies for carbon neutrality

### 4.2.1. Perceived importance of policies

Research and government reports suggest that switching from coal to natural gas for electricity generation contributes to the majority of emissions reduction for Beijing and Hong Kong. Commercial sector emissions decrease in both cities due to office building energy efficiency enhancement policies over the last decade. Industrial emissions in Beijing have decreased consistently as heavy industries have been moved out of the city limits. Transport emissions have decreased slightly with government policies encouraging electrification of public transport in Beijing and policies to popularize EV in Hong Kong.

Given the scale of change necessary for reaching carbon neutrality with early emissions reduction (IPCC, 2021), policy prioritization becomes extremely important. Stakeholders were asked to list their "top three most important energy policies" for Beijing and Hong Kong to attain carbon neutrality. "Important" was intentionally used instead of specific criteria like "effective" or "efficient" to allow for respondents to employ their distinctive prioritization frameworks.

Policies with similar attributes were grouped to form sub-themes under electricity generation, transport, commercial, residential and industry. Policies that contributed to more than one sectors are grouped under "cross-sector". Overall, policies of the highest perceived importance are related to electricity generation, followed by building, and cross-sectoral categories. Hong Kong stakeholders have a higher reliance on supply-side policies than Beijing. Despite the significant contribution of transport sector towards cities' emission profiles, transport policies have lower perceived importance. Measures for the industrial sector are raised in Beijing but not in Hong Kong, potentially due to the lower importance of industry in the economic structure of Hong Kong.

Among the top-ranked policies, importing clean energy is ranked highly important for both Beijing (rank 1st) and Hong Kong (rank 2nd). The two cities share similar challenges in generating sufficient renewable energy (RE) locally to meet their demand. Importing clean energy is especially valued by government officials and advisors interviewed in Beijing. Hong Kong respondents regarded local RE generation as even more important (rank 1st), given the untapped potential for offshore wind (World Bank, 2020a). Tightening building energy efficiency standards is another top-ranked policy shared by Beijing and Hong Kong. Retrofitting existing building is highlighted by Hong Kong given the average age of buildings is over 40. "If we only focus on new buildings, there is no future", remarked by a green building professional based on 300 new buildings built every year versus 43,000 old buildings (H-G2). Rigorous assessments like BEAM Plus are performed on new buildings annually, but we will need "at least 100 more years to completely retrofit inefficient building stocks, even if 430 old buildings are fixed each year" (H-G2).

While most policies have similar implications for Beijing and Hong Kong, strategies on importing green energy diverged. Beijing focused on importing RE from neighboring Chinese cities, whereas Hong Kong considered importing low-carbon energy from mainland China and globally. Beijing currently imports around 25% of electricity through interprovincial coordination to meet sustained growth in local consumption with reliability (Su, 2014). Emission reduction targets were incorporated in recent years (Wen, 2021). Provinces negotiated the capacity, duration, and tariff of electricity transfers, and the State Grid monitors the transfer process (B-A2). Beijing has the freedom to demand a designated capacity of green energy, but whether it can be supplied depends on the available capacity and negotiation processes. It is technically impossible for Beijing to import 100% green energy at present as no region can supply 100% of its energy demands using green energy. It

is only feasible for the Beijing government to directly purchase electricity from a green energy producer (B-A1, B-A2). Numerous respondents proposed importing wind power from Zhangjiakou and Inner Mongolia (North China Grid) as a crucial measure to decarbonize electricity generation for Beijing, a city with low RE generation capacity (B-A2, B-A3, B-G2, B-R1, B-R2, B-R3). This can be interpreted as buying wind power directly from producers rather than trading at the provincial level.

For Hong Kong, the discussion of energy import broadens to nuclear energy and import from regions outside of mainland China. Hong Kong began to import nuclear energy from mainland China in 1994. Around 25% of the current electricity demand is supplied by imported nuclear, with an agreement for similar imported capacity until 2034. A utility staff regarded it is “unavoidable” that Hong Kong would use nuclear energy as an intermediate energy source due to the variability of RE (H-I1). This point is substantiated by literature illustrating Hong Kong’s exceptionally high standard of supply reliability (Chung and Xu, 2020; Woo et al., 2006). Intending to balance reliability and sustainability, a “blend of RE and nuclear energy” is regarded as a viable option to meet consumer demand and “stabilize carbon emissions” (SDC, 2020). Akin to Beijing, respondents recognize geographical constraints for local RE generation, making a case for relying on importing “low-carbon energy from mainland China and countries like Australia and Japan” (H-R4). The scope also includes co-investment with foreign zero-carbon energy projects. Direct investment in clean energy production is a way to secure import agreements, particularly when parties need to compete for green energy (H-I1, H-I2, H-I4, H-R4). Such investments could serve as “offsets” for using fossil-based energy locally (H-I2). Further elaboration of the perceived importance of policies are summarized in Supplementary File C.

After comparing the two cities, scores of policy importance were summed up by stakeholder group to explore how their backgrounds and positions may influence stakeholders’ prioritization. As shown in Fig. 4, industry professionals and regulators showed a stronger preference for supply-side measures. The scores of regulators and academics were well-aligned across all sectors. Green groups appear to favour cross-sectoral policies such as civic education and carbon trading.

#### 4.2.2. Identifying SIPs for Beijing and Hong Kong

From literature analysis, it was found that energy decarbonization policies that exhibit SIPs’ qualities are related to energy technology, engagement, financial market, institutions, legal, and urban configuration (Hepburn et al., 2020; Otto et al., 2020; Sharpe and Lenton, 2021). Among the list of interventions implemented in Beijing and Hong Kong, those related to energy technology and financial markets focus on reducing the cost of deploying clean energy. Through incentivizing RE deployment, the costs are brought down through market competitiveness and the endogenous feedback loop associated with learning-by-doing – the more we deploy, the more we learn, the more costs decline, the more we demand (Ives et al., 2021). Engagement and education form a shared vision for enabling imaginaries of urban carbon neutrality (Tozer and Klenk, 2018). This intervention links to the perceptions of carbon neutrality among stakeholders. Environmental awareness and education level may affect public acceptance of climate policies. Environmental education is a means to change mindset, behaviour, and world views. Although they work on decadal timescales, once such deep leverage points are triggered, they can enable large-scale transformations (Meadows, 1999).

Institutional design is differentiated between Beijing and Hong Kong based on their differing governance structures. The Chinese central government is committed to stringent atmospheric control for air pollution alleviation, an approach that was extended to GHG emissions control with co-benefits generated (Hepburn et al., 2020). While Beijing follows many of these command-and-control policies from the Central Government, Hong Kong adopts collaborative environmental governance, characterized by multi-level participation and community engagement (Cheng and So, 2015). Including such engagement in interventions can have flow-on effects on other aspects of society, such as education to improve people’s connection with nature (Abson et al., 2017). For urban planning, land use arrangement affects mobility patterns and commuting distances that in turn influence transport emissions. Setting up carbon neutral cities as regional leaders can incentivize neighboring cities, creating cascading feedback to amplify carbon reductions.

Ultimately, four categories of SIPs relevant to Beijing and Hong Kong emerged from the literature, that are (1) Energy Technology, (2)

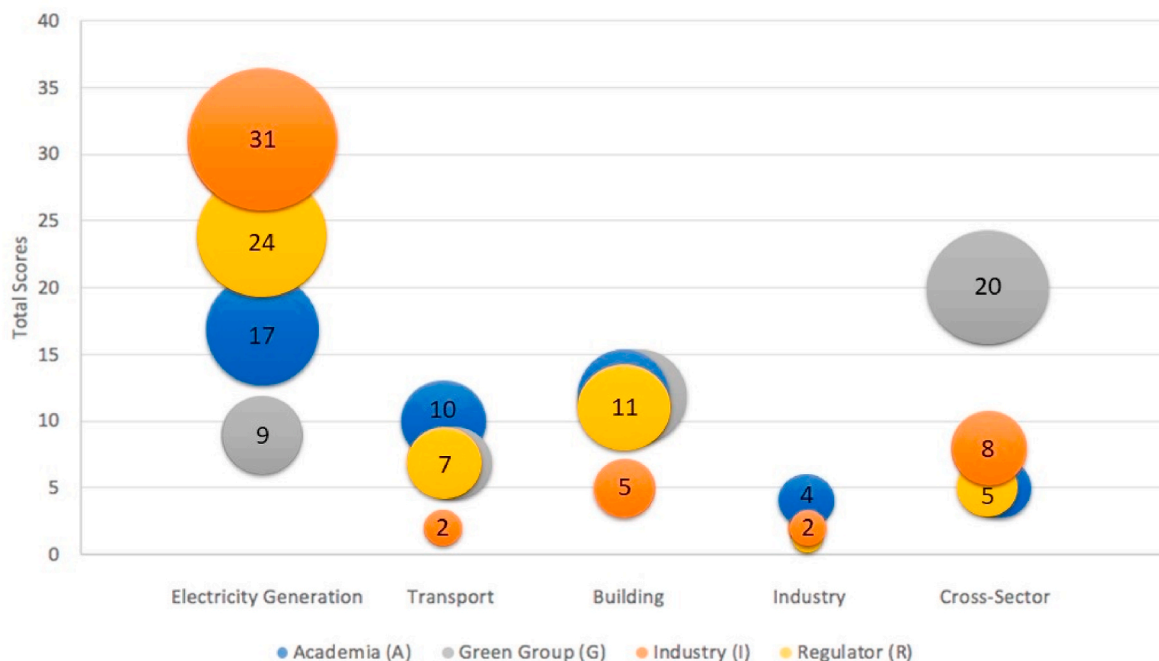


Fig. 4. Perceived importance of sectoral policies across different stakeholder groups in Beijing and Hong Kong, where larger bubble size denotes higher policy scores.

**Table 3**

SIPs for reaching carbon neutrality in energy-related sectors of Beijing and Hong Kong. Ratings have been made in terms of impact (10 being the largest and 1 being the smallest); speed (10 being the fastest and 1 being the slowest); persistence and feasibility (H: high, M: medium, and L: low); and risk (B: Biodiversity loss, E: Environmental damage, F: Financial burden on government or citizens, H: Public health and safety, P: Private sector interest harmed, S: Social inequality and underprivileged community lose out, T: Transition risk for workers and unemployment, V: Lack of monitoring and verification, and potential false reporting).

Beijing SIPs								
Final SIPs Rank	No	SIPs	Mentions	Impact	Speed	Persistence	Feasibility	Risks
1	A	Import renewable energy from other parts of China	21	10	8	H	H	B, F
2	H	Prohibit energy-intensive industries	2	8	8	H	H	S, T
3	C	Tighten building energy efficiency standards	8	8	5	H	H	F
4	B	Electrify public transport	9	6	6	H	H	F
5	E	Promote electric vehicles	5	7	5	M	H	E, H
6	D	Implement city-level emissions trading scheme with a cap on maximum emission level	8	5	4	H	M	V
6	J	Educate relevant professionals on carbon neutrality	2	8	1	M	H	/
8	F	Educate the public on carbon neutrality	3	7	1	M	H	/
9	G	Incorporate market mechanism in the electricity grid for demand management	4	5	3	M	L	P
9	I	Switch from coal to natural gas or electricity for warming	4	5	3	H	M	F
Hong Kong SIPs								
Final SIPs Rank	No	SIPs	Mentions	Impact	Speed	Persistence	Feasibility	Risks
1	A	Import low-carbon energy	16	9	6	H	M	F, P, S
2	E	Promote electric vehicles	5	8	5	H	H	/
3	B	Promote the generation and utilization of local renewable energy	18	6	7	M	H	B
4	C	Tighten building energy efficiency standards	11	5	6	M	H	F
5	I	Modify the Scheme of Control to increase renewable energy provision	5	8	5	M	L	P
5	J	Mobilize citizens for climate action	4	6	7	M	L	/
7	H	Redevelop urban area and change land use	4	7	4	M	M	/
8	D	Decarbonize existing building stock	7	6	4	M	M	F
8	F	Educate the public on carbon neutrality	7	7	4	L	M	/
10	G	Deploy green hydrogen for energy storage	6	6	2	L	L	F

Engagement, (3) Institutional Arrangement and (4) Urban Configuration. SIPs under these four categories, and with high impact and speed indicated by literature, combined with indicated importance by experts in the first-round interviews, gave rise to the “Preliminary SIPs Rank” to deduce the top 10 SIPs. The Preliminary SIPs Rank can be found in Supplementary File D.

From the second-round feedback surveys, we asked experts to score the preliminary SIPs based on their impact, speed, feasibility, and persistence. The SIPs were subsequently re-ranked according to their composite scores, with new SIPs created and some eliminated, to generate the “Final SIPs Rank” as shown in Table 3 for Beijing and Hong Kong.

A comparison of the scale and speed of impact of the SIPs identified for Beijing and Hong Kong is shown in Fig. 5. It can be inferred that the importation of clean energy and modification of the electricity market is expected to have relatively large impact and speed in both cities. An elaboration on the Final SIPs Rank and effectiveness of energy policies for the two cities is presented in Supplementary File E. Correlation between derived SIPs (Final SIPs Rank) and policies perceived important by stakeholders (Stakeholder Rank) in the two cities is also provided in Supplementary File F, alongside perspectives on overcoming the challenges to attain carbon neutrality in both cities.

### 5. Discussions

The emissions structures of the two cities examined in this study are similar, both dominated by electricity generation and buildings emissions. Perhaps not surprisingly Beijing largely follows the mainland Chinese ruling system, whereas Hong Kong operates under more of a free-market economy approach. Recalling the leverage points hierarchy proposed by Meadows (1999), governance structures are the underlying paradigms that differ between the two cities, leading to significant differences in infrastructure development, utility planning, institutional set-ups, and other attributes. Similarities and differences in SIPs derived for both cities will now be examined along with potential policy levers to trigger SIPs.

#### 5.1. Exploring the similarities

Increasing RE in the fuel mix is the top SIP for both Beijing and Hong Kong, because it can leverage the global trend of RE cost declines and benefit other systems being electrified like transport and buildings’ heating and cooling. Based on positive stakeholder feedback and actual policy outcomes, feed-in tariffs (FITs) are effective mechanisms for promoting local RE installation in Hong Kong, although such support might only be required for storage and hydrogen production given wind and solar PV are not reaching price parity with fossil fuels (IEA, 2022). Provided that much of the global deployment of renewables has occurred in China in recent years, and China has some of the lowest costs for these technologies (IEA, 2023), it is likely that Beijing and Hong Kong will be able to enjoy cost declines in alignment with these global trends. Through increasing flexibility and responsiveness to technological development, FITs can mitigate negative cost-related and distributional outcomes (Fagiani et al., 2013). However, tight tariffs with cost caps might lower incentives for innovation (Toby et al., 2010). Innovative incentives can be added directly on top of FIT pricing or by implementing complementary policies (Sun and Nie, 2015). For wind power development, socio-technical lock-in and path dependency for Hong Kong government officials has potentially led to slow progress over the past decades. Regular cost-benefit evaluations should be carried out on a regular basis by the government instead of private utility companies. With rapid cost declining trends in solar PV and offshore wind (Ives et al., 2021), Hong Kong should be proactive in seeking to take advantage of such benefits. For Beijing, importing green electricity can be achieved by enhancing the existing electricity transfer mechanism. According to the literature, Beijing can import 30–41% of its electricity demand from renewable sources in Zhangjiakou (Huang et al., 2020). While this is out of the remit of city government, Beijing government can concentrate on researching community-scale microgrids powered mainly by RE. Hybrid systems with wind power as the main energy source, supplemented with solar PV has been found to be currently the most cost-effective option (He et al., 2018) although this may change given solar PVs steeper learning rates (Way et al., 2022).

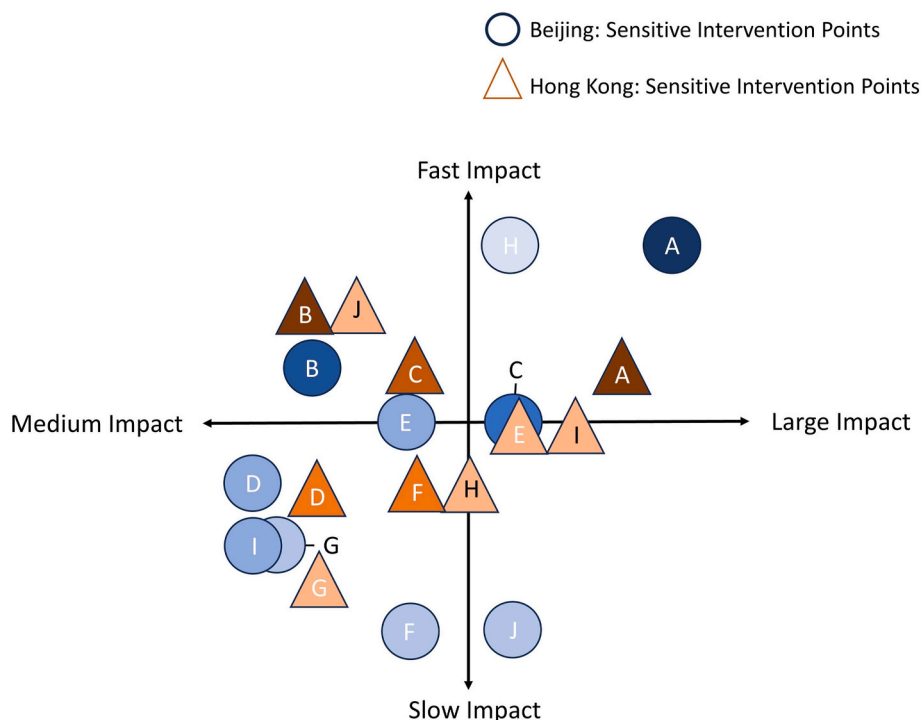


Fig. 5. The Final SIPs for Beijing and Hong Kong shown graphically on axes of the scale and speed of impact. Shading correlates with the frequency of mentions by first-round interviewees as an important policy (Darker colour implies more frequently mentioned).

Using battery for energy storage in the system will not only enable higher uptake of RE, it could potentially increase security, cut costs, and reduce environmental impact when paired with RE (He et al., 2018).

CCS is important for defining “carbon neutrality” among Beijing and Hong Kong experts, as it is a necessary component of their understanding of the “net” concept and offsetting. At the national level, China is actively researching nature-based solutions for sequestration, such as in ocean algae. However, CCS was rarely mentioned among “most important policies for carbon neutrality”, and not on the list of SIPs for both cities. Given the most aggressive IPCC scenarios to achieve Paris Agreement targets suggest we need to start building at least a million tonne per annum CCS facility every 3 days for the next 80 years to achieve net-zero (IPCC, 2018), there appears to be a disconnect between the modelling community and decision-makers on the ground. Beijing and Hong Kong are large cities that should have the power to decide on CCS. Despite research suggesting CCS plans for China’s future fuel mix (Xu and Liu, 2015), government plans only focus on importing more low-carbon energy sources like nuclear and RE. Experts interviewed believed offsetting is crucial for carbon neutrality yet assumed CCS would be dealt with at the national level. In contrast, RE is prominent at meso-level decision-making process because RE infrastructure is more modular, and is visible and ingrained in daily lives, whereas CCS remains at the national level and relatively undiscussed. This illustrates carbon neutrality targets can be influenced by multi-level dynamics and hindered by disconnections between the different levels of governance.

### 5.2. Navigating the differences

The discourse around policy alignment with the national agenda was prominent in interviews and surveys among Beijing stakeholders, regardless of their backgrounds. Whereas only a handful of Hong Kong respondents made references to China’s overall strategic plan. This can be explained by Hong Kong’s Special Administrative Region status. One example is R&D investment in new energy technologies, such as green hydrogen that is a useful energy carrier for cities with limited landmass. Stakeholders agreed green hydrogen will play an increasingly influential role for the cities, but commercial viability is unclear. Experts from Hong Kong showed more pronounced reluctance for green hydrogen as it is unlikely to become cost-effective in 10–15 years (IEA, 2021). For Beijing, stakeholders were confident in green hydrogen technology as it is embedded in the national agenda. Overall, Beijing respondents exhibited higher openness in terms of R&D for all new energy technologies, not just hydrogen. Beijing can gain direct support from national manufacturing bases more easily. As advised by Beijing experts, Hong Kong can also tap in the national resource network, given China’s agenda in 14th FYP to build Hong Kong-Shenzhen Innovation and Technology Park in the GBA. To ensure their progress towards carbon neutrality, Hong Kong must finalize a long-term energy transition plan, enabled by more aggressive policies to promote the research and uptake of low-carbon sources.

### 5.3. Transcending paradigms

As Meadows (1999) proposed, transcending paradigms is the deepest leverage point that can tip the system. Taking a step back from policy measures captured in the SIPs, we can see that they are mostly planned and executed by government officials. Therefore, altering official appraisal mechanism is akin to transcending the underlying paradigm, which is likely to have profound and lasting implications for decarbonization progress, as the UK Climate Change Act has for the UK (Farmer et al., 2019).

For Beijing, government official evaluation is the main driver for deliverable outcomes. Such evaluation has been historically based on economic growth measured by GDP, which evolved to include “green GDP” in 2006 to factor in environmental costs. Although “green GDP” was shelved within a year due to resistance from regional and local

governments (Li and Lang, 2010), local governments were still held accountable for environmental quality and ecological conservation since then (Wang, 2016). Another fundamental shift in China’s governing ideology is that no economic growth target was proposed in the 14th FYP, further dissociating evaluation metrics of government officials with economic pursuits. Therefore, a new institutional SIP is proposed to tie carbon emissions with the evaluation of city governors. Chinese scholars also suggest defining officials’ responsibility for carbon reduction and correlating it with promotion opportunities (Dai et al., 2020). As described by a Beijing industry professional, “the challenge will be how officials square the circles to meet both growth goals and climate actions that may incur extra living costs” (B-II). Therefore, additional incentive structures should be built into the appraisal system to motivate officials make the necessary compromises for attaining climate targets without facing repercussions.

As aforementioned, local governments tend to prioritize policies that are low hanging fruits and exhibit co-benefits. This was confirmed by Beijing respondents, who described environmental governance as “dictated by the fight against smog and air pollution”. This echoes with research showing 80% of Beijing respondents is willing to pay for urban smog mitigation, with a maximum of 914 yuan (Dong and Zeng, 2018). Comparatively, government officials and the general public have yet to strongly associated climate change with immediate harms, although extreme events like dust storms have been exacerbated by drier climates. Beijing residents are willing to pay for climate change mitigation than doing nothing, but the magnitude of payment is relatively small (maximum 322 yuan) (Wu and Zhang, 2020). Assessing government officials based on carbon reduction creates incentives for bold policies which may be costly at first. Hong Kong government currently does not follow the appraisal system of mainland China. Low level of accountability among environmental officials is a concern shared by several Hong Kong respondents. Introducing a similar mechanism to hold officials accountable for carbon neutrality can potentially accelerate decarbonization in Hong Kong.

To ensure effective local urban climate governance, horizontal cooperation among city government departments and vertical cooperation with the national government are pertinent. Policymakers across different departments need to fully understand emissions targets and embed them across intersecting policy arenas to rally support with thorough information dissemination. In Hong Kong, policy bureaus on energy and climate policies have a clear segregation of duties, sometimes working in silo. Certain departments with relevant expertise only know their part of the work without seeing the full picture of the decarbonization roadmap, hindering horizontal cooperation and limits checks and balances. Technical experts may also lack motivation to innovate and push boundaries for maximum policy output. For vertical cooperation, energy sectors like transport and the electricity grid fit into the wider national network. City governments need to strategize around national policies to avoid missed opportunities.

Horizontal inter-municipal learning is a common attribute shared by cities successfully leading climate action. Both Beijing and Hong Kong stakeholders referenced the need to learn from one another and best-practice examples like Guangzhou. The low-carbon city initiative in China started over a decade ago but did not achieve significant progress in motivating decarbonization. While the C40 network strives to build capacity among Chinese cities through setting up a tailored programme, the participation is limited to large cities. There are no official channels for all Chinese cities to learn about policy instruments that facilitate effective decarbonization and how to implement policies with societal acceptance. Lee and van de Meene (2012) find that learning usually happens when there are “champions” with more advanced climate policies, and when cities share similar languages and geographies. This suggests the value of establishing a multi-stakeholder governing body to foster representative engagement and policy learning on climate and energy policies, which is a well-proven SIP that replicate successes rapidly.

#### 5.4. Factors influencing the prioritization of climate policies

Two methods of prioritizing climate policies are explored in this research, through expert elicitation and the lens of SIPs. The common underlying factors that influence policy prioritization were identified. Coming from the perspective of a city policymaker, the factors are the alignment with national agenda, ease of implementation, availability of co-benefits and financial costs.

Alignment with the national agenda is a recurrent theme. For instance, promoting EV is ranked as a more prominent SIP in Hong Kong because regulatory framework and incentives already exist. National and local policies need to meet at a point for climate action plans to work out successfully. Ease of implementation is another important factor when selecting climate policies, as local governments often aim for low-hanging fruits due to their brevity of service, which could align with the “speed” requirements of SIPs. Indeed, government stakeholders preferred faster policies, while the civil society like green groups were more invested in education solutions that have slower but deeper impact, leading to transformative rather than incremental changes. There may be downsides to the preference for quick wins, especially when policies can achieve results quickly but yield low impact. Nevertheless, SIPs identified in this study mostly exhibit relatively high impact alongside high speed.

Local governments also value climate policies that bring about co-benefits and generate synergies, although generating co-benefits is not a requirement for SIPs. Improving efficiency of the transportation system, pollution alleviation for public health are common entry points for climate action among local governments. As for the case in Beijing, the government is much more motivated to spend human and financial resources in fighting smog because it is closely linked with other aspects like public health and tourism. The Beijing city government representative interviewed has yet to see prominent “direct impact” of climate change on the community. Their views might have changed after heatwaves and serious flooding hit Beijing in summer 2023, which occurred after the interviews. Research also shows urban flooding is becoming more intense, frequent and uncertain under climate change and human factors, calling for updated flood risk assessment models to inform climate policies (Sun et al., 2023). Similarly, in other less developed cities, local governments usually prioritize policies related to public health and environmental safety, like solid waste management. Climate mitigation and adaptation solutions are seen as the add-on or co-benefit. As revealed from the interviews, this research has not captured the ability of a SIP to trigger other SIPs, and the cascading effect of SIPs when certain policies are dependent on other SIPs. This is an attribute of SIPs worthy for further research.

Financial cost is another essential factor. Although Beijing and Hong Kong are economically advanced cities, economic concerns were repeatedly brought up in the interviews. One prominent example is that the Hong Kong government rejected offshore wind construction based on the fear of having to raise electricity tariffs and transferring the financial burden to citizens. Spending is a concern for cities at different economic development stages. This illustrates why formulating a standardized prioritization framework for energy and climate policies is an important first step for cities to embed climate change in their future planning strategies. SIPs might be particularly useful for cities with limited resources to allow them to concentrate on policies that make significant decarbonization progress.

## 6. Conclusions

Policymakers can leverage complex system dynamics to identify policies that can achieve disproportionately large impact, thereby accelerating climate action and achieving carbon neutrality goals. This paper proposes an alternative approach to formulate a policy prioritization framework at the city level based on the concept of SIPs, resulting in recommended policies for Beijing and Hong Kong respectively for

accelerating their transitions to carbon neutrality. This approach, combined with engagement with representatives from academia, government, industry, and green groups, can provide a coherent framework to assist cities in identifying effective energy and climate policies.

The principal findings of the research are threefold: (1) The perceptions of carbon neutrality are largely similar in Beijing and Hong Kong as reflected from the 32 expert interviews - Beijing stakeholders are more aware of the political connotations associated with the national carbon neutrality pledge, representing China's aspiration to enter the global race for green energy and net-zero technologies; (2) Ten SIPs are identified for Beijing and Hong Kong respectively through literature review and expert elicitation, ranked according to impact, speed, feasibility and persistence - Beijing and Hong Kong share the same highest-ranked SIP of importing low-carbon energy from other regions, closely followed by measures such as promoting EVs and generating local RE; (3) On factors that influence the choice of policies related to carbon neutrality, interview results reveal that the conceptualization of carbon neutrality does not necessarily influence the course of action taken to achieve the target. Instead, the choice of policies is influenced by factors such as alignment with the national agenda, economic costs, ease of implementation, and the availability of co-benefits.

SIPs provide a useful reference for policymakers to concentrate resources on the most effective and scalable policies to decarbonize the energy sectors in Beijing and Hong Kong. Had an economy-wide carbon tax been implemented in the Chinese economy 30 years ago that gradually increased based on decarbonization progress, it could have potentially eliminated the need for accelerating climate action through SIPs. However, given the current urgency for climate action, and China's stated carbon neutrality goals, the SIPs approach offers a means by which decarbonization can be more strategic by focusing on significant emitters like energy and transport, as well as interventions that create momentum and yield disproportionately large impact. It is important to note that relying on such positive feedback dynamics also carries potential risks, including the pace of change leading to stranded assets, labor market frictions, and supply chain bottlenecks, as well as trade-offs causing unequal distributional impacts. Therefore, any policies designed based on SIPs should incorporate provisions to minimize the impact of these unintended consequences. Mealy et al. (2023) provides a more detailed analysis on the advantages and disadvantages of the SIPs approach that can guide future research.

Based on the research findings, identifying SIPs can be formalized in the policy cycle for prioritizing climate action in other Chinese cities. The wider application of SIPs at the city level enables optimized resource allocation for achieving maximum carbon reduction, which represents a significant stride forward for China in terms of climate change mitigation. As a developing country, China encounters challenges in balancing economic growth with the implementation of certain climate policies revealed from the study. In the future, the SIPs framework can be extended to encompass policies related to economic and urban development to achieve a holistic evaluation of short, medium, and long-term measures for addressing climate change.

#### CRediT authorship contribution statement

**Sum Yue Chung:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Matthew C. Ives:** Conceptualization, Formal analysis, Methodology, Resources, Supervision, Writing – review & editing. **Myles R. Allen:** Conceptualization, Methodology, Resources, Supervision, Writing – review & editing. **Jay R.S. Doorga:** Validation, Visualization, Writing – review & editing. **Yuan Xu:** Resources, Validation, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The data that has been used is confidential.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jclepro.2024.141681>.

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