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TECHNICAL NOTE

HONG KONG ENERGY POLICY SIMULATOR: METHODS, DATA, AND SCENARIO RESULTS FOR 2050

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EXECUTIVE SUMMARY

The government of Hong Kong published the *Hong Kong's Climate Action Plan 2030+* report in 2017 as a response to the Paris Agreement. The report states Hong Kong's carbon emission reduction target for 2030 and outlines action plans to meet it. Hong Kong has pledged to reduce 65 to 70 percent of its carbon intensity per gross domestic product (GDP) by 2030, using 2005 as the base. This is equivalent to a 26 to 36 percent reduction from 2005 emissions levels and an expected reduction to 3.3–3.8 tonnes on a per capita basis, compared with 6 tonnes per capita in 2005.

While not a party to the Paris Agreement itself, Hong Kong as a Special Administrative Region of China contributes to the fulfillment of China's Nationally Determined Contribution of the Paris Agreement. Hong Kong similarly plays a part in contributing to meeting the long-term target of the Paris Agreement to limit global temperature increase to less than 1.5 to 2 degrees Celsius. Hong Kong currently does not have a long-term decarbonization strategy or target beyond 2030 in place. Thus, it is critical for Hong Kong to formulate a long-term decarbonization plan to which the short- and medium-term actions could conform.

In order to inspire ambition and mobilize action to advance Hong Kong through a cross-sectoral transition

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Technical notes document the research or analytical methodology underpinning a publication, interactive application, or tool.

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toward long-term deep decarbonization, World Resources Institute (WRI) and Civic Exchange (CE) jointly initiated the project "Hong Kong 2050 Is Now." Under this project, WRI and CE collaborated with Energy Innovation LLC to develop the Hong Kong Energy Policy Simulator (EPS), which aims to provide technical support for developing Hong Kong's 2050 deep decarbonization strategy. The "Hong Kong 2050 Is Now" project provides policy recommendations based on the results of the Hong Kong EPS. Meanwhile, the Hong Kong EPS also allows users to create their own scenarios to see impacts of different policy combinations.

This technical note describes the structure, input data sources, outputs, limitations, and future development, as well as the online interface, of the Hong Kong EPS. A subsequent policy report will present the model's results and policy recommendations in more detail.

INTRODUCTION

The Paris Agreement, entered into force in November 2016 in advance of the 22nd Conference of the Parties (COP 22), brings together nations of the world to put forward determined efforts to reduce greenhouse gas (GHG) emissions, and to adapt to the effects of climate change. The Hong Kong Special Administrative Region (SAR) of China (hereinafter referred to as Hong Kong) is covered under China's Nationally Determined Contribution (NDC) of the Paris Agreement and contributes to its fulfillment.

In 2010, Hong Kong announced its initial target to reduce its carbon intensity by 50 to 60 percent from 2005 levels before 2020 (Environment Bureau 2015b).[1] In 2017, the Hong Kong government published *Hong Kong's Climate Action Plan 2030+* report in response to the Paris Agreement. The report states the government's carbon emissions reduction target for 2030 and outlines action plans to meet it. Hong Kong has pledged to reduce 65 to 70 percent of its carbon intensity by 2030, using 2005 as the base. This is equivalent to a 26 to 36 percent absolute reduction and a reduction to 3.3–3.8 tonnes on a per capita basis, compared with 6 tonnes per capita in 2005 (Environment Bureau 2017).[2]

In addition to these climate targets, the Hong Kong government made corresponding targets in the areas of energy saving, energy efficiency, electricity generation fuel mix, buildings, transportation, and waste management. These targets contribute to the achievement of climate change objectives. For example, Hong Kong is attempting to reduce energy intensity by 40 percent of its 2005 level before 2025 (Environment Bureau 2015a),[3] reduce the share of coal in the power generation sector to 25 percent, and increase the share of natural gas to 50 percent by 2020. Through 2030, coal will continue to be phased out while the use of natural gas and non-fossil fuels will be increasing (Environment Bureau 2017).[4] Government buildings are targeted to decrease energy consumption by 5 percent between 2015 and 2020 (Government of Hong Kong 2015).[5] There are also targets to cut down the amount of food waste that goes to landfills by at least 40 percent before 2022 and to reduce the municipal solid waste disposal rate to landfills by 40 percent on a per capita basis by 2022, relative to 2011 numbers. (Environment Bureau 2014; Environment Bureau 2013).[6] While plentiful, these policy initiatives are designed for the short and midterm.

A key aspect of the Paris Agreement is to strengthen global efforts to meet the long-term target of limiting the global temperature increase to below 1.5 - 2 degrees Celsius. However, Hong Kong currently does not have a long-term decarbonization strategy or target beyond 2030. Formulation of long-term low GHG development plan is crucial for Hong Kong in planning a path toward decarbonization, as well as to guide its short- and mid-term actions to be in line with the global deep decarbonization target.

In order to inspire ambition and mobilize action to advance Hong Kong through a cross-sectoral transition toward long-term deep decarbonization, World Resources Institute (WRI) and Civic Exchange (CE) jointly initiated a project called "Hong Kong 2050 Is Now." Under this project, WRI and CE collaborated with Energy Innovation LLC to develop the Hong Kong Energy Policy Simulator (EPS), which aims to provide technical support for developing Hong Kong's 2050 deep decarbonization strategy. The "Hong Kong 2050 Is Now" project provides policy recommendations based on the results of the Hong Kong EPS. Meanwhile, the Hong Kong EPS also allows users to create their own scenarios to see impacts of different policy combinations.

This technical note discusses the structure, function, input data, and output specific to the Hong Kong EPS. A complementing policy report will introduce more detailed analysis and policy recommendations.

BACKGROUND ON THE ENERGY POLICY SIMULATOR

About the Hong Kong Energy Policy Simulator

The Hong Kong Energy EPS is a version of the Energy Policy Simulator, https://www.energypolicy.solutions/, an open source, system-dynamics computer model. The EPS is able to estimate the effects of various policies on many indicators, such as emissions, financial metrics, electricity system structure, deployment of different types of vehicles, as well as many other data.[7] The EPS simulates energy policies as well as non-energy policies, such as those affecting industrial processes. EPS policies are actions taken, not targets. The EPS is generally a forward-simulating, not goal-seeking, model. Therefore, policies generally constitute specific actions or measures that influence actions, such as changing the price of something, rather than specifying targets to be met via unknown actions. The tool allows users to explore various policy combinations to create policy scenarios, including custom policy implementation schedules. The EPS simulates the years 2017 to 2050 by using annual time steps and offers hundreds of environmental, economic, and social outputs. Significant output indicators include emissions of 12 pollutants,[8] cash flows (first-order costs and savings to government, consumer or labor, non-energy industries, and each of the energy industries),[9] capacity and generation of electricity by different types of power plants, market share of different vehicle technologies, and premature deaths avoided by reductions in particulate emissions. These output metrics can help policymakers anticipate long-term economic impacts and costs of implementing new policies. Some of the policies included in the EPS have not yet been explored in Hong Kong, thus offering novel options to policymakers.

More detail on the technical aspects of the Hong Kong EPS is available in the EPS online documentation at https://hongkong.energypolicy.solutions/docs/. The model is free and open source. It can be used via an interactive web interface at https://hongkong.energypolicy.solutions/ or can be downloaded from the same site. Previous adaptation of EPS in other regions is introduced in Box 1.

Why Use a Computer Model?

Before considering the structure and uses of the Hong Kong EPS, it is worthwhile to ask, "Why should we use a computer model at all?" A policymaker seeking to reduce emissions faces a dizzying array of policy options that might advance policy goals. Policies may be specific to one sector or type of technology (for instance, light-duty vehicle fuel economy standards) or might be economy-wide (such as a carbon tax). Sometimes a market-driven approach or a direct regulatory approach or a combination of the two can be used to advance the same goal. For instance, to improve

Box 1 | **Previous Adaptation of EPS in Other Regions**

EPS has been successfully applied in many other regions, including Canada, the Alberta Province of Canada, China, India, Indonesia, Mexico, Poland, Saudi Arabia, and the United States. All the models can be found at https://www.energypolicy.solutions/.

WRI contributed to the development of the India (Mangan et al. 2019), Indonesia (Rissman and Chrysolite 2017), and Mexico models (Altamirano et al. 2016). The relevant technical note and working paper can be found on WRI's website:

- *Achieving Mexico's Climate Goals: An Eight-Point Action Plan*
  https://www.wri.org/publication/achieving-mexicos-goals
- *A Tool for Designing a Policy Package to Achieve Indonesia's Climate Targets: Summary of Methods and Data Used in the Indonesia Energy Policy Simulator*
  https://www.wri.org/publication/indonesia-eps-tech-note
- *A Tool for Designing Policies to Achieve India's Climate Targets: Summary of Methods and Data Used in the India Energy Policy Simulator*
  https://www.wri.org/publication/achieve-india-climate-targets

the efficiency of home appliances, a government may offer rebates to buyers of efficient models or mandate that the appliance manufacturers meet specific energy-efficiency standards or both. To navigate this field of options, policymakers require an objective, quantitative mechanism to determine which policies will meet their goals and at what cost.

Many studies have examined certain energy policies in isolation. However, it is of greater value to policymakers to understand the effects of a package of different policies because the policies may interact nonlinearly. This interaction among policies can produce results different from the sum of the effects of the individual policies. For example, a policy that promotes energy efficiency in addition to a policy that reduces the cost of wind energy, enacted together, are likely to reduce emissions by a smaller amount than the predicted sum of each of those two policies enacted separately. This is because some of the electricity demand that was eliminated by the efficiency policy would otherwise have been supplied by additional zero-emissions wind generation caused by the wind policy. In this case, the total effect is less than the sum of the individual effects. The opposite is also possible. For example, policies that promote the electrification of light-duty vehicles in addition to making wind energy cheaper are likely to have a greater impact on emissions together than the sum of these policies' individual effects.

Due to the strength of integrated computer models at simulating complex systems, a customized integrated dynamic computer model is a crucial tool to help Hong Kong policymakers evaluate a wide array of policies. A satisfactory model must be able to represent the entire economy and energy system with an appropriate level of disaggregation, be easy to adapt to represent Hong Kong, be capable of computing a wide array of relevant policy options, and offer results that include a variety of policy-relevant outputs. Additionally, the model must capture the interactions of policies and other forces in a system the parameters of which change dramatically over the course of the model run as Hong Kong continues to grow and develop.

About System Dynamics Modeling

Many approaches exist for representing the economy and the energy system in a computer simulation. The Energy Policy Simulator is based on a theoretical framework called "system dynamics." As the name suggests, this approach views the processes of energy use and the economy as an open and fluctuating non-equilibrium system.

System dynamics models often include stocks or variables the values of which are affected by flows in and out of these variables. For example, a stock might be the total installed capacity of wind power plants, which can only grow or shrink gradually from the construction of new turbines (an inflow) and retirement of old turbines (an outflow). In contrast, the amount of energy generated by wind turbines in a given year is calculated afresh every year (based on the installed capacity in that year) and therefore is a normal variable, not a stock variable. The Energy Policy Simulator uses stock variables for two purposes:

- Tracking quantities that grow or shrink over time (such as the total wind electricity generation capacity)
- Tracking differences from the current policy scenario input data that are prone to change over the course of the model run (for instance, the cumulative differences caused by enabled policies in the potential fuel consumption of the light-duty vehicle fleet)

System dynamics models often use the output of the previous timestep's calculations as input for the following timestep.[10] The Energy Policy Simulator follows this convention, with stocks like the electricity generation fleet, the types and efficiencies of building components, and other stocks recorded from one year to the next. Therefore, an efficiency improvement in a prior year will result in fuel savings in all subsequent years until the improved vehicle, building component, or other investment is retired from service. The industrial sector is handled differently. The available input data come in the form of potential reductions in fuel use and process-related emissions due to policy. We gradually implement these reductions (with corresponding implementation costs), rather than recursively tracking a fleet-wide efficiency. Due to the diverse forms of input data in the many sectors we model, one approach rarely works for all sectors. Accordingly, the Hong Kong EPS attempts to use a suitable approach that makes the most sense in the context of a specific sector.

Structure of the Hong Kong EPS

The structure of the Hong Kong EPS can be envisioned along two dimensions:

- The visible structure that represents the equations that define relationships between variables (viewable as a flowchart)
- A behind-the-scenes structure that consists of arrays (matrices), in addition to their elements that contain data that are acted on by the equations

For example, the transportation sector's visible structure consists of policies (such as a fuel economy standard), input data (such as the kilometers traveled by a passenger or a ton of freight), and calculated values (such as the quantity of fuel used by the vehicle fleet). The arrays in the transportation sector consist of vehicle categories (light-duty vehicles [LDVs], heavy-duty vehicles [HDVs], motorbikes, etc.), cargo types (passengers or freight), and engine types (petroleum gasoline, petroleum diesel, electricity, liquified petroleum gas (LPG), etc.). The model generally performs a separate set of calculations, based on each set of input data, for every combination of array element. For example, the model will calculate different fuel economies for passenger HDVs and freight HDVs.

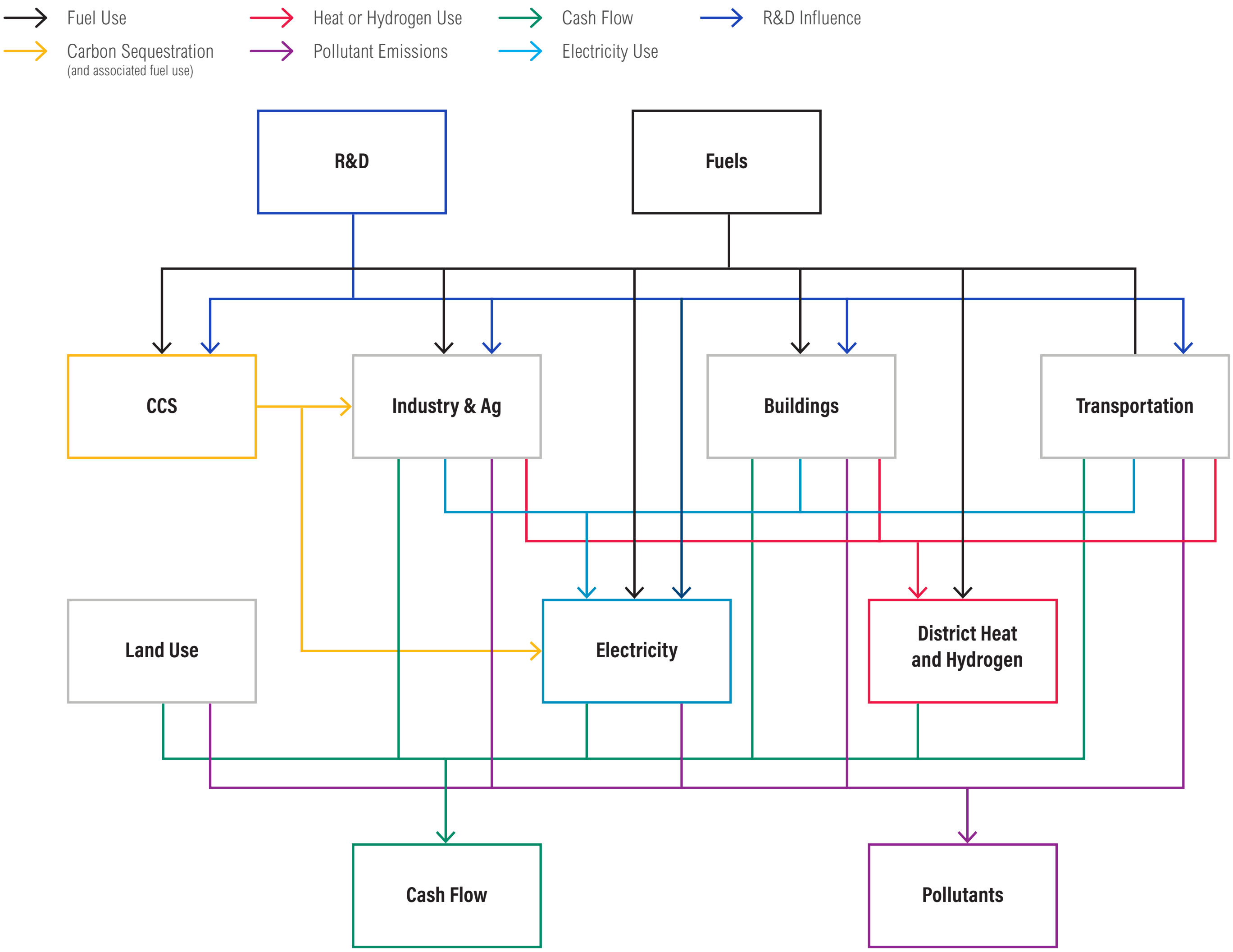
The model has six main sectors: industry (including manufacturing and related industries, construction, agriculture, and waste management); buildings; transportation; electricity generation; land use, land-use change, and forestry; and district heat and hydrogen. In addition, there are several supporting modules handling other functions, as depicted in Figure 1. The model's calculation logic begins with the fuels section where basic properties of all fuels are set, and policies that affect the price of fuels are applied. Information about the fuels is used in all sectors except land use.

The transportation, buildings, and industry sectors calculate their respective emissions from direct fuel use (e.g., fossil fuel combustion in vehicles, buildings, and industrial facilities). These sectors also specify the amount of electricity or hydrogen (energy carriers supplied by other parts of the model) required each year. The electricity sector, in addition to the district heat and hydrogen module, consumes fuel to supply the energy needs of these three sectors. The sixth sector, land use, does not consume fuel or electricity.

All six sectors produce emissions of each pollutant that are summed at the bottom of Figure 1. The same is true for cash-flow impacts, which are calculated separately for individual actors such as government, industry, consumers, and the five energy industries. At this stage, calculation of changes in spending are carried out on items like capital equipment, operations and maintenance (O&M), and monetized social benefits from avoided public health impacts and climate damages. Cash flows are calculated on a first-order basis, as noted above and described in endnote 9. Box 2 provides an example of how EPS determines Hong Kong's electricity generation.

Two components of the model—research and development (R&D) and carbon capture and storage (CCS)—affect the operation of various sectors. A set of R&D levers allows the user to specify improvements in fuel economy and reductions in capital cost for technologies in each of the five sectors, as well as in the CCS module. The CCS module affects the industry and electricity sectors by reducing their CO_2 emissions, increasing their fuel usage due to the energy-intensive CCS process, and changing their cash flows.

Figure 1 | **Hong Kong's Energy Policy Simulator Model Structure**



Source: Energy Innovation Policy and Technology LLC.

Box 2 | **How EPS Determines Hong Kong's Electricity Generation**

The two power companies in Hong Kong, Hong Kong Electric (HKE) and China Light and Power (CLP), currently have significant coal capacity (2,000 and 4,108 megawatts, respectively). As coal is also the cheapest energy source, by default, the EPS model assumes around 70 to 80 percent of base year energy generation to be coal. However, in reality the generation from these coal power plants is constrained by government policy. The seventh *Technical Memorandum for Allocation of Emission Allowances in Respect of Specified Licenses for Hong Kong* sets emission limits for air pollutants, which apply to the power companies. Because of these limits, the power companies can only generate a certain amount of electricity generation from coal power plants, the remaining generation has to be supplied by gas, nuclear, and renewables. Moreover, *Hong Kong's Climate Action Plan 2030+* specifies the government's vision for a reduction in coal use. By 2020, there is an electricity generation target of 50 percent natural gas, 25 percent coal, and 25 percent non-fossil fuels. In order to account for these deviations from what the model predicts based purely on capacity availability and resource prices, we tuned the EPS parameters "BAU Expected Capacity Factor" (BECF) and assumed that coal power plants have a lifetime of 40 years before they retire. This leads to major coal retirements in 2020 and 2025, which makes the projection in the current policy scenario consistent with existing policies.

Source: HKE, CLP, *Hong Kong's Climate Action Plan 2030+*.

INPUT DATA SOURCES

The Hong Kong EPS is adapted from the international, open-source release of Energy Innovation's Energy Policy Simulator (version 2.0.0). To adapt the model to Hong Kong, significant data requirements are needed to be met using a variety of data sources for the variables. The variables are rated with ranked importance from very high to high to medium to low, primarily based on the impact the variable might have on modeling results and how varied the value could be between regions. The input data were sourced via the following approaches, in order of priority:

- For variables that have a significant effect on modeling results and that need to be region-specific (with a very high and high importance rating), we use publicly available data published by the Hong Kong government. Examples of such variables include population, start year electricity capacity, and building energy use by building type or purpose. For macro data and general energy data, the source is primarily the Census and Statistics Department. For sector-related, climate change - specific-related, or detailed energy consumption data, the sources include Environmental Protection Department, Labor Department, Civil Aviation Department, Housing Department, Marine Department, Transport Department, Electrical and Mechanical Services Department, and others. Another source is through stakeholder consultation. The project team organized seven roundtables on electricity generation, distributed gas, transportation, building, carbon price and CCS, waste management, and lifestyle. The team also had more than 20 in-depth conversations with local stakeholders on the above-mentioned topics.

- For the variables that are likely to be different from region to region but will not generate unreasonable results (with medium importance rating), we used Hong Kong data where available and data from the existing China or U.S. models when Hong Kong data are not available. Input data from China or the U.S. EPS were selected, depending on the variable and which would most closely represent the circumstances in Hong Kong. For example, U.S. data are used for the elasticity of building service demand with regard to energy cost, for which we could not find a source for a Hong Kong - specific value. While the elasticity might be different between United States and Hong Kong, using the U.S. value will still produce reasonable results in the model.

- If the data are unlikely to vary by region (with low importance rating)–for example, the global warming potentials of various gases—and/or when data from Hong Kong were unavailable and scaling another region's data would be irrelevant or inappropriate, the input data from other regions were used unchanged. For example, the expected lifetime of a building component like an air conditioner in another region may be the best available estimate of the lifetime of that same type of building component in Hong Kong.

Appendix Table A-1 indicates the data source used for each variable.

SCENARIOS AND RESULTS

This section explains how we designed the scenarios and presents preliminary modeling results from Hong Kong EPS.

Scenarios Setting

In the Hong Kong EPS, we considered two scenarios:

- Current Policy Scenario: presents the existing policies up to 2030 and projection up to 2050, based on the trends from current policies

- Decarbonization Scenario: presents our principal recommendations for Hong Kong to achieve deep decarbonization by 2050

The Current Policy Scenario is established through setting input data based on the current policies, while the Decarbonization Scenario layers policies on top of the Current Policy Scenario with the objective of deep decarbonizing by 2050.

Table 1 summarizes the data of the major parameters in the Current Policy Scenario. Some of the data are assumptions used in the Hong Kong EPS, while some are calculations from the model, which are presented in order to help readers better understand the model setting. Table 1 also summarizes policy settings in the Decarbonization Scenario. Explanations and assumptions for the main parameters are summarized as follows:

- **Population:** This study uses Hong Kong population projection statistics published by the Census and Statistics Department (C&SD) in September 2017. Using the local population in mid-2016 as a baseline, the statistics forecast population trends between 2017 and 2066 (2017–2050 data are used in the model) and includes projections of domestic households and the labor force. Hong Kong's population projection is affected by several factors, such as total fertility rate, mortality, and the number of new immigrants as measured by the number of one-way permit holders. The C&SD produced baseline, high, and low population projections. In this study, only the baseline projections are adopted whereas the high population projection will be tested in further development of the model. According to the C&SD statistics, Hong Kong's population in mid-2016 was 7.34 million. In the baseline condition, the local population is projected to reach a peak of 8.22 million in mid-2043 and then gradually drop to 7.72 million in mid-2066. The average growth rate between 2016 and 2043 is 0.4 percent per annum, and the rate of decrease between 2043 and 2066 is 0.3 percent per annum (Census and Statistics Department 2017). Following the baseline population projections, this study adopts 8.15 million as the Current Policy and Decarbonization Scenario population in 2050.

- **GDP:** Hong Kong has a small, open, and advanced economy, yet its growth is expected to decelerate steadily. To assess economic growth rates, this study uses figures issued in Treasury Branch, Financial Services and the Treasury Bureau (2014). The base case of the report assumes that real GDP growth would be maintained at 3.5 percent per annum between 2014 and 2021 (actual annual growth was 2.9 percent on average during 2014–18), gradually decelerate to 3 percent between 2022 and 2025, then further decrease to 2.5 percent between 2026 and 2041. Because there have not been any relevant studies projecting local economic growth beyond 2041, this study assumes that between 2042 and 2050, growth would be maintained at 2.5 percent. The base case assumptions from 2014 to 2050 suggest an average projected real GDP growth rate of 2.7 percent per annum.

- **Fuel mix:** In 2017, Hong Kong consumed 157,604 terajoules of electricity (Census and Statistics Department 2018)[11] while fossil fuel - powered electricity generation emitted 26.6 million tonnes CO_2 equivalent (EPD 2019).[12] Coal-fired power (48 percent of total electricity) is the major fuel source for electricity generation. HKE and CLP are operating six and eight coal-fired units in their plants, respectively. Electricity from natural gas (27 percent) and imported nuclear power (25 percent) are the second and third largest sources for Hong Kong. As stated by *Hong Kong's Climate Action Plan 2030+*, Hong Kong will be gradually phasing out coal-fired electricity generation and switching to natural gas - fired electricity generation.

  In the short term (up to the mid-2020s), natural gas will contribute about half of Hong Kong's electricity generation whereas coal will drop to about 25 percent. This is expected to be achieved through retiring coal generation units in the Lamma Power Station and Castle Peak Power Station by retrofitting them to burn gas. The government did not publish any further road maps for the fuel mix beyond 2030. In the *Long-Term Decarbonization Strategy Public Engagement* document, the government suggests that 80 percent of Hong Kong's electricity would need to come from zero-carbon energy sources to meet the Paris Agreement's 2°C target (Council for Sustainable Development 2019). An even more ambitious fuel mix blueprint is necessary for Hong Kong to be on a trajectory consistent with limiting the global temperature rise to no more than 1.5°C and achieve zero emissions in the long term.

  For Hong Kong to meet the net-zero emissions target by 2050, this study crafts a scenario to increase renewable energy (RE) use to 38 percent by 2050. For instance, 3 percent of renewable energy can be generated locally (the existing official projection for Hong Kong's local RE potential is 3–5 percent[13]), and 35 percent can be imported from Mainland China. There will be about 0.7 percent of electricity generated from the municipal solid waste treatment plant, which has the capacity to treat 3,000 tonnes of waste per day and can generate 480 million kilowatt-hours (kWh) per year.[14]

  Hong Kong's current contract with Daya Bay terminates in 2034. Daya Bay nuclear plant started operation in 1993, and its life will be 40 to 60 years. There will be tests of the plant at the 30-year mark in 2023 to see whether it can run for 40, 50, or 60 years. Also, consideration of market conditions will decide whether to extend the contract past 2034. Because of the uncertainty—in particular, plant life span, site availability, safety, and public acceptance—this study maintains the nuclear share of generation as 25 percent.

The remaining generation portion, about 34 percent, should be powered by natural gas with CCS, an emerging technology. CCS has been deployed in multiple countries, such as China, Japan, the United States, and Canada, over the last 20 years. The cost of CCS in power plant is about US$40/tonne of CO_2. This might be important to keep essential services running—in particular, hospitals, the airport, and the water supply.

- **Town planning:** The *Long-Term Housing Strategy Annual Progress Report 2018 (LTHS)* was released in December 2018 (Transport and Housing Bureau 2019). The LTHS study produced Hong Kong's long-term housing demand projection. The government estimates that, between 2016 and 2046, total housing demand will be about 1 million. This study assumes that in 2050, 60 percent of residents will live in public housing while 40 percent will live in private houses.

- **Transportation:** The continuous growth of private vehicle ownership is a major factor contributing to air pollution, GHG emissions, and traffic congestion. The government tackled the importance of private vehicle fleet size control and appointed the Transport Advisory Committee to compile the report "Study of Road Traffic Congestion in Hong Kong." (Transport Advisory Committee 2014). Short-, medium-, and long-term measures for controlling the private vehicle fleet size have been recommended. This study adopts "EMFAC-HK Vehicle Emission v4.1 Calculation" by the Environmental Protection Department for providing the activity projection for vehicles between 2016 and 2041 (EPD 2019b). The number of private cars and motorcycles was projected to increase to 896,500 in 2041.

- **Energy efficiency:** The government still hasn't rolled out a clear long-term efficiency road map for buildings or vehicles. Therefore, this study references the International Energy Agency (IEA) research "Market Report Series: Energy Efficiency 2018" (IEA 2018) in determining the energy efficiency improvement parameter for the building and transportation sectors and adopted a revised efficiency rate after consultation with relevant stakeholders. For example, to calculate the building energy efficiency improvement rate for different energy use purposes, we used data recommended by the Hong Kong Green Building Council.

Table 1 | **Scenarios Setting in the Hong Kong EPS**

	Key Variables	Unit	2017	2050 Current Policy Scenario*	2050 Decarbonization Scenario
Social and Economic	Population [a]	Thousands	7,391	8,152	8,152
	GDP [b]	HK$ trillions	2,578	6,233	6,233
	GDP per capita	HK$/capita	359,374	687,434	687,434
Electricity	Electricity demand [c]	TWh	44	61	49
	- Share from coal [d]	%	45	0	0
	- Share from gas [d]	%	30	69.3	35 (with CCS), considering energy security and reliability
	- Share of local RE [d]	%	0.04	3.1	Additional renewable portfolio standard to increase the percentage to 4.
	- Share of waste-based energy [j]	%	0	0.7	1
	- Share from imported electricity from renewables and nuclear [d]	%	26	26.9	60, including 25 from nuclear remain, additional 35 RE import from Mainland China
	Electricity consumption per capita	KWh/capita	5953	7450	5950
Buildings	Population living in private homes [e]	%	55	40	40
	Population lived in public housing [e]	%	45	60	60
	Commercial building floor area [f]	Million m^2	47	54	54
	Energy demand per capita	MJ/capita	7609	7984	1. Additional energy efficiency improvement of new equipment in 2050: • Cooling and ventilation: 40%, • Lighting: 35% • Envelope: 30% • Appliance: 25% • Other components: 11% 2. Additional 100% of new equipment is electric in 2050 3. Retrofit existing buildings rate in 2050: • Commercial: 48% • Residential public: 48% • Residential private: 48%
	Energy demand per unit of floor area	MJ/m^2	2648	2867	2867
	Share of electricity in total energy consumption in buildings [h]	%	80	86	100
Transportation [i]	**LDVs, passenger**	Vehicle fleet	575,004	830,586	1. Electric Vehicle Sales Mandate: • EV contributes to 50% of new vehicle sales by 2025, 100% from 2030 for buses and taxis • EV contributes to 50% of new vehicle sales by 2030, 100% from 2040 for passenger and freight LDVs 2. Fuel economy standard • Additional 30% improvement in 2050 for all types of vehicles
	Gasoline vehicle	%	94%	30%	
	LPG	%	2.7%	0.05%	
	Diesel vehicle	%	1.8%	2.2%	
	Battery electric vehicle	%	1.6%	60%	
	Plug-in hybrid vehicle	%	0.02%	7%	
	Natural gas vehicle	%	0.004%	0.1%	
	Hydrogen	%	0%	0%	
	Buses	Vehicle fleet	21,131	21,090	
	Diesel vehicle	%	80%	2.7%	
	LPG	%	19.8%	0.01%	
	Battery electric vehicle	%	0.2%	84%	
	Natural gas vehicle	%	0%	9%	
	Plug-in hybrid vehicle	%	0%	3.1%	
	Gasoline vehicle	%	0%	0%	

Table 1 | **Scenarios Setting in the Hong Kong EPS (Continued)**

	Key Variables	Unit	2017	2050 Current Policy Scenario*	2050 Decarbonization Scenario
Transportation[i]	Hydrogen	%	0%	0%	1. Electric Vehicle Sales Mandate: • EV contributes to 50% of new vehicle sales by 2025, 100% from 2030 for buses and taxis • EV contributes to 50% of new vehicle sales by 2030, 100% from 2040 for passenger and freight LDVs 2. Fuel economy standard • Additional 30% improvement in 2050 for all types of vehicles
	Taxis	Vehicle fleet	53764	53872	
	LPG	%	99.95%	4.5%	
	Gasoline vehicle	%	0.05%	0%	
	Battery electric vehicle	%	0%	94%	
	Plug-in hybrid vehicle	%	0%	0.8%	
	Natural gas vehicle	%	0%	0%	
	Diesel vehicle	%	0%	0%	
	Hydrogen	%	0%	0%	
	LDVs, freight	Vehicle fleet	71469	83882	
	Diesel vehicle	%	97%	3.4%	
	Gasoline vehicle	%	2.9%	0.2%	
	Battery electric vehicle	%	0.1%	88.2%	
	Natural gas vehicle	%	0.004%	0.05%	
	Plug-in hybrid vehicle	%	0.01%	8.1%	
	LPG	%	0%	0%	
	Hydrogen	%	0%	0%	
	HDVs, freight	Vehicle fleet	44111	51109	
	Diesel vehicle	%	99.1%	83.9%	
	LPG	%	0.4%	0.6%	
	Gasoline vehicle	%	0.2%	0.1%	
	Battery electric vehicle	%	0.2%	0%	
	Natural gas vehicle	%	0.2%	11.7%	
	Plug-in hybrid vehicle	%	0.002%	3.8%	
	Hydrogen	%	0%	0%	
	Motorcycle	Vehicle fleet	77200	77334	
	Gasoline vehicle	%	99.9%	54.1%	
	Battery electric vehicle	%	0.1%	45.9%	
	Natural gas vehicle	%	0%	0%	
	Diesel vehicle	%	0%	0%	
	Plug-in hybrid vehicle	%	0%	0%	
	LPG	%	0%	0%	
	Hydrogen	%	0%	0%	
Cross-Sector	CCS	%	0	0	99% of emissions from industry and power sector will be captured and stored through CCS technology, starting from 2030.

Note 2: * Numbers are for 2050, linear growth from 2017 unless explanation provided
Some percentage numbers may not add up to 100 due to rounding. Industry-related data are not shown in the table because they only account for a very small portion of total emissions in Hong Kong. [a] Hong Kong Census and Statistics Department. [b] Treasury Branch, Financial Services, and the Treasury Bureau. [c] EPS Hong Kong output, based on electricity demand from end-use sectors including buildings, transportation, and industry. [d] 2017 data are from EMSD; 2020 data are from *Hong Kong 2030+* report; 2030 and 2050 data are assumptions. [e] 2017 data are from Housing in Figures 2017 (Transport and Housing Bureau 2017). Other years' data are assumptions based on trends and consultation with local stakeholders. [f] 2017 data are estimates based on the internal floor area figures in RVD's Hong Kong Property Review series, assuming an internal floor area or gross floor area conversion factor of 0.75. Other years' data are assumptions based on population. [g] 2017 data are calculated based on population and energy consumption data from EMSD (2017). Other years' data are forecast based on trends, local stakeholder consultation, and reference to other cities. [h] Not input data but calculated from input data. [i] Data for 2017 vehicle fleet by vehicle type are from statistics (Transport Department 2019), and other years' data are assumptions. [j] There is a waste-to-energy power plant under construction, which will be in operation in 2024. The designed capacity is 3,000 tonnes of municipal solid waste per day, according to the EPD.

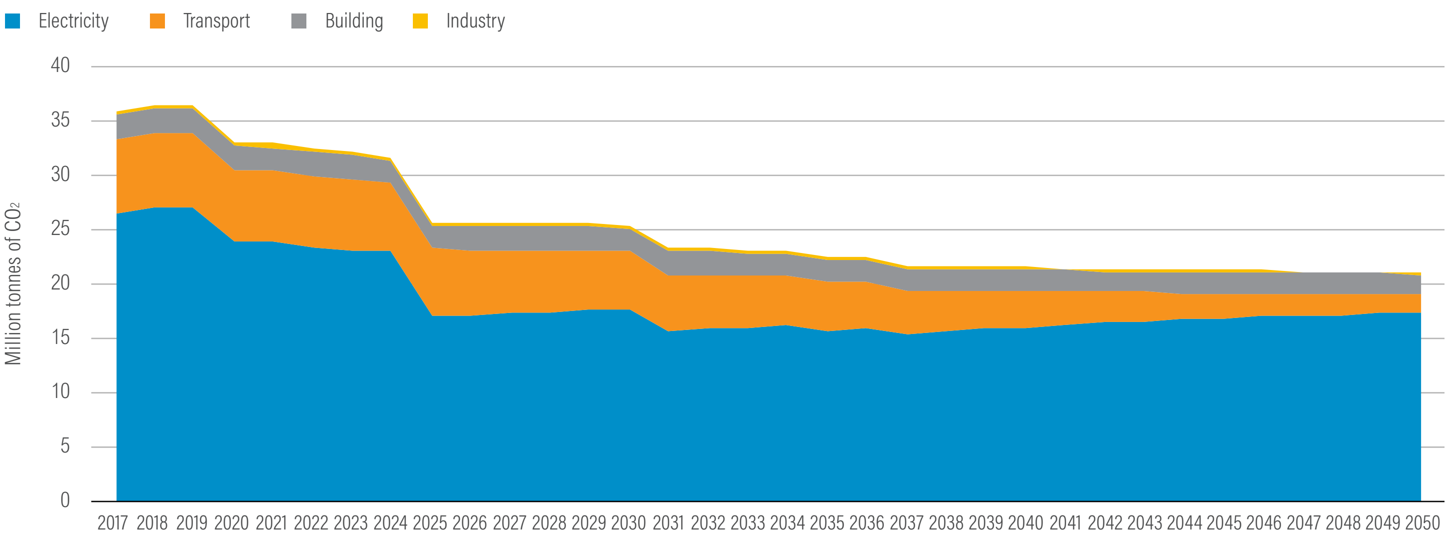
Sources: Hong Kong Census and Statistics Department; Treasury Branch, Financial Services, and the Treasury Bureau; *Hong Kong 2030+* report; Transport and Housing Bureau 2017; EMSD 2017; and Transport Department 2019.

Results of the Current Policy Scenario

- Overview

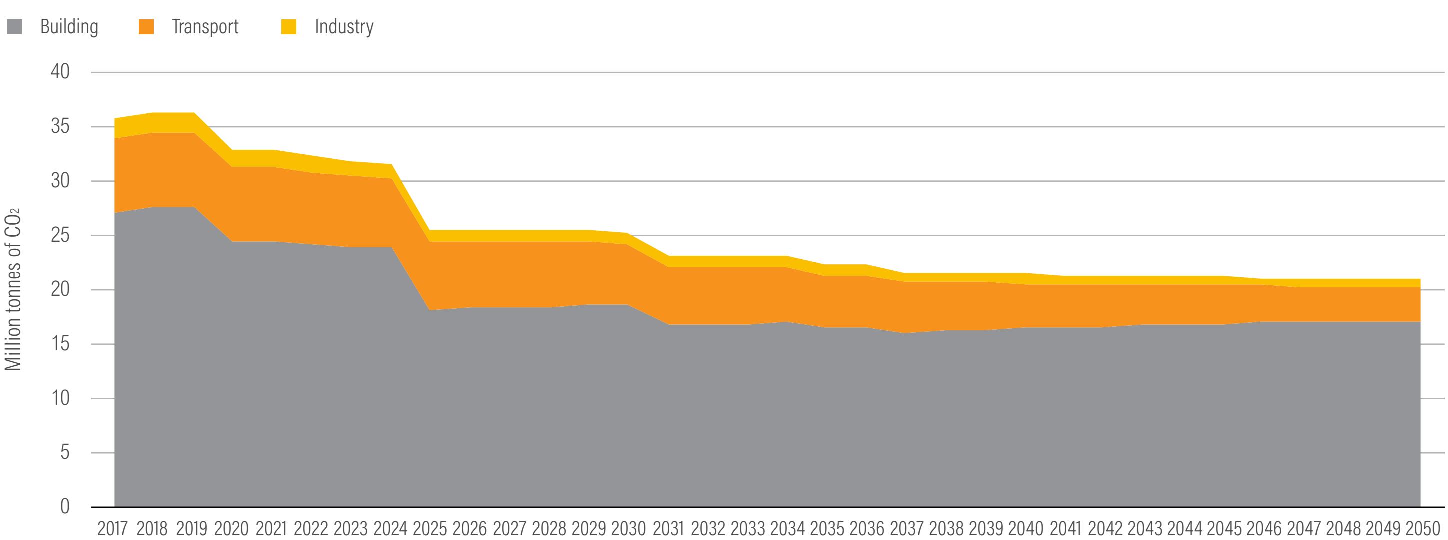
Under the Current Policy Scenario, the Hong Kong EPS results show that, in 2017, total energy-related CO_2 emissions were 36 million tonnes. By 2050, emissions are projected to decrease to 22.5 million. Figure 2 shows direct emissions for which electricity generation is the largest contributor. Figure 3 shows emissions from a consumption perspective, in which the building sector is the largest contributor. This is due to the large amount of cooling demanded in buildings, the energy for which is provided by electricity. In Hong Kong's case, the net import of electricity is set to only include nuclear and renewable energy; therefore, there are no emissions related to imported electricity, and production-based emissions and consumption-based emissions are the same.

Figure 2 | **Energy-Related CO_2 Emissions by Sector in the Current Policy Scenario**



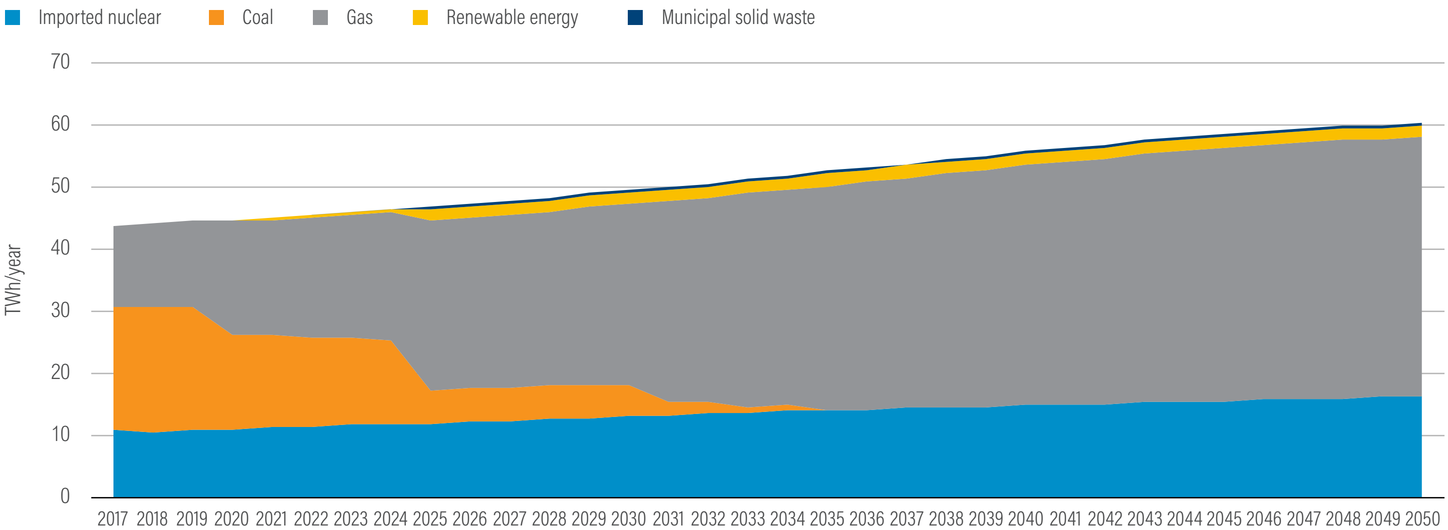
Note: These are production-based emissions, or scope 1 emissions.
Source: Hong Kong EPS.

Figure 3 | **Energy-Related CO_2 Emissions by Sector with Reallocated Electricity Emissions in the Current Policy Scenario**



Note: These are consumption-based emissions, or scope 1 and scope 2 emissions in the building, transportation, and industry sectors.
Source: Hong Kong EPS.

Figure 4 | **Electricity Demand by Sources in the Current Policy Scenario**



Source: Hong Kong EPS.

- Electricity

Under the Current Policy Scenario, Hong Kong will maintain 25 percent of total electricity use from nuclear electricity imported from Mainland China. Coal power will be gradually phased out by 2038, and natural gas will contribute to about 69 percent of electricity generation in 2050. Only limited electricity will come from renewable energy (3 percent) and municipal solid waste (0.7 percent), as shown in Figure 4.

Comparisons of the Hong Kong EPS Current Policy Scenario to Other Similar Scenarios

In this section, we compare the outputs from the Hong Kong EPS's Current Policy Scenario to equivalent outputs from the projections of other studies. Depending on the quality of the documentation of assumptions and calculations used in other projections, it is sometimes possible for us to identify why our own projection is lower or higher than that of other projections. In these instances, we include notes of possible reasons for differences.

This note includes the following other projections or current status studies:

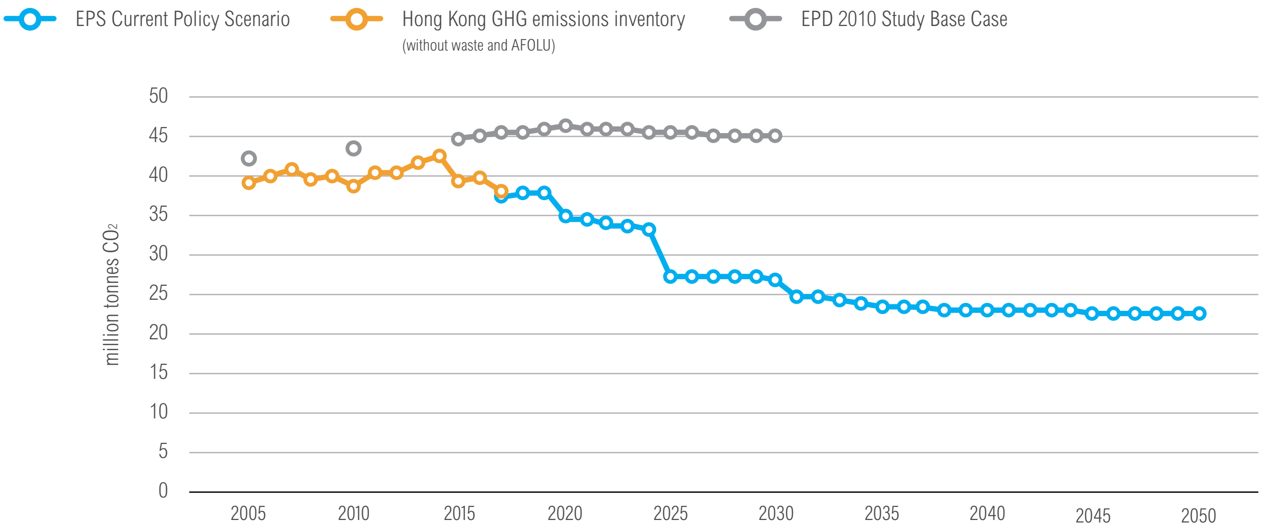
- Environment Protection Department (EPD) 2010 study: "A Study of Climate Change in Hong Kong—Feasibility Study" (EPD 2010), conducted by Environmental Resources Management in 2010 for EPD. This study uses 2005 as the base year and forecast emissions for 2030. http://www.deltacityofthefuture.com/documents/study_of_climate_change_HK.pdf

- World Wildlife Fund (WWF) study: "Energy Vision for HK 2050," conducted by WWF in 2015 (WWF 2015). This study analyzes Hong Kong's energy projection to 2050. https://www.wwf.org.hk/en/?13120

- "Hong Kong Greenhouse Gas Emission Inventories, 1990–2017," released by EPD in 2019 (EPD 2019a). This contains the official data on Hong Kong's historical GHG emissions. https://www.climateready.gov.hk/page.php?id=23&lang=1

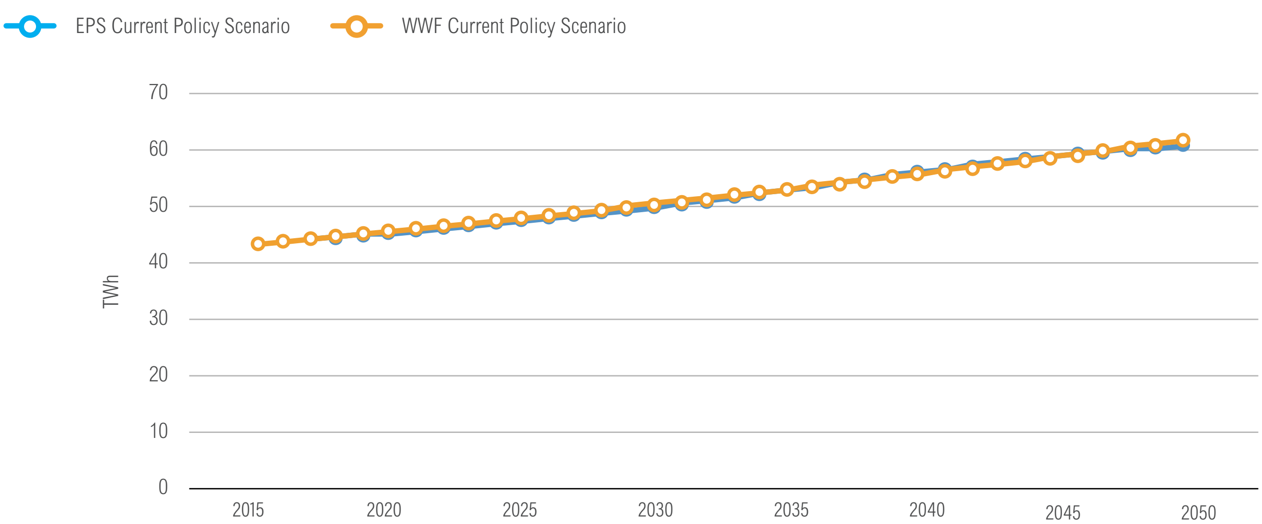
Figure 5 shows the comparison of total GHG gas emissions from the EPS, Hong Kong GHG emissions inventory, and EPD 2010 study. The Hong Kong EPS 2017 emissions are nearly identical to the 2017 emissions from Hong Kong's official GHG emissions inventories. The former was 37.54 million tonnes of CO_2 while the latter was 37.85 million tonnes of CO_2 (only includes energy- and industrial processes - related emissions). The Hong Kong EPS projection is much lower than the EPD study conducted in 2010. The reason is that the EPD 2010 study was conducted nearly 10 years ago and used some assumptions that are out of

Figure 5 | **Comparison of Total Greenhouse Gas Emissions**



Sources: Hong Kong EPS, EPD 2010, and EPD 2019.

Figure 6 | **Comparison of Total Electricity Demand**



Sources: Hong Kong EPS; WWF 2015.

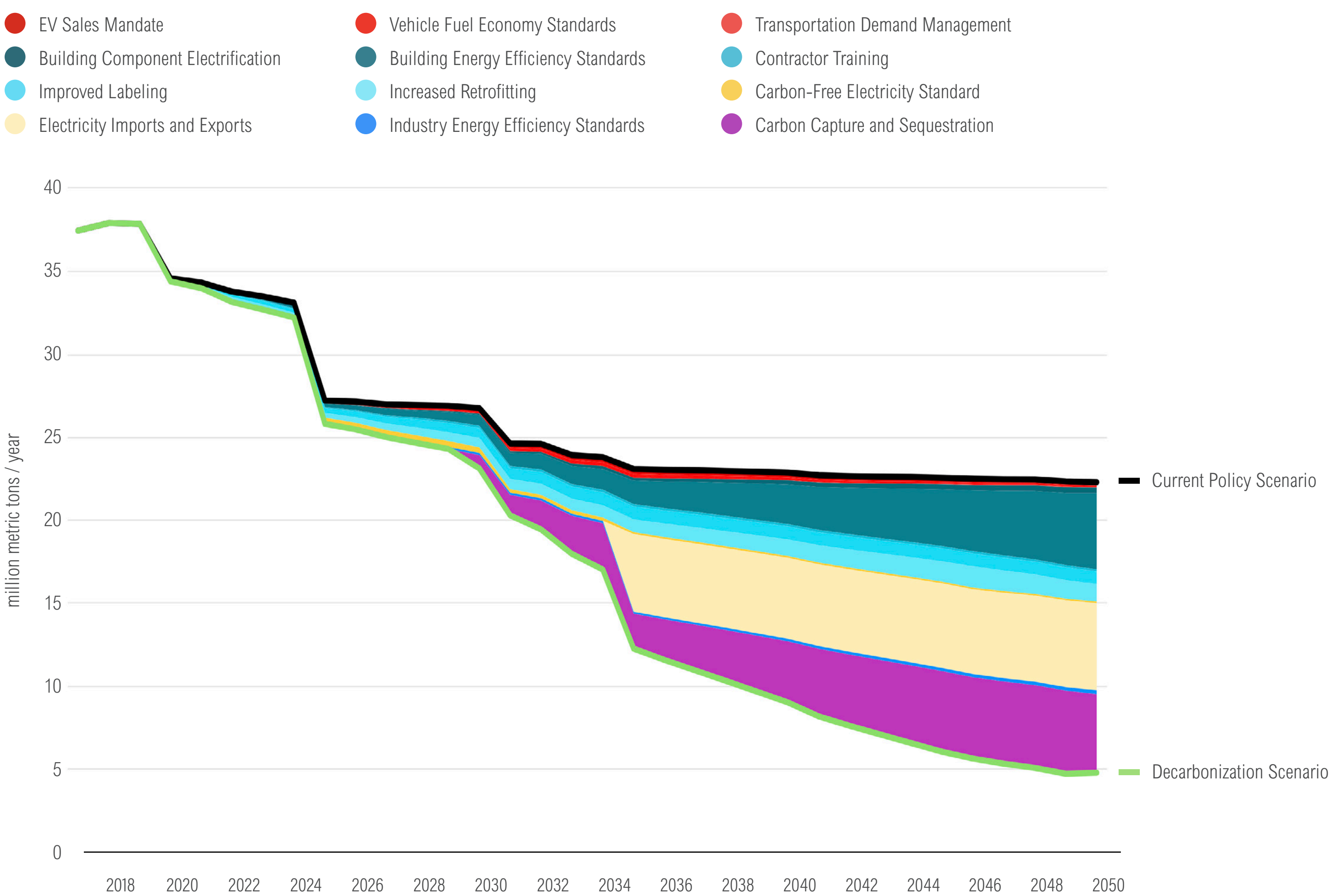
date. The EPD 2010 study didn't reflect the most up-to-date policies, such as switching from coal to gas in the power generation sector, which was announced in 2017. There was a downward trend in Hong Kong's emissions since 2014 in actuality, but the EPD 2010 study didn't reflect this change. In addition, the EPD 2010 study used 2005 as the base year and did forecasting for 2030. The population used in this study for 2030 was 8.3 million people , while the Hong Kong EPS used 8.0 million people for 2030, the more up-to-date data from the Census and Statistics Bureau.

Figure 6 shows total electricity demand projections from the Hong Kong EPS and WWF. The two studies' results are quite similar, despite differing methodologies. WWF used a top-down approach in which the base year (2015) demand was 43 terawatt-hours (TWh). Demand increases 1.5 percent annually between 2016 and 2025, 0.9 percent annually between 2026 and 2040, and 0.3 percent annually between 2041 and 2050. The Hong Kong EPS uses a bottom-up approach where electricity demand is determined by input data choices and model calculations in the building, transportation, and industry sectors. Electricity demand from these sectors is determined by factors such as population and economic growth, newly built commercial and residential buildings, electrification in building appliances, and electric vehicle (EV) sales share. The Hong Kong EPS result also reflects factors contributing to reduced electricity demand, chiefly from energy-efficiency improvements.

Comparisons of the Hong Kong EPS Current Policy Scenario with the Decarbonization Scenario

Under the Decarbonization Scenario, Hong Kong's CO_2 emissions in 2050 decrease to around 5 million tonnes, much lower than the 23 million tonnes in the Current Policy Scenario. The policies that have the most impact are increased retrofitting, building energy-efficiency standards, carbon capture and storage, increased imported nuclear and renewable energy electricity, renewable portfolio standards, and an EV sales mandate (as shown in Figure 7). Detailed analysis and policy recommendations will be included in a forthcoming policy report.

Figure 7 | **Effects by Policy**



Source: Hong Kong EPS.

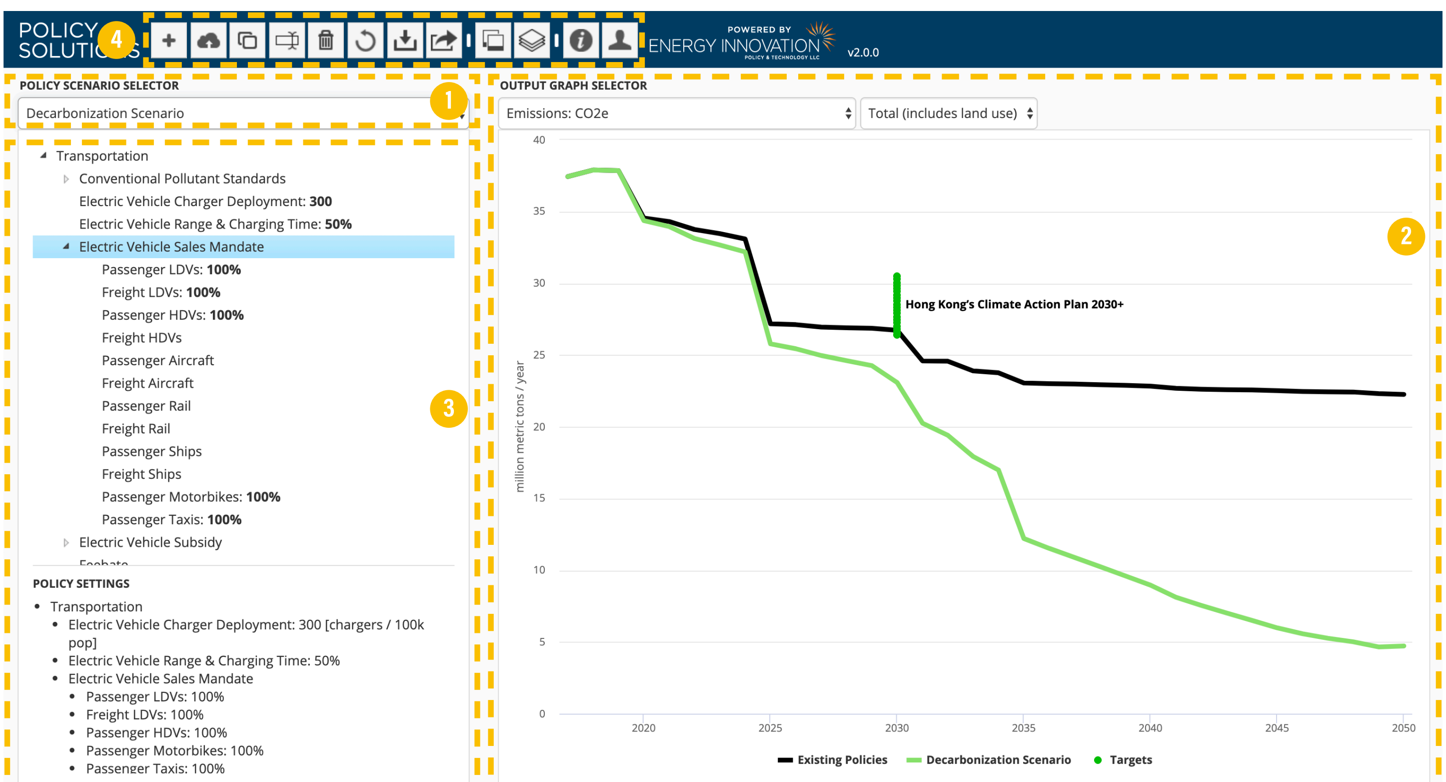
ONLINE HONG KONG ENERGY POLICY SIMULATOR

The Hong Kong EPS can be accessed through the webpage hongkong.energypolicy.solutions. Users can choose an included scenario to view the results (area 1 in Figure 8). Users can check 128 charts showing various results (area 2 in Figure 8), such as electricity generation, building energy consumption, vehicle fleet, emissions, and policy effects under different scenarios. For some parameters such as total emissions, human health and social benefits, policy effects, and emission reductions, users can compare results among scenarios. Users can view policy settings under all policy scenarios (area 3 in Figure 8), such as share of imported electricity or EV sales mandate.

In addition to visualizing the results of included scenarios, users also can create their own scenarios through functions in area 4 shown in Figure 8. The functions include starting a new scenario, saving the scenario, saving the scenario with a new name, renaming the scenario, deleting the scenario, reverting to the saved scenario, downloading graph data policy settings, sharing the scenario by e-mail, toggling one or two charts, selecting scenario and target comparisons, viewing the online guide, and creating one's own account. Users can save the new scenario in that personal account and share with others by e-mail. When creating scenarios, users are running the model in real time on the server.

For more details, a series of four videos providing a helpful walk-through of how to use the simulator can be found at https://us.energypolicy.solutions/docs/video-series.html.

Figure 8 | **The Hong Kong EPS Website Interface**



Source: Hong Kong EPS.

LIMITATIONS

To create a computer model that is less complex than the real world, it is necessary to make assumptions and simplifications. Similarly, model capabilities and results may be affected by limitations in the available data.

Two types of assumptions underlie the Hong Kong EPS: structural assumptions common to all versions of the EPS and Hong Kong - specific assumptions that relate to input data. Structural assumptions are described in detail in the EPS's online documentation at https://us.energypolicy.solutions/docs/assumptions.html and https://us.energypolicy.solutions/docs/how-the-eps-avoids-double-counting.html.

Limitations common to all EPS models are included here:

- **Uncertainty is greater with larger numbers of policies or tougher policies**. Input values in the EPS must be studied, measured, or simulated under a particular set of conditions or assumptions. These conditions cannot reflect all possible combinations of policy settings that a user might select in the EPS. Generally, the model's Current Policy Scenario is likely to be closest to the conditions reflected by the input data. Therefore, the uncertainty of policy effects is likely smallest when a small number of policies are used and enabled policies are set at low values. Uncertainty increases as the policy package includes a greater number of policies and the settings of those policies become more extreme.
- **Characterizing uncertainty is not numerically possible**. Uncertainty bounds were not available for input data; therefore, uncertainty bounds are not available on output data. As an alternative, the EPS model supports Monte Carlo analysis, which can highlight the sensitivity of the model results to changes in any particular input or set of inputs.
- **Several techniques are used to avoid double-counting policy effects, and these techniques involve trade-offs**. Pricing policies (and other price effects) alter the demand for goods or services and alter the decisions of consumers looking to buy new equipment; however, they cannot holistically account for all possible responses that individuals and businesses may have without duplicating certain responses already governed by other policy levers. Other policy levers' effects must be additive to pricing effects or provide a floor or ceiling governing the underlying effects.
- **We assume that all the current policies will continue**. There are possibilities that the trajectory of the current policy will change if there is any economic shock or major change to the government policy.

Hong Kong - specific limitations are as follows:

- **In Hong Kong, not all data needed are available**. For example, certain elasticities of demand for services with respect to price have not been studied in Hong Kong. When data from Hong Kong for a variable are completely unavailable, foreign data have been scaled or adapted to fit Hong Kong, thus producing inaccuracy. All data are meticulously cited and included with the downloadable version of the model, allowing model users to update the data and test new assumptions if desired.
- **We decided to exclude some sectors due to their very limited impact**. Agriculture, forestry and other land-use sectors account for only 0.1 percent of Hong Kong's emissions. Very little data exist on these sectors, and the potential for any policy is extremely limited due to the small land area of Hong Kong. Therefore, we decided not to include these sectors in the model.
- **Inconsistency of underlying assumptions**. This study sources assumptions and projections from various sources, including other studies or plans, expert judgment, and stakeholder feedback. These sources are likely to have inconsistent underlying assumptions, either explicitly or implicitly.
- **Some sectoral aggregation is required for industry**. One such example is that while industry is the major emissions contributor in many places of the world, Hong Kong's industry emissions only account for 7 percent. In the EPS, the embedded subsectors include the traditionally energy-intensive industries like cement, natural gas and petroleum, iron and steel, chemicals, and mining while there are no such industries in Hong Kong except textile and apparel, non-manufacturing[15] food and beverage, metal and machinery, and some other industries. We, instead, included all the sectors added together in the EPS category "other industries."

FUTURE DEVELOPMENT

At present, the Hong Kong EPS contains a Current Policies Scenario and one example policy scenario, the Decarbonization Scenario, in which strong policies are implemented starting in 2018 aiming to achieve deep decarbonization by 2050.

In a future stage of this project, we could conduct further analysis, such as creating a net zero scenario in which hydrogen and carbon taxes will be needed so that Hong Kong's emissions can reach zero in 2050. Parallel calculations can be conducted to analyze the different impact of policies, for example, by testing different proportions of electricity generation sources and different energy-efficiency improvement rates in buildings and transportation, using a downloadable model that benefits from the fact that the model is open-sourced and publicly accessible. Also, scenarios with different GDP and population assumptions or combined model outputs with sector-specific models can be created. This could allow the analysis of more complex possibilities and comparison of the costs versus the benefits among different pathway options. The tool may also be updated and revised to use different or additional data sources. It could potentially be used to help determine the stringency of a 2050 target and subsequently analyze the implications of different policy pathways for achieving that target to contribute to the Paris Agreement goals.

Some functions in the EPS are not currently used but may be added in the future. For example, the district heating module could be adapted into a district cooling module, thus estimating relevant policy effects. Being a very hot place, Hong Kong does not need district heating. However, the Hong Kong government has recently started to promote district cooling as an alternative to conventional air conditioning. The prospects of this nascent technology are still relatively uncertain; however, it could be interesting to include it in the EPS. For now, we leave it as an option for future improvement.

APPENDIX. DATA SOURCES FOR VARIABLES IN THE HONG KONG EPS

Table A-1 presents the data source, including all the variables. Information includes the meaning, the importance to update for a new region, whether it is a Hong Kong - specific value, and the specific data source for each variable.

The importance ratings column indicates the importance of updating the variable when adapting the model to a new region–in our case to Hong Kong. Variables are rated "very high," "high," "medium," "low," or "n/a" in importance, explained as follows:

- The very high and high importance variables are the ones that have a significant effect on the results of the output of the model or ones that will likely vary significantly from region to region. Not using regional-specific data will likely result in inaccurate modeling results.
- The medium importance variables are those likely to vary among regions, but are still likely to generate reasonable results. Examples for those include elasticities.
- Low importance variables are those that are unlikely to vary greatly among regions; for example, global warming potential values or lifetime estimates for a given type of power plant.
- Certain variables are determined via calibration and are dependent on other data variables in the model. Variables designated "n/a" are constants that do not need to be updated.

Table A-1 | **Data Sources for Variables in the Hong Kong EPS**

Section	Abbrev	Meaning	Importance to Update for New Region	Hong Kong-Specific Values?	Data Source
Additional Outputs	SCoC	Social Cost of Carbon	low	No	Interagency Working Group on Social Cost of Carbon, U.S. Government
Additional Outputs	SCoHIbP	Social Cost of Health Impacts by Pollutant	medium	No	U.S. Environmental Protection Agency
Additional Outputs	VoaSL	Value of a Statistical Life	medium	No	China data from World Bank
Buildings & Appliances	BASoBC	BAU Amount Spent on Building Components	high	No	U.S. Energy Information Administration; Census and Statistics Department (CSD)
Buildings & Appliances	BCEU	BAU Components Energy Use	very high	Yes	EMSD; CSD; HK Development Bureau, HK Planning Department
Buildings & Appliances	BDEQ	BAU Distributed Electricity Quantities	high	Yes	None in HK
Buildings & Appliances	BFoCSbQL	BAU Fraction of Components Sold by Quality Level	medium	No	Data from China EPS model
Buildings & Appliances	BRESaC	Building Retrofitting Energy Savings and Costs	medium	No	LBNL; Building Energy Exchange, PNNL, U.S. Energy Information Administration
Buildings & Appliances	CL	Component Lifetime	low	No	data from US and China model, sources from ERI, U.S. Department of Housing and Urban Development, State of California
Buildings & Appliances	CpUDSC	Cost per Unit Distributed Solar Capacity	low	No	Yantao et al. (2016)
Buildings & Appliances	DSCF	Distributed Solar Capacity Factor	medium	No	Yantao et al. (2016)
Buildings & Appliances	ECiCpCU	Embedded Carbon in Components per Currency Unit	low	No	Resources for the Future, a U.S. nonprofit
Buildings & Appliances	EoBSDwEC	Elasticity of Building Service Demand with Regard to Energy Cost	medium	No	U.S. Energy Information Administration
Buildings & Appliances	EoCEDwEC	Elasticity of Component Energy Demand with Regard to Energy Cost	medium	No	U.S. Energy Information Administration
Buildings & Appliances	EoCPwEU	Elasticity of Component Price with Regard to Energy Use	low	No	U.S. Department of Energy
Buildings & Appliances	EoDSDwSP	Elasticity of Distributed Solar Deployment with Regard to Subsidy Percentage	medium	No	Bloomberg New Energy Finance
Buildings & Appliances	FoBObE	Fraction of Buildings Owned by Entity	medium	No	data from China EPS model, source from ERI
Buildings & Appliances	MSCdtRPbQL	Market Share Changes Due to Rebate Program by Quality Level	medium	No	U.S. academic working paper
Buildings & Appliances	PCFURfE	Percentage Components Fuel Use Reduction for Electricity	low	No	U.S. Department of Energy
Buildings & Appliances	PEUDfSbQL	Percentage Energy Use Difference from Standard by Quality Level	medium	No	data from China EPS model, source from ERI
Buildings & Appliances	PPEIdtICEaT	Potential Percentage Efficiency Improvement due to Improved Contractor Edu and Training	low	No	American Council for an Energy-Efficient Economy
Buildings & Appliances	PPEIdtIL	Potential Percentage Efficiency Improvement due to Improved Labeling	low	No	Lawrence Berkeley National Laboratory

Table A-1 | **Data Sources for Variables in the Hong Kong EPS (Continued)**

Section	Abbrev	Meaning	Importance to Update for New Region	Hong Kong-Specific Values?	Data Source
Buildings & Appliances	SoCEUtiNTY	Share of Components Energy Use That Is New This Year	to be determined via calibration	No	U.S. Energy Information Administration
Carbon Capture and Storage	CC	CCS Costs	low	No	Massachusetts Institute of Technology
Carbon Capture and Storage	CPbE	CCS Percentages by Entity	medium	No	Partly NCSC SACC model, partly International Energy Agency
Carbon Capture and Storage	CSA	Carbon Sequestration Amounts	high	Yes	Feasibility Study of CCS-Readiness in Guangdong Province (GDCCSR)
Cost Outputs	CFQS	Cash Flow Quantization Size	n/a (only adjust if needed to dampen rounding error in near-zero changes in cash flows)	No	n/a
Cost Outputs	DR	Discount Rate	low	No	Interagency Working Group on Social Cost of Carbon, U.S. Government
District Heating	BFoHfC	BAU Fraction of Heat from CHP	high	Yes	no heating in Hong Kong
District Heating	BFoHPbF	BAU Fraction of Heat Provided by Fuel	high	Yes	no heating in Hong Kong
District Heating	EoCtUH	Efficiency of Conversion to Usable Heat	low	No	International Energy Agency
District Heating	RHFF	Recipient Heat Fuel Fractions	optional		
Electricity Supply	ARpUIiRC	Annual Retirement per Unit Increase in Relative Cost	to be determined via calibration	No	Resources for the Future
Electricity Supply	BCpUC	Battery Cost per Unit Capacity	low	No	Partly Rocky Mountain Institute and Sandia National Laboratory
Electricity Supply	BCRbQ	BAU Capacity Retirements before Quantization	high	Yes	HK Electric & CLP
Electricity Supply	BDPbES	BAU Dispatch Priority by Electricity Source	high (only if applicable to new country)		n/a
Electricity Supply	BDSBaPCF	Boolean Do Suppliers Bid at Peak Capacity Factors	low	No	n/a
Electricity Supply	BECF	BAU Expected Capacity Factors	medium		Matched to historic generation and Climate Action Plan 2030+
Electricity Supply	BGCL	BAU Generation Capacity Lifetime	low	No	National Renewable Energy Laboratory, EIA
Electricity Supply	BGDPbES	BAU Guaranteed Dispatch Percentage by Electricity Source	high (only if applicable to new country)	No	China Electricity Council

Table A-1 | **Data Sources for Variables in the Hong Kong EPS (Continued)**

Section	Abbrev	Meaning	Importance to Update for New Region	Hong Kong-Specific Values?	Data Source
Electricity Supply	BGrBSC	BAU Grid Battery Storage Capacity	high	Yes	None in HK
Electricity Supply	BHRbEF	BAU Heat Rate by Electricity Fuel	medium	Yes	CLP, U.S. Energy Information Administration
Electricity Supply	BPaFF	Boolean Peaking and Flexibility Flags	high	Yes	n/a
Electricity Supply	BPHC	BAU Pumped Hydro Capacity	high	Yes	HK Water Supplies Department
Electricity Supply	BPMCCS	BAU Policy Mandated Capacity Construction Schedule	high (only if applicable to new country)	Yes	HK Electric & CLP
Electricity Supply	BRPSPTY	BAU RPS Percentage This Year	high	Yes	no RPS in Hong Kong currently
Electricity Supply	BTaDLP	BAU Transmission and Distribution Loss Percentage	high	Yes	HK Electric & CLP, HK Census and Statistics Department
Electricity Supply	BTC	BAU Transmission Capacity	high	No	Scaled from U.S. model
Electricity Supply	CCaMC	Capacity Construction and Maintenance Costs	medium	No	National Renewable Energy Lab, U.S. Energy Information Administration, IRENA, World Energy Council
Electricity Supply	DCpUC	Decommissioning Cost per Unit Capacity	Low	No	Resources for the Future, Callan Institute, California Energy Commission
Electricity Supply	DPbES	Dispatch Priority by Electricity Source	n/a (policy lever)		n/a
Electricity Supply	DRC	Demand Response Capacities	high	No	Scaled from U.S. model
Electricity Supply	DRCo	Demand Response Costs	low	No	U.S. Energy Information Administration
Electricity Supply	ElaE	Electricity Imports and Exports	high	Yes	HK Census and Statistics Department
Electricity Supply	FoOMCtiL	Fraction of O&M Costs That Is Labor	medium	No	U.S Environmental Protection Agency
Electricity Supply	FoTCAMRBtPF	Fraction of Transmission Capacity Across Modeled Region Border That Provides Flexibility	low	No	U.S. Energy Policy Simulator
Electricity Supply	FPC	Flexibility Point Calculations	low, except medium for BAU Transmission Connectivity Coefficient	No	U.S. National Laboratories, U.S. Western Electricity Coordinating Council, Energy + Environmental Economics (U.S. firm)
Electricity Supply	FPCbS	Flexibility Points Consumed by Source	low	No	n/a
Electricity Supply	GDPbES	Guaranteed Dispatch Percentage by Electricity Source	n/a (policy lever)	No	n/a
Electricity Supply	MCGLT	Maximum Capacity Growth Lookup Table	very high	Yes	HK Electric & CLP
Electricity Supply	MPCbS	Max Potential Capacity by Source	high	Yes	HK Electric & CLP
Electricity Supply	MPPC	Minimum Power Plant Capacity	low	No	U.S. Energy Information Administration

Table A-1 | **Data Sources for Variables in the Hong Kong EPS (Continued)**

Section	Abbrev	Meaning	Importance to Update for New Region	Hong Kong-Specific Values?	Data Source
Electricity Supply	NGEpUO	Nonfuel GHG Emissions per Unit Output	medium	No	U.S. National Renewable Energy Laboratory; Warner and Heath (2012)
Electricity Supply	NSDoDC	Normalized Standard Deviation of Dispatch Costs	low	No	U.S. Energy Information Administration, International Energy Agency
Electricity Supply	NSDoNCC	Normalized Standard Deviation of New Capital Costs	low	No	U.S. Congressional Research Service, U.S. National Renewable Energy Laboratory, Energy & Environmental Economics
Electricity Supply	PMCCS	Policy Mandated Capacity Construction Schedule	n/a (policy lever)	Yes	None in HK
Electricity Supply	PTCF	Peak Time Capacity Factors	high	Yes	HK Environmental Bureau, Hong Kong Engineer
Electricity Supply	RM	Reserve Margin	low	No	Lawrence Berkeley National Laboratory
Electricity Supply	RQSD	RPS-Qualifying Source Definitions	medium (n/a for RPS qualifying sources, as it is a policy lever)	No	China 13th Five-Year Plan for energy
Electricity Supply	SLF	System Load Factor	medium	No	U.S. Energy Information Administration
Electricity Supply	SYC	Start Year Capacities	very high	Yes	HK Electric & CLP
Electricity Supply	TCAMRB	Transmission Capacity across Modeled Region Border	high	Yes	China Electricity Council
Electricity Supply	TCCpUCD	Transmission Construction Cost per Unit Capacity Distance	medium	No	National Renewable Energy Laboratory
Electricity Supply	WUbPPT	Water Use by Power Plant Type	optional	No	Joint Global Change Research Institute; Pacific Northwest National Laboratory
Endogenous Learning	BCbVT	Battery Capacity by Vehicle Type	low	No	IRENA, CleanTechnica, Electrek, Battery University, Wikipedia
Endogenous Learning	BCSG	BAU CO_2 Sequestered Globally	low	No	IEA
Endogenous Learning	BGBSC	BAU Global Battery Storage Capacity	low	No	Bloomberg
Endogenous Learning	BGSaWC	BAU Global Solar and Wind Capacities	low	No	IEA
Endogenous Learning	GBEtPR	Grid Battery Energy to Power Ratio	low	No	Bloomberg
Endogenous Learning	PDiBCpDoC	Percentage Decline in Battery Cost per Doubling of Capacity	low	No	Bloomberg
Endogenous Learning	PDiCCpDoC	Percentage Decline in Capacity Cost per Doubling of Capacity	low	No	Bloomberg; Rubin et al. (2015)
Endogenous Learning	PDiCECpDoC	Percent Decline in CCS Equipment Cost per Doubling of Capacity	low	No	CRS
Endogenous Learning	SYSoCCtaSC	Start Year Shares of Capacity Costs that are Soft Costs	low	No	U.S. Department of Energy, NREL
Fuels	BFCpUEbS	BAU Fuel Cost per Unit Energy by Sector	high	Yes	HK Electric & CLP, EMSD

Table A-1 | **Data Sources for Variables in the Hong Kong EPS (Continued)**

Section	Abbrev	Meaning	Importance to Update for New Region	Hong Kong-Specific Values?	Data Source
Fuels	BFPIaE	BAU Fuel Production Imports and Exports	High	Yes	Hong Kong Energy Statistics 2017 annual report
Fuels	BS	BAU Subsidies	high	Yes	IMF, Census and Statistics Department
Fuels	BSoFPtiT	BAU Share of Fuel Price That Is Tax	high	Yes	Customs and Excise Department, various fuel providers
Fuels	EQS	Energy Quantization Size	n/a		n/a
Fuels	ETRbF	Export Tax Rate by Fuel	medium		None in Hong Kong
Fuels	GbPbT	GWP by Pollutant by Time Frame	low	No	IPCC
Fuels	IMFPbFT	International Market Fuel Price by Fuel Type	medium		Based on BFCpUEbS
Fuels	MPIiFE	Maximum Percentage Increase in Fuel Exports	optional		n/a (no cap, also not allowed as set in PoFDCtAE)
Fuels	MPIiFI	Maximum Percentage Increase in Fuel Imports	optional		n/a (no cap)
Fuels	MPIiFP	Maximum Percentage Increase in Fuel Production	optional		n/a (no cap)
Fuels	PEI	Pollutant Emissions Intensities	medium	No	Argonne National Laboratory, International Council on Clean Transportation, Japanese public journal article, Indonesian public journal article, and (for CO_2 emissions factors) NCSC calculations
Fuels	PEIIR	Pollutant Emissions Intensity Improvement Rate	Low	No	n/a (none assumed)
Fuels	PoFDCtAE	Percentage of Fuel Demand Change That Alters Exports	High	Yes	Hong Kong has few fuel exports
Hydrogen	BHPSbP	BAU Hydrogen Production Shares by Pathway	medium	No	Hong Kong has no existing plan for hydrogen
Hydrogen	EHPpUC	Electrolyzer Hydrogen Production per Unit Capacity	low	No	EPS-US
Hydrogen	HPEbP	Hydrogen Production Efficiency by Pathway	low	No	IEA, Acar and Dincer (2014)
Hydrogen	HPEC	Hydrogen Production Equipment Costs	low	No	IEA
Hydrogen	HPPECbP	Hydrogen Production Percent Excess Capacity by Pathway	low	No	EPS-US
Hydrogen	HPtFM	Hydrogen Pathway to Fuel Mappings	n/a	No	n/a
Hydrogen	RHPF	Recipient Hydrogen Pathway Fractions	n/a	No	n/a
Industry	BIFUbC	BAU Industrial Fuel Use before CCS	very high	Yes	EMSD
Industry	BPEiC	BAU Process Emissions in CO_2e	very high	Yes	Climate Ready Hong Kong
Industry	BPoIFUfE	BAU Proportion of Industrial Fuel Used for Energy	optional	Yes	IEA
Industry	BSoAIGtAP	BAU Share of Agriculture Industry Going to Animal Products	medium	Yes	No animal products

Table A-1 | **Data Sources for Variables in the Hong Kong EPS (Continued)**

Section	Abbrev	Meaning	Importance to Update for New Region	Hong Kong-Specific Values?	Data Source
Industry	CESTR	Capital Equipment Sales Tax Rate	medium	Yes	China State Administration of Taxation published regulation
Industry	CtIEPpUESoS	Cost to Implement Efficiency Policy per Unit Energy Saved or Shifted	low	No	NCSC calculations
Industry	EoP	Elasticities of Production	medium	No	Resources for the Future; Aswath (2014)
Industry	FLRbI	Foreign Leakage Rate by Industry	optional	No	n/a
Industry	FoISaGPbE	Fraction of Inputs Supplied and Goods Purchased by Entity	High	Yes	OECD
Industry	FoNEtVwP	Fraction of Nonenergy Expenditures That Vary with Production	medium	No	*The Wall Street Journal*, ArcelorMittal, World Steel Association, PriceWaterhouseCoopers, U.S. Bureau of Economic Analysis
Industry	MHV	Methane Heating Value	low	No	Engineering Toolbox
Industry	PERAC	Process Emissions Reductions and Costs	high, but included data source supports multiple countries, after taking data from industry/ BPEiC (do that variable first)	No	U.S. Environmental Protection Agency, European Cement Association, World Business Council for Sustainable Development
Industry	PIFURfE	Percentage Industry Fuel Use Reduction for Electricity	low	No	U.S. Department of Energy
Industry	PPRiFUfERoIF	Potential Percentage Reduction in Fuel Use from Early Retirement of Inefficient Facilities	medium	No	China Ministry of Industry and Information Technology, NCSC result, and published article in a journal
Industry	PPRiFUfICaWHR	Potential Percentage Reduction in Fuel Use from Increased Cogeneration and Waste Heat Recovery	medium	No	China Ministry of Industry and Information Technology
Industry	PPRiFUfIIaIoE	Potential Percent Reduction in Fuel Use from Improved Installation and Integration of Equipment	low	No	China Ministry of Industry and Information technology, NCSC result, and published article in a journal
Industry	RIFF	Recipient Industrial Fuel Fractions	low	No	NCSC staff judgment
Industry	RoPSoPBvOD	Ratio of People Supportable on Plant-Based vs Omnivorous Diet	Low	No	Shepon et al. (2018)
Industry	TNRbI	Total Nonfuel Revenue by Industry	High	Yes	HK Census and Statistical Department
Industry	WMITR	Worker Marginal Income Tax Rate	medium	No	KPMG International consulting firm
Transportation	AVL	Average Vehicle Lifetime	low	Yes	partly from EPD
Transportation	AVLo	Average Vehicle Loading	medium	No	U.S. Energy Policy Simulator

Table A-1 | **Data Sources for Variables in the Hong Kong EPS (Continued)**

Section	Abbrev	Meaning	Importance to Update for New Region	Hong Kong-Specific Values?	Data Source
Transportation	BAADTbVT	BAU Average Annual Distance Traveled by Vehicle Type	high	Yes	HK Transport Department, MTR, Star Ferry Limited, Cathay Pacific
Transportation	BCDTRtSY	BAU Cargo Distance Transported Relative to Start Year	high	Yes	Hong Kong Population Projections, Census and Statistics Department
Transportation	BESP	BAU EV Subsidy Percentage	high	Yes	Government of Hong Kong Special Administrative Region Environmental Protection Department
Transportation	BHNVFEAL	BAU Historical New Vehicle Fuel Economy after Lifetime	medium (relies on BNVFE)	No	BNVFE, BTFURfE, BPoEFUbVT, AVL
Transportation	BLP	BAU LCFS Percentage	high	Yes	None in HK
Transportation	BMRESP	BAU Minimum Required EV Sales Percentage	high	Yes	None in HK
Transportation	BNVFE	BAU New Vehicle Fuel Economy	medium	No	U.S. Energy Information Administration; Bureau of Transportation Statistics, U.S. Coast Guard, U.S. Department of Energy Hydrogen Program, National Academies Press
Transportation	BNVP	BAU New Vehicle Price	medium (LDVs, HDVs, motorbikes), low (nonroad vehicle types)	No	U.S. Energy Information Administration, Environmental and Energy Study Institute, TruckerToTrucker.com, *The Wall Street Journal, Popular Mechanics* magazine
Transportation	BPoEFUbVT	BAU Percentage of Each Fuel Used by Vehicle Technology	medium	No	EIA, DOE
Transportation	BRAaCTSC	BAU Range Anxiety and Charging Time Shadow Cost	medium	No	Lin and Greene (2010)
Transportation	BVTStL	Boolean Vehicle Types Subject to LCFS	low	No	California Air Resources Board
Transportation	CIRbTF	Carbon Intensity Ratios by Transportation Fuel	n/a (unless overriding model calculations)		n/a
Transportation	ECpV	Embedded Carbon per Vehicle	low	No	PE International, BNVP
Transportation	EoCSoEVMS	Effect of Charging Stations on EV Market Share	low	No	Sierzchula et al. (2014)
Transportation	EoDfVUwFC	Elasticity of Demand for Vehicle Use with Regard to Fuel Cost	medium	No	University of California - Davis, International Air Transportation Association, China Industrial Economics
Transportation	EoFoNVFE	Effect of Feebate on New Vehicle Fuel Economy	medium	No	Oak Ridge National Laboratory, ICCT
Transportation	EoNVFEwFC	Elasticity of New Vehicle Fuel Economy with Regard to Fuel Cost	medium	No	Resources for the Future
Transportation	EoVPwFE	Elasticity of Vehicle Price wrt Fuel Economy	low	No	U.S. Environmental Protection Agency, U.S. Center for Automotive Research

Table A-1 | **Data Sources for Variables in the Hong Kong EPS (Continued)**

Section	Abbrev	Meaning	Importance to Update for New Region	Hong Kong-Specific Values?	Data Source
Transportation	EVCCC	EV Charger Capital Cost	low	No	U.S. Department of Energy
Transportation	EVCLC	EV Charger Labor Cost	low	No	U.S. Department of Energy
Transportation	FoVObE	Fraction of Vehicles Owned by Entity	high	Yes	HK Transport Department
Transportation	GCApLC	Grams CO_2e Avoided per LCFS Credit	n/a (unlikely to apply to most regions)	No	California Air Resources Board
Transportation	ICtPSFfL	Incremental Cost to Produce Substitute Fuel for LCFS	optional	No	ICCT, American Public Transportation Association
Transportation	LCPC	LCFS Credit Price Cap	n/a (unlikely to apply to most regions)	No	California Air Resources Board
Transportation	MPNVbT	Max Percent New Vehicles by Technology	medium	No	BNEF, U.S. Energy Information Administration
Transportation	MPoEFUbVT	Maximum Percentage of Each Fuel Usable by Vehicle Technology	low (but copy new nonroad values from BPoEFUbVT if they changed)	No	Wikipedia, U.S. Department of Energy, IEA, Ship&Bunker
Transportation	P	Population	High	Yes	Hong Kong Census and Statistical Department
Transportation	PCiCDTdtTDM	Percentage Change in Cargo Distance Transported Due to TDM	medium	No	IEA
Transportation	PTFURfE	Percentage Transportation Fuel Use Reduction for Electricity	low	No	U.S. Department of Energy, M.J. Bradley & Associates (U.S. consulting firm)
Transportation	SDoVPbT	Standard Deviation of Vehicle Prices by Technology	low	No	NDTV; MotorBazee; *Wall Street Journal* prices by technology
Transportation	SoCDTtiNTY	Share of Cargo Distance Transported That Is New This Year	to be determined via calibration		n/a
Transportation	SRPbVT	Separately Regulated Pollutants by Vehicle Type	medium	No	U.S. Environmental Protection Agency
Transportation	SYBSoEVP	SYBSoEVP Start Year Battery Share of Electric Vehicle Price	low	No	UBS
Transportation	SYFAFE	Start Year Fleet Average Fuel Economy	medium	No	U.S. Energy Information Administration, BTS, U.S. Coast Guard
Transportation	SYVbT	Start Year Vehicles by Technology	very high	Yes	HK Transport Department, Cathay Pacific
Transportation	VBDR	Vehicle Buyer Discount Rate	medium	No	U.S. Environmental Protection Agency
Transportation	VQS	Vehicle Quantization Size	n/a		n/a

Table A-1 | **Data Sources for Variables in the Hong Kong EPS (Continued)**

Section	Abbrev	Meaning	Importance to Update for New Region	Hong Kong-Specific Values?	Data Source
Transportation	VTStFES	Vehicle Technologies Subject to Fuel Economy Standards	low		n/a
Web Application Support	BCF	BTU Conversion Factors	medium	No	U.S. Energy Information Administration, Argonne National Laboratory
Web Application Support	BpTPEU	BTU per Total Primary Energy Unit	medium	No	International Energy Agency
Web Application Support	CDCF	Cargo Distance Conversion Factors	medium	No	n/a
Web Application Support	LpWOU	Liters per Water Output Unit	Low	No	n/a
Web Application Support	OCCF	Output Currency Conversion Factors	medium	No	U.S. Bureau of Labor Statistics

Note: Full source information is available in each variable's associated spreadsheet file, which can be downloaded as part of the Hong Kong EPS package (free and open source) from https://hongkong.energypolicy.solutions/.

Source: WRI authors.

ENDNOTES

1. *Hong Kong Climate Change Report 2015*.

2. *Hong Kong's Climate Action Plan 2030+* report.

3. *Energy Saving Plan for Hong Kong's Built Environment 2015~2025+*.

4. *Hong Kong's Climate Action Plan 2030+* report.

5. 2015 Policy Address.

6. *A Food Waste and Yard Waste Plan for Hong Kong 2014–2022, Hong Kong Blueprint for Sustainable Use of Resources 2013–2022.*

7. The Energy Policy Simulator was developed by Energy Innovation LLC with help from the Massachusetts Institute of Technology and Stanford University. The model has been peer reviewed by individuals associated with Argonne National Laboratory, the National Renewable Energy Laboratory, Lawrence Berkeley National Laboratory, Stanford University, China's National Center for Climate Change Strategy and International Cooperation, China's Energy Research Institute, and Climate Interactive. The adaptation of the model to Hong Kong was carried out jointly by Energy Innovation LLC, Civic Exchange, and World Resources Institute.

8. Pollutants estimated by the EPS include four greenhouse gases (CO_2, CH_4 , N_2O, and F-gases), four types of particulates ($PM_{2.5}$, PM_{10}, black carbon, and organic carbon), and four other gaseous pollutants (NO_X , SO_X , CO, VOCs).

9. The Energy Policy Simulator calculates first-order costs and savings (which entities pay other entities more or less money relative to the BAU case). It does not include a full macroeconomic simulation of the economy, which would consider questions such as how government spends increased tax revenues (or what government cuts in response to reduced tax revenues), because these decisions are beyond the scope of the energy and non-energy policies that the computer model seeks to evaluate.

10. In EPS, timestep is annually based.

11. *Hong Kong Energy Statistics 2017 Annual Report.*

12. *Hong Kong Greenhouse Gas Emissions Inventory 2017.*

13. *Hong Kong's Climate Action Plan 2030+* report.

14. EPD, https://www.epd.gov.hk/epd/english/environmentinhk/waste/prob_solutions/WFdev_IWMF.html.

15. The nonmanufacturing segment includes construction and other miscellaneous nonmanufacturing industrial activities.

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

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

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

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

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