Appendix B

Mitigation Assessment

CONTENTS

1 PROPOSED POLICIES AND MEASURES

1.1 CRITERIA FOR SELECTION OF POLICIES AND MEASURES

If Hong Kong were to adopt a mitigation objective for GHG, it would be setting out to contribute to the international response to climate change and to achieving the ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC). There are four distinct mechanisms by which Hong Kong might establish a mitigation objective:

- establishing an emission reduction target, which could take several forms, as discussed below;
- introducing certain specific policies and measures;
- specifying levels of performance for the emission intensity or the energy intensity of the economy as a whole or certain individual sectoral components; or
- introducing a system of economic instruments, such as carbon taxes, to provide incentives for the adoption of mitigation measures.

Key criteria for the selection of the policies and measures to be analysed were as follows:

- **Technical feasibility -** measures in the mitigation scenarios are based on international technology and policy reviews. Detailed feasibility studies for individual measures are required at a later stage, taking into account their limitations, uncertainties and practicability if proposed for adoption within Hong Kong's local context.

- **No- or low-cost measures** – measures that will limit the total and per metric ton cost of emission control in Hong Kong to below some accepted threshold. The emphasis of these approaches is to minimise costs associated with the achievement of some level of emission reduction.

- **Maximising co-benefits** - measures that provide collateral benefits by simultaneously reducing emissions of other air pollutants or achieving environmental benefits in other media. For example, a measure that reduces coal use for electricity generation would also reduce emissions of sulphur dioxide.

- **Suitable for research, development, and demonstration (RD&D)** – measures that might be suitable for investment in research, development and demonstration, but are not presently at the stage of widespread commercial application in Hong Kong. Promising medium- to long-term technologies such as some forms of renewable energy or electric vehicles are examples of such measures.

Classification of the different measures into these four categories can assist decision-making by providing a context of likely effects and implementation requirements. There are several other attributes of policies and measures that need to be borne in mind when assessing their desirability for inclusion in a climate-change response strategy.

- **The distribution of burdens and benefits across the various segments of society**. All other things being equal, a desirable response strategy might strive to distribute the burdens of cost and implementation, as well as the environmental and collateral benefits, as evenly as possible across affected individuals and strata of society. This may ease the concerns of parties who are required to take abatement measures, by demonstrating that they are not being "singled out" by Government for action. Thus, it may facilitate the success of the programme.

- **Other effects of the policies and measures, including the secondary environmental and wider socio-economic effects**. Some measures may be successful at reducing GHG emissions from one sector by shifting the burden to another sector. For example, introduction of electric vehicles reduces emissions from the combustion of petrol in vehicles but may increase emissions from the combustion of fossil fuels in power stations. Socio-economic issues might arise when the burden of cost falls inequitably on the poorer segments of society or causes unemployment to rise.

- **Ease of implementation**. Measures can seem to have attractive cost-effectiveness attributes but may be difficult to implement, monitor, and/or enforce. Related issues include questions of whether measures can be introduced under existing legislation and what pressures might result from forces outside Hong Kong.

1.2 ASSESSMENT OF MITIGATION MEASURES

An assessment of the economic, social and environmental implications of these measures has been undertaken. Further explanation of the methodology and quantitative output are provided in *Sections 2 and 3.* This section discussed the proposed mitigation measures qualitatively by sector. It provides discussions of the opportunities and potentials for GHG mitigation, as well as institutional/social barriers that have to be removed for their effective implementation. The impacts of some mitigation policies and options are not readily quantifiable. This is particularly true in the aviation and marine sectors. Other measures such as RD&D and general supportive programs have an intangible impact on their sector.

1.2.1 Buildings and Appliances

End-use efficiency improvement to reduce the electricity generation output, which is applied on the demand-side, is among the most cost-effective of GHG emission control measures. The proportional contribution of various sources of GHG emissions in Hong Kong shows the potential significance of end use efficiency, particularly in electrical end uses.

Efficiency improvements in the end-uses have the potential to reduce peak loads, thereby reducing generation plant capacity requirements. This would bring economic benefits in addition to those associated with electrical energy and fuel savings, further off-setting the cost of investment in the more efficient equipment and thereby reducing the GHG emission reduction cost.

Many current technologies allow building energy consumption to be reduced through better thermal envelopes, improved design methods and building operations, more efficient equipment, and reductions in demand for energy services. Emerging areas for energy savings in commercial buildings include the application of controls and information technology to continuously monitor, diagnose and communicate faults in commercial buildings ("intelligent control"), and systems approaches to reduce the need for ventilation, cooling and dehumidification. Advanced windows, passive solar design, techniques for eliminating leaks in buildings and dusts, energy efficient appliances, and controlling standby and idle power consumption as well as solid-state lighting are also important in both residential and commercial sectors. Occupant behavior, including avoiding unnecessary operation of equipment and adaptive rather than invariant temperature standards for cooling, is also a significant factor in limiting building energy use[1].

Air conditioning and lighting are the most significant end-uses in Hong Kong. There are a range of technical options available for reducing the energy required to provide air conditioning services. These include using more efficient components (such as chillers) in central systems, more efficient packaged and room units, expanding the use of district cooling/water-cooled air conditioning system, and reducing the heat load on air conditioning plant by, for example, reducing the internal and external heat loads in buildings.

In order to promote the use of more energy efficient air-conditioning systems in Hong Kong, a pilot scheme for the use of fresh water for non-domestic air-conditioning in selected areas commenced in June 2000. In view of the support from the property owners and the environmental benefits, the Government decided to keep promoting the scheme in 2008 [2].

Lighting is a major end use. A survey of 80 studies show that efficient lighting technologies are among the most promising GHG-abatement measures in buildings in almost all countries, in terms of both cost-effectiveness and potential savings. There are many well known options to improve lighting efficiency available in the market, ranging from simple substitution of luminaries to the re-design of lighting systems. Lighting design, particularly commercial lighting design, is a complex and specialised field in its own right. Capturing efficiencies (and often simultaneous cost and employee productivity benefits) through better design is very building-specific.

Energy standards specifically aimed at appliances and equipment are widespread. Canada, Korea, Japan, the EU, the US and Singapore have all promoted such policies. Hong Kong's Voluntary Energy Efficiency Labelling Scheme (EELS), introduced in 1995, has been amended several times (most recently on 17 April 2008) and now covers 18 types of household and office appliances, including 10 types of electrical appliances (refrigerators, washing machines, compact fluorescent lamps, dehumidifiers, electric clothes dryers, room coolers, electric storage water heaters, television sets, electric rice-cookers and electronic ballasts, hot / cold bottled water dispensers), 7 types of office equipment (photocopiers, fax machines, multifunction devices, laser printers, LCD monitors, computers), domestic gas instantaneous water heaters. The *Energy Efficiency (Labelling of Products) Ordinance* of 9 May 2008 provides for a Mandatory Energy Efficiency Labelling Scheme (EELS) which currently covers room air conditioners, refrigerating appliances, and Compact Fluorescent Lamps (CFL).

Multiple obstacles exist and make it difficult to adopt more efficient technologies and realize the energy efficiency improvement potential in Hong Kong as rapidly as desired. These barriers include:

- availability of technology;
- higher costs of getting reliable information on energy efficient technology;
- limitations inherent in building designs;
- mixture of building ownership;
- allocation of costs and benefits associated with capital expenditure, i.e., the owners bear the cost while the tenants get the benefit;
- cash flow constraints of some Small and Medium-sized Enterprises (SMEs) in relation to the initial investment cost; and
- lack of an appropriate portfolio of policies and programs.

The following measures may be considered by the Government to overcome these constraints:

- implement a mandatory scheme that sets energy efficiency targets for different types of buildings under the Building Energy Codes;
- use guidelines, training workshops and public campaigns to enhance the understanding of the stakeholders on the importance of building energy efficiency improvement and the mandatory scheme;
- financial support in the form of an environment fund, tax incentives and a loan funding scheme from power companies which could be used to encourage the enhancement of energy efficiency in buildings;

- implement the mandatory scheme in phases, with the priority focused on new buildings and the common areas of the buildings where the building owners/property managers have control of, and then extend the coverage to the tenant area in the long run.

- expand the scope and tighten the energy efficiency standards gradually

Consumer behaviour is not modelled or quantified in *Section 3,* as it is difficult to accurately predict its effect on energy consumption or carbon emissions in advance. However, consumer behavior, including avoiding unnecessary operation of equipment and adaptive rather than invariant temperature standards for cooling, is also a significant factor in limiting building energy use[3]. Information and education are important to promote climate-friendly consumer behaviour and thus help reduce energy demand.

1.2.2 Road Transportation

Transport is distinguished from other energy-using sectors by its predominant reliance on a single fossil resource and by the infeasibility of capturing carbon emissions from transport vehicles. It is also important to view GHG-emission reduction in conjunction with local air pollution, traffic management and energy security. Solutions therefore have to take into consideration of transportation problems as a whole, not just GHG emissions[4].

Mitigation measures includes vehicle efficiency improvement, alternate vehicle and fuel types (hybrid petrol-electric vehicles and petrol to bio-fuel blended petrol), as well as other policy options.

<u>Vehicle Efficiency Improvement</u>

Improved vehicle efficiency measures, leading to fuel savings, in many cases have net benefits, but the market potential is much lower than the economic potential due to the influence of other consumer considerations, such as performance. A major risk to the potential for future reductions in CO_2 emissions from the use of fuel economy technologies is that they can be used to increase vehicle power and size rather than to improve the overall fuel economy and cut carbon emissions. The preference of consumers for power and size has consumed much of the potential for GHG mitigation reduction achieved over the past two decades[5].

<u>Alternative Vehicle and Fuel Types</u>

Various forms of vehicle fuel switching measures are potentially feasible in Hong Kong, and include the following.

- *Diesel to LPG:* The Hong Kong SAR Government has already committed to changing taxis from diesel to LPG, principally as a measure to improve urban air quality. That measure and its associated policy instrument are included here to show the effect of the measure on GHG emissions. LPG could also be used for other small- to medium-sized diesel vehicles.

- *Bio-Fuel Mixtures*: The introduction of bio-fuels by mixing with traditional petro-fuels is a way of reducing net GHG emissions. Bio-fuels are considered GHG emission neutral, since the emission of CO_2 from the consumption of the fuels has already been off-set by the absorption of atmospheric CO_2 during the growth of the source crops. The GHG emission reduction possible is therefore a direct function of the proportion of fuel that can be substituted with bio-fuel. It is possible to mix a small proportion of bio-fuel such as methanol or ethanol with existing petrol, or biodiesel with diesel, without any change to existing engines[6]. The introduction of biofuel such as adding ethanol to petrol could be more readily effected. No additional infrastructure or change to vehicle engines is required if, for example, all petrol is required to include a 10% bio-ethanol. Hence, it is assumed that biofuel can be introduced but some form of government support or regulation would be needed to encourage or require its use. Specifically, biodiesel produced from waste cooking oil should be considered.

- *Electricity Vehicles:* Electricity produced from any primary energy source, with the exception of coal, is likely to offer significant CO_2 savings compared with petrol and diesel. Electric-powered cars could become increasingly prevalent in the future – for example, plug-in hybrids, running partly on electricity, could be commercial in a few years' time.

- *Hydrogen Vehicles:* Hydrogen produced from low-carbon sources can offer large carbon savings compared with petrol and diesel. In the short term, the scope to reduce the carbon intensity of the fuel mix through hydrogen is limited by the lack of availability and high cost of low-carbon hydrogen (except in special cases such as from intermittent electricity generation at times of day when there is no other use for that power) along with the lack of available vehicles and supply infrastructure.

- There may also be scope for future innovative *future fuel developments* to contribute to CO_2 reductions from fuels.

Policy Instruments

A range of transport-focused policy instruments with potential for controlling GHG emissions were considered and include the following:

- *Road Pricing*: a road pricing is usually used to overcome local traffic congestion problems, to create a revenue stream for highway infrastructure investment projects or to implement a 'user-pays' or 'cost-reflective pricing' philosophy. The technology now exists to allow road pricing to be administered automatically and hence it is often called electronic road pricing (ERP). Road pricing schemes may be expected to have some impact on GHG emissions, but the relationships are not straight-forward and are specific to particular schemes, geographical locations, local economic and transport sector conditions. Furthermore, the results could potentially be either positive or negative, since some effects (such as reduction of engine idling during congestion) will tend to reduce GHG emissions, but others (such as increased driving distances to by-pass critical areas) will tend to increase GHG emissions.

From the transport perspective, feasibilities studies conducted previously conclude that the case for introducing road pricing in Hong Kong is considered weak[7] . From overseas experience, a road pricing scheme that aims to relieve traffic congestion can only be implemented equitably and effectively in the presence of alternative routes with adequate capacity for motorists to by-pass the charging zone. In the case of Hong Kong, such an alternative route is the Central-Wanchai Bypass (CWB) which will not be in place before 2017. While the case for road pricing implementation in Hong Kong as a measure to combat GHG emissions has yet to be established, there is a possibility that the measure could remain under consideration in the long term.

- *Replacement of Goods Vehicles*: the main target vehicle groups for replacement are old, inefficient vehicles and heavy goods vehicles. It is a practice which has been implemented in Hong Kong as well as in many other jurisdictions. The HKSAR Government from 1 April 2007 to 31 March 2010 offered a time-limited one-off grant to vehicle owners to replace their pre-Euro and Euro I diesel commercial vehicles with Euro IV compliant vehicles[8]. Internationally, the State of California has several programs intended to phase out polluting or inefficient vehicles such as incentives for voluntary retirement of high emitting passenger cars and light- and medium-duty trucks as well as incentives to retrofit old polluting school buses[9]. While Canada has committed CA$92 million over four years beginning in 2009 to create incentives for Canadians to trade in vehicles made in 1995 or earlier which do not meet today's emission standards for newer, more efficient vehicles[10].

- Emission reduction from *off-road vehicles and equipment:* electrification of vehicles and equipment operated at the airport and the ports has the potential to reduce GHG emissions from these sources. The electrification of port yard equipment is currently being considered by other jurisdictions and could be feasible for consideration in Hong Kong. The California Air Resources Board, California Climate Action Registry, and South Coast Air Quality Management District are considering the development of a protocol for the electrification of truck stops which would establish a standard methodology in determining greenhouse gas emission reduction from the use of electric power as opposed to a diesel-powered engine on a truck for idling purposes[11]. As a port initiative, the Port of Long Beach is considering "Green-Container" Transport Systems which will involve broadening the use of electrification (from "green energy" sources) in port-related sources[12]. The Port of Long Beach had also previously requested proposals for electrification of rubber tired gantry cranes[13]. Another case is the Port of Seattle, Port of Tacoma, and Vancouver Port Authority who published the Northwest Ports Clean Air Strategy in 2007 which considers the electrification of lift equipment as an efficiency improvement[14].

- Implementation of the Hong Kong "*Importers' Average Fleet Efficiency*" *Standard*. This Study examined a standard whereby the average imported vehicle efficiency should be 20% higher than the 2005 market average efficiency by 2015. This is an alternative to introducing an environmental tax on high emitting vehicles and its implementation cost would be relatively low.

- Given the positive effects of higher population densities on *public transport use, walking, cycling* and CO_2 emissions, further improved integrated spatial planning is an important policy element in the transportation sector.

- *Vehicle Information and Driver Education Programmes*: driving style affects fuel consumption and emissions. Information about opportunities to reduce vehicle fuel consumption could cover the vehicles themselves and driving style and habits. Vehicle energy labelling and driver education programmes should be considered.

Measures such as vehicle efficiency improvement, alternative vehicle and fuel types are quantified and analysed under *Section 3*.

1.2.3 Marine Transportation

At present, no comprehensive international requirements exist to address CO_2 emissions from ocean-going ships. Under the Kyoto Protocol, there are no national GHG emission caps for the aviation and marine sectors as they cannot be fully controlled by one jurisdiction. Sectoral targets and the participation of multinational corporations are crucial to curb the carbon emissions in these two sectors.

<u>Shipping</u>

Shipping is more efficient per tonne of CO_{2-e} per km than air or road transport; however, recent research has found that total CO_2 emissions from ocean going ships are double those from aviation, and will continue to increase in line with the projected growth of trade. The 2020 emissions from shipping are expected to be 75% higher than at present due to increased trade volumes[15].

The *Second IMO GHG Study 2009*[16] provides technological, operational, and policy options for emissions reduction. These measures may not be implemented unless coordinated policies are established to support their adoption. An overall assessment of the potential of these options to achieve a reduction in CO_2 emissions is shown in *Figure 1.1*.

Figure 1.1 ***Assessment of Potential Reductions of CO_2 Emissions from Shipping by using Known Technology and Practices***

DESIGN (New ships)	**Saving of CO_2/tonne-mile**	**Combined**	**Combined**
Concept, speed and capability	2% to 50%+	10% to 50%+	25% to 75%+
Hull and superstructure	2% to 20%		
Power and propulsion systems	5% to 15%		
Low-carbon fuels	5% to 15%*		
Renewable energy	1% to 10%		
Exhaust gas CO_2 reduction	0%		
OPERATION (All ships)			
Fleet management, logistics and incentives	5% to 50%+	10% to 50%+	
Voyage optimization	1% to 10%		
Energy management	1% to 10%		

Source: IMO, *Second IMO GHG Study 2009*
Note: + Reductions at this level would require reductions of operational speed.
* CO_2 equivalent, based on the use of LNG.

In addition to the *Environmental Shipping Index*, Mitigation options proposed in this Study include:

- *Better routing and timing for ships*

According to the *IPCC Fourth Assessment Report*, the short-term potential for operational measures to reduce emissions ranged from 1-40%.

- *Environmental Tax on Shipping*

An environmental tax on shipping has been implemented by various ports through initiatives such as incentives or differentiated dues and could possibly be considered for application in Hong Kong.

Ports

Shoreside power has the potential to reduce the carbon emissions; however, although some ports have begun to install the necessary infrastructure power, and large ships are being built to accommodate it, there is no international standard regulating the voltage or physical design of this technology. The US and some countries provide power at 60Hz, while Europe and many other countries provide 50 Hz. Also, there is no global standard for a connector that would easily handle 6,600 volts on a container ship and 11,000 for a cruise ship. In practical terms, the switch to 6,600 volts from the standard 440 volts generated by a container ship is a significant change that requires a converter, a cable management system, and a synchroniser to enable a smooth power transfer from dock to ship[17].

In HK, there is a proposal for development of an onshore support power supply at the cruise terminal at Kai Tak. The HK Tourism Commission has included the provision of on-shore support power supply to cruise vessels during berthing as a condition in the development of the cruise terminal[18]. Similar to the EVs, the use of shore power can contribute to carbon emission abatement only if the electricity generation in Hong Kong is from less carbon intensive sources such as nuclear and RE.

The HKSAR Government may seek to lead a process of deliberation including the relevant departments and private sector stakeholders. Regional collaboration should also be explored. In view of cross-ownership and cross-management between the terminal operators in Hong Kong and Shenzhen, there are opportunities to extend the deliberation process to not only the terminals in each city but to the ports in the region as a whole.

If any of the proposed potential mitigation measures for the marine sector is to be further explored for implementation in the future, its feasibility applicability and cost-effectiveness have to be considered in further detail, having regard to, amongst other things, the international nature of the industry and the socio-economic context of Hong Kong. Consultation of the stakeholder groups should also be conducted.

1.2.4 Aviation

The fuel efficiency of civil aviation can be improved by a variety of means, including technology and operational measures.

<u>Technology</u>

Technology development might offer a 20% improvement in fuel efficiency over 1997 levels by 2015, with a 40-50% improvement likely by 2050[19]. As civil aviation continues to grow at around 5% each year, such improvements are unlikely to keep carbon emissions from global air travel from increasing. The introduction of biofuels could mitigate some of aviation's carbon emissions, if biofuels can be developed to meet the demanding specifications of the aviation industry. Both the costs of such fuels and the emissions from their production process are uncertain at this time[20].

<u>Operational Measures</u>

Energy use by aircraft operations can be optimized by minimizing taxiing time, flying at optimal cruise altitudes, flying minimum-distance great-circle routes, and minimizing holding and stacking around airports. From a global perspective, the GHG-reduction potential of such strategies has been estimated at 6-12%[21].

As Hong Kong is an aircraft and fuel importer, the proposed mitigation measures are more focused on the operation and management side within the boundaries of the HKSAR only.

- Energy efficiency improvement of ground support equipment.

Hong Kong Airport Services Limited (HAS)[22] has taken to improve the energy efficiency and reduce carbon emissions of ground support equipment.

- Emission trading scheme for aviation sector.

A trading scheme for the aviation sector would have the potential to reduce emissions. The geographical scope (routes and operators covered), the amount of allowances to be allocated to the aviation sector and the coverage of non-CO_2 climate impacts will be key design elements in determining the effectiveness of any emission trading scheme. Emission charges or trading should lead to an increase in fuel costs that can be expected to have a positive impact on engine efficiency[23].

As not all airlines have the necessary data or tracking methodologies in place, there are costs associated with carbon measurement, reporting and verification under a trading scheme. Hong Kong should closely follow international developments in the sector and is not in the position to implement an emission trading scheme for the aviation sector on its own.

- Rationalization of flight paths.

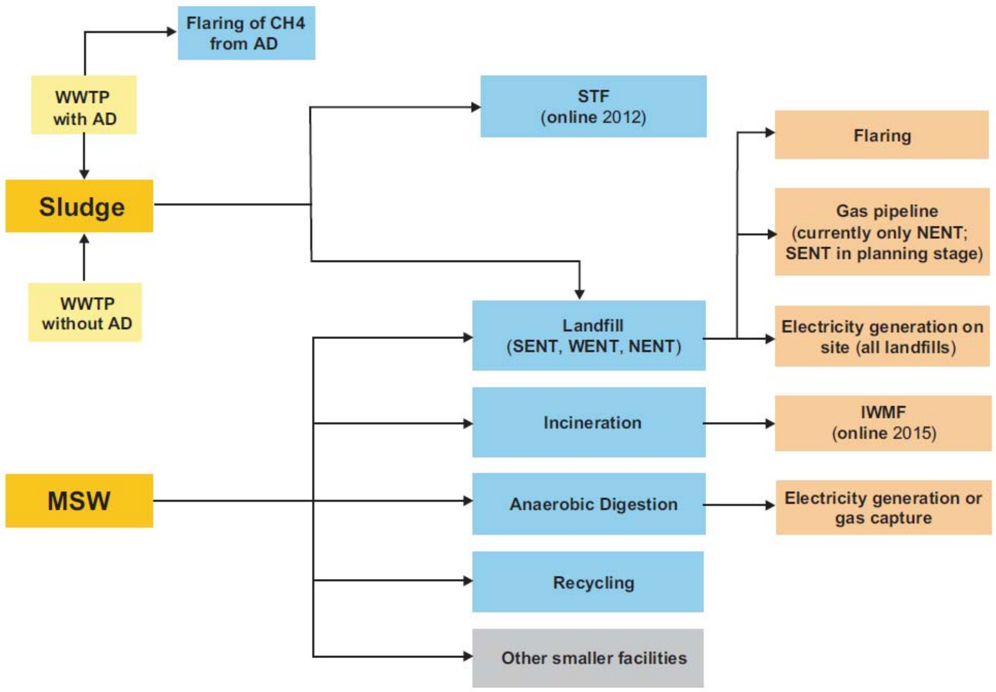
Available data were not sufficient to estimate the potential emission reductions available from the rationalization of flight paths in Hong Kong. Flight path designation is a complex process involving various considerations, most notably aviation safety.

It should be noted that the overall climate impact of aviation is considered to be much greater than the impact of CO_2 emissions alone. As well as emitting CO_2, aircraft contribute to climate change through the emission of NO_x, which is particularly effective in forming the GHG ozone when emitted at cruise altitudes. These effects are estimated to be about two to four times greater than those of aviation's CO_2 alone, even without considering the potential impact of cirrus cloud enhancement which some consider to be a contributing factor. The environmental effectiveness of future mitigation policies for aviation will depend on the extent to which these non-CO_2 effects are also addressed[24].

1.2.5 Waste

Figure 1.2 summarises the waste and wastewater management strategy in Hong Kong. Waste management is relevant from a climate change mitigation perspective as the anaerobic decomposition of organic material at landfill sites leads to the emission of methane (CH_4). A reduction in the amount of waste landfilled will reduce emissions.

Figure 1.2 Waste and Wastewater Management in Hong Kong



The most relevant climate change mitigation measure in the waste sector in Hong Kong is the recovery and utilisation of landfill gas in operating and closed/restored landfills. The recovered landfill gas, which essentially consists of CO_2 and CH_4, can then either be utilised as an alternative energy source on-site or off-site, or flared as an alternative way of reducing emissions. At present, all three strategic landfills have been utilising landfill gas for energy production and/or for Towngas production[25]. It is proposed that the landfill recovery rate would become higher, and there will be full utilisation of the landfill gas in the alternative mitigation scenarios.

With landfills expected to be exhausted earlier than first envisaged, the Government promulgated a policy framework in late 2005 with a view to manage Hong Kong's municipal solid waste in a sustainable manner. One element of the framework is the development of Integrated Waste Management Facilities (IWMF) that would adopt advanced incineration as the core waste treatment technology. The advanced technology, which is much cleaner than that of the incinerators previously operated in Hong Kong, involves high temperature combustion and allows for considerable power generation while reducing pressure on landfill sites substantially. The first phase of the IWMF would have a capacity of 3,000 metric tons per day and is planned to be commissioned by 2015[26].

At present, all dewatered sewage sludge generated by sewage treatment works is disposed of at landfills in Hong Kong. This practice of sludge disposal at landfill is not considered sustainable from both environmental and technical perspectives. In 2009, the Director of Environmental Protection (DEP), with the support of the Secretary for the Environment, proposed to design and construct the Sludge Treatment Facilities (STF). The capacity of the currently planned STF is 2,000 tonnes per day. Depending on the actual sewage sludge arisings in future, future upgrading of the STF capacity or even a new STF may be required[27].

EPD is also planning to develop large scale Organic Waste Treatment Facilities (OWTF) to recycle organic waste from institutions, commercial and industrial establishments. Operation of the OWTF would reduce disposal of organic waste to landfills and produce useful products including compost and renewable energy. The first phase of OWTF would for 200 metric tonnes per day capacity and is planned to be commissioned by the mid 2010's. The second phase is of a similar capacity and its commissioning is anticipated in late 2010's.

Mitigation measures in the waste sector are quantified and analysed under *Section 3*. In addition to GHG mitigation, improved sanitation and waste management provide a wide range of public health and environmental co-benefits.

1.2.6 Energy Supply

Hong Kong has a reasonably diverse energy supply resource mix. Electricity is generated locally from coal and natural gas and a substantial quantity of nuclear electricity is imported from Guangdong. Reticulated consumer gas supplies use town gas manufactured from naphtha and natural gas.

Increasing the import of nuclear generated electricity from Mainland China, using more natural gas to generate electricity locally, and increasing the share of renewable energy would help Hong Kong to reduce carbon emissions. However, the potential for adverse effects in the long term, such as reduction in the overall energy supply security and reliability in Hong Kong, would need to be carefully considered before completely abandoning coal-fired electricity generation and converting the reticulated supply network to natural gas.

- Natural Gas

In August 2008, a Memorandum of Understanding (MOU) was signed between the HKSAR Government and the Central Government for the supply of nuclear electricity and natural gas to Hong Kong in the coming two decades. The MOU opens the opportunity to draw natural gas from three sources: first, from new gas fields planned to be developed in the South China Sea; second, from the second east-west gas pipeline bringing gas from Turkmenistan; and third, from a Liquefied Natural Gas (LNG) terminal to be located in the Mainland.

If all of the gas supply to Hong Kong were to pass through a single point somewhere in the network, it would be possible for a single catastrophic event to interrupt supply and hence to disrupt electricity generation. If, as could be the case in Hong Kong, an increased proportion of future electricity generation was reliant on the same gas supply as the gas network supplying consumers, the provision of the two major energy forms to end users could then be simultaneously affected.

- Nuclear

If Hong Kong is to expand its electricity import capacity from the Mainland and within the SAR itself, it needs not only to enhance the existing Nuclear Transmission Network (NTS), but also to build new transmission infrastructure between Hong Kong and the Mainland. Actual project costs are uncertain and will be subject to final network design and construction methods. The project lead time after a decision to proceed with such a project would be more than 8 years to allow for planning, design, permitting, construction and commissioning.

Currently, the import electricity price is based on a commercial negotiation and, as such, the future imported electricity price is unknown and uncertain.

Renewable Energy

New energy infrastructure investments, upgrades of energy infrastructure, and policies that promote energy security, can, in many cases, create opportunities to achieve GHG emission reductions[28]. Renewable energy, such as large scale wind and solar, as well as the waste-to-energy opportunities discussed above, requires significant initial investment and operational costs.

In 2005 the First Sustainable Development Strategy the Government set a target of 1 to 2% renewable energy in electricity use by 2012. In addition to the IWMF being planned, both CLP and HEC are currently planning to develop off-shore wind farms. *Box 1.1* provides a cost and environmental benefit estimation for CLP's off-shore wind farm.

Box 1.1 ***CLP Off-shore Wind Farm***

The investment cost of CLP's off-shore wind farm is about HK$80-100 Million per 3MW turbine[29]. This is on par with other wind farms and less than the cost of solar[30]. According to the CLP offshore wind stakeholder consultation website[31], the Project would also provide benefits to local air quality since the wind farm will produce clean energy and would offset emissions from fossil fuels. Every year of operation of the project would offset approximately:

- 343,000 - 383,000 tonnes of CO_2;
- 54 - 60 tonnes of SO_2;
- 394 - 440 tonnes of NOx; and
- 14 - 16 tonnes of particulate matter.

Overall Considerations

Quantitative analysis for electricity generation is provided under *Section 3*. Hong Kong may import more nuclear electricity from Mainland China and more natural gas to generate electricity locally. The marginal electricity prices of both natural gas and nuclear are higher than that of coal, and the natural gas price is expected to increase rapidly in this region[32]. Although the impact from fuel price changes on Hong Kong's aggregate GDP growth is small, the change of fuel mix will influence the future electricity tariff.

Further challenges are likely to be presented by both the increased import of natural gas and nuclear power. Generation and network infrastructure takes a long time to implement, requiring the resolution of a range of engineering issues, permitting processes and liaison with stakeholders. Continued engagement between industry and different stakeholder groups is needed to enable the development of feasible engineering options that meet the required programme.

Climate change policy objectives and other policies such as improving air quality should be well integrated to avoid wasteful investments and adverse effects on electricity supply reliability. Utilities need to plan effectively on the basis of asset lives which span more than two decades. Clear emission reduction targets at least for 2020 and 2030 are necessary for practical planning and sustainability assessment.

1.2.7 Carbon Tax, Cap and Trade

General economic instruments that apply across the various sectors of the economy and are not specific to particular GHG emission reduction measures may be implemented in addition to, or more likely as an alternative to, government policy instruments targeting particular measures. This approach is characteristic of a laissez faire philosophy of governance and economic management.

The general economic instruments relevant to the control of GHG emissions are emission taxes or levies (referred to here as "taxes") and a cap-and-trade permit system, referred to here as "permits." These two alternative approaches both seek to send economic signals to decision-makers to limit their GHG emissions. The effects of emission tax and cap and trade could be the same as they approach the problem from opposite ends. In the HKMM model, emission tax was selected for analysis and consideration as a non-measure-specific, cross-sectoral policy instrument.

Each approach is applicable to a particular policy context. The characteristics of these two alternative approaches are shown in *Table 1.1*.

Table 1.1 Key Characteristics of Emission Taxes and Tradable Permits

Variable	No Generic GHG Economic Instruments	Emission Levies or Taxes	Tradable Permits
Quantity of Emissions	Completely unconstrained, the indirect result of other economic decisions	Reduced according to the level of the tax and the extent to which emitters are price elastic	Directly controlled by a cap, so an emission target must be met, subject to the scope of the constraint and the effectiveness of enforcement
Cost / Price / Market Value of GHG Emissions	No economic value, because unconstrained – no scarcity	Determined directly by the tax level	Determined by the costs of abatement and the laws of supply-and-demand in the market
Broad Policy Context	No change, business-as-usual economics with direct government planning and intervention	Require a definite position to be taken on emission cost adder – may be perceived as the imposition of a direct economic penalty	Requires a definite position to be taken on the quantity of emissions allowed – more likely to be perceived as primarily an environmental action
Issues	Which measures to select and promote, which policy instruments to select to promote them, how to implement	How to determine the correct level of tax or levy; assignment of liability (upstream versus downstream, point of emission versus point of end use); Tax adjustment based on a regular basis in view of environmental outcomes; Use of revenues (retained versus recycled)	Assignment of liability (upstream versus downstream, point of emission versus point of end use); Allocation (auctioning, grandfathering, or mix); Use of revenues (retained versus recycled)
Implementation		Long planning period, including the consultation with stakeholders	Long planning period, including the consultation with stakeholders and the development of the trading scheme

1.2.8 General Support Measures

The success of any climate change policy cannot be achieved without support measures, such as public awareness raising and education. They help to change lifestyle and behaviour patterns, overcome barriers to particular Government actions, and enhance the success of policies.

The aims of these support measures are to:

- inform all members of society of the importance of the climate change issue and why the Hong Kong SAR Government has decided to take action;
- inform all members of society of what the goals and components of the Government's policy are and how individuals and organisations can help achieve them;
- advise consumers of the economic benefits that they can avail themselves of by adjusting their purchasing habits, as well as the environmental benefits that would accrue to society at large if they would change their habits;
- develop and enforce laws and regulations that can effectively achieve the aims of the Government's policy; and
- improve the effectiveness with which Government can administer the strategy and monitor its progress.

The first three items can be termed as education and information, while the last two are institutional measures. They can be considered as a foundation or as social infrastructure on which to build other measures and policies.

<u>Education and Information</u>

Education and information may be considered as providing a foundation on which to build other measures. The provision of information and the use of communication strategies and educational techniques can encourage a change in personal behavior. It will be easier to implement measures and policy instruments for a general GHG emission control policy if the wider community and business sector understand the issues and the thinking behind the policy responses.

A public education programme could include the development of printed, visual and multi-media materials for schools, colleges, businesses, or organisations, the development of a dedicated website or TV programme devoted to climate change topics and the production of leaflets and other promotional materials for vendors and distributors of energy-efficient appliances, products, and materials.

Education and training are likely to influence people's behaviour patterns and make them more likely to adopt appropriate actions in response to more specific options to mitigate climate change across different sectors. According to the IPCC AR4, changes in occupant behaviour, cultural patterns and consumer choice and use of technologies can result in considerable reductions in CO_2 emissions related to energy use in buildings. Transport Demand Management, which includes urban planning (that can reduce the demand for travel) and provision of information and educational techniques (that can reduce car usage and lead an efficient driving style) can support GHG emissions mitigation. In industry, management tools that include staff training, reward systems, regular feedback, and documentation of existing practices can help overcome organization barriers, reduce energy use, and GHG emissions[33].

Education programmes are expected to have short lead time, possibly one year to at most 18 months to plan and develop. However, estimating quantitatively the effectiveness of public awareness and education policies is also difficult. Most analysts agree that these programmes enhance the effectiveness of other measures and as such are important components of a comprehensive climate change strategy, but that it is not possible to quantify emission reductions or the extent to which other measures and policy instruments would have been less successful without the general publicity. However, a comparative back-calculation can be made from the cost and a comparative cost per unit of emission reduction to the minimum impact that would be needed to justify the cost. For instance, if the cost of a public awareness programme is HK$1 million and leads to emission reductions of 20,000 tonnes $CO_{2\text{-}e}$, and if the emissions reduction is not attributable to other factors, it implies a unit cost of the education programme is HK$50 per tonne of $CO_{2\text{-}e}$ reduction.

Institutional Measures

Institutional measures could include the establishment of new focal points in Government to administer the climate change policy, to co-ordinate the various arms of Government charged with implementing its component elements, to monitor its success over time, to develop and enforce the necessary implementing laws and regulations, and to review and update the policies.

The implementation of the proposed measures and policies is affected by a number of factors, including:

- the availability of the required infrastructure and conditions;
- the availability of funding; and
- the status of the required technologies.

In general, there are four generic phases for the implementation of each measure or policy.

- *Planning and Approval*. This refers to the internal government procedures for deciding on the details of the proposed measures or policies. These may include liaising with various government departments and relevant public bodies. This also includes the time required to carry out feasibility studies, where appropriate. This phase ends when approval is obtained and the measures or policies are adopted.

- *Development*. Once approval is obtained, the next phase requires the design and preparatory work for the implementation of the measures or policies. In the case of new facilities or infrastructure this phase will include the construction and the commissioning of the facilities. In the case of regulation or incentive schemes, this will include the time required for drafting and enacting the regulations, as well as the time for consultation, where appropriate.

- *Full Implementation*. This refers to the time when the measures and policies will start to make the expected impacts on the reduction of GHG emissions.

- *Monitoring, Audit and Evaluation.* This refers to the measurement of carbon stock, GHG emissions, and socio-economic and environmental benefits and costs that occur as a result of the implementation[34].

Inventories and indicators provide a macro-level assessment of the success of an overall policy but do not enable policy makers to decide the extent to which individual policy instruments have contributed towards emerging trends. In most cases it requires the establishment of a counter-factual: what would have happened in the absence of the policy. For some emission sources of non-CO_2 GHGs, the emission control measure involves the capture or direct measurement of the gas. For example, landfill methane capture can be directly measured, even if the total aggregate emissions for the HKSAR cannot. Establishing a counter-factual for other measures is less straightforward. For example, when evaluating the improvements in energy efficiency in specific industry groups, the difficulties include:

- obtaining energy use data at the level of the individual industry;

- separating out efficiency changes from other changes, eg in product lines;

- identifying which efficiency improvements result from responses to policy and which are simply business as usual and reflect some autonomous level of energy efficiency improvement.

Achieving the targeted emission reductions is the primary objective regardless of which measures result in the reductions. However, because most measures impose costs both on industry, consumers and the public purse, it is useful to know where the most cost-effective reductions are occurring and if some measures perform better than others.

In order to assess the effectiveness and costs of particular policy instrument, a review process might involve one or more of the following elements:

- development of industry level indicators of energy and/or emission intensity;
- development of a business as usual baseline for sectors or industry groups targeted by policy against which future energy use or emission rates or intensities can be compared;
- surveys of sectors to identify penetration rates of specific technologies and industry estimates of investments and behavioural changes in response to policy

Once decisions have been made regarding the introduction of a policy in Hong Kong an interdepartmental process will need to be established for its ongoing review. This should include the monitoring data in the form of an inventory and indicators, and a process for its review.

There are a number of reasons why cost-effective, energy-efficiency measures might not be taken up. For example:

- lack of information - building owners or occupiers may not have access to information about the energy efficiency of a building or an appliance in an understandable form, for example, in a way that shows the impact of an energy-efficient appliance on their electricity bill.
- lacks of incentives - developers find it difficult to recoup the added costs of energy-efficient features in a building, as these enhancements are not recognised or credited in the selling price or rental received. Similarly, landlords have little incentive to include energy-efficient appliances in apartments, because rental values do not increase as a result.

Overcoming these barriers requires policy instruments that provide information, or enforce particular actions, eg, through the use of energy-efficiency standards or building codes. However, introducing these measures is not cost-free, and the energy savings need to be offset against the costs of the programme, as well as the costs of the technologies themselves. In general, these programme costs are not included in our cost estimates. Including these costs may reduce the net benefits of some of the measures or transform some that are presently estimated to be zero or negative cost measures into positive cost measures. In other instances, the existence of cost-effective measures may be time dependent. For example, if significant energy savings are available, it might be expected that eventually energy service companies will advise firms of their discovery. Thus, the savings may be limited in time[35].

1.2.9 *Research, Development, and Demonstration (RD&D)*

Climate change mitigation will involve increased expenditures at all stages of the technology development process, ranging from research and development upstream to demonstration, deployment, and ultimately diffusion downstream. Most importantly, empirical evidence suggests that most emerging low carbon energy technologies are subject to sizeable "learning effects", *ie* their costs fall as experience accumulates through cumulative production[36]. For example, learning rates – the percentage reduction in unit investment costs for each doubling of cumulative investment – in the order of 10% to 20% have typically been reported for wind and solar power technologies. In that context, significant technology deployment costs may have to be incurred before low-carbon technologies can become competitive at market prices. However, wide uncertainties remain surrounding the magnitude and even the nature of learning effects, and their policy implications are far from obvious[37].

A cost-effective approach to addressing climate change should not only tend towards marginal abatement cost equalisation across current economic activities, but also help shape future economic activities so that marginal abatement costs will be lowered. This can be achieved through efficient R&D, innovation and diffusion of GHG emissions-reducing technologies. Technological progress will be needed both to:

- bring down the cost of available or emerging emission-reducing technologies; and
- expand the pool of available technologies and their mitigation potential.

A number of measures have been identified in this study as promising options to reduce GHG emissions in Hong Kong out to 2030 and beyond, but which are not viable commercial options today. This may be because they are too expensive, the technology is not yet fully commercialised in Hong Kong, or simply that the technology has not yet been commercialised anywhere in the world to any great extent. It is not likely that some of these technologies will have significant application in Hong Kong in the near term under market forces alone. However, with Government support and incentives, costs might be reduced or offset and the level of consumer comfort rise such that they could make a notable contribution in the longer term.

There are many examples of how Government could invest in the future of clean technologies. At the level of fundamental research into advanced technologies with potential in Hong Kong, Government could provide research grants to local universities. Government could support the demonstration of advanced technology options by, for example, promoting the use of hybrid cars or installing photovoltaic systems in schools. Cost-sharing of demonstration programmes or provision of low-interest loans for innovative technology installations are ways to provide financial inducements for investors to assume the risks associated with first-of-a-kind projects.

Another option is for Government to demonstrate new technologies in the facilities it owns. It could, for example, convert Government transport vehicles to clean fuels, further improve the air conditioning and lighting energy efficiency in Government buildings, finance some carbon neutral programmes. One advantage of programmes such as these is that they demonstrate Government's commitment to climate change action and may thereby encourage similar initiatives from the private sector.

Speeding up the emergence and deployment of low-carbon technologies will ultimately require increases in – and reallocation of – the financial resources channelled into energy-related RD&D. The actual expenditure on energy-related RD&D in Hong Kong is not available. The total R&D expenditure of Hong Kong has also increased from 0.43% of the GDP in 1998 to 0.77% of the GDP in 2007, with the business sector's share rising from 29% in 1998 to 50% in 2007[38]. The R&D expenditure as a ratio to GDP and the portion of R&D expenditure invested by the private sector are low when compared to those of the neighboring and comparator economies such as Korea, Taiwan, Singapore and the Mainland.

It is not possible to measure the cost-effectiveness of RD&D measures. Costs can be estimated readily beforehand, but the effects cannot. This is because the ultimate penetration of any path-breaking innovation hinges on a series of additional incremental innovations and learning gains, which are largely unpredictable ex-ante[39]. The eventual investment and commercial penetration of new technologies happens long after the RD&D activity and because the relationship between the RD&D and the final outcome is highly uncertain. In other words, it is practically impossible to estimate to what extent the GHG emission reduction effect is attributable to RD&D. Given that the effectiveness part of the cost-effectiveness equation is difficult to assess, even *ex-post*, cost-effectiveness is practically impossible to estimate *ex-ante*. Therefore, these measures are discussed separately and not included in the HKMM model.

Price Incentive to Stimulate RD&D

Pricing GHG emissions increases expected returns from RD&D in low-carbon technologies. In the presence of learning effects, it also reduces expected cumulative deployment costs needed for existing climate-friendly technologies to become competitive. The effects of emission pricing on expected returns are likely to be largest for technologies, such as CCS, which would yield no private financial gain otherwise as they affect only the carbon intensity of energy (GHG emissions per unit of energy) but not energy efficiency (number of units of energy per unit of output). More broadly, emission pricing gives emitters a continuing incentive for emissions-reducing RD&D and technology deployment, the so-called "dynamic efficiency" of price-based mechanisms. However, the credibility of the price signal also matters since investments in RD&D and/or deployment of emerging technologies entail sunk costs. In practice, empirical evidence has found private energy-related RD&D and innovation at the company level to be responsive to past fluctuations in energy prices[40], while the fairly strong correlation until recently between fluctuations in oil price and public R&D spending suggests that governments also respond to price incentives.

1.2.10 *Water Management, Energy Use, and Carbon Emissions*

Hong Kong has enjoyed a secure and stable supply of water from the Dongjiang River in Guangdong Province, which is capable of meeting 70% to 80% of Hong Kong's raw water supply needs as well as an ultimate supply of up to 1,100 million cubic metres which could meet the projected demand up to 2030. Despite the assured supply of water from the Mainland, Hong Kong has a responsibility to contribute to water conservation in the region. In aspiring to sustainable development, the Total Water Management Strategy was promulgated in 2008 to better prepare Hong Kong for uncertainties such as acute climate change and low rainfall and so to enhance the SAR's role as a good partner to other municipalities in the Pearl River Delta[41].

The Strategy suggests that through various measures, water consumption can be reduced by 236 mcm from the projected 1,315 mcm by 2030 (compared with currently around 1,000mcm). If the water conservation target can be achieved, the carbon emissions are expected to be reduced by around 0.4% of the total, assuming other factors remain unchanged[42].

1.2.11 *Carbon Leakage and Interactions with Other Government Policy Objectives*

"Carbon leakage" is a phenomenon whereby emitters relocate from an economy with a GHG emission tax or cap to a location where they are free from that cost burden. Carbon leakage operates through two distinct channels: a competitiveness effect, and an energy-intensity effect that may also lead to increased emissions outside the participating countries. The energy-intensive effect would arise because abatement in participating countries would reduce demand for fossil fuels worldwide, pushing their price down. This may lead non-participating countries to produce and consume more energy-intensive products than they otherwise would as these become cheaper.

This may not be as significant an issue in Hong Kong as it would be in economies with substantial energy-intensive industries, which could choose to relocate to locations without limits on GHG emissions. Much of Hong

Kong's manufacturing sector relocated its productive capacity to Mainland China during the 1980s and so there are very limited large, energy-intensive industries in Hong Kong today. However, there are still some sectors of the economy that may be susceptible to the phenomenon of carbon leakage, for example, electricity generation and local or coastal shipping.

An increase in electricity prices as a result of GHG emission control policies would be unlikely to cause companies in Hong Kong to relocate. However, policy instruments such as a GHG emission tax or a GHG emission cap may act as driver for the generation facilities themselves to relocate outside of Hong Kong, depending on the size of the cost adder due to the tax or cap relative to the overall financial position. The existence of either a GHG emission tax or a GHG emission cap affecting the electricity generation industry in Hong Kong could have a significant influence both on where plants are located and on the competitive position of Hong Kong-based plants relative to competing plants in Mainland China if there was not a similar constraint on generators in Mainland China. Thus the imposition of a tax or a cap in Hong Kong could simply move GHG emissions off Hong Kong's inventory without reducing emissions either for the PRC as a whole or globally. This effect would likely be exacerbated if wholesale (generation supply) competition was introduced to the Hong Kong and southern China electricity sector while a tax or cap was applied in Hong Kong, but not in Mainland China.

2 METHODOLOGY AND ANALYTICAL APPROACH

This section describes the Hong Kong MARKAL-MACRO (HKMM) model, the development of the Base Case.

2.1 QUANTITATIVE APPROACH

An integrated energy-economic-environmental modelling framework is an essential tool for carrying out quantitative analysis of climate change mitigation. The Hong Kong MARKAL-MACRO model has been selected as the primary tool for this assessment, since it is uniquely suited to the framework listed in the *Reporting on Climate Change: User Manual for the Guidelines on National Communications from non-Annex I Parties*[43]. More than 60 countries (including China) use country-specific MARKAL-MACRO models for GHG mitigation analysis, which enables simple comparison of cross-country results on a consistent basis.

2.1.1 Overview of MARKAL-MACRO Model

MARKAL-MACRO model is an integration of a bottom-up MARKAL model and a top-down MACRO module. MARKAL provides a framework to evaluate resource and technology options within the context of the entire energy/environment system. It captures the market interactions among fuels to be used for power generation (eg competition between LNG and coal) and other processes to meet end-use demands. It explicitly tracks the vintage structure of all capital stocks in the economy that produces, transports, transforms or uses energy. In MARKAL, the entire energy system is represented as a network, based on the Reference Energy System (RES) concept, which depicts all possible flows of energy from resource extraction, through energy transformation, distribution and transportation, to end-use devices that satisfy the demands of useful energy services. The solution algorithm evaluates all resource and technology options within the context of the entire energy system and reaches a least-cost solution at partial equilibrium of the energy sector. The model evaluates each of the available energy technologies by looking at the type and amount of fuel consumed, capital and operating costs, availability constraints and capital stock turnover. The model also evaluates the cost and availability of domestic and imported energy resources, including all of the intermediate processing and conversion costs and efficiencies, as well as and other assumptions such as electric generation reserve requirements and environmental constraints.

The top-down component MACRO is a one-sector neoclassical growth model based on the maximization of a utility function subject to a national budget constraint. National output is produced by a single sector, represented by a nested production function with constant elasticity of substitution between three inputs (Labour, Capital and Energy). The linkage between MARKAL and MACRO is formulated at the level of demands for energy services. In MARKAL these demands are specified exogenously in the reference case, and are then endogenously altered by the model for alternative scenarios. MARKAL-MACRO uses a different approach: the demands are variables of the model that are aggregated to become the Energy input into the MACRO production function, alongside Labour and Capital. Merging these two components results in a new model that captures the characteristics of an inter-temporal general equilibrium model, while retaining the rich technological details of MARKAL. The equilibrium is based on the assumption of perfect foresight and competitive markets in the sense of neo-classical economic theory. The solutions of the integrated model maximize social utility while assuring the least life-cycle costs in the energy system that meets the end-use service demands for each sector. A detailed description of the model can be found at the website of the Energy Technology and Systems Analysis Program[44] operated by the International Energy Agency.

2.1.2 *Development of Hong Kong MARKAL-MACRO Model*

The overall approach to developing the Base Case is to update the existing HKMM model using the latest energy and economic information available. The 2009 version of the model developed for this assessment involves a comprehensive update in data input and enhancement in energy system configuration built in an earlier version of the model[45,46]. To establish the Base Case, all parametric values and assumptions (technical, environmental, and economic) required in the model were updated based on the latest available data and trends for shaping the future Hong Kong energy markets (2005 – 2030). The model solution attains an inter-temporal general equilibrium that provides optimal energy demand-supply balances and development path, the associated environmental emissions and economic costs (eg the impact on GDP).

2.1.3 *Base Case and Development*

For the purpose of measuring the energy-environmental-economic impact of the mitigation scenarios formulated in the Climate Change Mitigation Assessment (the Study), it is necessary to develop a Base Case. The Base Case developed in the Hong Kong MARKAL-MACRO (HKMM) model provides energy supply-demand projections in a detailed and disaggregated pattern. This is required to model the individual mitigation measures at the end-use/technology level. The fuel and technology specific flows in the energy system also facilitate more accurate accounting of their associated environmental emissions. *Annex A* provides a description of how the Base Case is formulated. It also identifies the data resources and major assumptions used.

Although the Base Case projects a "business as usual" energy system path by incorporating existing and planned measures and development programs into the model, it should not be taken as the prevailing energy market for the future in the absence of additional mitigation policies and measures. Rather, it provides a reference basis to evaluate impacts of additional alternative scenarios, representing recommended policies and measures, to provide useful insights into the future and the impacts of these scenarios. The uncertainties inherent in any long-term scenario (eg GDP projection, population growth, future energy prices) suggest that, it is most useful to focus only on the differences in the results between the mitigation scenarios and the Base Case rather than on the absolute numerical results in a single scenario. It is the differences, not the absolute results that reflect the impact of the additional technologies, policies and measures.

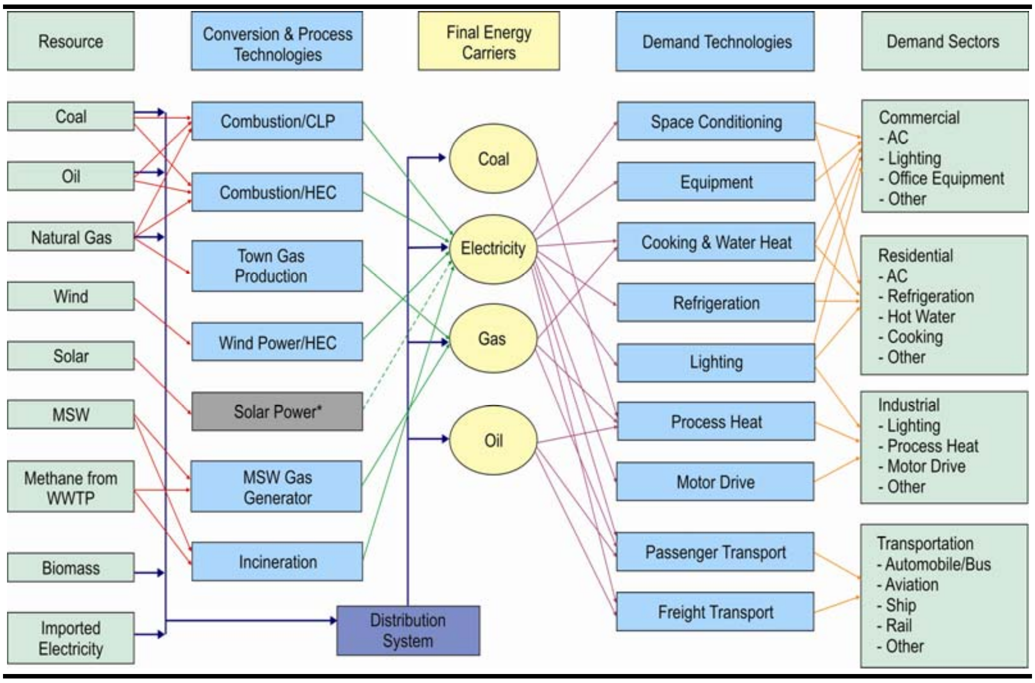
2.1.4 Base Case Energy System Data Input and Organization

The Reference Energy System (RES) underlying the MARKAL-MACRO modelling system requires input data (actual and projected) from primary energy supply (eg diesel fuel imports), intermediate conversion and process (eg electricity generation), to end-use technologies (eg air conditioners) that satisfy energy service demands (eg space conditioning). Each element in the RES is characterized by three groups of data: technical (eg efficiency), economic (eg capital cost), and environmental (eg carbon emission coefficient). *Table 2.1* shows the six main data input categories, including the four energy system building blocks depicted in *Figure 2.1*: resources/primary energy supply, conversion & process technologies, end-use technologies, and demand for energy services. The other two categories are economic parameters of energy carrier/technology and emission factors associated with elements within the four building blocks.

Table 2.1 Data Category

Data Category	**Model Input**
Demand for Energy Service; End-use Technologies	Demand Module
Conversion Technologies	Power Sector; Process
Primary Energy Supply	Resource
Price of energy carrier/technology	Price
Emission Factors	Emission Factors

Figure 2.1 *HK Simplified RES*

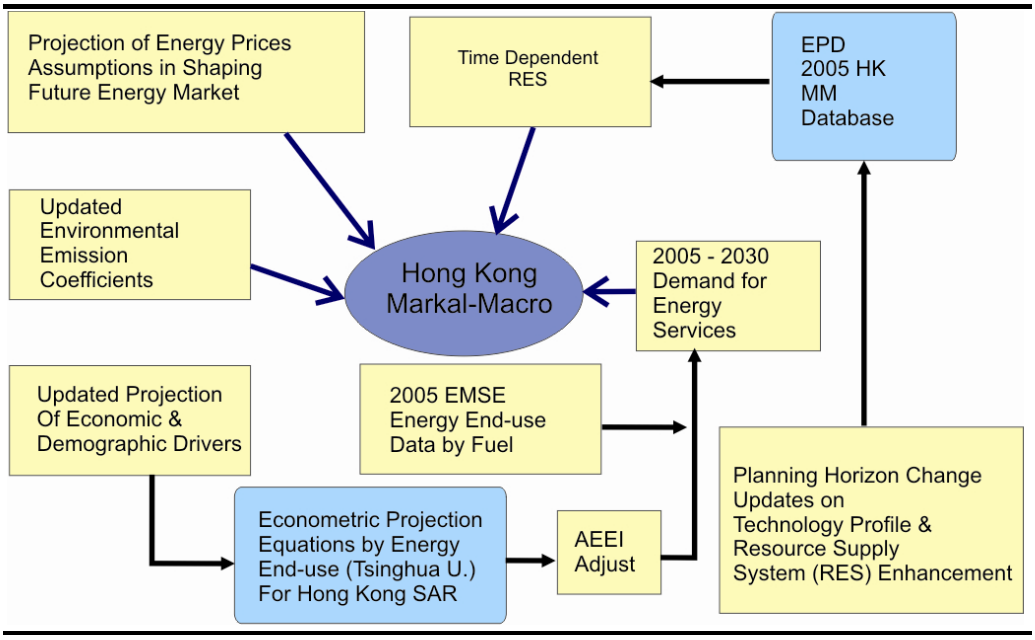


Source: ERM and BNL.
Note: Technologies in gray boxes are those that can be developed in HK in the future.

2.1.5 *Development of the Hong Kong Base Case*

Figure 2.2 depicts schematics of the interrelated tasks in the development of the Base Case. In general, Hong Kong specific historical energy demand-supply data were used to establish the base year (2005) RES in the Hong Kong MARKAL-MACRO model. The base year RES provides a balanced stance (partial equilibrium) based on which future energy-environmental-economic scenarios can be formulated. If no Hong Kong specific data are available, data can be taken from many existing MARKAL databases in the world community as a starting point.

Figure 2.2 HKMM Baseline Dataflow



Source: ERM and BNL.

Annex A details the structure of different modules, the sources of data, and key assumptions for the projections. It should be noted that there are uncertainties inherent in the input data and projections used to develop the Base Case. In considering the results of modelling analysis, it is most useful to focus on the differences between the scenarios representing the situation with and without (Base Case) the additional technologies, policies and measures selected for the study, rather than on the absolute numerical results for either scenario. This approach minimizes the significance of these uncertainties.

Please note that the Hong Kong MARKAL-MACRO model accounts for energy related CO_2 emissions. Other carbon emissions from non-energy sources are estimated outside the Model based on historical trend and their driving factors. The energy related CO_2 emissions and other carbon emissions under different sectors are added up to derive the total carbon emissions (CO_{2-e}).

2.2 *BASE CASE RESULTS*

The major indicators for the Base Case derived from the HKMM model results are summarized in *Table 2.2*.

Table 2.2 Major Indicators: Base Case

	2005	2010	2015	2020	2025	2030	Annual Growth 2005-2030(%)	Total Growth 2005-2020 (%)	Total Growth 2005-2030 (%)
Population (Thousand)	6,813	7,094	7,391	7,719	8,035	8,312	0.80	13	22
GDP (Billion 2005 HK$ Exchange Rate) (1)	1,383	1,596	1,911	2,258	2,567	2,905	3.01	63	110
Per Capita GDP (Thousand HK$)	203	225	259	293	320	349	2.20	44	72
Primary Energy (TJ) (2)	591,601	631,258	678,823	744,786	770,817	822,488	1.33	26	39
Final Energy (TJ) (3)	294,968	306,121	348,700	396,211	432,533	460,729	1.80	34	56
Carbon Emissions (Million tonnes $CO_{2\text{-}e}$)	42.0	42.8	44.1	46.1	42.6	44.8	0.26	10	7
Primary Energy Intensity (TJ/Billion HK$) (4)	428	395	355	330	300	283	-1.64	-23	-34
Final Energy Intensity (TJ/Billion HK$)	213	192	182	175	168	159	-1.18	-18	-26
Carbon Emissions per Capita (Tonnes $CO_{2\text{-}e}$) (5)	6.16	6.04	5.97	5.97	5.30	5.39	-0.53	-3	-13
Carbon Intensity (kg $CO_{2\text{-}e}$/ HK$)	0.0304	0.0268	0.0231	0.0204	0.0166	0.0154	-2.68	-33	-49

Notes:

(1) The GDP projections are based on the best available working assumptions for future economic growth. It is noted that the growth rate working assumptions from 2014 onwards are subject to a large degree of uncertainty.

(2) Primary energy is energy found in nature that has not been subjected to any conversion or transformation process. Examples of primary energy resources include coal, crude oil, sunlight, wind, running rivers, vegetation, and uranium.

(3) Final energy refers to the amount of energy consumed by final users for all energy purposes such as heating, cooking and driving machinery, but excludes non-energy usages such as using kerosene as solvent. It differs from primary energy in that the latter includes all energy used or lost in the energy transformation and the distribution process.

(4) Energy intensity is a measure of the energy efficiency of a nation's economy. It is calculated as units of energy per unit of GDP.

(5) Carbon intensity in this study is calculated as total GHG emissions per unit GDP.

2.2.1 *Energy and Energy Intensities*

The total primary energy consumption in the Base Case is projected to grow at an annual rate of 1.33% during the period 2005-2030, while the final energy demand is projected to grow at an annual rate of 1.80%. Compared to the projected 3.01% annual growth rate in GDP[47] over the same period, the decoupling trend between GDP and primary energy consumption implied in the annual growth rates is consistent with the historical data reported by the Hong Kong Census and Statistics Department (C&SD). During the period 1997-2007, C&SD's data show that primary energy consumption grew at 2.1% per year when the annual growth rate in GDP was 3.8% in real terms. The projected values in GDP, final energy demand and primary energy consumption imply that the final energy intensity will decrease from 213 TJ/Billion HK$ in 2005 to 159 TJ/Billion HK$ in 2030. The primary energy intensity, currently among one of the lowest in the world, will further decrease from 428 TJ/Billion HK$ to 283 TJ/Billion HK$ during the same period.

2.2.2 *Carbon Emissions and Intensities*

The annual growth rate of total carbon emissions (0.26% per year between 2005 and 2030) is projected to decouple from primary energy growth, which increases at an annual rate of 1.33% over the same period. In comparison, the total carbon emission grew at an annual rate of 1% during the period 1990–2006, as reported in ***Appendix A: Update of GHG Inventory***. The relatively low carbon emission growth rate projected is mainly due to the scheduled decommissioning of coal-fired power plant units in Hong Kong by 2030. The phase-out of existing coal-fired power plants and the assumption in the Base Case to replace them with high efficiency combined cycle gas turbines are the main factors that limit the carbon emission growth in Hong Kong. As a result, Hong Kong's carbon emission per GDP output, already one of the lowest in the world, is projected to continuously decrease from 0.0304 kg CO_{2-e} per HK$ in 2005 to about 0.0154 kg CO_{2-e} per HK$ in 2030. In terms of carbon emissions per capita, the model projects a very slight decrease (-0.53% per year for the period 2005-2030), based on the population growth rate provided by C&SD.

2.2.3 *Sensitivity of MARKAL Model Output to GDP Projections*

The model outputs might be different should deviations occur for key assumptions. Sensitivity of Base Case MARKAL Model outputs to GDP projections are discussed under this section.

Figure 2.3 shows the percent change in final energy demand while *Figure 2.4* depicts the percent change in carbon emissions under different GDP projection paths, ranging from 5% above to 5% below their respective values in the Base Case for each period. In absolute terms, these deviations represent significant differences from the Baseline GDP in dollar amounts over time. The Hong Kong MARKAL output from these sensitivity runs indicate that the percent changes in final energy demand and carbon emissions are linearly proportional to the percentage change in GDP in a converging pattern. Since this study focuses on the differences in the model results between the mitigation scenarios and the Base Case (ie, the impact of additional technologies, policies and measures), the uncertainties inherent in the long-term GDP projections have only a minimal impact on the general conclusions that can be drawn from the Study.

Figure 2.3 *Final Energy Demand Change by GDP Projection*

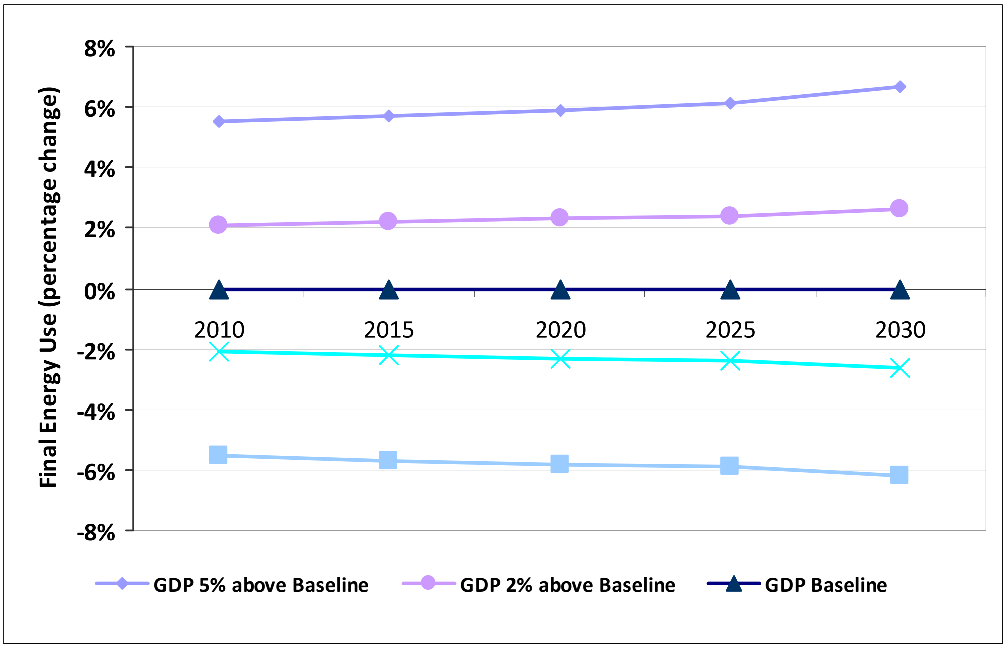
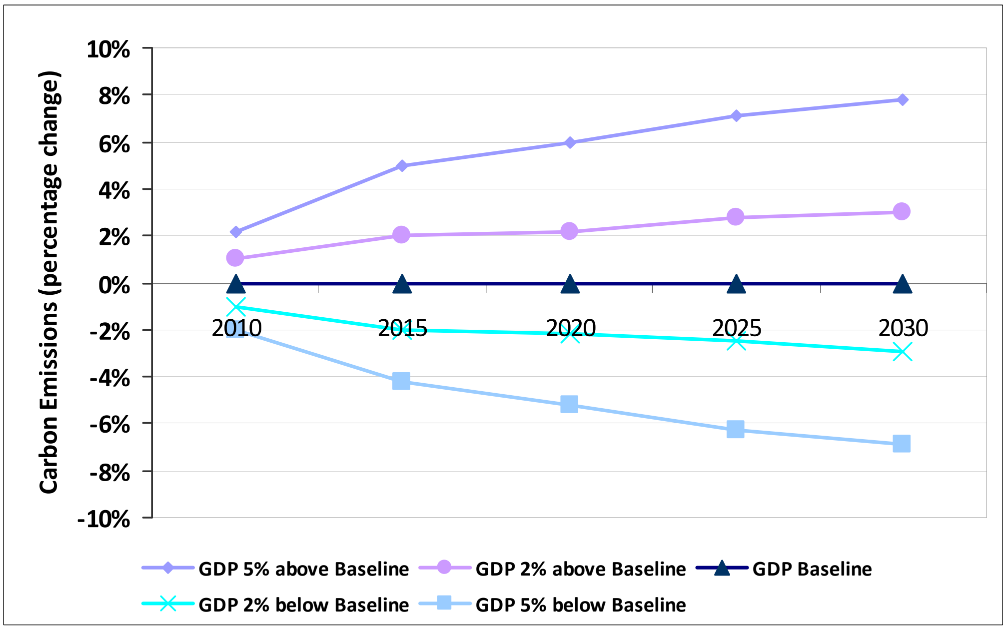


Figure 2.4 *Carbon Emissions by GDP Projection*



3 SCENARIO FORMULATION AND ANALYSIS

The Study examined three scenarios in the mitigation analysis: Scenarios 1 to 3. These three scenarios were formulated by incorporating specific policy targets and market penetration rates for measures selected in four sectors (Buildings, Transport, Electricity Generation, and Waste), as described in the *Table 3.1*[48]. It should be noted that the Scenarios were developed for the purpose of analyzing the effectiveness of alternate packages of practices and policies and hence to inform a decision on the likely ranges of emissions reduction that may be viable. There remains a degree of uncertainty both as to the practices and policies that will ultimately be adopted and the degree to which they are effective. The degree of uncertainty is greater in the 2020 to 2030 time period that in the period up to 2020 and hence the policies and measures assumed for the purposes of this analysis may well be subject to change.

3.1 ALTERNATIVE SCENARIO ASSUMPTIONS

Scenario 1 (the 'AQO Scenario') includes relevant mitigation measures proposed in the AQO Study[49], including the increased use of natural gas and renewable energy sources for electricity generation, wider use of road vehicles using clean fuels, and enhanced energy efficiency in the building and appliance sector. It required some refinement of the AQO policy options for the following reasons.

- The AQO Study options were considered individually rather than in combination and thus not compatible with MARKAL-MACRO (MM), which is a dynamic macroeconomic model and considers measures in an integrated manner.

- For a number of options examined in the AQO Study, the required input parameters and assumptions for the HKMM model were not available. In these cases ERM and US's Brookhaven National Laboratory (BNL, the model developer) have made assumptions based upon our understanding of the particular policy or measure (as implemented internationally) and/or the technology in question.

- Some measures proposed in the AQO Study were not assessed in the HKMM model either because they are not associated with GHG reduction or because they are not considered to be commercially viable within the necessary timeframe.

Specifically, Scenario 1 assumes the following.

Building and Appliance Sector[50]

- Annual 0.6% energy saving in total energy consumption in Hong Kong from energy efficiency improvement through mandatory implementation of Building Energy Code (BEC) by 2015.
- 0.011% energy saving in total energy consumption in Hong Kong from energy efficiency improvements in street lighting and traffic signals by 2020.
- 0.5% energy saving in total energy consumption in Hong Kong from district cooling system by 2020.
- 0.3% energy saving of total energy consumption in Hong Kong from energy efficiency improvements in electrical appliances for domestic use by 2015.

Transport Sector

- Wider use of hybrid, electric powered, and biodiesel vehicles:
  - Penetration rates of hybrid/EV or other vehicles with similar environmental performance by 2020: 30% private cars, 15% buses, 15% heavy goods vehicles (HGVs) and light goods vehicles (LGVs)
  - Penetration rates of hybrid/EV or other vehicles with similar environmental performance by 2030: 50% private cars, 50% buses, 50% HGVs and LGVs

Electricity Generation

- All power plants will retire according to their expected life.
- RE is to meet 4% of the local demand for electricity by 2020 and 6% by 2030 (including RE generated locally or imported from the Mainland)[51].
- Import of nuclear power maintained at the same level as in 2005.
- Apart from electricity generated by RE, nuclear, and remaining coal, all other local electricity consumption is from natural gas by 2030.

3.1.1 Scenario 2

Scenario 2 (the 'Accelerated Scenario') builds upon Scenario 1 and includes additional efforts on measures to increase energy efficiency and reduce energy demand, particularly in the building and transport sectors. Local sources of renewable energy such as waste-to-energy facilities are utilised by 2020. This scenario also assumes a certain level of integration of the power system between Hong Kong and its neighbouring areas. Electricity imported from Mainland China in 2020 is the same as that in 2005. In 2030, the scenario assumes, as a stress test, the notion that 50% of the electricity demand could be met by sources from the Mainland with no associated carbon emissions[52]. Specifically, Scenario 2 assumes the following.

Building and Appliance Sector

- Up to 50% energy saving of major installations in all new commercial buildings through measures such as expanding the scope, and tightening the requirements of the Building Energy Codes by 2020.

- 0.011% energy saving in total energy consumption in Hong Kong from energy efficiency improvements in street lighting and traffic signals by 2020.

- Up to 20% of all commercial buildings will be up to 50% better in refrigeration performance compared with buildings using regular air conditioners by 2020; up to 50% energy efficiency improvement in all commercial buildings through measures such as expanding the use of district cooling system (DCS) and water-cooled air conditioning system (WACS). Energy efficiency improvement is compared with that of the regular air conditioning system.

- Up to 50% cooling demand reduction by 2020 in all new commercial buildings from measures such as new overall thermal transfer value (OTTV) standards and extensive green roofing.

- Appliances sold in the market in 2020 will be up to 25% more energy efficient; appliances sold in the market in 2030 will be up to 50% more energy efficient, compared with 2005 level by expanding the scope and tightening energy efficient electrical appliance standards.

- Up to 15% Energy efficiency improvement in up to 25% of existing commercial buildings by 2020; up to 15% energy efficiency improvement in all existing commercial buildings from improving energy efficiency from Building Environmental Management System by 2030.

Transport Sector

- Wider use of hybrid and electric powered vehicles (EV):
    - Penetration rates of hybrid/EV or other vehicles with similar environmental performance by 2020: 30% private cars, 15% buses, 15% HGVs and LGVs.
    - Penetration rates of hybrid/EV or other vehicles with similar environmental performance by 2030: 50% private cars, 50% buses, 50% HGVs and LGVs.

- Petrol blended with 10% ethanol by 2020 (E10)[53].

- Diesel blended with 10% biodiesel by 2020 (B10)[54].
- Implementation of the Hong Kong "Importers' Average Fleet Efficiency" standard by 2020 - new vehicles will be 20% more energy efficient than the 2005 market average.

Waste Sector

- Waste-to-energy facility:
  - One IWMF with a treatment capacity of 3,000 tonnes/day by 2020.
  - Sufficient IWMFs to treat all MSW in HK by 2030 (projected to be 10,300 tonnes/day in 2030).
  - two OWTFs operating at full capacity of 400 tonnes per day[55].
- Full utilization of the recovered landfill gas.
- Full utilization of gas generated from waste water treatment.
- One sludge treatment facility operating at full capacity by 2020.

Electricity Generation

- All power plants retire according to their expected life.
- Import of nuclear power maintained at the same level until 2020; approximately 50% of local electricity consumption by 2030 is from sources in the Mainland with no associated carbon emissions[56].
- Apart from electricity generated by RE, nuclear, and remaining coal, all other local electricity consumption is from natural gas by 2030.

3.1.2 Scenario 3

Scenario 3 (the 'Aggressive Scenario') builds upon Scenario 2 and accelerates the integration of the power system in Hong Kong with its neighbouring areas. It assumes that Hong Kong would make full use of natural gas supply guaranteed by the Mainland under the relevant Memorandum of Understanding (MOU) on Energy Co-operation, for electricity generation in 2020. It also assumes that nuclear electricity imported from the Mainland in 2020 would be able to meet 50% of the local demand for electricity. Specifically, Scenario 3 assumes the following.

Building and Appliance Sector

- Up to 50% energy saving of major installations in all new commercial buildings through measures such as expanding the scope, and tightening the requirements of the Building Energy Codes by 2020.

- 0.011% energy saving in total energy consumption in Hong Kong from energy efficiency improvements in street lighting and traffic signals by 2020.

- Up to 20% of all commercial buildings will be up to 50% better in refrigeration performance compared with buildings using regular air conditioners by 2020; up to 50% energy efficiency improvement in all commercial buildings through measures such as expanding the use of DCS and WACS. Energy efficiency improvement is compared with that of the regular air conditioning system.

- Up to 50% cooling demand reduction by 2020 in all new commercial buildings from measures such as new OTTV standards and extensive green roofing.

- Appliances sold in the market in 2020 will be up to 25% more energy efficient; appliances sold in the market in 2030 will be up to 50% more energy efficient, compared with 2005 level by expanding the scope and tightening energy efficient electrical appliance standards.

- Up to 15% Energy efficiency improvement in up to 25% of existing commercial buildings by 2020; up to 15% energy efficiency improvement in all existing commercial buildings from improving energy efficiency from Building Environmental Management System by 2030.

Transport Sector

- Wider use of hybrid and electric powered vehicles (EV):
  - Penetration rates of hybrid/EV or other vehicles with similar environmental performance by 2020: 30% private cars, 15% buses, 15% HGVs and LGVs.
  - Penetration rates of hybrid/EV or other vehicles with similar environmental performance by 2030: 50% private cars, 50% buses, 50% HGVs and LGVs.

- Petrol blended with 10% ethanol by 2020 (E10).

- Diesel blended with 10% Biodiesel by 2020 (B10).

- Implementation of the Hong Kong "Importers' Average Fleet Efficiency" standard by 2020 - new vehicles will be 20% more energy efficient than the 2005 market average.

Waste Sector

- Waste-to-energy facility:
  - One IWMF with a treatment capacity of 3,000 tonnes/day by 2020.

- Sufficient IWMFs to treat all MSW in HK by 2030 (projected to be 10,300 tonnes/day in 2030).

- Two OWTFs operating of 400 tonnes per day by 2020.

- Full utilization of the recovered landfill gas.
- Full utilization of gas generated from wastewater treatment.
- One sludge treatment facility operating at full capacity by 2020.

<u>Electricity Generation</u>

- 10% coal penetration in 2020, and zero in 2030.
- Making full use of natural gas supply guaranteed by the Mainland under the relevant Memorandum of Understanding (MOU) on Energy Co-operation for electricity generation.
- Nuclear electricity imported from the Mainland would be able to meet 50% of the local demand for electricity from 2020.
- Local RE sources are sufficient to meet 3-4% of local electricity consumption in 2020, and 4% in 2030.
- No primary energy source accounts for more than around 50% of Hong Kong's total electricity supply.

3.1.3 Cross-sectoral Measure - Carbon Tax

Analysis in the Study applies a carbon tax schedule from HK$500/tonne to HK$5,000/tonne of carbon (ie approximately US$17 to US$175/tonne CO_{2-e}) to the three mitigation scenarios. By introducing progressively higher carbon taxes and recording the quantity of abated emissions from the MARKAL-MARCO model output, marginal abatement cost (MAC) curves can be generated for different portfolios of policies and measures specified in the different scenarios.

Table 3.1 Alternative Scenario Assumptions

Measures	Scenario 1 (2005-2030)	Scenario 2 (2005-2030)	Scenario 3 (2005-2030)
Buildings and Appliances (1)			
Expanding the scope and tighten the requirements of the Building Energy Codes	0.6% energy saving of total energy consumption by 2015	Up to 50% energy saving of major installations in all new commercial buildings by 2020	Up to 50% energy saving of major installations in all new commercial buildings by 2020
Expanding the use of district cooling system (DCS)/water-cooled air conditioning system (WACS)	0.5% saving in total energy consumption by 2020	Up to 20% of all commercial buildings will be up to 50% better in refrigeration performance compared with buildings using regular air conditioners by 2020; All commercial buildings will be up to 50% better in refrigeration performance compared with buildings using regular air conditioners by 2030	Up to 20% of all commercial buildings will be up to 50% better in refrigeration performance compared with buildings using regular air conditioners by 2020; All commercial buildings will be up to 50% better in refrigeration performance compared with buildings using regular air conditioners by 2030
Reducing energy demand in new buildings through e.g. tightening the overall thermal transfer value (OTTV) standards and promoting wider adoption of green roofing	N/A	Up to 50% cooling demand reduction in all new commercial buildings by 2020	Up to 50% cooling demand reduction in all new commercial buildings by 2020
Expanding the scope and tightening the energy efficient electrical appliance standards for domestic use	0.3% energy saving of total energy consumption by 2015	Appliances sold in the market in 2020 will be up to 25% more energy efficient, compared with 2005 level; Appliances sold in the market in 2030 will be up to 50% more energy efficient, compared with 2005 level	Appliances sold in the market in 2020 will be up to 25% more energy efficient, compared with 2005 level; Appliances sold in the market in 2030 will be up to 50% more energy efficient, compared with 2005 level
Improving energy efficiency from Building Environmental Management System	N/A	Up to 15% energy efficiency improvement in up to 25% of existing commercial buildings by 2020; Up to 15% energy efficiency improvement in all existing commercial buildings by 2030	Up to 15% energy efficiency improvement in up to 25% of existing commercial buildings by 2020; Up to 15% energy efficiency improvement in all existing commercial buildings by 2030
Transport			
Wider use of motor vehicles running on alternative fuel	2020: Hybrid/EV or other vehicles with similar performance: 30% private cars, 15% buses, 15% HGV and LGV 2030: Hybrid/EV or other vehicles with similar performance: 50% private cars, 50% buses, 50% HGV and LGV	2020: Hybrid/EV or other vehicles with similar performance: 30% private cars, 15% buses, 15% HGV and LGV 2030: Hybrid/EV or other vehicles with similar performance: 50% private cars, 50% buses, 50% HGV and LGV	2020: Hybrid/EV or other vehicles with similar performance: 30% private cars, 15% buses, 15% HGV and LGV 2030: Hybrid/EV or other vehicles with similar performance: 50% private cars, 50% buses, 50% HGV and LGV
Petrol blended with 10% Ethanol (E10)	N/A	All petrol to be blended with 10% of ethanol by 2020	All petrol to be blended with 10% of ethanol by 2020
Diesel blended with 10% Biodiesel (B10)	N/A	All diesel to be blended with 10% of biodiesel by 2020	All diesel to be blended with 10% of biodiesel by 2020
Implementation of "Importers' Average Fleet Efficiency" standard	N/A	New vehicles will be 20% more energy efficient than the 2005 market average by 2020	New vehicles will be 20% more energy efficient than the 2005 market average by 2020
Waste			

Measures	Scenario 1 (2005-2030)	Scenario 2 (2005-2030)	Scenario 3 (2005-2030)
Construction and operation of waste-to-energy facilities	N/A	One IWTF with a treatment capacity of 3,000tonnes/day by 2020; Sufficient IWMFs to treat all MSW in HK by 2030. Two OWTFs operating at a total capacity of 400 tonnes per day by 2020.	One IWTF with a treatment capacity of 3,000tonnes/day by 2020; Sufficient IWMFs to treat all MSW in HK by 2030. Two OWTFs operating at a total capacity of 400 tonnes per day by 2020.
Utilization of landfill gas as energy source	N/A	Full utilization of recovered landfill gas	Full utilization of recovered landfill gas
Utilization of gas generated from wastewater treatment	N/A	Full utilization	Full utilization
Utilization of sludge treatment with energy recovery	N/A	One sludge treatment facility operating at full capacity	One sludge treatment facility operating at full capacity
Energy Supply			
Use of coal in electricity generation	All power plants retire according to their expected life	All power plants retire according to their expected life	Accounting for less than 10% of fuel mix in 2020; zero in 2030
Use of natural gas in electricity generation	Natural gas makes up the balance of the share of the overall fuel mix, after taking account of RE, nuclear import and remaining coal	Natural gas makes up the balance of the share of the overall fuel mix, after taking account of RE, nuclear import and remaining coal	Making full use of natural gas supply guaranteed by the Mainland under the relevant Memorandum of Understanding (MOU) on Energy Co-operation (2)
Import of nuclear generated electricity	Maintained at the same level as in 2005	Maintained at the same level as in 2005 until 2020; meeting 35% of the local demand for electricity 2030	Nuclear electricity imported from the Mainland to meet 50% of the local demand for electricity from 2020 (2)
Renewable energy (RE) (3)	Meeting 4% of the local demand for electricity by 2020; 6% by 2030	Meeting 4% of the local demand for electricity by 2020; 15% by 2030	Meeting 3-4% of the local demand for electricity by 2020; 4% in 2030

Notes

(1) The purpose of the Study is to assess the impacts of various mitigation measures and scenarios on GHG emission abatements. Measures and assumptions in mitigation scenarios are based on international technology and policy reviews. They are not implementation targets, but provide an envelope within which the impacts of alternative assumptions can be inferred. Detailed feasibility studies for individual measures are required at later stages, taking into account limitations, uncertainties and practicability of the measures within Hong Kong's local context.

(2) Assumptions provided by the Government.

(3) RE includes wind energy, and energy recovered from landfill gas (LFG), Integrated Waste Management Facilities (IWMF) and Organic Waste Treatment Facilities (OWTF). Scenarios 1 and 2 include RE imported from the Mainland, although the availability of this additional amount of RE sources in the neighbouring areas which may be able to supply electricity to Hong Kong in a technically feasible and cost-effective manner is subject to further studies.

3.2 *MITIGATION SCENARIO ANALYSIS*

This section evaluates the impact and cost-effectiveness of the three alternative scenarios by comparing their key model output with the Base Case.

The key criteria used for evaluating the policies and measures in subsequent sections by the HKMM model are categorized in the three basic types of costs and benefits:

- **Energy:** effects on energy flow and technological activities, such as oil and gas imports, electricity generation capacity mix, etc.
- **Environmental:** effects on GHG emissions and local air pollutants.
- **Economic:** effects on GDP and marginal abatement cost of carbon.

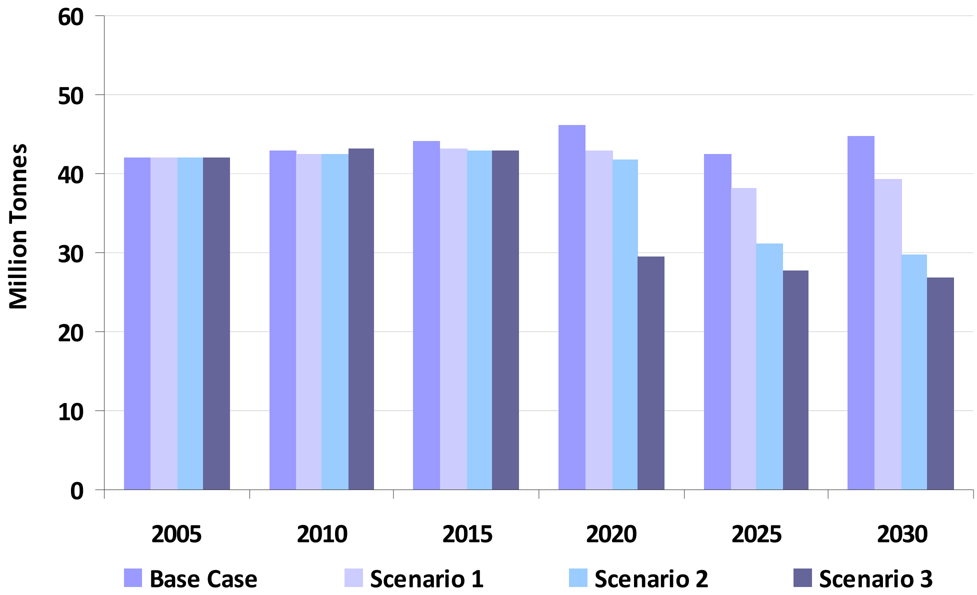
3.2.1 *Carbon Emissions Abatement and GDP Impact*

Table 3.2 and *Figure 3.1* show that the total annual carbon emission in 2030 falls to 39.3 million tonnes CO_{2-e} for Scenario 1, 29.8 million tonnes CO_{2-e} for Scenario 2, and 26.8 million tonnes CO_{2-e} for Scenario 3, down from 44.8 million tonnes CO_{2-e} projected for the Base Case. The reduced emissions in 2030 are 6%, 29% and 36% below the 2005 carbon emission level for Scenarios 1, 2 and 3, respectively. In the Base Case emissions were predicted to be 7% above the 2005 level by 2030.

Table 3.2 Carbon Emissions in Hong Kong by Scenario (Million Tonnes CO_{2-e})

	2005	2010	2015	2020	2025	2030	2020 vs. 2005	2030 vs. 2005
Base Case	42.0	42.8	44.1	46.1	42.6	44.8	10%	7%
Scenario 1	42.0	42.6	43.1	43.0	38.3	39.3	2%	-6%
Scenario 2	42.0	42.4	42.9	41.9	31.0	29.8	0%	-29%
Scenario 3	42.0	43.3	43.0	29.5	27.8	26.8	-30%	-36%

Figure 3.1 *Carbon Emissions in Hong Kong by Scenario (Million Tonnes CO_{2-e})*



Results of Scenario 1 show that although co-benefits from measures targeted at improving air quality are found to be large, and may help to offset mitigation costs, they alone are unlikely to provide sufficient incentives to achieve an aggressive GHG emission reduction target.

In Scenarios 1 and 2, most of the GHG emissions reductions are achieved after 2020. This is mainly due to the fact that most of coal-fired power plant units are assumed to be decommissioned between 2020 and 2025. In Scenario 3, however, most of the GHG emission abatement is achieved between 2015 and 2020 as about half of the electricity is from nuclear sources by 2020.

The GDP is projected to grow at an annual average growth rate of 3.01% in the Base Case, and it is not predicted to be materially affected under the alternative scenarios. The annual average GDP growth rate for the period 2005 to 2030 is 0.02, 0.03, and 0.06 percentage points higher than that under the Base Case for Scenario 1, 2 and 3 respectively. These additional GDP increases are attributable to the low carbon intensities and low cost (no regret) mitigation measures included in the demand sectors (ie buildings and transport) as well as the lower energy costs in the alternative scenarios when compared with the Base Case.

3.2.2 *Carbon Intensity*

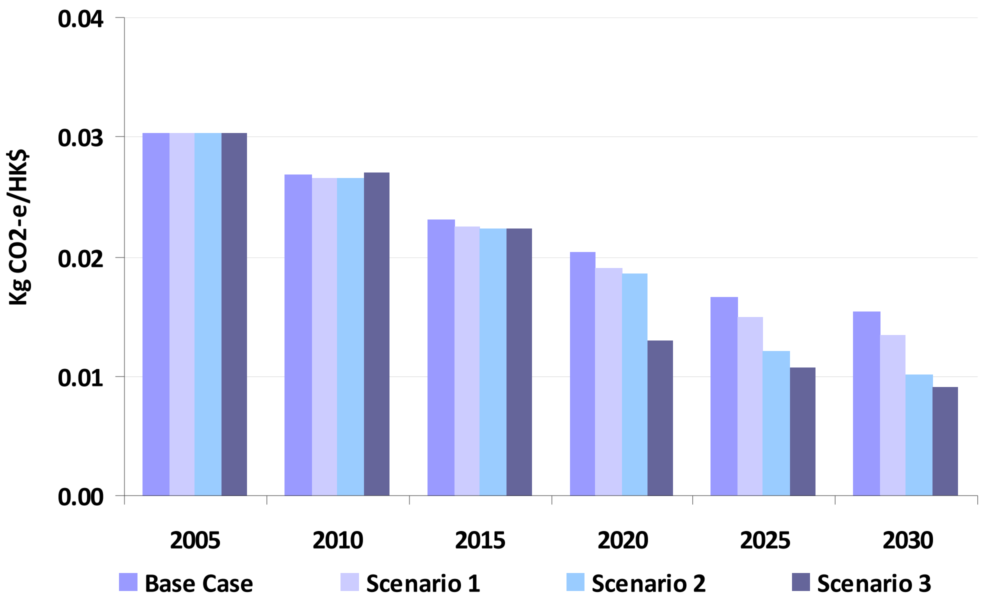
In 2005, the carbon intensities in Hong Kong, both in terms of GHG emissions per GDP value or on a per capita basis are among the lowest in the world's developed economies[58]. As shown in *Table 3.3* and *Figure 3.2*, the intensity against GDP in 2030 is projected to decrease to 0.0154, 0.0135, 0.0102, and 0.0091 kg CO_{2-e} /HK$ GDP by 2030 in the Base Case, Scenario1, Scenario 2, and Scenario 3, respectively, from the current level of 0.0304 kg CO_{2-e} /

HK$GDP. Taking into account the uncertainties of the MARKAL-MACRO model and the projection in economic output, Scenario 3 can be expected to deliver a carbon intensity reduction of 54% to 60% by 2020[59].

Table 3.3 ***Carbon Intensity (GHG Emissions per unit GDP in kg $CO_{2\text{-}e}$/ HK$)***

	2005	2010	2015	2020	2025	2030	2020 vs. 2005	2030 vs. 2005
Base Case	0.0304	0.0268	0.0231	0.0204	0.0166	0.0154	-33%	-49%
Scenario 1	0.0304	0.0266	0.0225	0.0190	0.0149	0.0135	-37%	-56%
Scenario 2	0.0304	0.0265	0.0224	0.0185	0.0120	0.0102	-39%	-66%
Scenario 3	0.0304	0.0271	0.0224	0.0130	0.0107	0.0091	-57%	-70%

Figure 3.2 ***Carbon Intensity (GHG Emissions per unit GDP in kg $CO_{2\text{-}e}$/ HK$)***

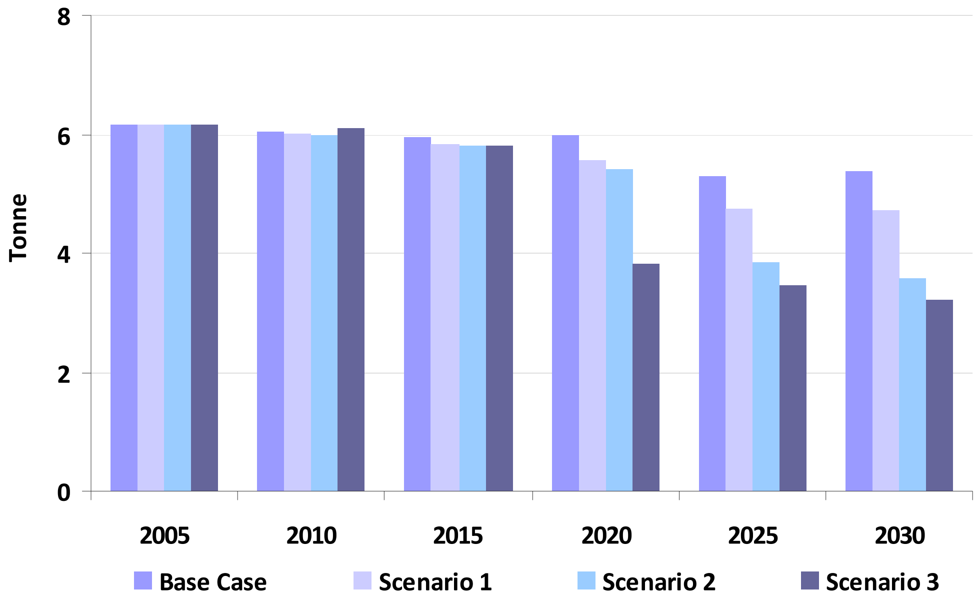


As shown in *Table 3.4* and *Figure 3.3*, the intensity of carbon emissions per capita in 2030 is projected to decrease to 5.39, 4.72, 3.58, and 3.23 tonnes $CO_{2\text{-}e}$ in the Base Case, Scenario 1, Scenario 2, and Scenario 3, respectively, from the current level of 6.16 tonnes $CO_{2\text{-}e}$. Except for Scenario 3, both measures of carbon intensity are projected to drop at a faster rate between 2020 and 2025 in all cases because most of the existing coal-fired power plant units are scheduled to decommission during this period.

Table 3.4 ***Carbon Emissions per Capita (Tonne $CO_{2\text{-}e}$)***

	2005	2010	2015	2020	2025	2030	2020 vs. 2005	2030 vs. 2005
Base Case	6.16	6.04	5.97	5.97	5.30	5.39	-3%	-13%
Scenario 1	6.16	6.00	5.83	5.57	4.76	4.72	-10%	-23%
Scenario 2	6.16	5.98	5.80	5.43	3.86	3.58	-12%	-42%
Scenario 3	6.16	6.10	5.81	3.83	3.46	3.23	-38%	-48%

Figure 3.3 Carbon Emissions per Capita (Tonne CO_{2-e})



3.2.3 *Final and Primary Energy Demand*

Table 3.5 and *Figure 3.4* present the HKMM output of final energy demand. These values represent the energy used by various end-use devices (eg air conditioning systems and passenger cars) in the demand sectors defined in the model.

Table 3.5 Final Energy Demand (TJ)

	2005	2010	2015	2020	2025	2030	2020 vs. 2005	2030 vs. 2005
Commercial								
Base Case	106,222	121,193	150,122	179,315	204,768	229,371	69%	116%
Scenario 1	106,222	121,210	148,575	171,884	193,711	219,557	62%	107%
Scenario 2	106,222	121,484	149,178	172,255	195,029	222,558	62%	110%
Scenario 3	106,222	125,667	151,104	189,068	208,572	233,738	78%	120%
Residential								
Base Case	52,857	56,049	61,143	70,218	76,031	81,103	33%	53%
Scenario 1	52,857	55,435	58,853	62,771	68,302	72,140	19%	36%
Scenario 2	52,857	55,207	59,447	63,112	68,241	78,765	19%	49%
Scenario 3	52,857	56,527	59,776	67,550	71,238	79,581	28%	51%
Transportation								
Base Case	111,866	111,577	121,929	131,826	137,753	137,879	18%	23%
Scenario 1	111,866	109,782	118,351	124,894	126,216	121,580	12%	9%
Scenario 2	111,866	109,778	118,675	125,734	127,473	123,695	12%	11%
Scenario 3	111,866	110,041	118,969	127,353	128,899	124,711	14%	11%
Industrial								
Base Case	24,023	17,301	15,506	14,851	13,981	12,376	-38%	-48%
Scenario 1	24,023	17,034	15,494	14,638	13,824	12,410	-39%	-48%
Scenario 2	24,023	17,057	15,514	14,716	13,833	14,165	-39%	-41%
Scenario 3	24,023	17,999	15,683	17,885	15,926	15,252	-26%	-37%
Total								
Base Case	294,968	306,121	348,700	396,211	432,533	460,729	34%	56%
Scenario 1	294,968	303,461	341,273	374,187	402,053	425,686	27%	44%
Scenario 2	294,968	303,526	342,814	375,817	404,576	439,184	27%	49%
Scenario 3	294,968	310,234	345,533	401,857	424,636	453,282	36%	54%

Figure 3.4 *Final Energy Demand by Scenario (Thousand TJ), 2005-2030*

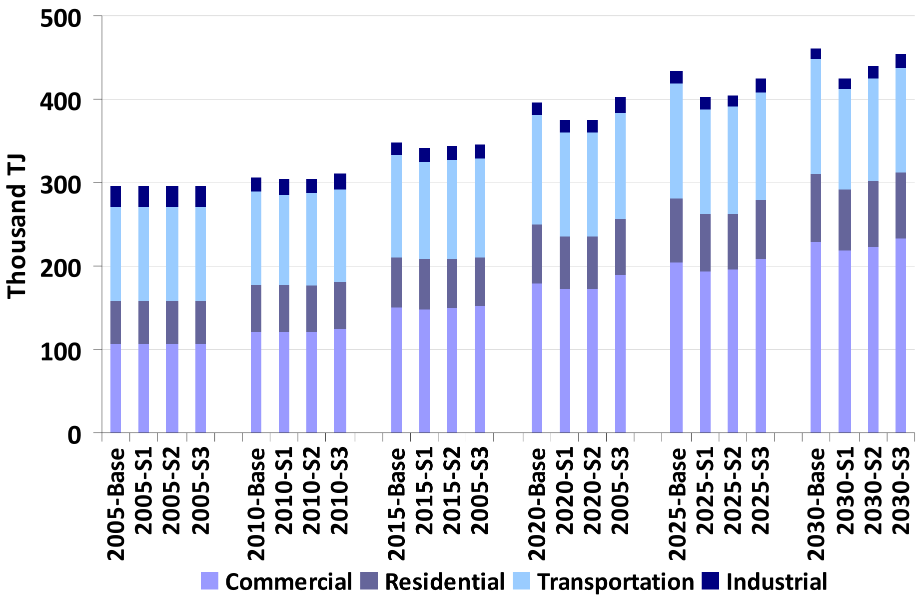


Table 3.5 and *Figure 3.4* show that the projected final demand grows more slowly in the alternative scenarios relative to the Base Case, especially in Scenarios 1 and 2, as the overall end-use efficiencies improve due to the market penetration of demand-side mitigation measures. In Scenario 3, it is projected that the energy cost will be lower than that in other scenarios. As a result, it will stimulate more economic activities not related to the energy supply sector and thus boosts the final energy demand.

Among the demand sectors, the final energy demand in the commercial sector is projected to grow at the fastest rate between 2005 and 2030 in all cases, followed by residential, transportation and the industrial sector.

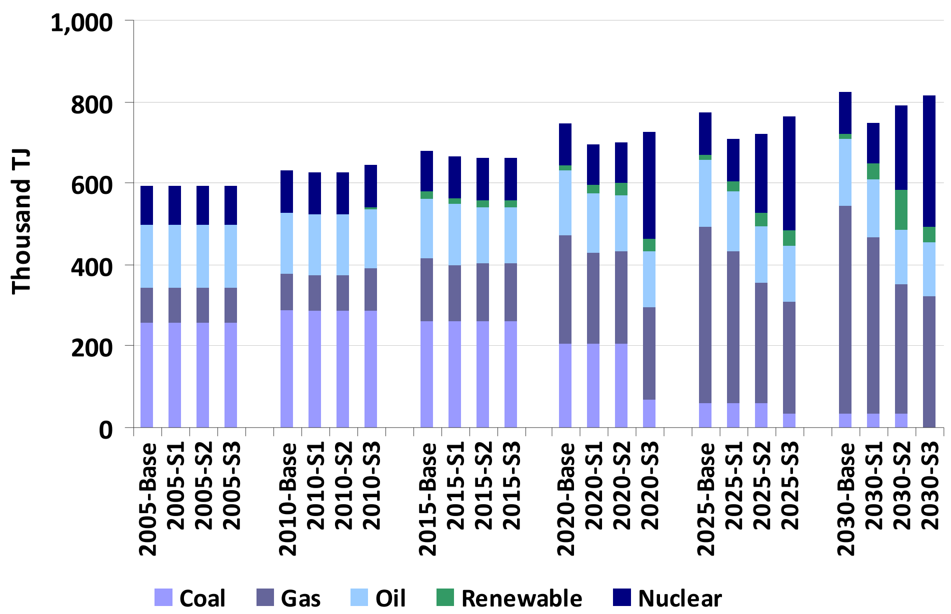
Table 3.6 and *Figure 3.5* presents the HKMM output of primary energy demand. These values represent the energy from different sources such as gas, oil, coal, renewable and nuclear electricity import.

Table 3.6 ***Primary Energy Demand (TJ)***

	2005	2010	2015	2020	2025	2030	2005	2005
Gas								
Base Case	85,732	89,776	155,174	266,099	433,244	509,361	210%	494%
Scenario 1	85,732	85,732	135,634	220,549	372,718	433,816	157%	406%
Scenario 2	85,732	85,898	141,954	227,009	295,440	317,569	165%	270%
Scenario 3	85,732	101,062	142,861	227,109	274,574	321,178	165%	275%
Oil								
Base Case	153,548	150,328	146,769	156,758	162,605	162,634	2%	6%
Scenario 1	153,548	149,366	150,727	147,631	148,017	142,640	-4%	-7%
Scenario 2	153,548	149,177	136,661	136,712	137,963	132,932	-11%	-13%
Scenario 3	153,548	149,514	137,095	137,414	139,033	133,017	-11%	-13%

	2005	2010	2015	2020	2025	2030	2020 vs. 2005	2030 vs. 2005
Coal								
Base Case	258,018	287,591	261,746	206,551	59,388	34,770	-20%	-87%
Scenario 1	258,018	287,591	261,746	206,551	59,388	34,770	-20%	-87%
Scenario 2	258,018	287,591	261,746	206,551	59,388	34,770	-20%	-87%
Scenario 3	258,018	287,591	261,746	67,830	34,770	45	-74%	-100%
RE								
Base Case	1,867	2,165	13,736	13,980	14,182	14,325	649%	667%
Scenario 1	1,867	2,165	13,762	21,005	24,990	35,584	1025%	1806%
Scenario 2	1,867	2,183	17,994	29,045	35,028	98,022	1456%	5151%
Scenario 3	1,867	2,183	18,004	29,128	35,361	38,024	1460%	1937%
Nuclear								
Base Case	92,436	101,398	101,398	101,398	101,398	101,398	10%	10%
Scenario 1	92,436	101,398	101,398	101,398	101,398	101,398	10%	10%
Scenario 2	92,436	101,398	101,398	101,398	194,758	205,157	10%	122%
Scenario 3	92,436	101,398	101,398	263,921	278,303	321,755	186%	248%
Total								
Base Case	591,601	631,258	678,823	744,786	770,817	822,488	26%	39%
Scenario 1	591,601	626,252	663,267	697,134	706,511	748,209	18%	26%
Scenario 2	591,601	626,247	659,752	700,716	722,577	788,450	18%	33%
Scenario 3	591,601	641,748	661,105	725,402	762,041	814,018	23%	38%

Figure 3.5 ***Primary Energy Demand by Scenario (Thousand TJ), 2005-2030***



Currently, coal has the largest share in the total primary energy supply. This share is expected to drop sharply beginning in 2025 when almost all coal-fired power plants are scheduled to have been decommissioned. Except in Scenario 3, natural gas is projected to account for the largest share in all cases due to the increased use of combined cycle gas turbines for electricity generation. In Scenario 3, the nuclear electricity import from China is projected to account for approximately 40% of the total primary energy consumption beginning in 2020[60].

Except for Scenario 3, it is assumed that all power plants retire according to their expected life. In Scenario 3, electricity from coal-fired power plants accounts for approximately 10% of the total electricity demand in 2020, and no coal-fired power units will be used in 2030. As coal will be replaced by RE or nuclear sources, carbon emissions and intensities are predicted to be further reduced in Scenario 3.

3.2.4 *Energy Intensity*

The three mitigation scenarios represent a progressively increasing use of low carbon energy sources on the supply side (including electricity generation) and more efficient end-use devices on the demand side. As a result, both primary energy consumption and final energy use decrease relative to the Base Case. *Table 3.7* and *Figure 3.6* depict the decreasing trend of the primary energy intensity relative to the GDP. In general, this intensity is lower in the alternative scenarios according to their level of market penetration of more efficient energy technology/devices.

Table 3.7 Primary Energy Intensity (TJ per Billion HK$)

	2005	2010	2015	2020	2025	2030	2020 vs. 2005	2030 vs. 2005
Base Case	428	395	355	330	300	283	-23%	-34%
Scenario 1	428	392	347	308	275	257	-28%	-40%
Scenario 2	428	392	345	309	280	269	-28%	-37%
Scenario 3	428	401	344	319	293	276	-25%	-35%

Figure 3.6 Primary Energy Intensity (TJ per Billion HK$)

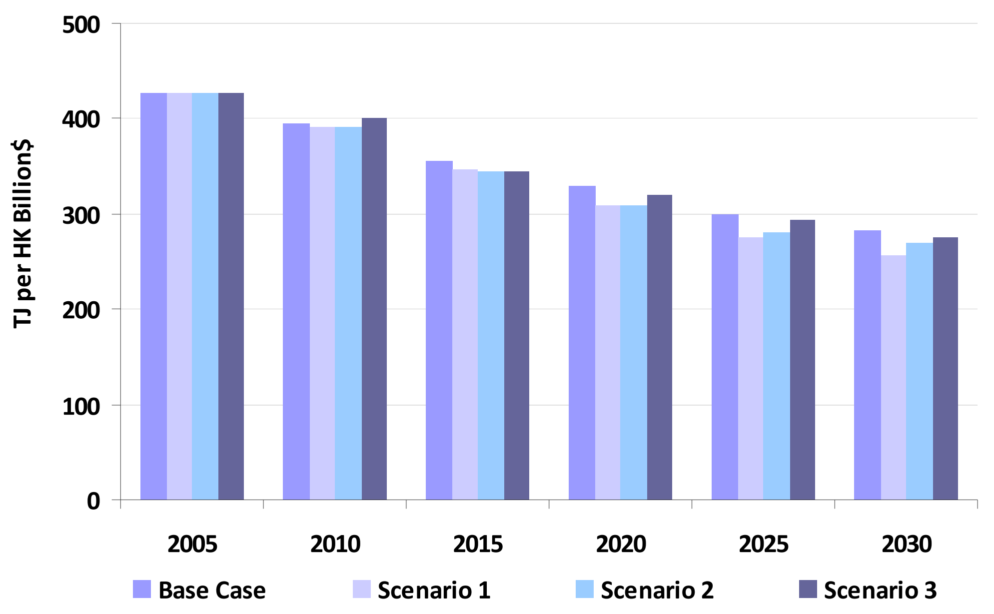


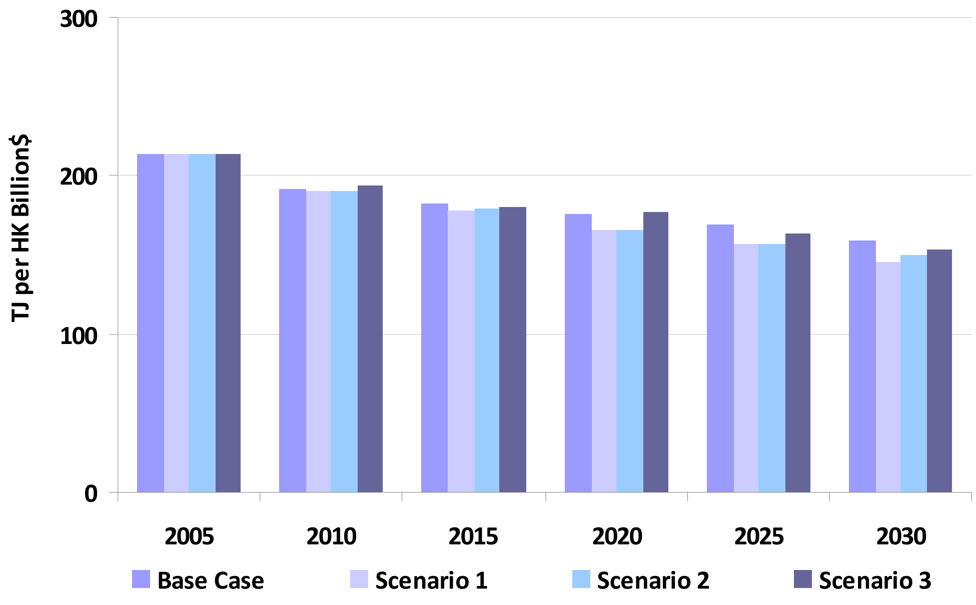
Table 3.8 and *Figure 3.7* d epict a similar trend for final energy use. The energy intensity in Scenario 3 is higher than that of Scenarios 1 and 2. Again, this is attributable to the lower marginal energy costs and thus higher energy demand in Scenario 3 as discussed in Section 3.2.3.

The ratio of the final energy intensity to the primary energy intensity represents the overall energy system efficiency in converting primary energy resources to useful energy for end-uses, which improves from about 50% in 2005 to approximately 56% in 2030 for all cases[61].

Table 3.8 ***Final Energy Intensity (TJ per Billion HK$)***

	2005	2010	2015	2020	2025	2030	2020 vs. 2005	2030 vs. 2005
Base Case	213	192	182	175	168	159	-18%	-26%
Scenario 1	213	190	178	165	156	146	-22%	-32%
Scenario 2	213	190	179	166	157	150	-22%	-30%
Scenario 3	213	194	180	177	163	154	-17%	-28%

Figure 3.7 ***Final Energy Intensity (TJ per Billion HK$)***



3.2.5 *Electricity Output*

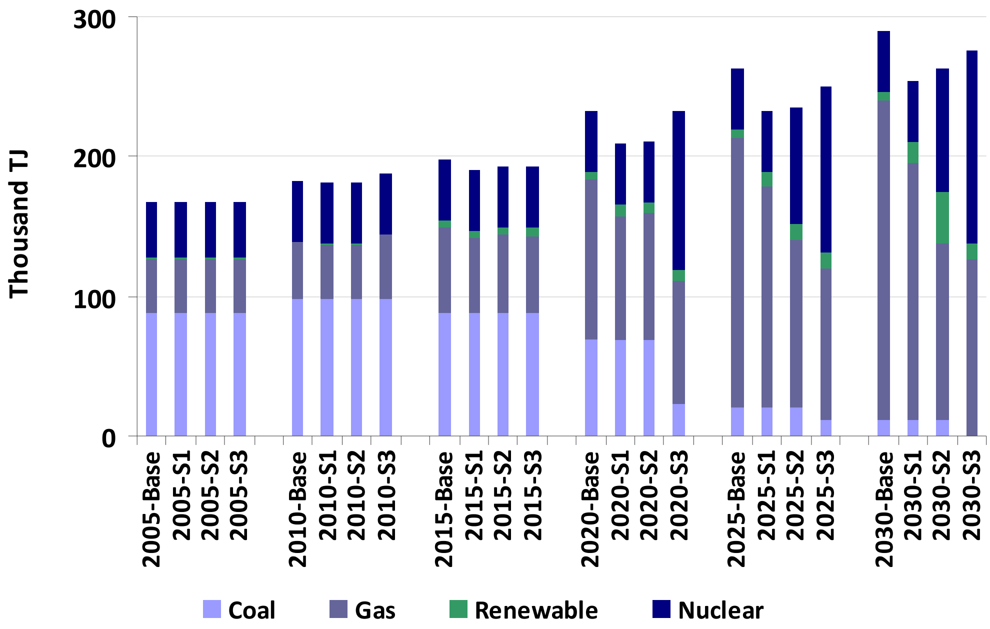
In Hong Kong, electricity is the dominant energy carrier, accounting for more than 50% of the final energy use in 2005. This share is projected to increase to over 60% in 2030 in the Base Case. The future may see two opposing trends: on the one hand, more efficient end-use devices reduce electricity demand, whereas new electricity-using devices such as electric cars may be introduced to replace conventional gasoline vehicles, as assumed in the three mitigation Scenarios, thereby increasing the electricity use in the transportation sector.

Table 3.9 and *Figure 3.8* present the electricity output by source as well as the fuel mix in 2020 and 2030 for different scenarios. In 2005, coal has the largest share and generates about 50% of electricity in Hong Kong. Under the Base Case, natural gas will progressively replace coal and generate approximately 80% of the electricity in 2030. In the Base Case, the use of natural gas will be 5 times greater in 2030 than that in 2005 for electricity generation. Under Scenario 3, no coal will be used for electricity generation in 2030. Natural gas used for electricity generation doubles in 2020, and almost triples in 2030, compared to the quantity used in 2005. Electricity from natural gas is projected to grow to 40% of the total. Electricity from renewable energy produced locally is expected to grow from less than 1% in 2005 to 4% of the total in 2030. Electricity from nuclear sources in the Mainland China in 2030 is expected to be more than three times the quantity used in 2005. It is projected to account for approximately half of the electricity usage beginning in 2020.

Table 3.9 Electricity Output by Source (TJ)

	2005	2010	2015	2020	2025	2030	Fuel mix in 2020	Fuel mix in 2030
Natural Gas								
Base Case	39,148	40,994	61,936	114,274	193,716	228,701	49%	79%
Scenario 1	39,148	39,148	53,640	88,280	158,516	183,962	42%	72%
Scenario 2	39,148	39,224	56,461	90,796	121,036	125,573	43%	48%
Scenario 3	39,148	46,147	56,000	87,905	108,599	125,957	38%	46%
Coal								
Base Case	87,656	97,801	87,501	69,080	19,936	11,811	30%	4%
Scenario 1	87,656	97,801	87,501	69,080	19,936	11,811	33%	5%
Scenario 2	87,656	97,801	87,501	69,080	19,936	11,811	33%	4%
Scenario 3	87,656	97,801	87,501	22,811	11,811	0	10%	0%
RE								
Base Case	778	902	5,253	5,354	5,439	5,498	2%	2%
Scenario 1	778	902	5,264	8,364	10,069	14,607	4%	6%
Scenario 2	778	902	5,253	7,954	10,532	37,631	4%	14%
Scenario 3	778	902	5,253	7,954	10,639	11,898	3%	4%
Nuclear								
Base Case	39,604	43,444	43,444	43,444	43,444	43,444	19%	15%
Scenario 1	39,604	43,444	43,444	43,444	43,444	43,444	21%	17%
Scenario 2	39,604	43,444	43,444	43,444	83,444	87,899	21%	33%
Scenario 3	39,604	43,444	43,444	113,077	119,239	137,856	49%	50%
Total								
Base Case	167,186	183,142	198,134	232,152	262,535	289,454		
Scenario 1	167,186	181,295	189,849	209,169	231,965	253,824		
Scenario 2	167,186	181,371	192,659	211,274	234,948	262,915		
Scenario 3	167,186	188,295	192,198	231,747	250,288	275,711		

Figure 3.8 Electricity Output by Source (Thousand TJ)



3.2.6 *Reduction in Other Air Pollutants from Power Generation*

There is a potentially large and diverse range of co-effects from climate change mitigation policies, which lower the net costs of emission reductions and thereby may strengthen the incentives to reduce emissions. Many recent studies have demonstrated significant benefits of carbon-mitigation strategies on human health, mainly because they also reduce other airborne emissions, for example, SO_2, NO_x and particulate matter. This is projected to result in the prevention of some premature deaths due to air pollution. Quantification of mortality risks remains controversial, and hence a large range of benefits estimates can be found in the literature[62].

In the HKMM model, we have built in the emission coefficients for SO_2, NO_x, and PM_{10} for power plants. Based on the projected fuel use by the sector to meet demand at market equilibrium, the model is able to account for the total emissions for these air pollutants, as shown in *Table 3.10*, *Table 3.11, and Table 3.12.*

Table 3.10 Sulphur Dioxide from Electricity Generation (Thousand Tonnes)

	2005	2010	2015	2020	2025	2030	2020 vs. 2005	2030 vs. 2005
Base Case	61.5	60.0	19.2	11.1	4.8	4.3	-82%	-93%
Scenario 1	61.5	60.0	19.2	11.0	4.6	4.1	-82%	-93%
Scenario 2	61.5	60.0	19.2	11.0	4.5	3.8	-82%	-94%
Scenario 3	61.5	60.0	19.2	5.0	3.8	0.6	-92%	-99%

Figure 3.9 Sulphur Dioxide from Electricity Generation

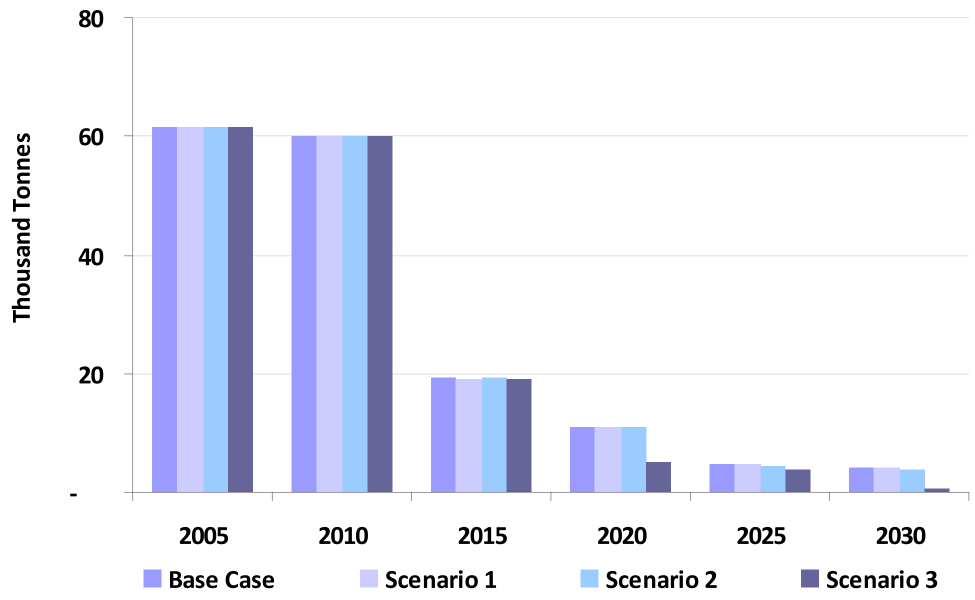


Table 3.11 Nitrogen Oxides from Electricity Generation (Thousand Tonnes)

	2005	2010	2015	2020	2025	2030	2020 vs. 2005	2030 vs. 2005
Base Case	42.2	44.4	38.0	34.6	24.5	24.3	-18%	-42%
Scenario 1	42.2	44.3	37.2	32.7	21.4	20.4	-23%	-52%
Scenario 2	42.2	44.3	37.4	34.4	18.2	15.5	-19%	-63%
Scenario 3	42.2	44.6	37.5	16.8	14.1	10.6	-60%	-75%

Figure 3.10 Nitrogen Oxides from Electricity Generation

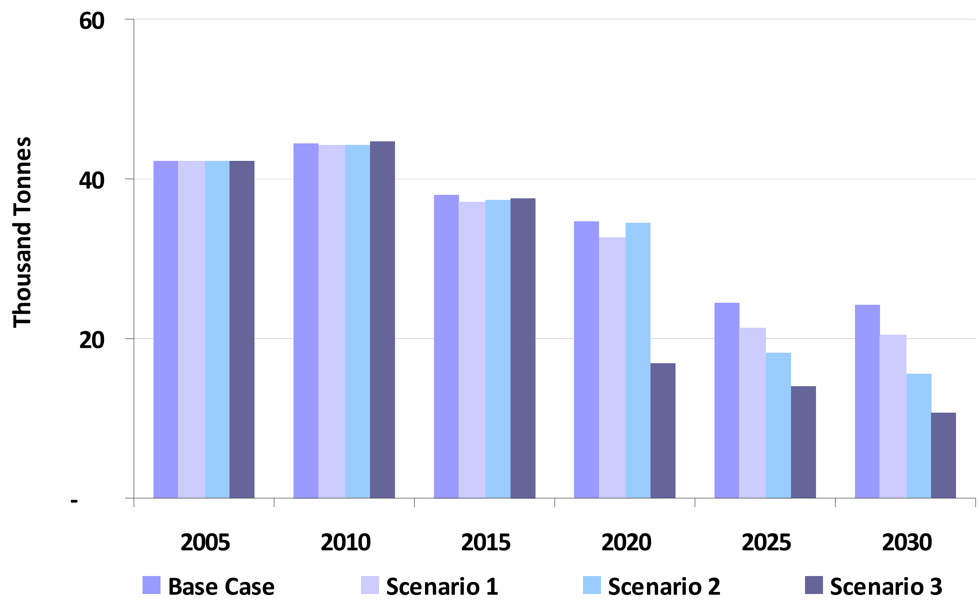
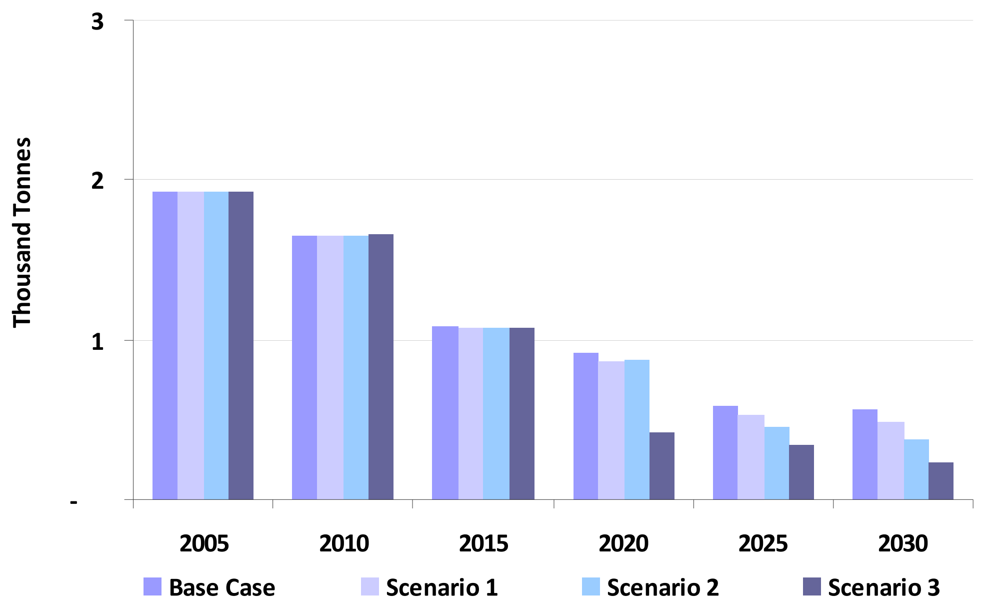


Table 3.12 Particulates (PM10) from Electricity Generation (Thousand Tonnes)

	2005	2010	2015	2020	2025	2030	2020 vs. 2005	2030 vs. 2005
Base Case	1.9	1.7	1.1	0.9	0.6	0.6	-52%	-70%
Scenario 1	1.9	1.6	1.1	0.9	0.5	0.5	-55%	-75%
Scenario 2	1.9	1.6	1.1	0.9	0.5	0.4	-55%	-80%
Scenario 3	1.9	1.7	1.1	0.4	0.3	0.2	-78%	-88%

Figure 3.11 Particulates (PM_{10}) from Electricity Generation



Compared with the Base Case for the year 2005, the results show that in 2030:

- Sulphur dioxide emissions reduce by 93%, 94%, and 99% in Scenarios 1, 2, and 3, respectively;
- Nitrogen oxides emissions reduce by 52%, 63%, and 75% in Scenarios 1, 2, and 3, respectively;
- PM_{10} emissions reduce by 75%, 80%, and 88% in Scenarios 1, 2, and 3, respectively[63].

These estimates should be used for indicative purposes only and have the following limitations:

- The estimates are based on the average emission rates for the existing assets and are not responsive to the change due to future decommissioning of individual units.
- The exact operation and fuel use by each unit in the future cannot be reliably determined.

3.2.7 *Carbon Tax*

The marginal abatement cost curves compare mitigation scenarios with the Base Case and quantify benefits of mitigation policies and measures in terms of their relative emission control costs. For this purpose, we applied a carbon tax schedule ranging from HK$500/tonne to HK$5,000/tonne of carbon to all the three scenarios (HK$5,000/tonne of carbon is close to US$175/tonne $CO_{2\text{-}e}$[64]). This range encompasses the range of historical and projected prices of carbon credits traded in the international market. The tax rate represents the marginal cost of reducing carbon at the corresponding carbon emission level obtained at the market equilibrium.

Marginal Abatement Cost Curves

The marginal abatement cost (MAC) curves characterize the cost related response of an energy market to attain a specific carbon emission target. Lower MAC curves imply that higher abatement potential can be achieved at a lower cost. On the other hand, higher MAC curves are associated with scenarios in which technologies to reduce carbon (through efficiency improvement or fuel substitution) are not available or costly.

MAC curves in *Figure 3.12* and *Figure 3.13* depict the carbon emissions reduction potential for various levels of carbon tax in 2030, in an attempt to bring down 2030 emissions to below the 2005 level. It clearly shows that the marginal cost of reducing carbon at a given level below the 2005 emission is the lowest in Scenario 3. The same costs for Scenarios 1 and 2 lie in between that of the Base Case and Scenario 3. It should be noted here that the extension of the MAC curve for the Base Case might never reach the abatement potentials achieved in the mitigation scenarios, indicating that such abatement goals are either technically unfeasible or economically unsustainable under the definition of the Base Case.

The stiffness of the slopes shown in these MAC curves reflect the rigidity of the energy system represented in the Base Case and the mitigation scenarios, while responding to further carbon emission reductions from their initial equilibrium positions (ie no carbon tax), since most of the mitigation policies and measures proposed in this study are defined with fixed market penetration, energy targets, or market shares. Further reduction potentials from these initial positions (shown in *Figure 3.12* and *Figure 3.13*) are largely generated from economic feedback on reduction in energy service demands and hence, affecting GDP due to increased energy cost with carbon taxes. Also, as the energy cost is lower in alternative scenarios, the effect of applying a tax on carbon is further reduced. The initial equilibrium positions of these MAC curves provide key information for Hong Kong SAR Government to formulate and adopt mitigation policies and measures, and decide on reduction targets.

Figure 3.12 *MAC Curves- % Difference in 2030 Emissions from 2005 Levels*

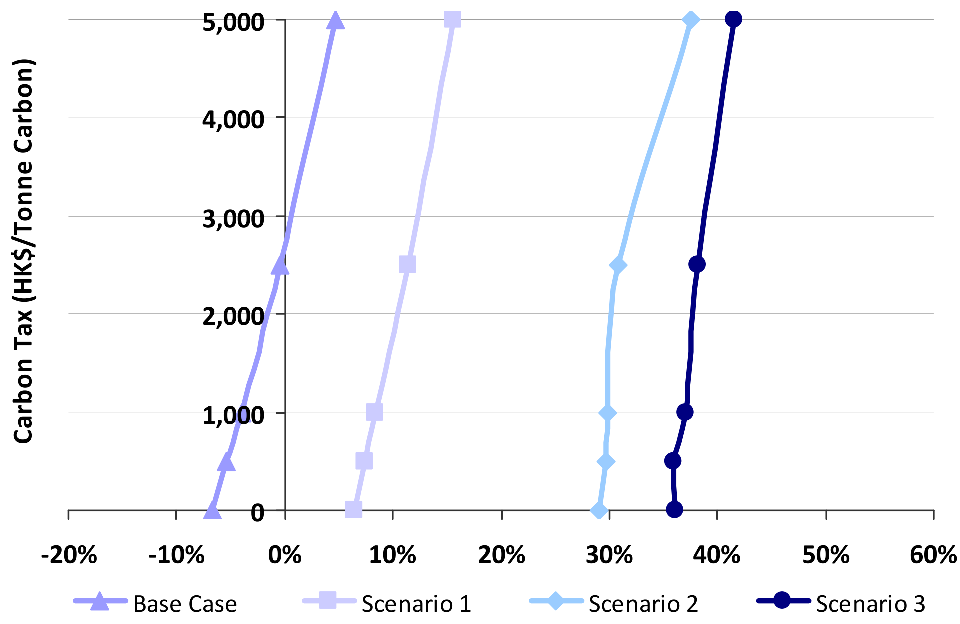
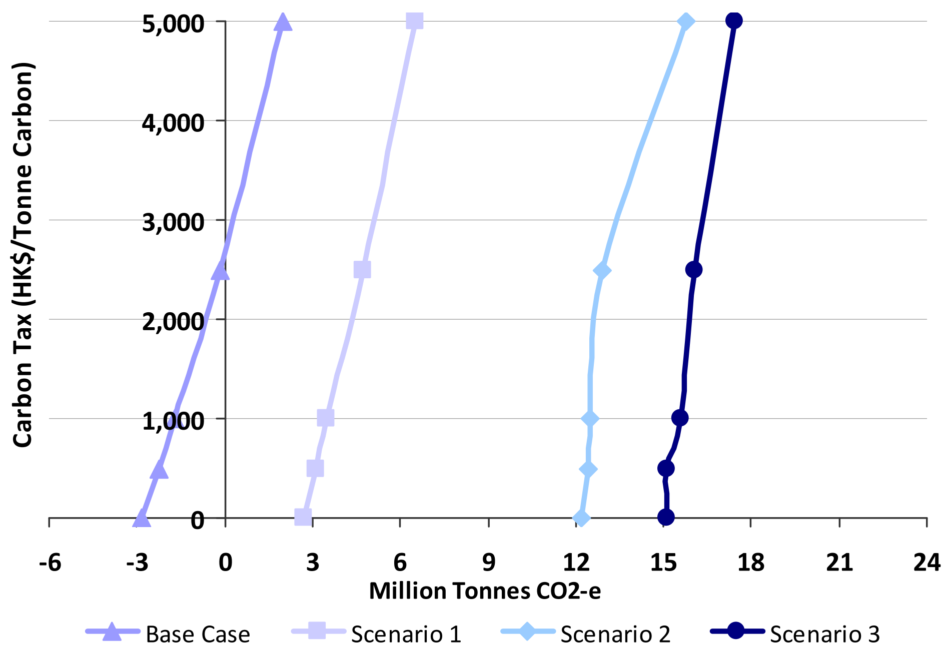


Figure 3.13 *MAC Curves- Emission Reduction in 2030 from 2005 Levels (Million Tonnes CO_{2-e})*



3.2.8 Scenario Analysis by Mitigation Sectors

This section evaluates the carbon abatement potentials and costs of mitigation in particular sectors (ie building, transport, electricity generation, and waste) for all three alternative scenarios in addition to those in the Base Case. This is achieved by performing a static comparative analysis on the MARKAL Model results obtained under partial equilibrium of the energy market. Carbon emissions and associated energy system costs for each sector in all three scenarios are compared to the Base Case to evaluate each sector's abatement potential and the average cost per metric tonne of carbon emissions to realize this potential[65]. *Figure 3.14* presents the carbon emission reduction potentials in 2020 and 2030 for Scenarios 1, 2 and 3 relative to the Base Case. *Table 3.13* details the emission reduction potentials and average costs in 2030 by mitigation group.

Figure 3.14 ***Additional Carbon Abatement Potential by Sector by Scenario (Thousand Tonnes CO_{2-e})***

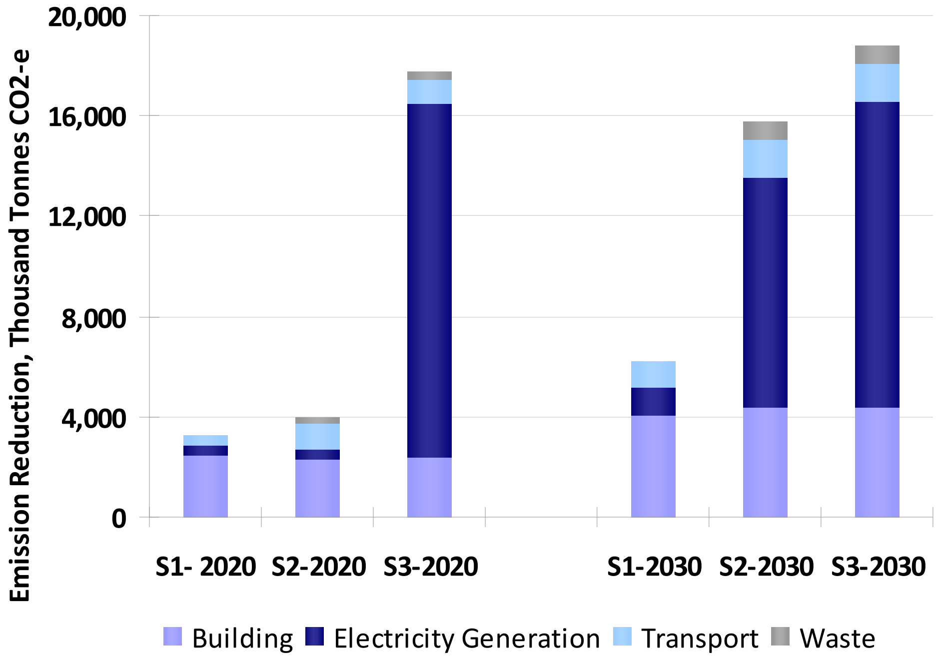


Table 3.13 ***Additional Carbon Abatement Potentials and Average Costs by Sector by 2030***

	Scenario 1		Scenario 2		Scenario 3	
	Cost (HK$/tonne CO_{2-e})	Potential (Thousand tonnes CO_{2-e})	Cost (HK$/tonne CO_{2-e})	Potential (Thousand tonnes CO_{2-e})	Cost (HK$/tonne CO_{2-e})	Potential (Thousand tonnes CO_{2-e})
Buildings	-487	4,039	-505	4,351	-505	4,351
Energy Supply	-303	1,159	-150	9,200	-167	12,244
Transport	-1,226	983	-1,007	1,517	-1,007	1,517
Waste	0	0	-747	725	-749	725

By 2030, the additional abatement potential in the buildings sector is projected to reach 4,039 thousand tonnes CO_{2-e} in Scenario 1 and 4,351 thousand tonnes CO_{2-e} in Scenarios 2 and 3, at average reduction costs per tonne CO_{2-e} of HK$-487 and HK$-505 respectively (benefits), compared with the Base Case. Most measures proposed in the building sector are "no regret" policies. The energy generation sector shows the largest abatement potential, estimated to reduce 9,200 thousand tonnes CO_{2-e} in Scenario 2 and 12,244 thousand tonnes CO_{2-e} in Scenario 3. As the energy cost in the Base Case is higher than that of the energy systems in alternative scenarios, accelerated use of more renewable technologies and imports does not result in higher abatement costs. The transport sector abatement potential is estimated at 983 and 1,517 thousand tonnes CO_{2-e} in Scenarios 1 and 2, respectively. However, this relatively modest potential can be realized at great benefit (negative costs) of HK$1,226, and HK$1,007 per tonne CO_{2-e}.

It is important to note that the abatement potentials calculated for each sector are not to be used to estimate the total system abatement potential. This is due to the fact that static comparative analysis does not catch the potential offsets (or synergies) among sectors and various sub-sectors. For example, a reduction in electricity demand in the buildings sector also reduces the size of the electricity market and hence, the abatement potential of the supply group. Another limitation of the static comparative analysis arises from that fact that mitigation measures in one sector may require the synergy provided from measures in another sector. For example, in the transportation sector in Scenario 3, the measures to switch all passenger cars and taxis to electric vehicles would increase electricity supply. This increase would result in a net increase in carbon emissions unless it is met by renewable or imported nuclear electricity instead of the gas combined cycles (a synergy required from the supply sector).

While the relative cost (or benefit) of abatement potential by sector calculated in this section provides a general guidance for prioritizing program implementation, the absolute quantities presented here are not to be used without careful interpretation from the perspective of policy making.

3.2.9 *Limitations and Challenges of the HKMM Modelling Methodology*

The HKMM model developed for this study represents the detailed energy and environmental system of the HKSAR, which facilitates the evaluation of GHG abatement potentials under various mitigation scenarios. The model measures the impact of alternative energy system development pathways determined under each scenario on economic growth, in terms of GDP changes. Even though the model's results and analysis presented in this section exhibit its diverse capability in achieving the objectives of the study, there are limitations and challenges to the approach that need further attention to refine and expand its current structure/approach. We outline the main limitations and challenges below.

- The current structure of HKMM confines the analysis of GHG mitigation impacts strictly within the Hong Kong SAR. A better coordination of joint analysis and implementation of these measures can be accomplished in a multi-regional MARKAL model framework.

- The embodied energy and GHG that are crucial to the manufacture and transportation of various consumer and industrial products and materials (eg cement) imported to the HKSAR are not considered in the HKMM. Additional mitigation measures (eg imports of green products and conservation of material use) need to be addressed to expand the abatement potential in Hong Kong SAR and beyond.

- Not all economic benefits can be reflected in the Model. For instance, green jobs can be created when renewable energy plants are built, but it is difficult to quantify and forecast the associated economic benefit. Also, the assessment doesn't quantify the energy reduction potential from changes of consumer habits.

- The impact of mitigation measures on consumer inflation and business costs is not quantified in the Model. In the short and medium term, inflation and business costs may be affected by the energy prices and investment costs. However, they are also influenced by a variety of factors such as relative elasticity of wages, interest rates, and growth rate of money supply.

- Normal climate conditions were assumed in the energy use projection. Should the prevailing temperatures change as a consequence of climate changes, the final energy demand might be different. For example, higher temperatures implies higher energy demands for cooling and hence an increase in carbon emissions.

- The assumptions and model outputs are not intended to represent very accurate projections. The purpose of the Study is to assess the impacts of various mitigation measures and scenarios on GHG emission abatement. Measures and assumptions in mitigation scenarios are based on an international technology and policy review. They are not implementation targets, but provide an envelope within which the impacts of alternative assumptions can be inferred. Detailed feasibility studies for individual measures are required at a later stage.

3.3 *CONCLUSION*

The Study examines three scenarios for the mitigation analysis quantitatively.

Scenario 1 (the 'AQO Scenario') includes relevant mitigation measures proposed in the AQO Study, including the increased use of natural gas and renewable energy sources for electricity generation, wider use of road vehicles using clean fuels, and enhanced energy efficiency in the building and appliance sector.

Scenario 2 (the 'Accelerated Scenario') builds upon Scenario 1 and includes additional efforts on measures to increase energy efficiency and reduce energy demand, particularly in the building and transport sectors. Local sources of renewable energy such as waste-to-energy facilities are utilised by 2020. This scenario also assumes a certain level of integration of the power system between Hong Kong and its neighbouring areas. Electricity imported from Mainland China in 2020 is the same as that in 2005. In 2030, the scenario assumes that approximately 50% of the electricity used has no associated carbon emissions[66], and is either locally produced or imported from the Mainland.

Scenario 3 (the 'Aggressive Scenario') builds upon Scenario 2 and accelerates the integration of the power system in Hong Kong with its neighbouring areas. It assumes that Hong Kong would make full use of natural gas supply guaranteed by the Mainland under the relevant Memorandum of Understanding (MOU) on Energy Co-operation, for electricity generation in 2020. It also assumes that nuclear electricity imported from the Mainland in 2020 would be able to meet 50% of the local demand for electricity.

Details of GHG emissions reduction measures in each of the scenarios are set out in *Section 3.1*. Results for the Base Case and three alternative scenarios are detailed under *Section 3.2*. Due to the uncertainties of the projections, key results are presented in ranges in *Table 3.14*.

Table 3.14 Summary Table for Base Case, Scenarios 1, 2 and 3

	Base Case		Scenario 1		Scenario 2		Scenario 3	
	2020	**2030**	**2020**	**2030**	**2020**	**2030**	**2020**	**2030**
Fuel Mix – Electricity Output (%)(1)								
Natural Gas	46-52%	76-82%	39-45%	69-75%	40-46%	45-51%	35-41%	43-49%
Coal	27-33%	1-7%	30-36%	2-8%	30-36%	1-7%	7-13%	0-3%
	0-5%	0-5%	1-7%	3-9%	1-7%	11-17%	0-6%	1-7%
Nuclear	16-22%	12-18%	18-24%	14-20%	18-24%	30-36%	46-52%	47-53%
Carbon Emission Reduction - Compared with 2 (%)(1)	7-13% Increase	4-10% Increase	1% reduction - 5% increase	3-9%	3% reduction - 3% increase	26-32%	27-33%	33-39%
Carbon Intensity Reduction– Compared with 2005 (%)(1)	30-36%	46-52%	34-40%	53-59%	36-42%	63-69%	54-60%	67-73%

Note:
(1) Based on -3%/+3% from the outputs

The low carbon intensities in Hong Kong SAR provide significant potential in abating carbon emissions from the energy sector with a very small impact on the SAR's economic growth. These reduced emission levels in 2030 amount to 3-9%, 26-32% and 33-39% % below the 2005 carbon emission level for Scenarios 1, 2 and 3 respectively, whereas 2030 emissions are 4-10% above the 2005 level in the Base Case. GDP is project to grow at an annual average growth rate of 3.01% in the Base Case, and it is not predicted to be materially affected under the alternative scenarios[67]. The findings of the Mitigation Assessment indicate that it is possible to achieve the National Target (reduction of 40% - 45% of CO_2 per unit of GDP by 2020) by the implementation of the mitigation measures recommended in Scenario 3.

In the power sector, the use of coal currently contributes to more than half of the total carbon emission from the energy sector. This provides a good potential in reducing carbon emissions as the coal-fired units are decommissioned progressively over the next 20 years. The building sector in Hong Kong consumes more than half of the final energy – a significant market potential in which low cost policies and measures are available to reduce energy use with net economic benefits. Implementation of energy demand side measures may require new or updated legislation, on matters such as energy efficiency standards for buildings, electrical appliances, motor fuel standards etc.

The Study also discussed mitigation policies and options that are not readily quantifiable. They can help to further reduce carbon emissions. Further studies should be carried out to establish the technical feasibility and cost-effectiveness of these options for the implementation within HKSAR.

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[37] OECD, *The Economics of Climate Change Mitigation: Policies and Options for the Future*, Economics Department Working Paper No. 658, 2008.

[38] http://www.info.gov.hk/gia/general/200901/09/P200901090139.htm

[39] Stern, N., *The Economics of Climate Change: The Stern Review*, 2007.

[40] Johnstone, N., I. Hascic and D. Popp, "Renewable Energy Policy and Technological Innovation: Evidence Based on Patent Counts", *NBER Working Paper* No. 13760, 2008.

[41] http://www.devb.gov.hk/en/secretary/press/press20090622.htm

[42] As the local carbon emission factor of water is not available, average emission factor from the Carbon Trust was used to estimate the reduced emissions (emission factor is around 0.271 kg CO2/m3 for water, and 0.476 kgCO2/m3 for wastewater). 236 million m3 * (0.271+0.476) = 176,292 tonnes CO2-e, which is approximately 0.4% of total emissions in 2030.

[43] UNFCCC, *Reporting on Climate Change: user manual for the guidelines on national communications from non-Annex I Parties*, 2003. http://unfccc.int/files/essential_background/application/pdf/userman_nc.pdf (accessed Oct 9 2009)

[44] www.etsap.org

[45] *Operation and Development of the Hong Kong MARKAL-MACRO Model Instruction Order 01: Updating HKMM, Version 1.0*, January 13, 2005, Tsinghua University

[46] Energy Environment Economy Research Institute, Tsinghua University, for Environmental Protection Department, HKSAR, *Operation and Development of the Hong Kong MARKAL-MACRO Model Instruction Order 01: Updating HKMM, Version 1.0*, 2005.

[47] The GDP projection and impact evaluated by the models is on the basis of real terms.

[48] The purpose of the Study is to assess the impacts of various mitigation measures and scenarios on GHG emission abatements. Measures and assumptions in mitigation scenarios are based on some international technology and policy reviews. They are not implementation targets, but provide an envelope within which the impacts of alternative assumptions can be inferred. Detailed feasibility studies for individual measures are required at later stages, taking into account limitations, uncertainties and practicability of the measures within Hong Kong's local context.

[49] Review of Air Quality Objectives and Development of a Long Term Air Quality Strategy for Hong Kong, July 2009.

[50] All energy saving information is based on the AQO Study assumptions.

[51] In 2005 the First Sustainable Development Strategy sets a target of 1~2% RE in electricity use by 2012. The assumption made for 2020 and 2030 does not reflect the actual availability of RE in the neighbouring areas for consumption in Hong Kong.

[52] This excludes remaining coal power plant generation. Among the 50% electricity with no associated carbon emissions, 35% is from import of nuclear generated electricity.

[53] All petrol contains a mixture of 10% ethanol by volume. Blends of ethanol above 10% are assumed to need engine modification.

[54] B10 Biodiesel, is comprised of a "blend" of 10% Biodiesel and 90% petroleum diesel. Blends biodiesel above 10% might need engine modification.

[55] OWTFs have not been modelled in the HKMM.

[56] According to the report "中国2050年低碳情景和低碳发展之路." released by the Energy Research Institute of NDRC in 2009, the ratio of no carbon emissions electricity from renewable sources (except hydropower) and nuclear power will be around 3:7 at national level by 2030. While this ratio will be used as assumption in this modelling exercise, it is not suggesting that the ratio is valid for Hong Kong's neighbouring areas which may be supplying additional electricity to Hong Kong in a technically feasible and cost-effective manner.

[58] http://www.iea.org/country/maps/world/co2_pop.htm; http://www.iea.org/country/maps/world/co2_gdp.htm (accessed on Oct 8 2009)

[59] The national carbon intensity target refers to the energy related CO_2 per GDP value, while the domestic carbon intensity for Hong Kong refers to total GHG emissions per GDP value. Hong Kong will control GHG emissions from all sources, including non-energy related carbon emissions such as methane from landfills, and thus the carbon intensity target includes all types of GHG emissions.

[60] The fossil fuel equivalent of electricity generated from renewable technologies and nuclear power (imports from China) is based on a thermal efficiency of 43%. This is based on the assumption that the alternative way to generate this electricity in Hong Kong.

[61] There are exceptional cases in which reduction in final energy use results in an increase in primary energy consumption. For example, the conversion of all passenger cars and taxis to electric in Scenario 3 in 2030 reduces about 2 energy units of liquid fuels for one additional unit of electricity in terms of final energy, but it will require more than 2.5 units of primary energy resources to generate that unit of electricity. This explains the increase in primary energy intensity in Scenario 3.

[62] IPCC, *Climate Change 2007 Mitigation*, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007.

[63] The air emission reductions in Scenario 1 are not directly comparable with those in the AQO study due to several factors including 1) different modelling approaches were adopted; 2) the AQO study assumes 50% nuclear and 50% natural gas will be used to generate electricity by 2030, which is different from the assumptions in Scenario 1.

[64] In the international carbon market, the price is projected to be around US$100/tonne CO2e in 2030.

[65] This approach is broadly similar to the method used in generating the McKinsey abatement cost curve.

[66] This excludes remaining coal power plant generation. Among the 50% electricity with no associated carbon emissions, 35% is from import of nuclear generated electricity.

[67] The current conclusion that GDP and its growth will not be materially affected in the alternative scenarios against the Base Case is made based on the currently available information. The economic modelling is at a macro scale, and the detailed economic impact of individual measure should be subject to further assessment at a later stage. In particular, some of the measures would require substantial investments, the costs of which and the resultant impacts on specific areas of the economy (e.g. electricity tariff) have not been assessed in detail. The consultants suggest that the Government should conduct a more detailed independent assessment when comprehensive information is available and when the Government proposes to pursue any of the proposed measures.

Annex A

Development of the Base Case

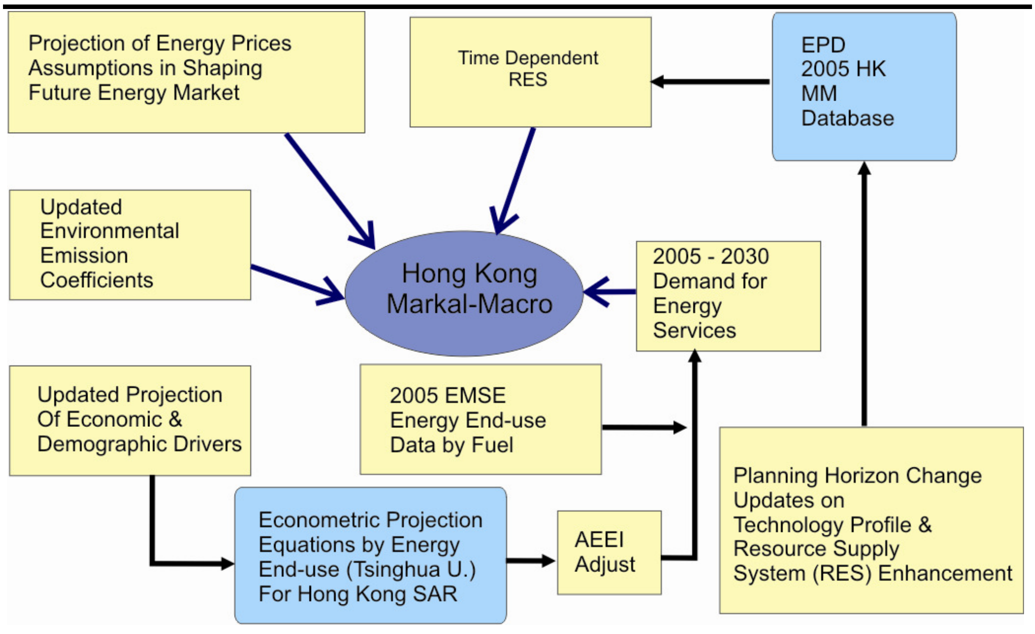
In Hong Kong MARKAL-MACRO Model

1 DEVELOPMENT OF THE BASE CASE

1.1 DEVELOPMENT OF THE BASE CASE

Figure 1.1 depicts schematics of the interrelated tasks in the development of the Base Case. In general, Hong Kong specific historical energy demand-supply data were used to establish the base year (2005) RES in the Hong Kong MARKAL-MACRO model. The base year RES provides a balanced stance (partial equilibrium) based on which future energy-environmental-economic scenarios can be formulated. If no Hong Kong specific data are available (characteristics of a specific technology, existing or future); they can be taken from many existing MARKAL databases in the world community as a starting point.

Figure 1.1 HKMM Baseline Dataflow



Source: ERM-HK and BNL.

The following sections detail the structure of different modules, the sources of data input, and key assumptions for projections. It should be noted that there are uncertainties inherent in the input data and projections used to develop the Base Case. In considering the results of modeling analysis, it is most useful to focus on the differences between the scenarios representing the situation with and without (Base Case) the additional technologies, policies and measures selected for the study than on the absolute numerical results for either scenario. This approach minimizes the significance of these uncertainties on the impact of alternative scenarios measured against the Base Case developed here.

1.2 DEMAND MODULE

The energy market represented in the RES of the Hong Kong MARKAL-MACRO is driven by demand for energy services. The demand for energy service breakdown is required in order to evaluate mitigation measures that may apply to very specific energy services. Projections of these demands determine the quantity and mix of the final energy used by end-use technologies to meet them. The energy consumed by the end-use technologies in turn determines the energy supply systems, creating a balance in the energy market. *Section 1.2.1* to *Section 1.2.3* describe the approach and assumptions of the projections, while *Section 1.2.4* and *Section 1.2.5* explain the detailed input data characterizing individual end-use technologies.

1.2.1 *Input of 2005 Energy End-use Data*

To establish the base year (2005) energy service demand (DM) in MARKAL, the detailed energy end-use by fuel type reported by EMSD [(1)] were obtained. It should be noted that the EMSD End-use data only considers the local energy use, and energy consumption for international and regional transportation in marine and aviation sectors is not included in the base case.

1.2.2 *Energy Service Demand*

In the HKMM model, the level of an energy service demand (DM) is the summation of the energy services provided by all end-use technologies (DMD) servicing that demand. Thus, for a given energy service demand DMi, where quantities of fuels, Di are used by DMDi at Ei (the relative efficiency of DMDi), then DMi equals the summation of the product Ei*Di, over i (the set of all DMDi servicing DMi).

DMi = (Σ Ei*Di)/i

It should be noted that the energy service demands are not the same as the end-use energy and they should not be compared directly against the end-use data. The energy service demands represent the need for which energy is used to provide (ie a person demands light to illuminate their home at night, rather than electricity). They use a mix of units and the values that cannot be added. The units include: Terajoules (TJ) of direct energy, Terajoules (TJ) of useful energy, and Terra Lumen-seconds, etc.

1.2.3 *Projections of Energy Service Demand*

The Base Case (2005-2030) is driven by the projected energy service demand (DM) in the Model [(2)]. This involves the insertion of the latest or updated projection values (2010-2030) of the explanatory variables (drivers) into the

(1) Hong Kong Energy End-use Data 2008, EMSD. Energy use breakdown by fuel type information for residential, industrial, and commercial sectors were provided by EMSD in October 2008.

(2) The projections of these energy service demands utilize the econometric equations estimated in the *Operation and Development of Hong Kong MARKAL-MACRO Model Instruction Order 02: Energy Projection* , Tsinghua University.

energy end use projection equations. Future energy service demands will be derived based on these projection results and used as the demand side input required by the Hong Kong MARKAL-MACRO model. The projected values of the key drivers are depicted in *Table 1.1*. Since there are discrepancies between the 2005 energy service demand derived (with 2005 actual data) and their corresponding values projected for 2005 from the econometric equations, we applied the period by period growth rates implied in these projections to the values for the base year calibration.

Table 1.1 Projected Divers for the Econometric Equations in Energy Service Demand Projections

Category	Unit	2005	2010	2015	2020	2025	2030	Source
Population	Million	6,813,200	7,094,000	7,391,400	7,718,600	8,034,800	8,311,700	C&SD data and projection. [1]
GDP Aggregate	Million 1990HK$	1,077,030	1,240,649	1,487,772	1,758,389	1,999,160	2,261,866	C&SD data and projection. [2]
Floor Space								
Domestic	Thousand Units	2,197	2,302	2,398	2,504	2,607	2,697	2005 data from C&SD 2006 Annual Digest of Statistics; growth rate from HK 2030 Study Working Paper.
Retail	Thousand sq.m	9,522	9,724	9,733	9,743	9,753	9,763	2005 data from C&SD 2006 Annual Digest of Statistics; growth rate from HK 2030 Study Working Paper.
Office	Thousand sq.m	9,770	11,660	12,255	12,880	13,537	14,227	2005 data from C&SD 2006 Annual Digest of Statistics; growth rate from HK 2030 Study Working Paper.
Industrial	Thousand sq.m	17,468	14,846	14,048	13,292	12,577	11,900	2005 data from C&SD 2006 Annual Digest of Statistics; growth rate from HK 2030 Study Working Paper.
Electricity Price	1990 HK$/kWh	0.739	0.761	0.741	0.750	0.757	0.764	CLP and HEC's Operating Statistics; 2009-2013. Development Plan; US EIA Energy Projection Index. [3]

Notes:

1. 2005 Population and projections are from C&SD website http://www.statistics.gov.hk/stat_table/population/D5320182BXXXXXXXXB.xls

2. 2005 to 2008 data are from the C&SD website and converted to 1990 HK dollars based on deflator of GDP.
According to the Government announcement in May 2009, the 2009 GDP growth rate is projected to be -4.5%.
According to EABFU/ FSO's estimation in 2009, the GDP growth rates are expected to be 3.5% between 2010 and 2013, 4% between 2014 and 2017; 3% between 2018-2021; and 2.5% between 2022 and 2030.

3. Electricity price is the weighted average of CLP and HEC's electricity tariff. The projection is based on EPD's advice. It is assumed that the basic tariff will stay the same, and the electricity price will fluctuate based on the fuel price projection.

There are inherent uncertainties in the long term projection of transportation fuel use. Factors including number of cars that are allowed in HK's limited space and consumer's desire to own automobiles cannot be easily captured by the econometrically determined equations. The Hong Kong vehicle kilometers travelled (VKT) data from 2002 to 2007 show that with a slow growth rate the VKT are quite stable in recent years. Transportation energy end use data from EMSD also suggest a similar trend. It is then instructive to choose different AEEI factors to evaluate the energy service demand for the transportation sector.

The "Working Paper on Traffic Forecasts Approach and Assumptions" in the AQO Review Study (1) provides projections of vehicle fleet sizes for private vehicles, taxis, and goods vehicles (2011 to 2030). The road network assumptions used in the study was sourced from committed government highway development plan, recommendations from various planning studies and advices from the Transport Department. As the fleet sizes of goods vehicles and private vehicles are closely related with their respective VKT and energy consumption, higher AEEI factors were adopted for them and the projected growth rates for energy service demand have been adjusted to be in line with the projected vehicle fleet sizes (2) .

1.2.4 *Input Future Efficiencies of Existing Demand Devices*

For some selected sector/devices, we assume there are efficiency improvements due to on-going efficiency improvement programs and autonomous efficiency improvements in these devices over time. On average, it is assumed that these efficiencies will improve 10% by 2030 over the current stocks.

1.2.5 *Input Investment Costs*

The investment and O&M costs for demand devices reported in *"Operation and development of Hong Kong MARKAL-MACRO Model Instruction Order 01: Updating HKMM"* were updated to 2005 Hong Kong dollars. For new technologies not included in that data base, we applied their relative cost factor reported in the world market (eg USDOE EIA data base) to obtain these costs.

1.3 POWER SECTOR

The power sector in the HKMM is modeled based on the detailed operating statistics reported by CLP and HEC. On a plant by plant basis, their actual generation, fuel use, thermal efficiencies, and other related parameters in 2005

(1) EPD, Review of Air Quality Objectives and Development of a Long Term Air Quality Strategy for Hong Kong – Feasibility Study, August 2007. It was circulated to both Transport Department and Planning Department for their agreement.

(2) The AQO review study doesn't provide the projection for buses. It also projects that the fleet size of taxis will keep the same from 2011 to 2030. Energy service demand of buses and taxis were not adjusted in the study as historical energy use data show that they have been growing.

were input to the model to construct the electricity/power supply side in the base year energy market. For future years between 2010 and 2030, we assumed that all existing power plants will continue to operate within their designed specifications, as defined by the value of these parameters for this period [1] . The following assumptions were made with regard to Hong Kong's future energy market:

- Assumption 1: electricity import from the mainland holds at the current level;
- Assumption 2: CLP and HEC will build all new power plants within the SAR to meet future increase in electricity/power demand. These power plants are assumed to be mainly natural gas fired technologies, with limited wind; and
- Assumption 3: system transmission efficiency stays at the current level of 92% throughout the planning period.

1.4 *PROCESS*

In MARKAL-MACRO, the Process is defined as a technology which converts one energy form to another (except electricity). Examples of common process are refineries and coal gasifiers. For Hong Kong SAR, town gas production from naphtha is the only operating process identified in the model.

The key assumption is that the production capacity stays unchanged in the planning horizon.

1.5 *RESOURCE*

The Hong Kong SAR imports almost all of its energy resources from outside the region. Production of indigenous resources is limited to the solid waste the region generates and limited potential in solar and wind power. Quantities of municipal solid waste (MSW) disposed and sewage sludge production in 2005 and their projections to 2030 are provided by the EPD. First Order Decay Model (FOD) introduced in the IPCC Guideline 2006 was adopted to derive the methane generation [2].

1.6 *PRICE*

As a price taker, Hong Kong SAR's energy import prices in the future depend on their movements in the world market. In Hong Kong MARKAL-MACRO, the 2005 prices were extrapolated to 2030 using projected prices for crude oil (USDOE EIA 2009) as a reference indicator for oil products and gas (*Table 1.2)*.

(1) The investment and O&M costs for the power plants reported in *Operation and development of Hong Kong MARKAL-MACRO Model Instruction Order 01: Updating HKMM" (Tsinghua Study)* were converted to 2005 dollars. In the absence of local information, assumptions and parameters in the "Assumptions to the Annual Energy Outlook"1 provided by the US EIA (Energy Information Administration) were used for future generation investment and fixed O&M costs.

(2) http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/IPCC_Waste_Model.xls

Table 1.2 ***Key assumptions: world reference price indicators for oil and gas (US$/Barrel)***

(2007 US$/barrel)	2005	2010	2015	2020	2025	2030
Imported Crude Oil	51.81	48.99	96.77	114.50	116.06	124.36

Source: 2009 US EIA Projection.
http://www.eia.doe.gov/oiaf/servicerpt/stimulus/aeostim.html

Table 1.3 presents the imported fuel prices in 2005 and their projections through 2030 in Hong Kong SAR. It is assumed that the import electricity price from PRC will stay at the 2005 level.

Table 1.3 ***Imported Fuel and Electricity Prices – HKSAR (Thousand 2005 HK$/TJ)***

Fuel [1]	2005	2010	2015	2020	2025	2030
Black Coal	14.09	13.33	26.33	31.15	31.57	33.83
Pipeline Natural Gas[2]	33.56	60.18	118.88	140.66	142.57	152.77
Electricity -PRC[3]	214.00	214.00	214.00	214.00	214.00	214.00

Sources:
1. 2005 imported fuel prices (except for LNG and Ethanol) are from Hong Kong Energy Statistics - 2005, page 24
2. Natural Gas in China Market ecolution and strategy, IEA, June 2009. It suggests that the LNG price would be USD 17.5 per Mbtu for an oil price of USD 100 per barrel
3. Imported electricity price is the estimation based on the Government press release http://www.info.gov.hk/gia/general/200909/22/P200909220194.htm

1.7 EMISSION FACTORS

In the Hong Kong MARKAL-MACRO model, a set of carbon emission coefficients is incorporated to track the carbon emissions released from fuel use in the RES for current and future years. These carbon emission coefficients are provided by the EPD and power companies. Parallel to these coefficients, emission coefficients of SOx, NOx, and PM_{10} are also being developed for the power sector to evaluate the co-benefit of GHG mitigation.

2 SENSITIVITY OF MARKAL MODEL OUTPUT TO GDP PROJECTIONS

The Base Case solution in the MARKAL model depends on the projected energy service demand. As GDP projection is a major driver to these energy service demand projections and it might vary through the years, further analysis is added in this section to examine the sensitivity of the model solutions to changes of these basic drivers. Two higher (2% and 5%) and two lower (2% and 5%) GDP projections were assumed in comparison to their corresponding values in the baseline for the period between 2010 and 2030. Alternative GDP projections were used to drive the econometric equations and their respective future energy service demands were obtained as input of Hong Kong MARKAL model.

Table 2.1 shows the final energy use change while *Table 2.2* depicts the change of carbon emissions under different GDP projections, compared with the baseline.

Table 2.1 Final Energy Use Change by GDP Projection

	Change of Final Energy Use (%)				
GDP Projection	**2010**	**2015**	**2020**	**2025**	**2030**
5% above baseline	5.50%	5.70%	5.90%	6.10%	6.68%
2% above baseline	2.10%	2.20%	2.30%	2.40%	2.65%
Baseline	0.00%	0.00%	0.00%	0.00%	0.00%
2% below baseline	-2.10%	-2.20%	-2.30%	-2.40%	-2.62%
5% below baseline	-5.50%	-5.70%	-5.80%	-5.90%	-6.17%

Table 2.2 Carbon Emissions Change by GDP Projection

	Change of Carbon Emissions (%)				
GDP Projection	**2010**	**2015**	**2020**	**2025**	**2030**
5% above baseline	2.20%	5.00%	6.00%	7.10%	7.80%
2% above baseline	1.00%	2.00%	2.20%	2.80%	3.00%
Baseline	0.00%	0.00%	0.00%	0.00%	0.00%
2% below baseline	-1.00%	-2.00%	-2.20%	-2.50%	-2.90%
5% below baseline	-2.00%	-4.20%	-5.20%	-6.30%	-6.90%

It should be noted that 2-5% GDP deviations from the Baseline projection represent significant dollar amount in absolute magnitude over time. Since this study focuses on the differences of the model results between the mitigation scenarios and the Base Case (i.e., the impact of additional technologies, policies and measures), the uncertainties inherent in the long-term GDP projections have minimal impact on the general conclusions drawn from this approach.

Annex B

Abbreviations

Abbreviations

AQO	Air Quality Objectives
BEC	Building Energy Codes
CCS	Carbon Capture and Storage
CFL	Compact Fluorescent Lamps
C&SD	Census and Statistics Department
DCS	District Cooling System
EEDI	Energy Efficiency Design Index
EELS	Energy Efficiency Labelling Scheme
EEOI	Energy Efficiency Operational Indicator
EMSD	Electrical and Mechanical Services Department
EPD	Environmental Protection Department
ERP	Electronic Road Pricing
EV	Electric Vehicle
GDP	Gross Domestic Product
GFA	Gross Floor Area
GHG	Greenhouse Gas
HGV	Heavy Goods Vehicle
HKMM	Hong Kong MARKAL-MACRO
HKSAR	Hong Kong Special Administrative Region
ICF	International Compensation Fund
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
IWMF	Integrated Waste Management Facilities
LCD	Liquid Crystal Display

LGV	Light Goods Vehicle
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MAC	Marginal Abatement Cost
METS	Maritime Emissions Trading Scheme
MOU	Memorandum of Understanding
MSW	Municipal Solid Waste
NTS	Nuclear Transmission Network
NGV	Natural Gas Vehicle
OTTV	Overall Thermal Transfer Value
OWTF	Organic Waste Treatment Facilities
RD&D	Research, Development, and Demonstration
RE	Renewable Energy
RES	Reference Energy System
SEMP	Ship Efficiency Management Plan
SME	Small and Medium-sized Enterprise
STF	Sludge Treatment Facilities
TJ	Terajoule
UNFCCC	United Nations Framework Convention on Climate Change
WACS	Water-cooled Air Conditioning System
WtE	Waste-to-Energy